Statewide Drought Response: Stressor Monitoring

SUMMARY REPORT • 2014-2017

COVER IMAGES, CLOCKWISE FROM TOP:

South Lake Reservoir with low water levels due to drought in California.
CDFW staff conducting a salmon carcass survey in the Merced River in 2012.
CDFW staff conducting a snorkel survey in Gobernador Creek in 2015.

Please direct questions about this report to Ms. Kristine Atkinson, Senior Environmental Scientist (Specialist), at Kristine.Atkinson@wildlife.ca.gov, CDFW Fisheries Branch, 830 S Street, Sacramento, CA 95811

Contributors

FISHERIES BRANCH
Kristine Atkinson
John Kelly
Stephen Swales
Melissa Mandrup
Patrick Mulcahy
Lydia Eldridge
Helen Benson
Stephanie Mehalick

BIOGEOGRAPHIC DATA BRANCH
Janet Brewster
Ryan Hill
Kristina White

OFFICE OF COMMUNICATION, EDUCATION AND OUTREACH
Meredith Fleener

NORTHERN REGION
COASTAL
Seth Ricker

CENTRAL VALLEY
Stacey Alexander
Jason Roberts

WILD TROUT / INLAND
Andrew Jensen
Jennifer Bull
Paul Divine
Steve Baumgartner
Mike Dege
Bernard Aguilar
Caitlin Bean
Tom Christy

NORTH CENTRAL REGION
CENTRAL VALLEY
Tracy McReynolds
Mike Healey
Jeanine Phillips
Colin Purdy
Clint Garman

WILD TROUT / INLAND
Kevin Thomas
John Hanson

BAY DELTA REGION
NORTH OF SAN FRANCISCO
Ryan Watanabe
Derek Acomb
George Neillands

SOUTH OF SAN FRANCISCO
Jennifer Nelson
Michelle Leicester
Jon Jankovitz
George Neillands

CENTRAL REGION
COASTAL
Dennis Michniuk
Matthew Michie
Margaret Paul

WILD TROUT / INLAND
Ken Johnson
Eric Guzman

SAN JOAQUIN BASIN
Pat Ferguson
Steve Tsao

SOUTH COAST REGION
COASTAL
Ben Lakish
Mary Larson
Kyle Evans
Marianne Pelletier

INLAND
Jennifer Pareti
Tim Hovey
Dylan Nickerson
Russell Barabe
Hans Hansen
John O'Brien

INLAND DESERTS REGION
NORTH
Nick Buckmaster
Dawne Emery
Steve Parmenter

SOUTH
Claire Ingel

Contents

Executive Summary

The state of California recently experienced a severe drought and one of the warmest and driest periods of recorded history. The drought lasted for five years, from 2012 to 2016. On January 17, 2014, Governor Jerry Brown declared the drought a state of emergency. This proclamation directed all state agencies to act to prepare for and mitigate drought-related effects on water supply and aquatic species. The California Department of Fish and Wildlife (CDFW) responded by developing and implementing "Drought Stressor Monitoring". In late 2016 to early 2017, drought conditions improved considerably throughout most of the state when winter storms delivered higher than average levels of rainfall. This report describes the results from a collaborative monitoring effort carried out during the period 2014 to 2017 by scientists from California Department of Fish and Wildlife and other agencies throughout the state.

The purpose of the Drought Stressor Monitoring initiative was to collect information on the status of populations of fish and other aquatic species, their habitats, and the water quality in the streams in which they reside. The intent of this project was to provide the scientific community and the public with a better understanding of potential drought-related threats to vulnerable species, and the measures taken by CDFW, and other agencies, to alleviate these threats. This information was also necessary to help CDFW make better-informed management decisions.

CDFW scientists monitored habitat conditions for 17 aquatic species and subspecies in 141 watersheds and sub-watersheds, spanning 28 counties statewide. Nearly all fish species monitored were listed under the state and/or federal Endangered Species Acts (CESA and ESA, respectively) or were state listed as Species of Special Concern. CDFW focused its monitoring efforts on watersheds that provided habitat to special status species, or those that were expected to face the greatest risks from drought. To better understand the extent to which habitats and populations may be affected by drought, monitoring focused on the following questions:

- Were streams drying and was aquatic habitat becoming fragmented?
- Were streams warming?
- Was there sufficient dissolved oxygen in the streams to support aquatic life?
- What were the effects of the drought on aquatic species?

A direct result of the drought was that many streams dried out throughout the state. As a result of reduced streamflow, streams usually characterized as wet year-round dried out and formed isolated pools. Streams that were typically intermittent during the dry summer months dried earlier in the year and for longer durations. Isolated pools provided temporary safe havens for many aquatic species; however, as the drought persisted, water quality in many of these pools quickly deteriorated. The effects of the drought often resulted in higher water temperatures. In some cases, reduced streamflow, stagnant water, and biological oxygen demand resulted in decreased levels of dissolved oxygen. Aquatic species were frequently stranded as streams dried, and were also impacted by reduced water quality, which frequently required emergency management actions, such as fish rescues. When the drought finally ended in early 2017, environmental conditions in most areas of the state improved markedly. The increased rainfall and streamflow reduced water temperatures in many streams, improving fish survival; however, many streams still experienced water temperatures high enough to negatively impact the survival of salmon and steelhead.

The drying of streams and increased habitat fragmentation experienced during the drought often resulted in less suitable habitat for native species. Low streamflow prevented salmon and steelhead from accessing spawning and rearing habitat. Increased rainfall in some northern areas of the state in 2016 improved stream connectivity and allowed fish to travel between habitats, decreasing the risk of stranding; however, streams in south central and southern California continued to experience drying, with deteriorating water quality.

River estuaries and lagoons were also found to be impacted by the drought. Tidal influence in these systems was more pronounced, largely due to reduced freshwater inputs, allowing saltwater layers to extend farther into streams and to persist longer than in previous years. During the summer and early fall, the bottom saltwater layer was often warmer and had lower dissolved oxygen levels than the upper freshwater layer. This likely placed increased stress on rearing juvenile salmon and steelhead. Conditions generally improved in 2016 as increased precipitation led to higher streamflow, resulting in estuaries and lagoons remaining open to the ocean for longer periods and receiving more freshwater input.

Wild trout populations in high elevation streams were also at increased survival risk throughout the drought years. In summer, trout faced reduced streamflow and warming waters, similar to the threats faced by salmon and steelhead. In winter, reduced or absent snowpack often coupled with low streamflow led to the formation of anchor ice on river beds. This, in turn, likely resulted in increased trout mortality at high elevations, as trout were not able to reach refuge areas to escape freezing. Increased precipitation during the winter of 2016-2017 restored snowpack to most high elevation streams, reducing the risk of anchor ice formation.

The information provided by Drought Stressor Monitoring helped to maintain adequate streamflows and water temperatures for fish survival. This information also allowed for adequate water supplies for communities and industry, and for hydroelectric power generation. In May 2014, CDFW and NOAA Fisheries developed a "Voluntary Drought Initiative" between the two agencies. This provided a framework for taking collaborative actions with water users to protect aquatic species. These actions included fish rescue, relocation, monitoring, and habitat restoration. The implementation of suitable environmental monitoring and management allowed CDFW to respond to changing environmental conditions.

The end of the prolonged drought early in 2017 presented new threats to California's vulnerable fish populations and their habitat, including increased frequencies of wildfires, mud slides, flash flooding, and debris flows. Future climate change predictions suggest that these threats may increase in frequency and severity in the coming years, potentially adversely affecting fish and other aquatic resources. These threats must be adequately monitored to protect fish and the environment. The knowledge and data gained through Drought Stressor Monitoring can be used to guide CDFW and other resource managers during future droughts.

Introduction

To conserve and manage aquatic species, it is necessary to collect information on the status and trends of populations, habitat, and water quality. This informs the scientific community and the public on the general health of populations and the environment. Scientists are then able to make informed decisions on species management and recovery, and the effectiveness of management and restoration actions can be evaluated. Many CDFW scientists, from both regional offices and Fisheries Branch, participated in monitoring the effects of the drought on fish and aquatic life in numerous streams, rivers, and lakes throughout the state.

The severe drought which California experienced was one of the warmest and driest periods on record. The drought lasted for five years, from 2012 to 2016 (Figure I-1). Concerns about the adverse effects of the drought on natural resources led Governor Jerry Brown to issue a proclamation on January 17, 2014, declaring a state of emergency. This proclamation directed all state agencies to act to prepare for and mitigate drought-related effects on water supply and aquatic species.

The California Department of Fish and Wildlife (CDFW) responded by developing and implementing several Drought Response Implementation Plans (DRIP), which included "Drought Stressor Monitoring." The purpose of Drought Stressor Monitoring was to increase the level of understanding of the effects of the drought on California's streams and aquatic species. This information would then allow CDFW and other agencies to take remedial action (e.g. DRIP fish rescue), as necessary. Many CDFW scientists, from both regional offices and Fisheries Branch, participated in monitoring the effects of the drought on fish and aquatic life in numerous streams, rivers, and lakes throughout the state.

From January 2014 through early 2017, CDFW scientists monitored habitat conditions for 17 aquatic species and subspecies in 141 watersheds and sub-watersheds, spanning 28 counties statewide (Tables I-1 and I-2). Nearly all monitored fish species were listed under the state or federal Endangered Species Acts or were Species of Special Concern[1]. The watersheds that CDFW selected for monitoring provided important habitat for special status species and/or were at greatest risk of being affected by drought.

To understand the extent to which habitats and populations were affected by drought, monitoring focused on the following questions:

- Were streams drying and was aquatic habitat becoming fragmented?
- Were streams warming?
- Was there sufficient dissolved oxygen in the streams to support aquatic life?
- What were the effects of the drought on aquatic species?

Of particular concern during the Drought Stressor Monitoring effort were salmonid fishes, a group that is extremely reliant on cool, highly oxygenated waters. Severe drought conditions can have a variety of adverse effects on salmon and trout living in streams and rivers. Low streamflow conditions that persist for several months can impact salmonid fish through reductions in water quality. Water temperature and dissolved oxygen levels can have pronounced effects on the survival of salmonids, which can exhibit signs of stress when water temperatures rise above 15-18°C. Increased fish mortality can also occur at water temperatures above 25°C (Bjorn and Reiser 1991). Levels of dissolved oxygen below 3.0 mg/L can be lethal for the survival of both adult and juvenile salmon and steelhead (Matthews and Berg 1996). Habitat availability may also be reduced by drought due to increasing habitat fragmentation, restricting fish immigration and emigration between freshwater and marine environments. Low streamflow can also reduce the available food supply, potentially negatively affecting fish growth and survival.

SPECIES FOCUS

Biological monitoring focused primarily on anadromous fish and their habitat in coastal watersheds and in the Central Valley. The term "anadromous" refers to fish species such as salmon which spawn and rear in freshwater, migrate to the ocean where they feed and mature, and then return to freshwater streams to spawn. Anadromous species monitored in this program included Chinook Salmon, Coho Salmon, and steelhead. Different populations of Chinook Salmon can coexist on some large rivers by spawning at different times of year. These populations, named for the time of year they return to freshwater (e.g. fall-run Chinook Salmon), are genetically distinct from each other and often display differences in physiology and behavior. Steelhead are the anadromous form of Rainbow Trout. The resident form, which remains in freshwater rather than migrating to the ocean, is referred to as rainbow trout. Both life history forms of Rainbow Trout may coexist downstream of major migration barriers (e.g. dams) within anadromous waters. It is well-known that both forms have the flexibility in their life-history to change from one form to the other. In other words, steelhead can become resident and rainbow trout can become anadromous, depending on environmental conditions.

For the purposes of this report, the term "steelhead" refers to Rainbow Trout in waters that have access to the ocean where anadromy is possible, the uncapitalized "rainbow trout" refers to the resident form located upstream of barriers to migration, while the capitalized name refers to the species as a whole. Capitalization throughout this report follows the guidelines of the American Fisheries Society, under which official common names (e.g. Rainbow Trout, Modoc Sucker, etc.) are capitalized and life history forms (e.g. steelhead and rainbow trout) are not capitalized (Page et al. 2013). Also, for this report, years refers to calendar years (January 1 — December 31), unless specifically referred to as a "Water Year" (October 1 — September 30).

Monitoring occurred in lakes and rivers upstream of anadromy, as well as streams and other water bodies that were not connected to the ocean, including those located in high mountain ecotones[2] (Figures I-2, I-3). The extent of drought stressor monitoring that occured throughout the state during 2012 to 2017 for environmental variables (dissolved oxygen, water temperature, stream fragmentation, streamflow and aquatic species) is illustrated in Figures I-4 to I-8.

REPORT STRUCTURE

The state of California covers a broad range of biogeographical ecoregions (Figure I-3), ranging from desert to temperate rainforest, each with its own landscape characteristics and unique collections of fauna and flora. The structure of this report reflects the organization of CDFW and describes the results of Drought Stressor Monitoring carried out in the six inland and coastal regions administered by the California Department of Fish and Wildlife: 1) Northern Region, 2) North Central Region, 3) Bay-Delta Region, 4) Central Region, 5) South Coast Region and 6) Inland Deserts Region.

The range of streams and rivers monitored for water quality, streamflow, habitat conditions and fish populations are shown in Figures I-4 to I-8. Throughout the state, Drought Stressor Monitoring either augmented existing monitoring or, in many locations, was the only monitoring that was conducted during that time period. CDFW scientists from each region and Fisheries Branch participated in environmental monitoring, data collection, and report writing. CDFW also coordinated its monitoring activities with numerous local, state and federal partners throughout California. This report represents a collaborative effort by many CDFW staff, as well as scientists from other agencies, and represents the first statewide summary of information obtained through Drought Stressor Monitoring.

Each chapter of this report was prepared by scientists from that CDFW regional office and Fisheries Branch. Within each chapter, the results of monitoring are presented by geographic ecoregion (e.g. Northern Region: Coastal Watersheds, Northern Region: Central Valley Watersheds etc.), along with the species focus and location characteristics. The local need for drought stressor monitoring in each area is described and the main findings and actions, sub-divided according to species, watershed or the environmental variables that were monitored, are presented. Finally, the overall findings of the Drought Stressor Monitoring initiative are discussed, along with recommendations for the future.

FIGURE I-1.
The distribution and progression of drought conditions in California from 2011 to 2016, depicting the level of drought at the beginning of each Water Year (October 1). Dark Red indicates exceptional drought. Map: U.S. Drought Monitor U.S. Drought Monitor

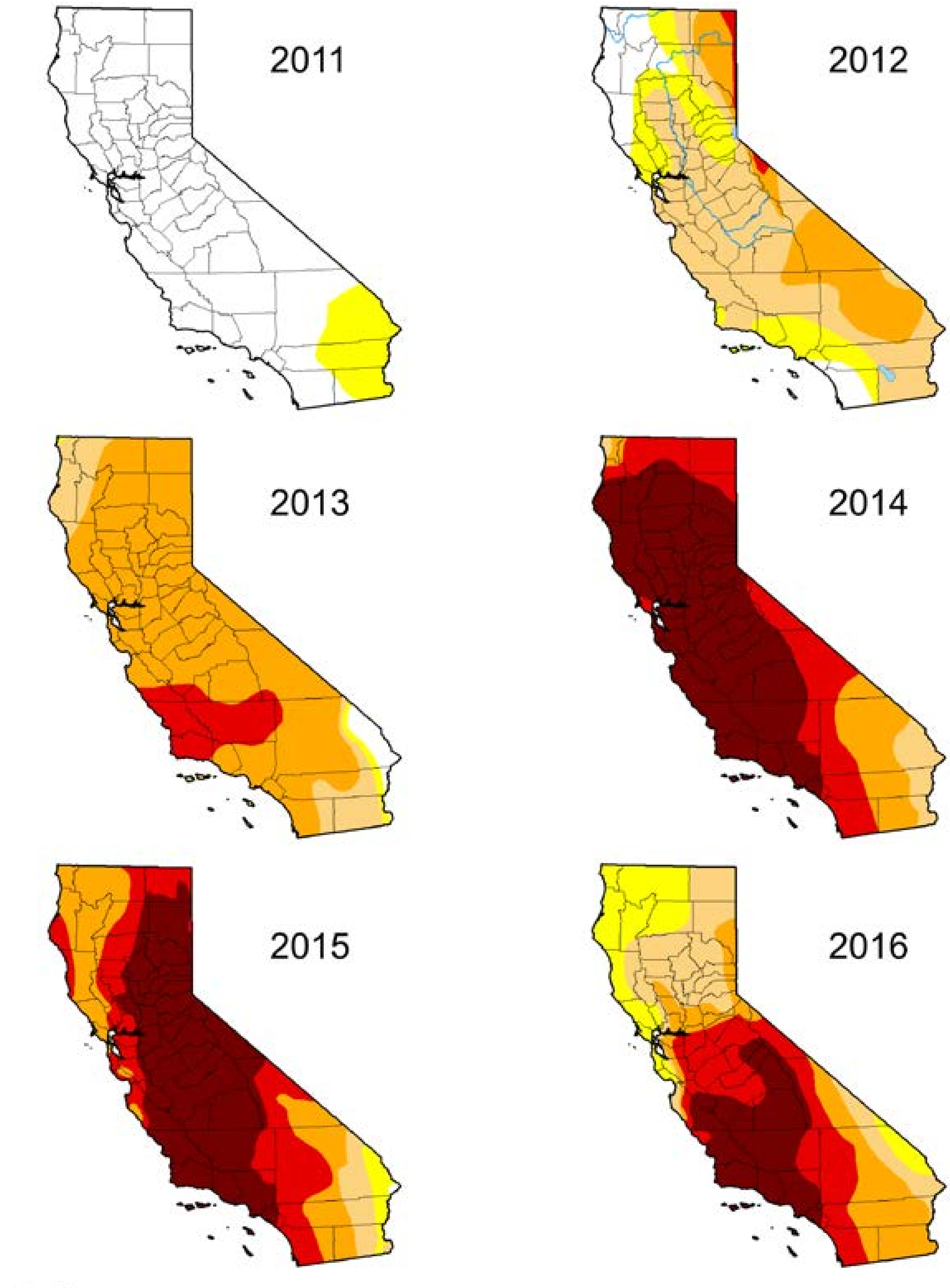


FIGURE I-2.
Major anadromous coastal and Central Valley river systems.

TABLE I-1.
List of aquatic species monitored by CDFW Region and geographic area.

AQUATIC SPECIES	**Northern Region** - Coastal	**Northern Region** - Central Valley	**Northern Region** - Wild Trout / Inland	**North Central Region** - Central Valley	**North Central Region** - Wild Trout / Inland	**Bay Delta Region** - North of San Francisco	**Bay Delta Region** - South of San Francisco	**Central Region** - Coastal	**Central Region** - Wild Trout / Inland	**Central Region** - San Joaquin Basin	**South Coast Region** - Coastal	**South Coast Region** - Inland	**Inland Deserts Region** - North	**Inland Deserts Region** - South
Spring-run Chinook Salmon *(Onchorynchus tshawytscha)*		X		X										
Fall-run Chinook Salmon *(Onchorynchus tshawytscha)*	X	X	X	X		X				X				
Winter-run Chinook Salmon *(Oncorhynchus tshawytscha)*		X												
Coho Salmon *(Oncorhynchus kisutch)*	X		X			X	X							
steelhead* *(Oncorhynchus mykiss)*	X	X	X	X		X	X	X		X	X			
rainbow trout* *(Oncorhynchus mykiss)*			X	X					X			X		X
Lahontan Cutthroat Trout *(Oncorhynchus clarkii henshawi)*					X								X	
Paiute Cutthroat Trout *(Oncorhynchus clarkii seleniris)*													X	
Golden Trout *(Oncorhynchus aguabonita)*									X					
Goose Lake Redband Trout *(Oncorhynchus mykiss* ssp.)			X											
Upper Pit River / Goose Lake Redband Trout *(Oncorhynchus mykiss* ssp.)			X											

AQUATIC SPECIES	**Northern Region** - Coastal	**Northern Region** - Central Valley	**Northern Region** - Wild Trout / Inland	**North Central Region** - Central Valley	**North Central Region** - Wild Trout / Inland	**Bay Delta Region** - North of San Francisco	**Bay Delta Region** - South of San Francisco	**Central Region** - Coastal	**Central Region** - Wild Trout / Inland	**Central Region** - San Joaquin Basin	**South Coast Region** - Coastal	**South Coast Region** - Inland	**Inland Deserts Region** - North	**Inland Deserts Region** - South
McCloud Redband Trout *(Oncorhynchus mykiss stonei)*			■											
Arroyo Chub *(Gila orcuttii)*												■		
Long Valley Speckled Dace *(Rhinichthys osculus)*													■	
Santa Ana Speckled Dace *(Rhinichthys osculus* ssp.*)*												■		
Pacific Lamprey *(Entosphenus tridentatus)*								■						
Red Hills Roach *(Lavinia symmetricus)*									■					
Unarmored Three-spine Stickleback *(Gasterosteus aculeatus williamsoni)*												■		
Modoc Sucker *(Catostomus microps)*			■											
Santa Ana Sucker *(Catostomus santaanae)*												■		
Sierra Nevada Yellow-legged Frog *(Rana sierrae)*													■	

**For purposes of this report, "steelhead" refers to Rainbow Trout in anadromous waters and "rainbow trout" refers to the resident form located upstream of anadromy.*

TABLE I-2.
Locations and watersheds where aquatic species, habitat, and water quality were surveyed for Drought Stressor Monitoring.

BRANCH/REGION – GEOGRAPHIC AREA	FOCUS WATERSHEDS / COUNTIES
NORTHERN REGION *Coastal*	**DEL NORTE CO.:** Smith River. **HUMBOLDT CO.:** Redwood Creek; Mad River; Freshwater Creek; Eel River and tributaries (South Fork Eel River, Chadd Creek, Van Duzen River, and Lawrence Creek); and Mattole River. **MENDOCINO CO.:** Albion River and tributaries (South Fork Albion River and North Fork Albion River), Big River and tributaries (North Fork Big River, South Fork Big River, and Daugherty Creek); Garcia River; Gualala River; Navarro River and tributaries (North Fork Navarro River and Little North Fork Navarro River); Noyo River and tributaries (North Fork Noyo River and Olds Creek); and Ten Mile River.
NORTHERN REGION *Central Valley*	**SHASTA AND TEHAMA COS.:** Sacramento River and tributaries (Clear Creek, Battle Creek, Mill Creek, and Deer Creek).
NORTHERN REGION *Inland*	**MODOC CO.:** Goose Lake tributaries (Cold Creek, Lassen Creek, and Willow Creek); Middle Alkali Lake and tributary (Cedar Creek); Pit River and tributaries (Turner Creek, Coffee Mill Creek, Dutch Flat Creek, Hulbert Creek, Johnson Creek, and Washington Creek). **SHASTA CO.:** Clover Creek; Middle Creek; and Salt Creek. **SISKIYOU CO.:** Scott River; Shasta River; Upper McCloud River and tributaries (Moosehead Creek, Edson Creek, Sheepheaven Creek, and Swamp Creek).
NORTH CENTRAL *Central Valley*	**BUTTE CO.:** Butte Creek; Big Chico; and Feather River. **SACRAMENTO CO.:** American River. **YUBA CO.:** Yuba River.
NORTH CENTRAL *Wild Trout*	**ALPINE CO.:** Pacific Creek and its unnamed tributary in Marshall Canyon; an unnamed tributary to North Fork Mokelumne River; and Carson River. **NEVADA CO.:** East Fork Creek (in Austin Meadow) and two unnamed tributaries and Macklin Creek **PLACER CO.:** Pole Creek and Truckee River.

BRANCH/REGION — GEOGRAPHIC AREA	FOCUS WATERSHEDS / COUNTIES
BAY DELTA REGION *North of San Francisco*	**SONOMA CO.:** Russian River and tributaries (Dutch Bill Creek, Green Valley Creek, Mark West Creek, Mill Creek, and Dry Creek); Salmon Creek; and Sonoma Creek. **MARIN CO.:** Lagunitas Creek and Walker Creek. **NAPA CO.:** Napa River.
BAY DELTA REGION *South of San Francisco*	**SAN MATEO CO.:** San Gregorio Creek; Pescadero Creek; and Gazos Creek. **SANTA CRUZ CO.:** Waddell Creek; Scott Creek; San Lorenzo River and tributaries (Bean Creek, Branciforte Creek, and Zayante Creek); Soquel Creek; and Aptos Creek. **SANTA CLARA CO.:** Pajaro River and tributary (Uvas Creek); Guadalupe River; Coyote Creek; and Stevens Creek. **ALAMEDA CO.:** Alameda Creek.
CENTRAL REGION *Coastal*	**MONTEREY CO.:** Carmel River; Big Sur River; and Salinas River and tributary (Arroyo Seco). **SAN LUIS OBISPO CO.:** Santa Rosa Creek; Chorro Creek; Pismo Creek; and San Luis Obispo Creek.
CENTRAL REGION *San Joaquin River Basin*	**MERCED CO.:** Merced River. **STANISLAUS AND TUOLUMNE COS.:** Stanislaus River and Tuolumne River. **FRESNO CO.:** Upper San Joaquin River.
CENTRAL REGION *Inland*	**TULARE CO.:** Golden Trout Creek; Volcanic Creek; and Left Stringer Creek. **TUOLUMNE CO.:** Red Hills Area of Critical Environmental Concern.
SOUTH COAST REGION *Coastal*	**SANTA BARBARA CO.:** Arroyo Hondo Creek; and Santa Ynez River and tributary (Hilton Creek and Salsipuedes Creek). **VENTURA CO.:** Santa Clara River and tributary (Santa Paula Creek); Sisar Creek; and Ventura River and tributaries (North Fork Matilija Creek, Upper Matilija Creek, Upper North Fork Matilija Creek, and San Antonio Creek).
SOUTH COAST REGION *Inland*	**LOS ANGELES CO.:** Big Tujunga Creek; Soledad Canyon Creek; San Francisquito Creek; San Gabriel River (North, West, East Forks San Gabriel River); and Santa Clara River. **SAN DIEGO CO.:** San Felipe Creek.
INLAND DESERTS REGION *North*	**MONO CO.:** Stella Lake; Leidy Creek and tributary (Cabin Creek); North Fork Cottonwood Creek; By-Day Creek; O'Harrell Creek; Slinkard Creek; Silver Creek; Wolf Creek; Little Alkali Hot Springs; and Whitmore Hot Springs.
INLAND DESERTS REGION *South*	**RIVERSIDE CO.:** Coldwater Canyon Creek.

FIGURE I-3.
Ecoregions within California and CDFW Regions.

FIGURE I-4.
Streams monitored for dissolved oxygen, 2014-2017.

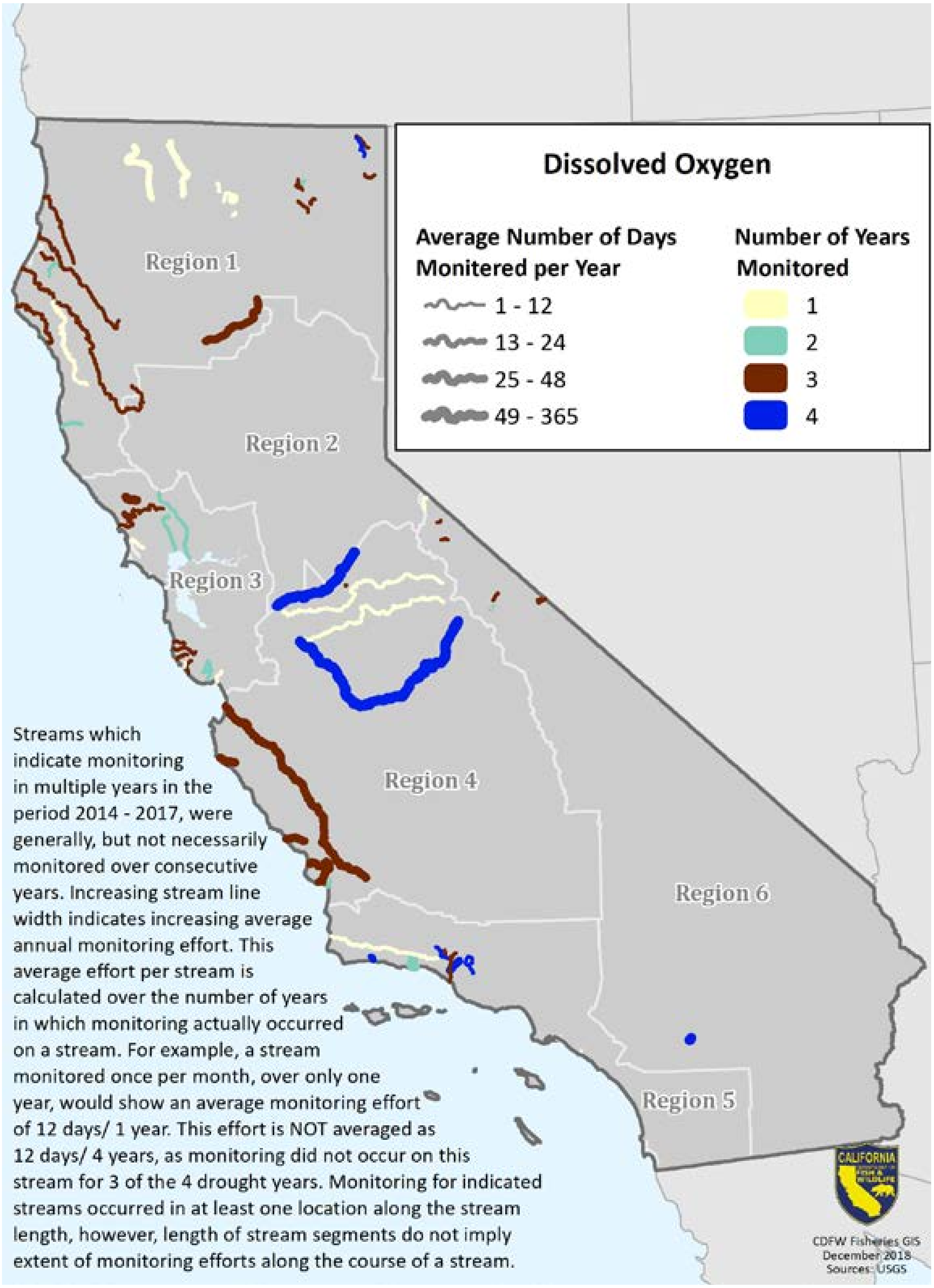


FIGURE I-5.
Streams monitored for stream fragmentation, 2014-2017.

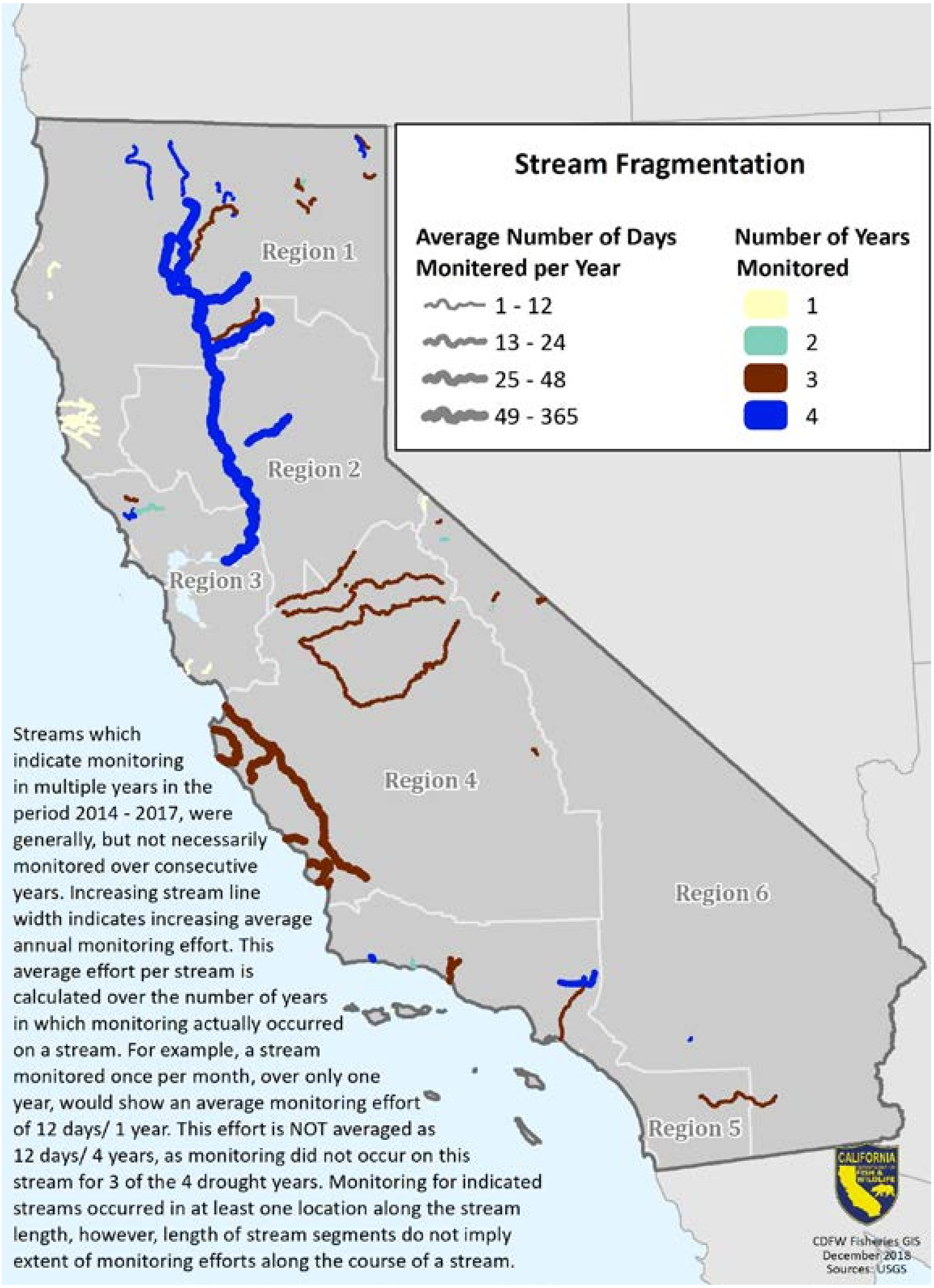


FIGURE I-6.
Streams monitored for aquatic species, 2014-2017.

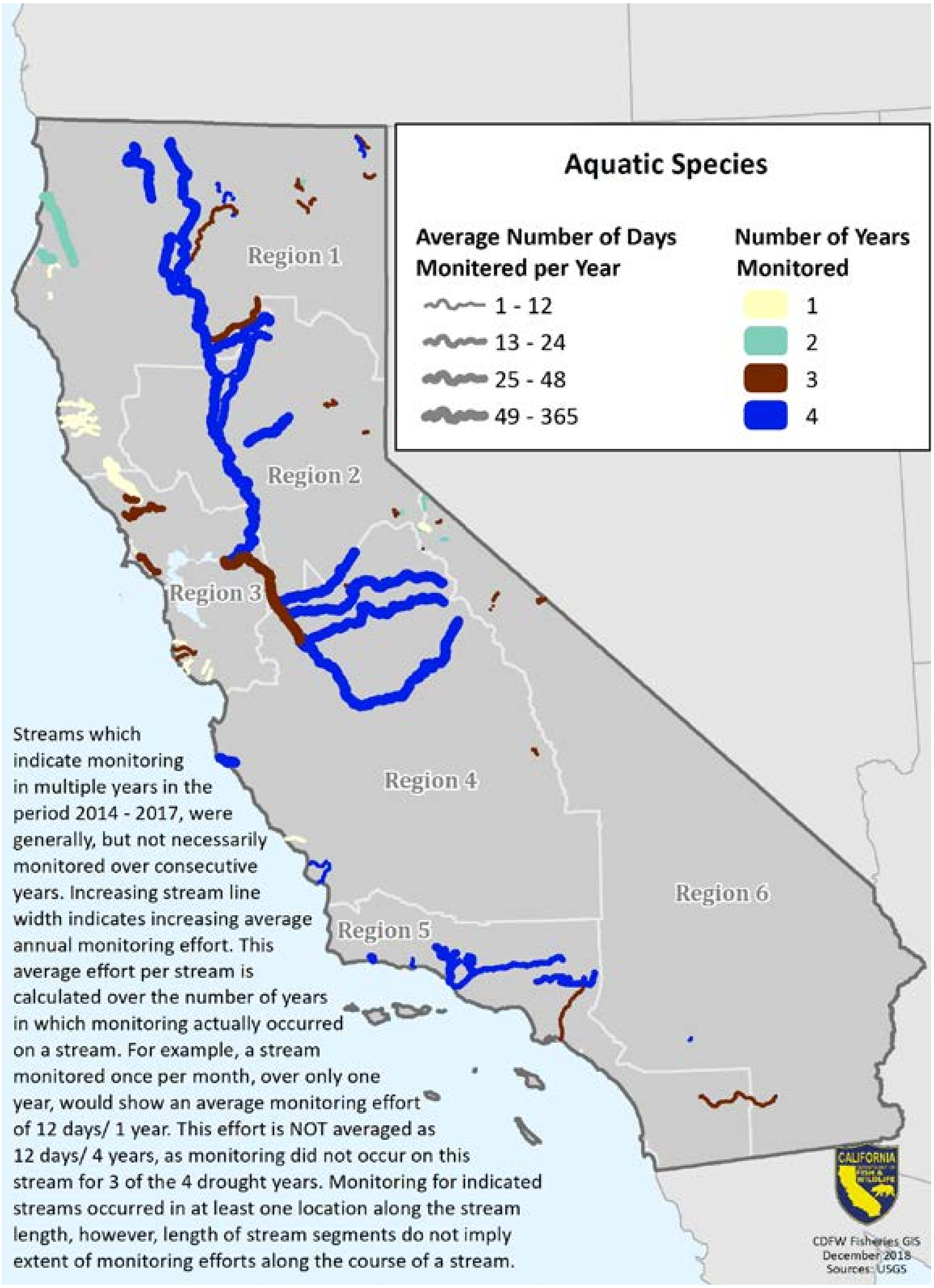


FIGURE I-7.
Streams monitored for water temperature, 2014-2017.

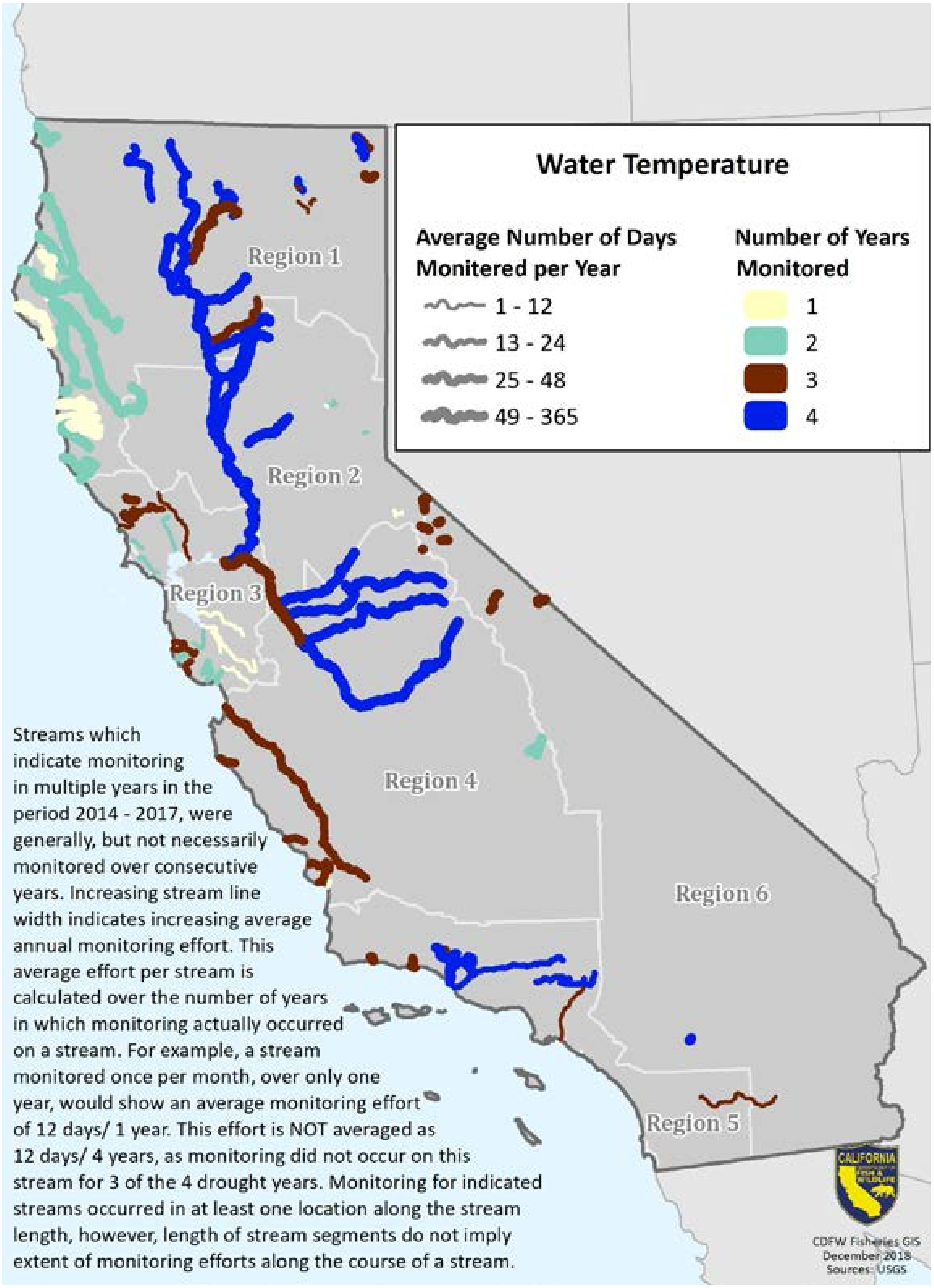
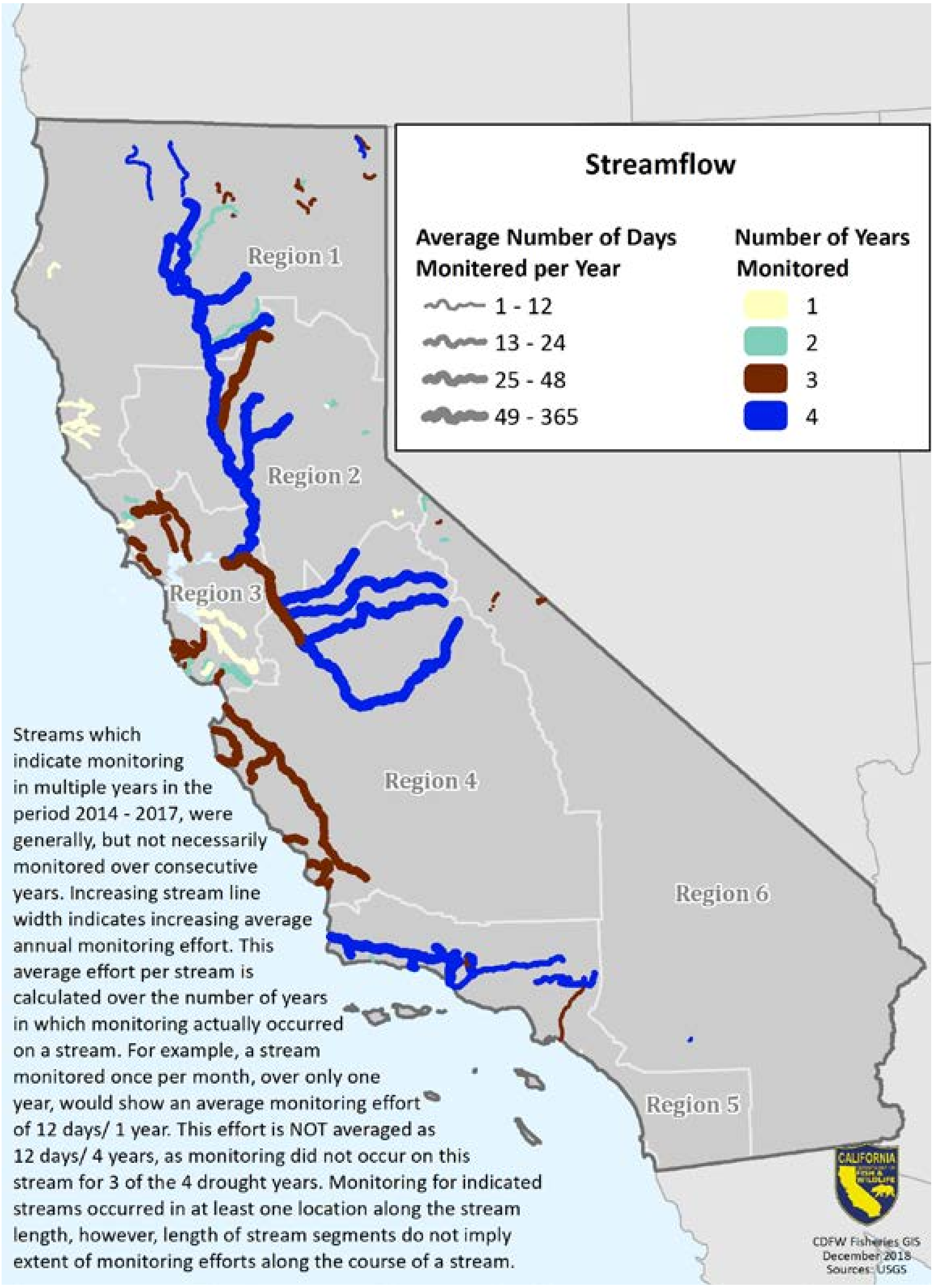


FIGURE I-8.
Streams monitored for streamflow, 2014-2017.



CHAPTER ONE

Northern Region

The Northern Region includes the following counties: Del Norte, Humboldt, Mendocino, Lassen, Modoc, Shasta, Siskiyou, Tehama, and Trinity. Terrestrial habitats range from the coastal redwood tree dominated forests along the coast to oak woodlands and sagebrush scrub in the interior. The Northern Region has some of the highest diversity biomes[3] in the state. This diversity is largely a function of differences in soil types, elevations, and the distribution of rainfall which has led to the evolution of diverse plant and animal communities with local adaptations.

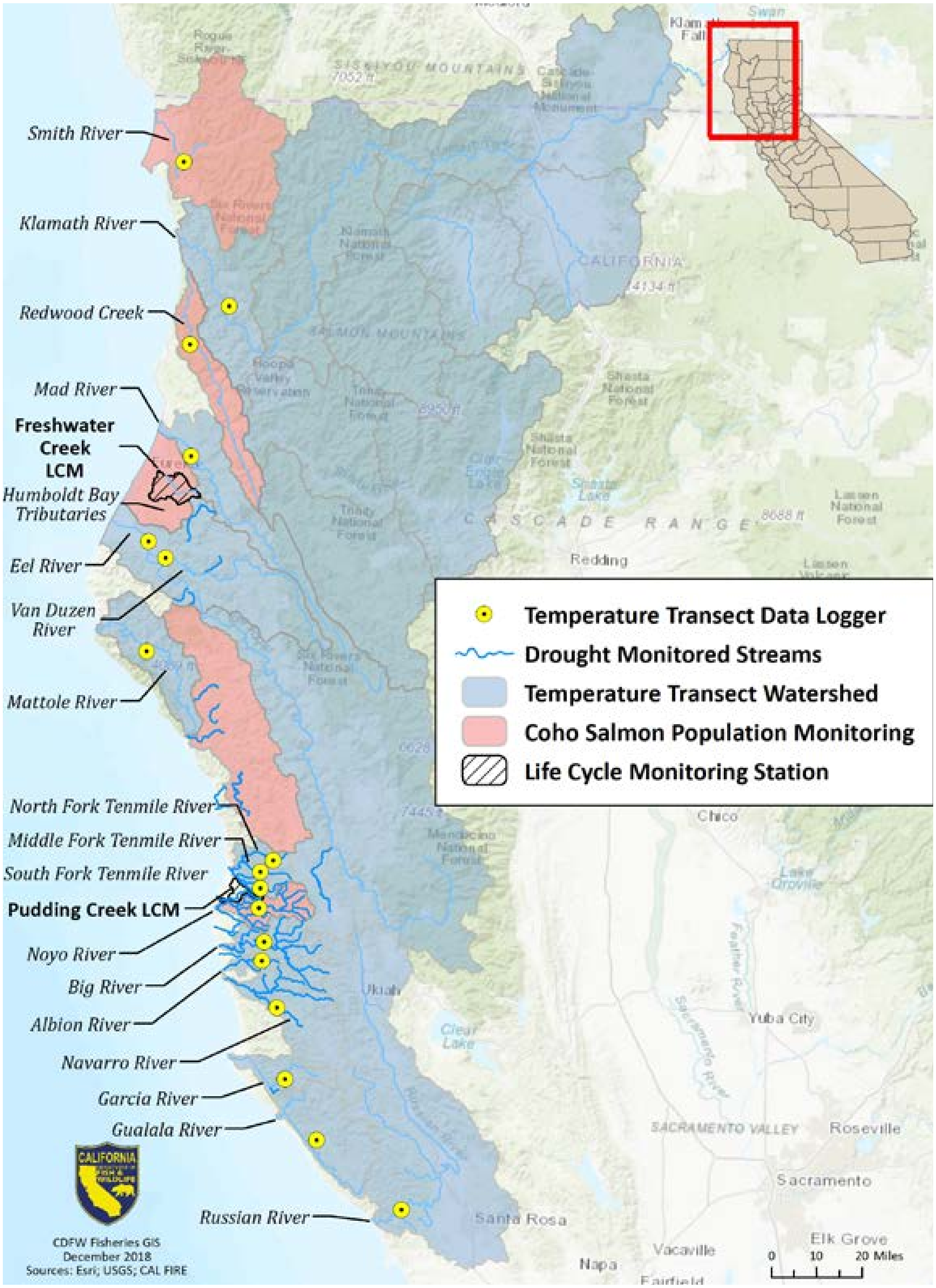
There are four mountain ranges in the Northern Region: The Cascade Mountains, the Klamath Mountains, the Sierra Nevada Mountains, and the Coastal Mountains. These mountain ranges cause major rivers to flow westerly to the Pacific Ocean and southerly through the Central Valley into San Francisco Bay. Drought monitoring strategies in the Northern Region were tailored to focus on fisheries resources and habitats that were at greatest risk of adverse impacts because of the drought. CDFW scientists from the Northern Region monitored water temperatures, streamflow, drying of streams, and special status species fish populations. This information enabled the extent of drought effects to be determined and allowed for science-based fisheries management decisions.

1.1 COASTAL WATERSHED

Species Focus and Location Description

Coastal Drought Stressor Monitoring in the Northern

FIGURE 1.1.1.
Locations and watersheds of enhanced Drought Stressor Monitoring relative to coastal monitoring sites in Northern California.



Region focused on waters containing populations of Coho Salmon, a species listed under both federal and California Endangered Species Act (ESA and CESA, respectively). Monitoring efforts included waters in Del Norte, Humboldt, and Mendocino counties. In some watersheds, environmental monitoring was carried out in conjunction with scientists from the CDFW Bay Delta Region.

Local Need for Drought Stressor Monitoring

As California endured historic drought conditions, populations of Threatened and Endangered riverine fishes in the Northern Region were increasingly vulnerable to warming waters and drying stream channels. In general, salmon and steelhead require cold, clean freshwater to spawn, hatch, and rear before migrating to the sea to mature. Typically, juvenile Coho Salmon rear in freshwater for up to two years, so they must survive the hot and dry summer months, making the species particularly susceptible to drought conditions.

To determine the impacts of California's drought on Coho Salmon populations and their aquatic habitats, CDFW conducted aquatic monitoring at multiple spatial scales. Water temperature monitoring was carried out at a broad spatial scale across the coastal zone, from the Smith River in Del Norte County south to the Russian River in Sonoma County (Figure 1.1.1). The number of adult Coho Salmon returning to spawn was monitored at the watershed scale to detect long term trends in population abundance. Specific stronghold streams (streams where healthy populations use high quality habitat) within the most

FIGURE 1.1.2.
Mean August water temperature from 17 major California coastal river systems during the drought years 2015 and 2016 compared to water temperatures predicted by NorWest climate models.

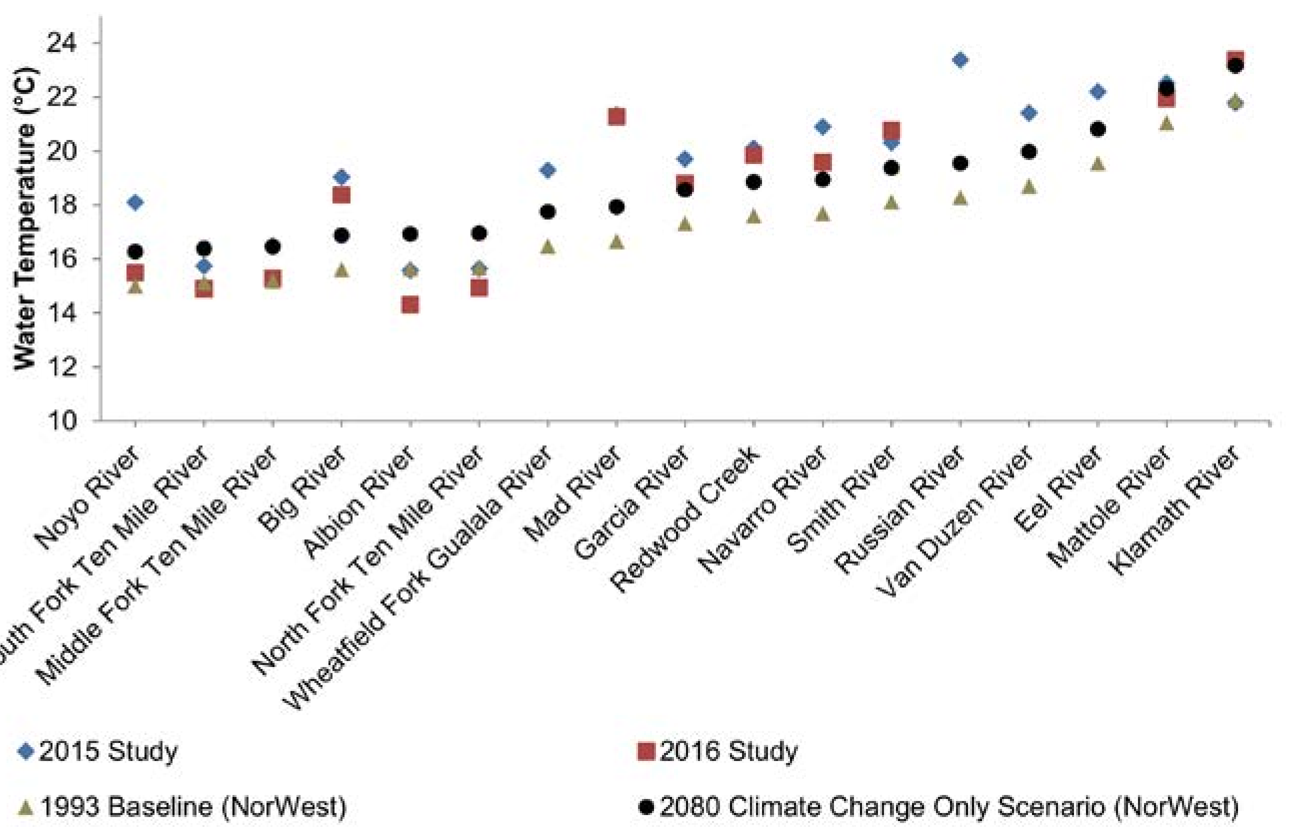


FIGURE 1.1.3. Relative abundance and marine survival of Coho Salmon from two Life Cycle Monitoring streams of the California Monitoring Program, presented as a "z score," or the number of standard deviations from the mean yearly value for each population.

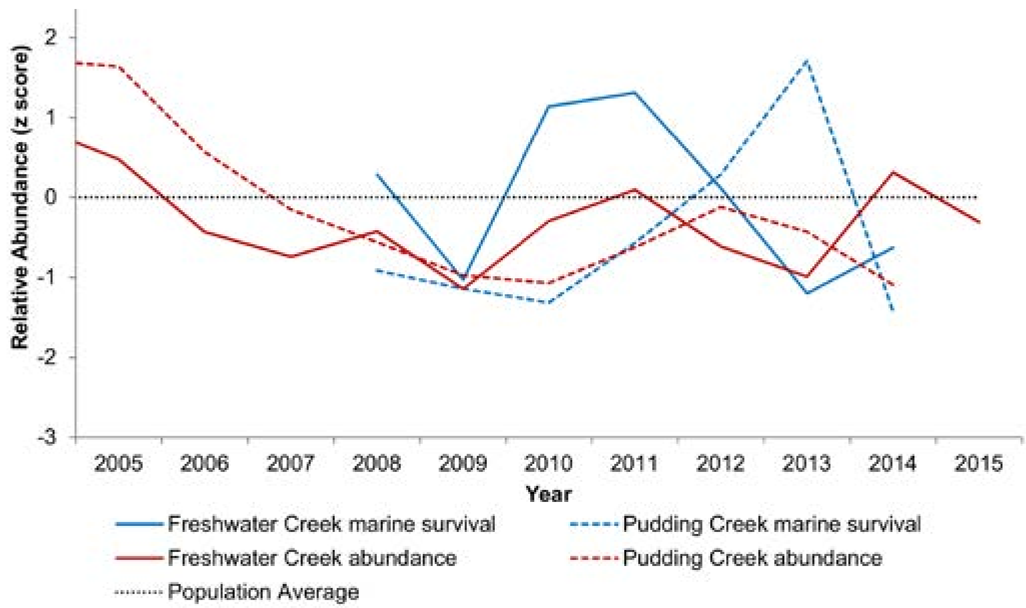
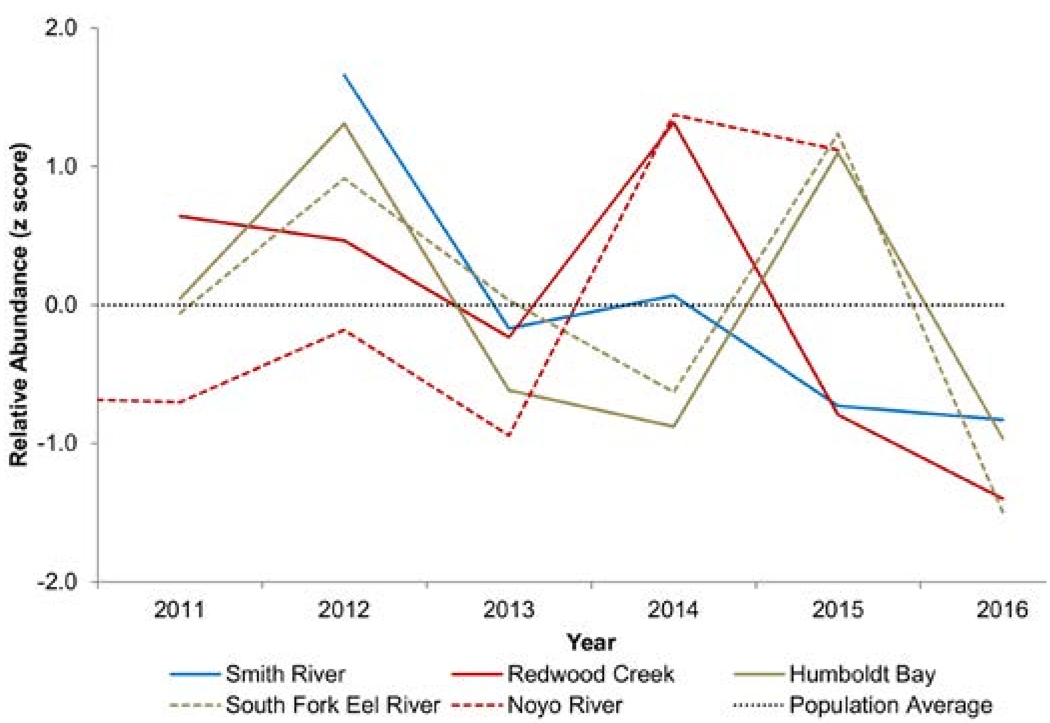


FIGURE 1.1.4. Trends in adult returns for priority populations of Coho Salmon monitored as part of the California Monitoring Program. The data are presented as "z scores," or the number of standard deviations from the mean yearly value for each population.



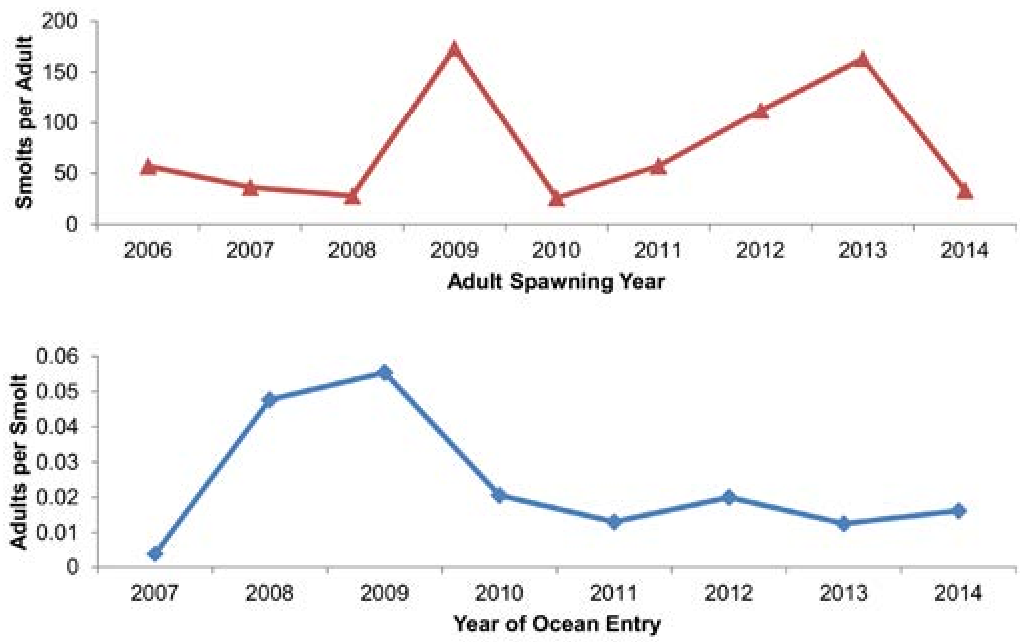


FIGURE 1.1.5. Trends of in-stream (top) and marine (bottom) productivity of Coho Salmon monitored as part of the California Monitoring Program.

affected areas in Mendocino County were monitored in real-time. These efforts informed science-based management decisions that were needed to avoid the local extirpation of the species.

Findings and Actions

Water temperature monitoring

The locations of water temperature monitoring stations were standardized along the coast so that all sites were inland from the influence of marine coastal air. CDFW scientists collected hourly water temperatures by deploying continuous water temperature data loggers. Water temperatures were evaluated by comparing pre-drought baseline temperatures to current water temperatures (Isaac et al. 2011). To assess potential future threats to salmon and steelhead survival, the current water temperatures were also compared to those predicted under various climate change scenarios.

The results indicated that in 12 out of 17 watersheds the average water temperature was more extreme during the drought than was predicted from climate change alone. This comparison showed severe landscape-wide water temperature increases in 2015 (Figure 1.1.2). Mean water temperatures in August were on average two-thirds of a degree Celsius cooler in 2016 than in 2015. In more than half of the monitored coastal rivers this difference was more extreme than was predicted, suggesting that the drought resulted in severe temperature effects beyond the impacts of climate change alone.

Higher than normal water temperatures associated with the drought exceeded survival thresholds and probably affected the spawning success and survival of salmon and steelhead in coastal watersheds. In 2016, streamflow and water temperature data recorded in Humboldt and Mendocino county streams showed that water temperatures remained suitable for salmon and steelhead survival throughout the summer/early fall months. Water temperatures in pool habitats never exceeded 20°C, well below the threshold temperature of 22°C for suitable habitat in this region (Garwood and Ricker 2013).

Salmon population abundance and life-cycle monitoring

In 2011, CDFW and NOAA Fisheries established the "California Coastal Salmonid Population Monitoring Plan" (CMP). The intent of this plan is to organize and standardize long-term science-based monitoring

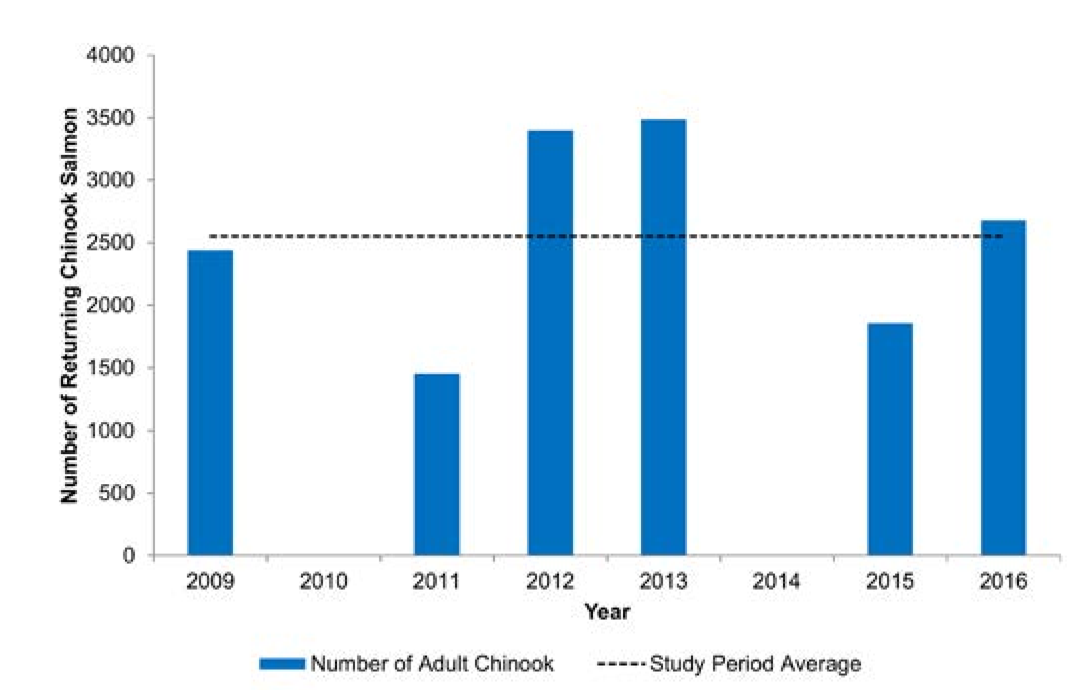


FIGURE 1.1.6. Number of adult Chinook Salmon returning to Redwood Creek (Humboldt County) pre (2013) and post (2016) drought impact.

PLATE 1.1.1.
CDFW divers counting Coho Salmon and steelhead, Freshwater Creek, Humboldt County.
Photo: Seth Ricker, CDFW, June 15, 2015.

of salmon and steelhead populations (Adams et al. 2011). The CMP plan institutes consistent and rigorous data collection protocols throughout the region and across multiple years, providing resource managers and the public with a means to assess the population trends of salmon and steelhead in meaningful and comparable ways.

CDFW scientists routinely monitor adult salmon returns and reproductive abundance at two Life Cycle Monitoring Stations located on Freshwater Creek in Humboldt Bay and Pudding Creek in Mendocino County. The monitoring data allows scientists to interpret trends in salmon abundance and to separate the marine and freshwater phases of the salmon life cycle.

Prior to the drought, Coho salmon observations at both monitoring stations recorded a period of very low abundance between 2008-2009, followed by a modest rebound in numbers commencing in 2010 (Figure 1.1.3). The observed variability in abundance is largely a response to unstable ocean conditions during the period 2008-2009 (Holloway et al. 2014, Anderson et al. 2015) which caused the number of adult Coho Salmon returning to spawn in the monitored streams to fluctuate considerably from year to year (Figure 1.1.4). The effects of river conditions during the drought on the number of returning adult salmon in Northern California will be seen over the coming 3-5 years when juveniles that were in freshwater during the drought return from the ocean as adults. Continued monitoring

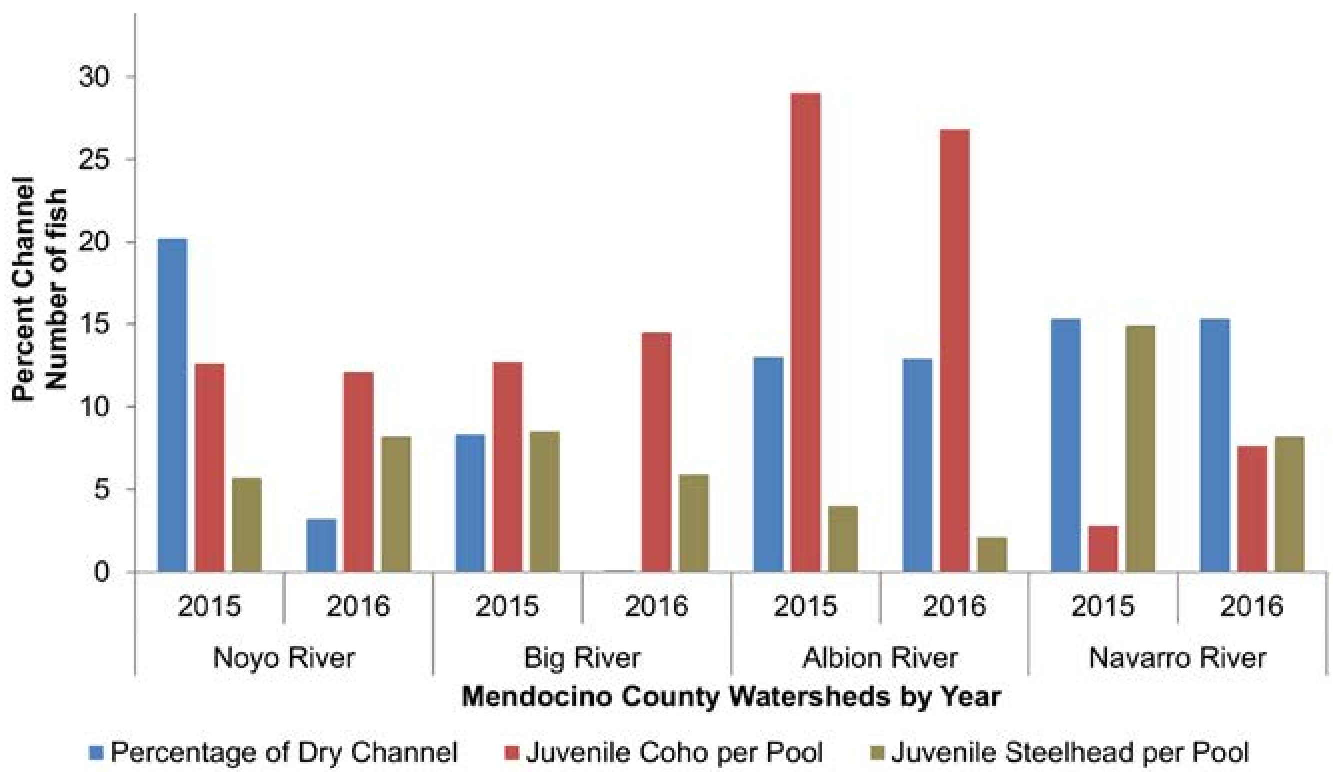


FIGURE 1.1.7.

Comparison of habitat availability, and juvenile Coho Salmon and steelhead density in Mendocino County coastal streams between 2015 and 2016.

of these populations will be critical to understand the overall population level response of Coho Salmon to the California drought.

In both Freshwater Creek and Pudding Creek, juvenile in-stream productivity (i.e. the number of ocean-going smolts[4] as a function of the number of parents) of Coho Salmon showed significant variability and resiliency during the drought years (Figure 1.1.5). Despite the fluctuations in the number of juveniles produced per adult, the proportion of smolts that matured and returned as adults to spawning streams to reproduce was relatively consistent. This pattern may have been linked to both instream habitat conditions and oceanographic factors, such as food availability.

In Redwood Creek, Humboldt County, low streamflow in 2013 due to the drought restricted the upstream migration of adult Chinook Salmon. As a result, most salmon were not able to return to the middle and upper portions of the basin to spawn. It was estimated that this resulted in an overall loss of 440,000 juvenile salmon in the system; however, 224,000 smolts did survive to migrate to the Pacific Ocean (Sparkman et al. 2015). In 2016, when this age class returned to Redwood Creek, monitoring showed that the number of adult returns was slightly above average (Figure 1.1.6).

In the summer and early fall of 2015 and 2016, CDFW scientists carried out snorkel surveys of juvenile salmonid abundance in 18 streams over 33.4 miles of critical Coho Salmon stream habitat. Stream surveys in Mendocino County in 2016 recorded higher numbers of juvenile Coho Salmon and steelhead than in 2015 (Figure 1.1.7). In 2015, rescues of juvenile Coho Salmon were needed in coastal streams in Mendocino County; however, due to sufficient streamflow in 2016, fish rescue operations were not required. With increased rainfall in 2016, drought conditions lessened in some areas of Northern California (including Humboldt and Mendocino counties) and stream habitat conditions improved considerably. The amount of dry channel decreased from 15.5% in 2015 to 7.9% in 2016.

PLATE 1.1.2.
CDFW scientists rescuing juvenile Coho Salmon from isolated and drying pool habitats in Olds Creek, a tributary to the Noyo River, Mendocino County. Photo: Tyler Brown, CDFW, October 8, 2015.

1.2 CENTRAL VALLEY WATERSHEDS

Species Focus and Location Description

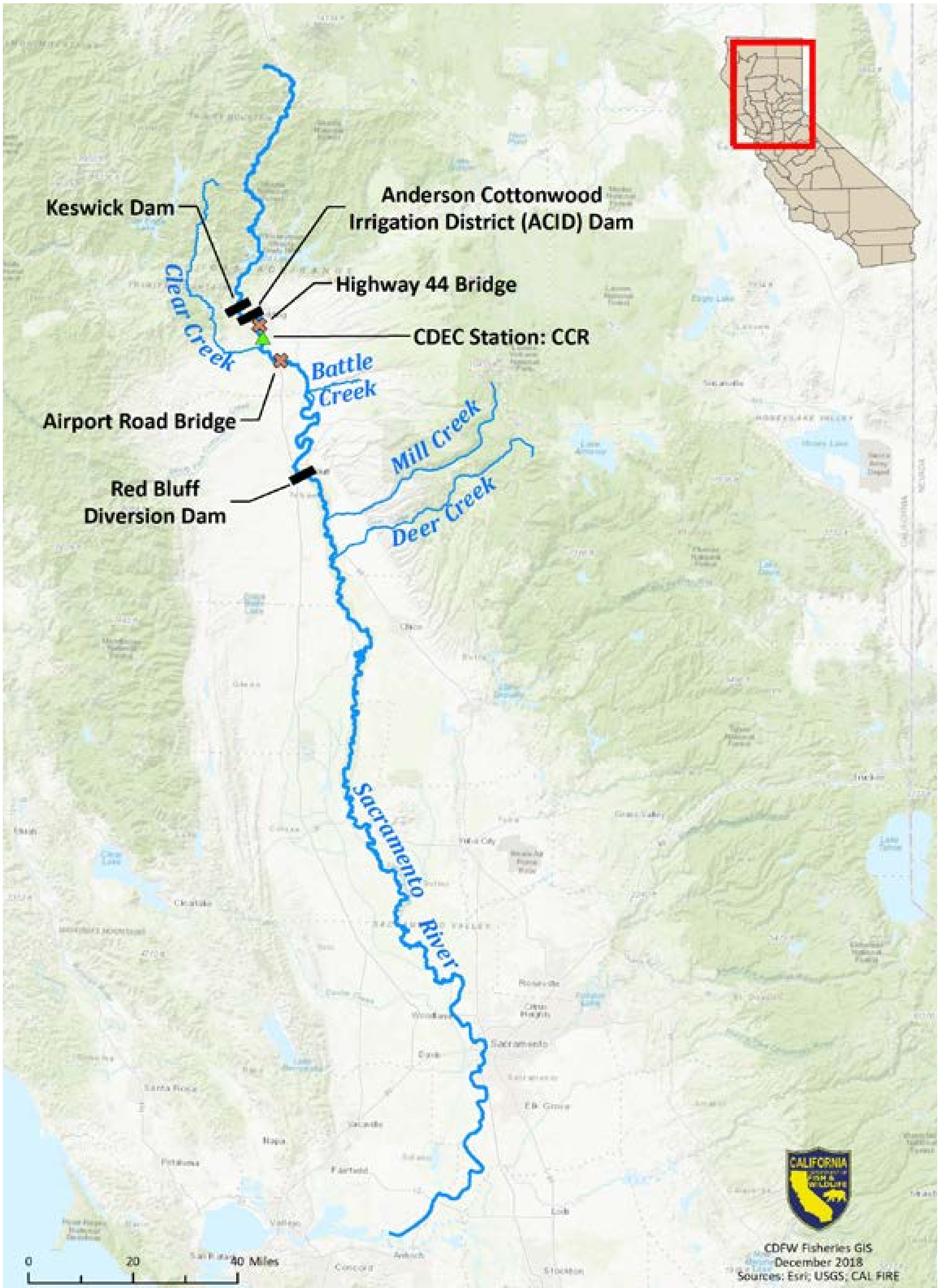
Clear, Battle, Mill and Deer creeks are tributaries to the Sacramento River situated between the cities of Redding (Shasta County) and Corning (Tehama County) (Figure 1.2.1). These tributaries are particularly important because they have significant spawning and rearing habitat for Central Valley spring-run Chinook Salmon, a species listed as threatened under ESA and CESA, along with steelhead, which are listed as threatened under the ESA. The mainstem Sacramento River is also a vital habitat for Central Valley steelhead and state and federally-list Endangered Sacramento River winter-run Chinook Salmon. The four tributaries and mainstem Sacramento River also provide key habitat for fall-run Chinook Salmon.

Local Need for Drought Stressor Monitoring

These four tributaries and the mainstem of the Sacramento River are impacted by various water users (e.g. agricultural diversions, hydropower generation, etc.). For example, water diversions on Mill and Deer creeks reduce streamflow in the late fall and spring and dewater the creeks below the lowest point of diversion, starting in the late spring through the summer and early fall. Reduced streamflow has the potential to increase water temperature and reduce levels of dissolved oxygen. Reduced streamflow can also result in extensive shallow stream sections, which may impede the upstream passage of adult salmon and steelhead.

CDFW scientists have documented that poor water quality associated with low streamflow leads to increased mortality of various life stages of spring- and winter-run Chinook Salmon. Therefore, in 2014, CDFW increased existing monitoring efforts by implementing both water quality monitoring and snorkel surveys to assess the abundance of both adult and juvenile salmon populations. In 2016, CDFW scientists also conducted enhanced monitoring of water temperatures and salmon redds[5] in the upper Sacramento River and Clear Creek (Figure 1.2.1).

FIGURE 1.2.1.
Map of the Sacramento River and tributaries: Deer, Mill, Battle, and Clear creeks. Also noted are major dams, bridges, and the California Data Exchange Center (CDEC) monitoring station at Clear Creek (CCR).



Findings and Actions

Upper Sacramento River

The effects of the prolonged drought increased the extinction risk for listed salmon and steelhead in Central Valley streams. Low streamflow, severely reduced snowpack, and above-average air temperatures resulted in increased water temperatures in the upper Sacramento River watershed. As a result of a reduced cold-water pool in Shasta Reservoir, the 13.3 °C temperature compliance point was moved 26 Rkm upstream from Balls Ferry gauge (BSF, RM 276, RKm 444) to the Clear Creek temperature gauge (CCR, RM 292, Rkm 470), and in 2015, the compliance target was increased to 13.9 °C. Despite these regulatory changes, water temperatures frequently exceeded the compliance thresholds in 2014 and 2015.

High water temperatures had a dramatic effect on the winter-run Chinook Salmon population. Monitoring by CDFW scientists showed that the distribution pattern of spawning winter-run Chinook Salmon was shifted upstream (Table 1.2.1). Also, in 2014 and 2015, elevated water temperatures at the rotary screw trap monitoring location at Red Bluff Diversion Dam resulted in lower than expected survival of juvenile winter-run Chinook Salmon. It is estimated that only four to six percent of all winter-run Chinook Salmon eggs survived to become fry[6] (Table 1.2.2).

Water Year 2016 brought some drought relief, with above average precipitation in Northern California. The quality of water discharges from Keswick Dam (located on the mainstem) improved, and water

TABLE 1.2.1.

Percentage of total Sacramento River winter-run Chinook Salmon spawning by location between Keswick Dam and Airport Road Bridge from 2003 to 2015.

LOCATION	2015	2014	2003-2013 AVG
Keswick Dam to A.C.I.D. Dam	38%	56%	43%
A.C.I.D. Dam to Highway 44 Bridge	61%	37%	43%
Highway 44 Bridge to Airport Rd. Bridge	1%	7%	14%

TABLE 1.2.2.

Sacramento River winter-run Chinook Salmon egg-to-fry survival rate at Red Bluff Diversion Dam. Shading denotes the three recent years with the lowest precipitation in the northern Central Valley. Increased precipitation in 2016 returned the egg-to-fry survival rate to per-drought levels.

YEAR	EGG-TO-FRY SURVIVAL
2003	23%
2004	20.9%
2005	18.5%
2006	15.4%
2007	21.1%
2008	17.5%
2009	33.3%

YEAR	EGG-TO-FRY SURVIVAL
2010	37.5%
2011	48.6%
2012	26.9%
2013	15.1%
2014	5.9%
2015	4.2%
2016	24%

temperatures were considerably cooler at the downstream temperature compliance point at Clear Creek. During the critical winter-run incubation period in May through June from 2015 to 2016 there was an average 1.4°C decrease in water temperature. There was also an average decrease in water temperature at this location from 2014 to 2016 of 0.9°C (Figure 1.2.2). Cooler water temperatures in 2016 increased the egg to fry survival rate to 24% (Table 1.2.2). Streamflow in Clear Creek, a major tributary, also increased by an average of 60 cfs[7] in 2016, compared to 2015 (Figure 1.2.3); however, water temperatures were only 0.4 °C lower.

Mill and Deer Creeks

The number of adult spring-run Chinook Salmon returning to Mill and Deer creeks in 2015 was 74% lower than in 2014, the last pre-drought cohort or year-class (CDFW unpublished data). CDFW and NOAA Fisheries worked with local water users in 2014 and 2015 to develop Voluntary Drought Agreements to provide minimum protective streamflow for spring-run Chinook Salmon and steelhead. Without these voluntary agreements, water diversions on Mill and Deer creeks would have disconnected the creeks from the Sacramento River during the latter half of the spring-run migration period (late February - July), further limiting adult returns and reducing spawning success. Streamflow in Mill and Deer creeks improved in 2016 due to increased rainfall (Figures 1.2.4 and 1.2.5) which permitted spring-run Chinook Salmon to enter the creeks and spawn. In 2016, CDFW scientists detected a 22% increase in escapement[8] of spring-run Chinook Salmon to Mill and Deer creeks, compared to results from the previous year (Table 1.2.3).

TABLE 1.2.3.
Spring-run Chinook Salmon Escapement from 2014 to 2016.

SPRING-RUN CHINOOK SALMON ESCAPEMENT			
Year	2014	2015	2016
Mill Creek	679	127	175
Deer Creek	830	286	331

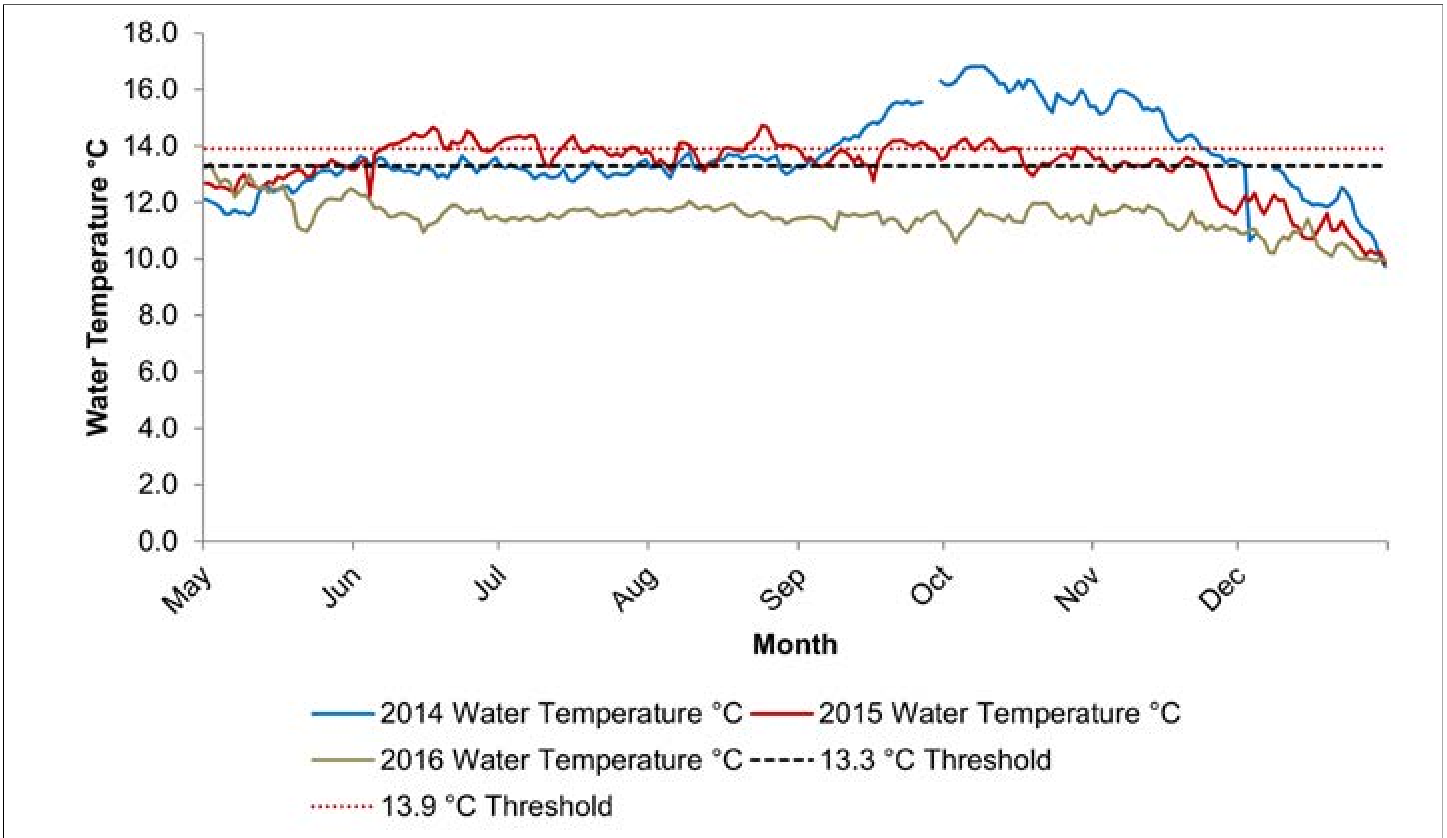


FIGURE 1.2.2.
Daily mean water temperature in the Sacramento River at the temperature compliance point at the Clear Creek temperature gauge (CCR, RM 292, Rkm 470). In 2014 the 13.3 °C compliance point (black dashed line) was moved upstream from the Balls Ferry gauge (BSF, RM 276, RKm 444), and in 2015, the compliance target was increased to 13.9 °C (red dotted line).

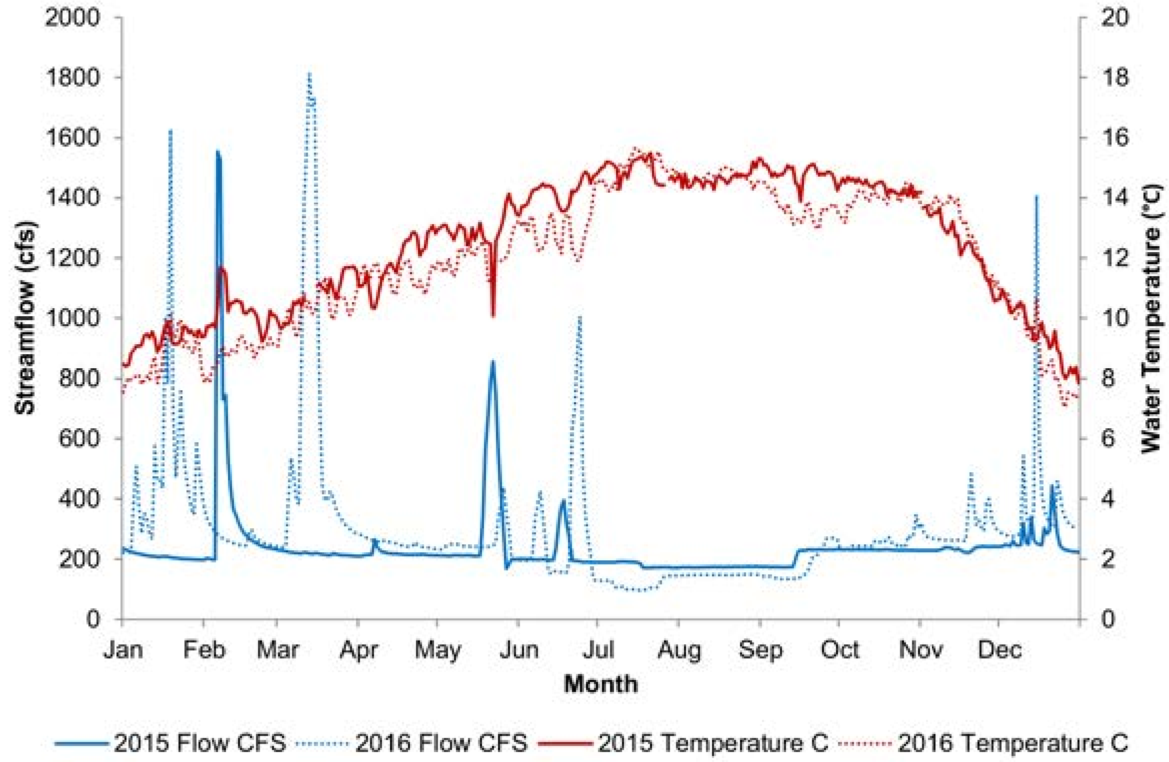


FIGURE 1.2.3.
Mean daily flow and water temperature in Clear Creek in 2015 and 2016 using data from the IGO gauge.

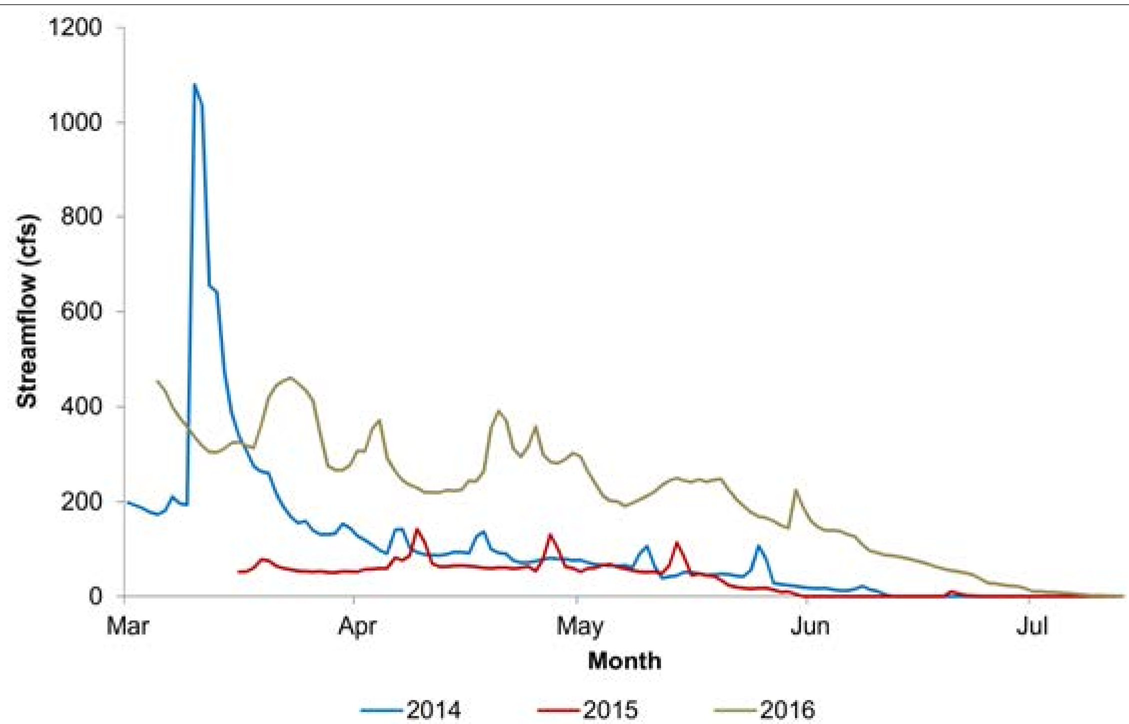


FIGURE 1.2.4.
Flow comparison in Mill Creek for years 2014, 2015, and 2016 using flow data from the MCH gauge.

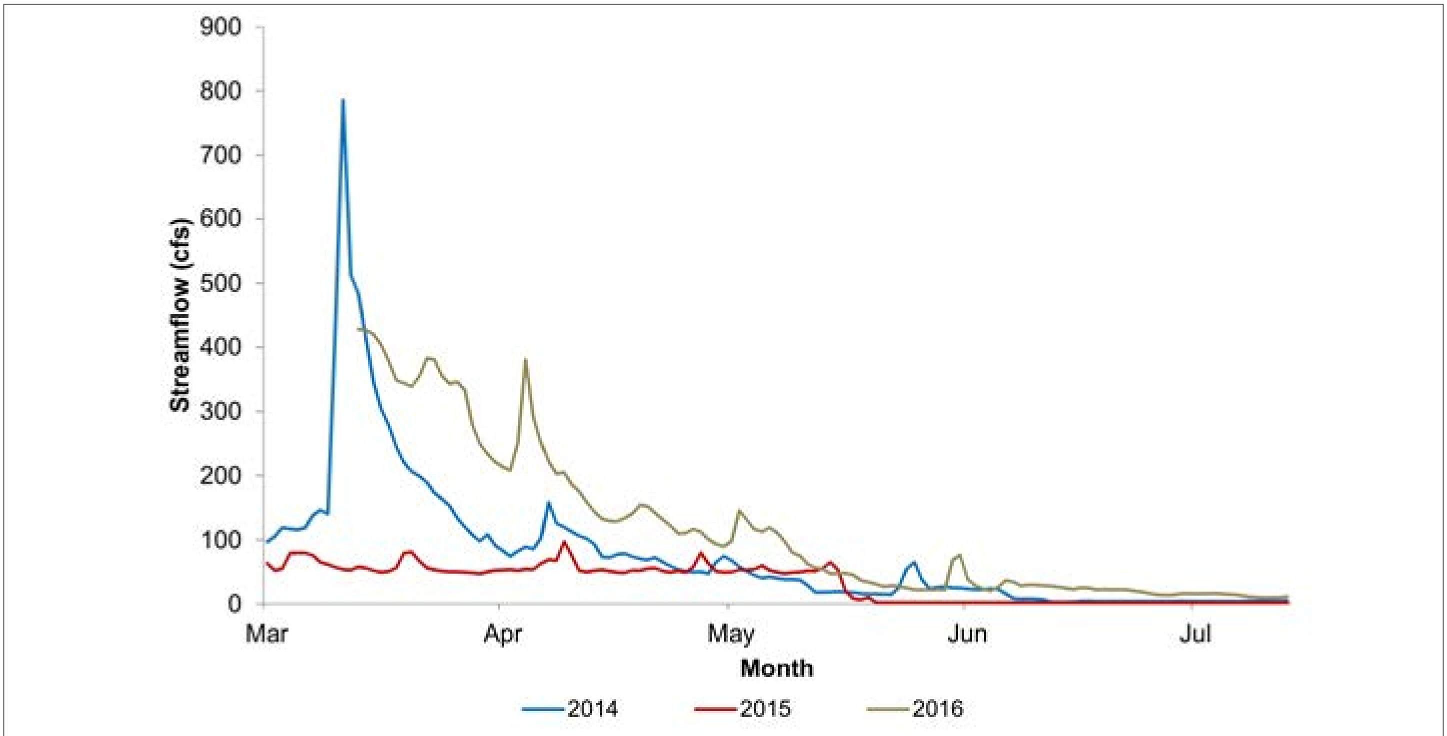


FIGURE 1.2.5.
Flow comparison in Deer Creek for years 2014, 2015, and 2016 using flow data from the DVD gauge.

1.3 WILD TROUT AND INLAND WATERSHEDS

Species Focus and Location Description

Drought Stressor Monitoring in the inland portion of the Northern Region focused on impacted waters in Shasta, Siskiyou, Tehama, Trinity, Lassen and Modoc counties (Figure 1.3.1). CDFW scientists monitored the following salmon and trout species and their habitats: state and federally threatened Coho Salmon; federally threatened steelhead; Fall-run Chinook Salmon; state Species of Special Concern McCloud Redband Trout; and state Species of Special Concern Goose Lake Redband Trout. CDFW scientists also studied Modoc Sucker, a state Endangered non-salmonid species. All these species require cold, clean water to spawn and rear, and are highly susceptible to the adverse effects of drought.

Local Need for Drought Stressor Monitoring

McCloud Redband Trout populations are restricted in their distribution to small and isolated headwater streams in the upper McCloud River basin, located in Siskiyou and Shasta counties (Figure 1.3.1). Low streamflow due to drought conditions, combined with porous volcanic soils in the basin, can cause McCloud Redband Trout habitat to become completely dry (USDA 2017). This makes the species particularly vulnerable to habitat changes associated with drought.

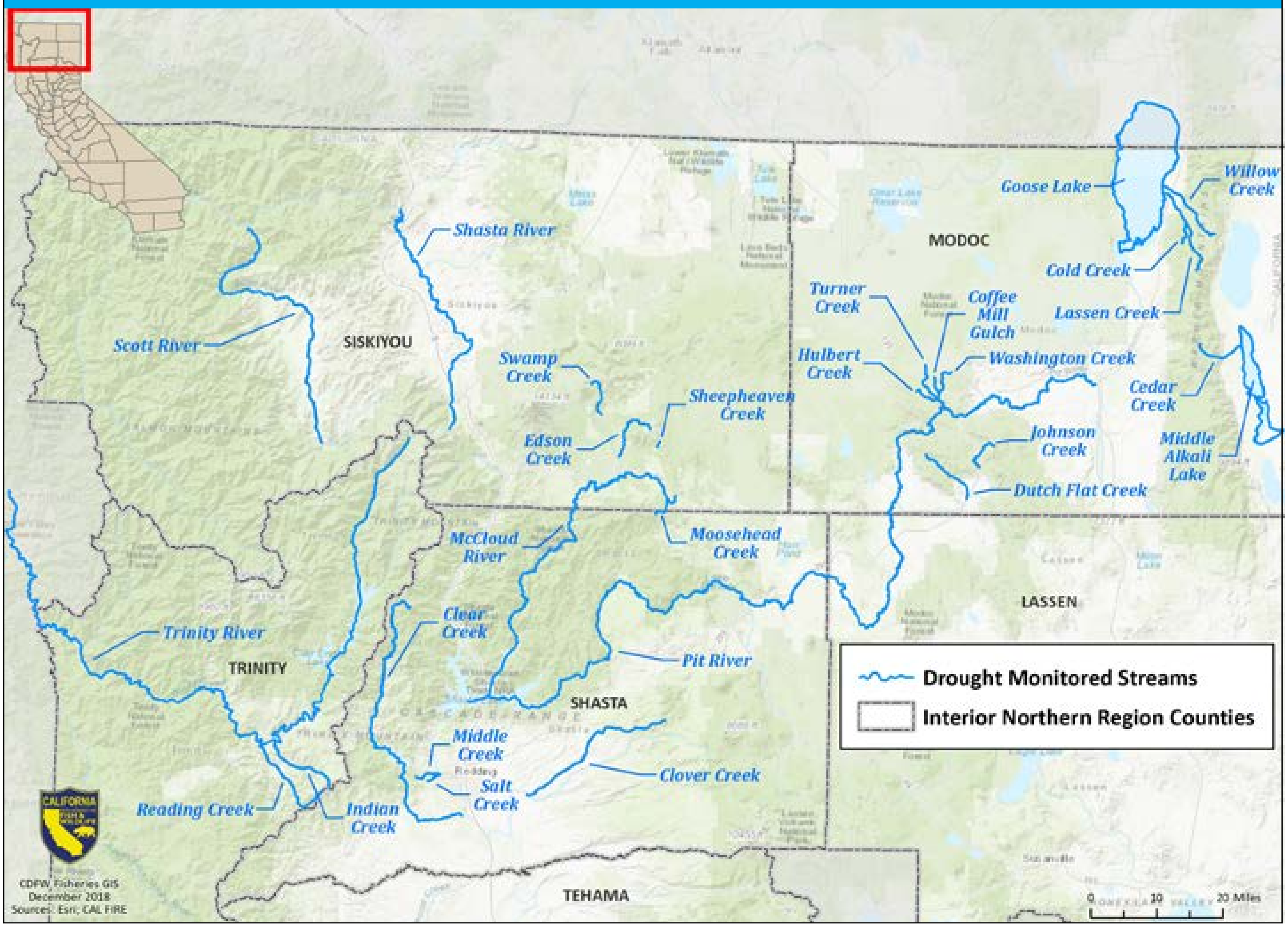
Goose Lake Redband Trout occur within the area of the Goose Lake basin. Lassen, Willow and Cold creeks, all tributaries to Goose Lake, served as refuge habitat during drought conditions. Goose Lake itself was dry throughout the summer and fall months of 2014, 2015, and 2016, highlighting the need for environmental monitoring and management of the California refuge stream populations. These persisting stream populations likely repopulate Goose Lake when hydrologic conditions improve.

Modoc Sucker occur in seven streams in the upper Pit River Watershed: Turner, Washington, Coffee Mill Gulch, Hulbert, Rush, Johnson, and Dutch Flat creeks (Figure 1.3.1). All seven streams were formerly identified as federally designated critical habitat for the species (USFWS 2009). Except for Rush and lower Turner creek, each stream is drought prone, and regularly has low flows or forms isolated pools during the summer.

Clover, Middle, and Salt creeks in Shasta County are tributaries of the Sacramento River that terminate near Redding, California (Figure 1.3.1). These streams provide important habitat for fall-run Chinook Salmon and Central Valley steelhead. During normal rainfall years, salmon and steelhead enter these tributaries to spawn, but drought conditions reduce habitat connectivity and impact water quality, thereby reducing spawning success.

The Scott River watershed is in Siskiyou County (Figure 1.3.1) and includes cold-water tributaries that provide valuable rearing habitat for juvenile Coho Salmon during the dry summer months. However, even in wet years, tributaries can become disconnected

FIGURE 1.3.1.
Locations of inland Drought Stressor Monitoring sites in Northern California.



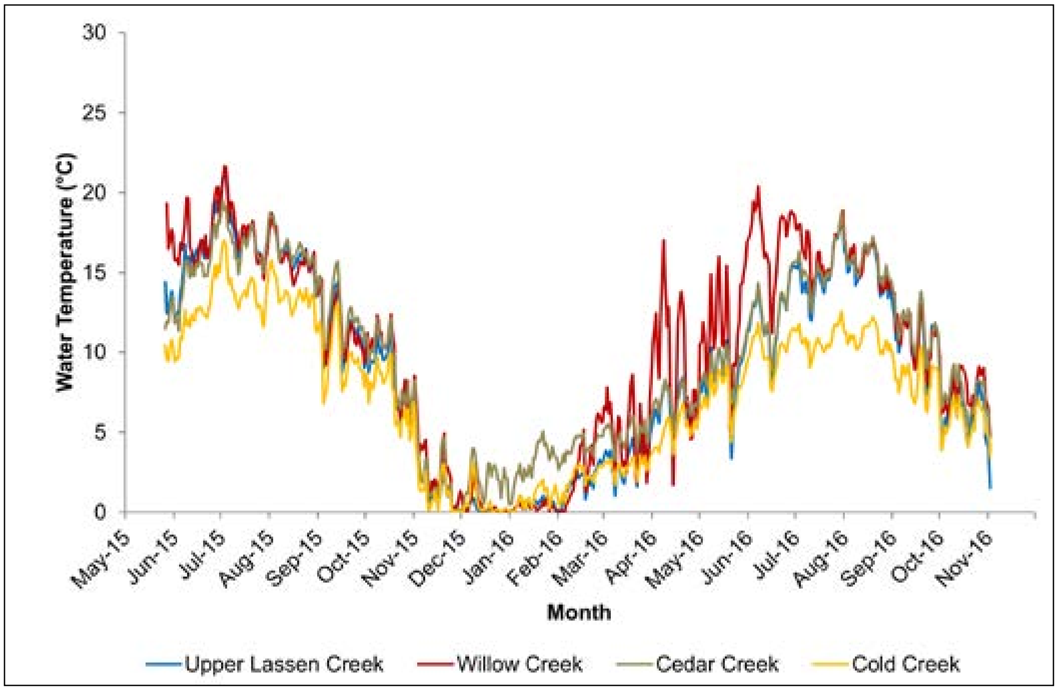


FIGURE 1.3.2. Daily mean water temperatures at upper Lassen, Willow, Cedar, and Cold creeks from May 15, 2015 to November 2, 2016.

PLATE 1.3.1. Summer streamflow on upper Turner Creek, a tributary of the upper Pit River in Modoc County, was extremely low. Large pools still provided adequate habitat for Modoc Sucker and rainbow trout. Photo: Paul Divine, CDFW, July 08, 2015.

from the mainstem, often requiring fish rescue. In the summer of 2016, diminished streamflow in portions of the Scott River and tributaries resulted in isolated pools and caused many sections of the mainstem to go completely dry. The Shasta River watershed in Siskiyou County (Figure 1.3.1) also provides important rearing habitat for over-summering Coho Salmon. The inflow of cold spring water means that fish rescues are rarely required in the Shasta River; however, summertime water temperatures can sometimes become detrimental to fish survival.

Findings and Actions

CDFW scientists monitored the streams in the above watersheds for water temperature and streamflow. Monitoring was necessary to evaluate habitat conditions and determine if fish rescues or other management actions were necessary. They

PLATE 1.3.2.
Johnson Creek (left) and Coffee Mill Gulch (right), tributaries of the upper Pit River in Modoc County, experienced reduced flows, but streamflow was sufficient to maintain suitable habitat. Photo: Paul Divine, CDFW, July 08, 2015.

PLATE 1.3.3.
Dutch Flat Creek (left) and Washington Creek (right), tributaries of the upper Pit River in Modoc County, were reduced to isolated pools due to drought. These pools provided habitat for Modoc Sucker. Photo: Paul Divine, CDFW, July 07, 2015.

PLATE 1.3.4.
CDFW scientists measuring streamflow at Sheepheaven Creek, a tributary of the McCloud River, Siskiyou County. Photo: Michael Dege, CDFW, September 11, 2015.

PLATE 1.3.5.
CDFW scientist downloading water temperature data from a data logger at Sheepheaven Creek, a tributary of the McCloud River Creek, Siskiyou County. Photo: Robert Roy, CDFW, May 21, 2015.

PLATE 1.3.6.
CDFW crew relocating steelhead and Coho Salmon to a lower pool on East Weaver Creek, Trinity County, on June 2015. Photo: CDFW.

PLATE 1.3.7.
Isolated pools in August 2015 on West Weaver Creek, Trinity County. Photo: Bernard Aguilar, CDFW.

PLATE 1.3.8.
Reading Creek, Trinity County, was reduced to isolated pools in May (left) and the creek dried completely later in the summer (right). Photo: Bernard Aguilar, CDFW.

found that low streamflow during the drought reduced available wetted habitat, increased water temperatures, and decreased the levels of dissolved oxygen, and potentially impacted the survival of McCloud Redband Trout.

McCloud River watershed

The distribution of McCloud Redband Trout is currently limited to small headwater streams in the upper McCloud River basin (Figure 1.3.1). These small streams, due to the precipitation patterns in the area, typically experience seasonal wet and dry periods; however, the multi-year drought extended the duration and intensity of the dry periods. The reduced streamflow and available habitat for McCloud Redband Trout prompted drought monitoring and rescue efforts (CDFW 2014).

CDFW scientists carried out stream monitoring from December 2013 through December 2015 to determine the extent of wetted habitat, water temperature, streamflow, and to evaluate the need for potential fish rescue. The drought decreased habitat connectivity and reduced the amount of wetted habitat available for Redband Trout populations beyond what is experienced in a normal dry season. In some cases, stream fragmentation was severe, especially in Edson and Moosehead creeks, where streamflow had ceased and pond habitat remained.

Tributaries of the upper McCloud River (Edson, Sheepheaven, and Swamp creeks) maintained acceptable water temperature and dissolved oxygen levels throughout the extended drought period, likely due to cold-water springs that feed the upper McCloud River headwater streams. Dense canopy cover and the mid to high-elevation location of the streams also provided for cooler summertime air temperatures and shade protection. Redband Trout are also believed to be more tolerant of high water temperatures and low dissolved oxygen than other trout species (Behnke 1992). Streamflow was lower than normal in 2016 but was higher than recorded in 2015, when no streams dried out completely or

PLATE 1.3.9.

Dutch Flat Creek, Modoc County, was reduced to large isolated pools which provided habitat for Modoc Sucker. The stream maintained continuity for much longer, and isolated pools were larger and deeper, in 2016 than in 2015. Photo: CDFW.

PLATE 1.3.10.

Hulbert Creek, Modoc County, maintained flow in June 2016 (left) but was dry in July 2016 (right). Photo: CDFW.

became fragmented. Based on prevailing conditions, CDFW scientists determined that fish rescues were not necessary.

Water temperatures in streams with Goose Lake Redband Trout were generally cooler in 2016 than in 2015. Daily average water temperatures in Lassen and Willow creeks exceeded 21 °C in 2015, while water temperatures in Cold Creek did not exceed 17 °C (Figure 1.3.2). Average water temperatures in Lassen and Willow creeks appeared to be higher than those observed in previous years (Tate et al. 2005). While

PLATE 1.3.11.
Fish and reptile rescue efforts on Clover Creek, Shasta County, as a result of fish passage project June-September 2016. None of the rescued fish were salmon or steelhead. Photo: CDFW.

dissolved oxygen was not monitored continuously, levels were expected to be generally adequate for fish survival. Dissolved oxygen measurements in Willow Creek ranged between 5 mg/L and 10 mg/L, sufficient for the survival of Goose Lake Redband Trout throughout the summer. Goose Lake Redband Trout were observed to be in good condition at all sites monitored in 2016. In general, stream conditions were adequate through the dry season and did not warrant any emergency actions.

Pit River watershed

Seven streams in the upper Pit River Watershed that provide critical habitat to Modoc Sucker were monitored during the drought period. Johnson, upper Coffee Mill Gulch, Washington and Turner creeks all experienced reduced streamflow but maintained habitat connectivity. Reduced streamflow in Dutch Flat Creek created isolated pools. Hulbert Creek dried nearly completely, and only Cedar Creek, a small spring fed tributary, maintained adequate streamflow. In 2016, all streams, except for Hulbert Creek, maintained higher flows or larger and more numerous pools than recorded in 2015.

At all sites, despite reduced streamflow, water temperatures remained lower than 25 °C and thus suitable for Modoc Sucker (Moyle 2002). Dissolved oxygen levels were also adequate for the survival of Modoc Sucker and other fish species, such as rainbow trout and Speckled Dace. It was noted that Modoc Sucker were restricted to isolated or deeper pools, which may be a typical behavior pattern for this species, even under normal conditions (Reid 2008). CDFW scientists did not observe any mortalities of Modoc Sucker or other fish species. Because of the improved conditions, no further management actions were needed to protect the species.

Sacramento River watershed

CDFW scientists monitored water temperature, streamflow, and the potential need for fish rescues in four streams (Middle, Salt, Clear, and Clover creeks) within the Sacramento River Watershed (Figure 1.3.1). All four streams were sensitive to the impacts of drought and exhibited low summer flows, and sometimes completely dried out. Middle and Salt creeks are usually seasonal and become fragmented or go completely dry before the end of July. The extended drought resulted in reduced quantity and duration of streamflow, severely limited the number of out-migrating fish. Middle and Salt creeks dried significantly earlier in the year than in normal water years. Clover and Clear creeks maintained their connectivity but had severely reduced flows. These conditions resulted in some fish kills and caused CDFW to perform several rescues. Clover, Middle, and Salt creeks saw high water temperatures and low streamflow, often leading to dry reaches.

Scott and Shasta River watersheds

The Scott River and Shasta River watersheds have been monitored continuously for many years. Ongoing monitoring includes surveys for spawning adult fish, trapping outmigrating juveniles, water temperature monitoring, streamflow assessment, fish rescue evaluation, and PIT[9] tag monitoring of the movements of juvenile salmon and trout. To assess if drought conditions merited a more extreme fish rescue approach, CDFW increased monitoring levels from early May 2014 through 2016.

Average daily water temperature on the mainstem Scott River from 2014-2015 ranged from 14.1°C to 25.2 °C. Stream reaches with hyporheic flow, a process through which surface water is cooled through mixing with shallow groundwater, recorded the lowest water temperatures. Streamflow in the canyon reach of the Scott River during 2016, measured at the USGS flow gauge, ranged from 1.9 cfs in late-August to 6,990 cfs in December.

During the monitoring period, Coho Salmon juveniles in the mainstem Scott River were restricted to isolated pools, where some fish were able to survive. However, in 2014, due to concerns about the largest run in ten years (2752 adult Coho Salmon), declining water quality, and drying stream reaches, it was necessary to relocate approximately 116,000 juvenile Coho Salmon. In 2015, 4,100 Coho Salmon were relocated as drought conditions were less severe. In the summer of 2016, CDFW scientists relocated approximately 240 juvenile Coho Salmon and 13,000 juvenile steelhead in the Scott River watershed. Out of the 3,685 juvenile Coho Salmon that were PIT tagged prior to relocation during the 2014 drought effort, only seven percent (246 individuals) are known to have survived to February 2015, the beginning of the outmigration season. In addition, when this cohort returned to the Scott River as adults in 2016, only 226 individuals were documented. The run size of this cohort had dropped by over 90% following the drought year relocation effort (Figure 1.3.3). Both metrics indicate a very low survival rate, despite the relocation efforts.

In the Shasta River, low summer streamflow during the drought also led to high water temperatures. Baseflows at the confluence with the Klamath River were the lowest ever recorded (less than 5 cfs). Maximum daily water temperatures during most of the summer remained above 18 °C. Temperatures above this are known to compromise the survival of Coho Salmon (Stenhouse et al. 2012); however, without long-term temperature data and a baseline dataset, it is difficult to determine whether the streams were becoming warmer in response to the drought conditions. In 2016 CDFW scientists did not initiate any fish rescues in the Shasta River. Throughout 2016, CDFW scientists also monitored McCloud Redband Trout in Edson, Moosehead, Sheepheaven, and Swamp creeks (Figure 1.3.1).

Trinity River watershed

CDFW scientists monitored nine streams in the Trinity River basin for water temperature, streamflow, and to evaluate the need for potential fish rescue. All nine streams (Reading, Indian, Rush, East Weaver, West Weaver, Weaver, Canyon, Browns, and Deadwood creeks) were identified as containing critical fish habitat. Streamflow was significantly reduced in all streams, forming isolated pools or, in some cases, causing the creeks to dry out completely. Despite reduced streamflow in Deadwood, Indian, Rush, and Canyon creeks, water temperature remained suitable for the survival of Coho Salmon and steelhead. Browns Creek dried out completely in many reaches during the drought. According to landowners, this was the first time this had happened in forty years.

CDFW scientists monitored water temperature and streamflow in Indian and Reading creeks from January 2016 through October 2016. In January, both creeks had high flows (30 cfs to 50 cfs), due to increased precipitation. Water temperatures ranged from 7.2 °C in January to 10.0 °C in October. In summer, streamflow remained between 2 cfs and 12 cfs and water temperatures between 15.6 °C and 21.1 °C; however, water quality and water temperatures were generally suitable for fish survival. Streamflow in upper Indian Creek during September declined to roughly 2 cfs, but water temperatures remained adequate for fish survival. In 2016, fish rescues were not needed in either Indian Creek or Reading Creek.

PLATE 1.3.12. Wild produced McCloud Redband offspring in a raising trough with artificial habitat at the Mount Shasta Hatchery on August 25, 2016. Photo: CDFW.

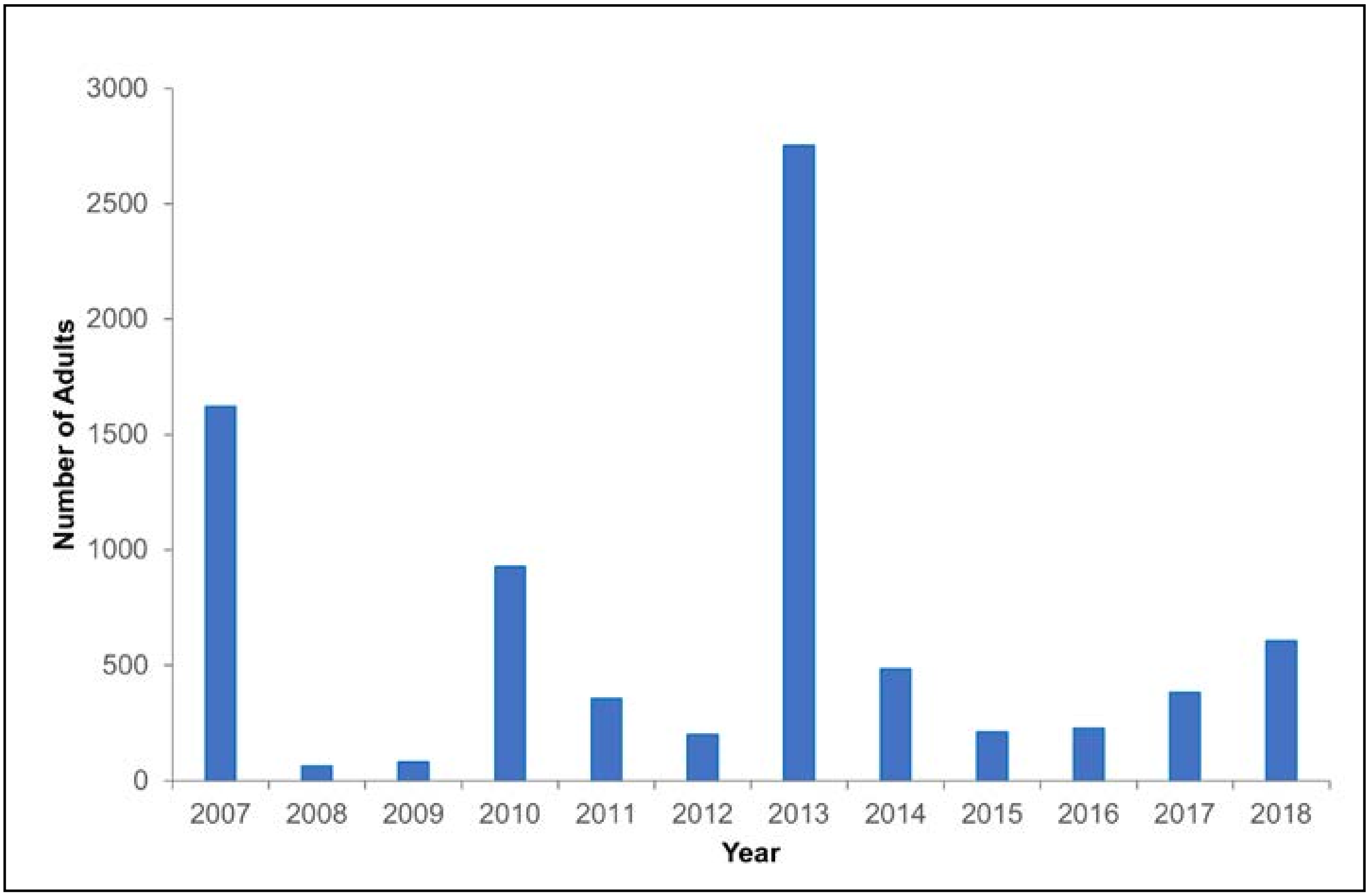


FIGURE 1.3.3. Number of adult Coho Salmon returning to the Scott River watershed from 2007 to 2018. Despite record returns in 2013, the offspring of those fish experienced drought conditions leading to a 90% drop in run size when those fish returned in 2015.

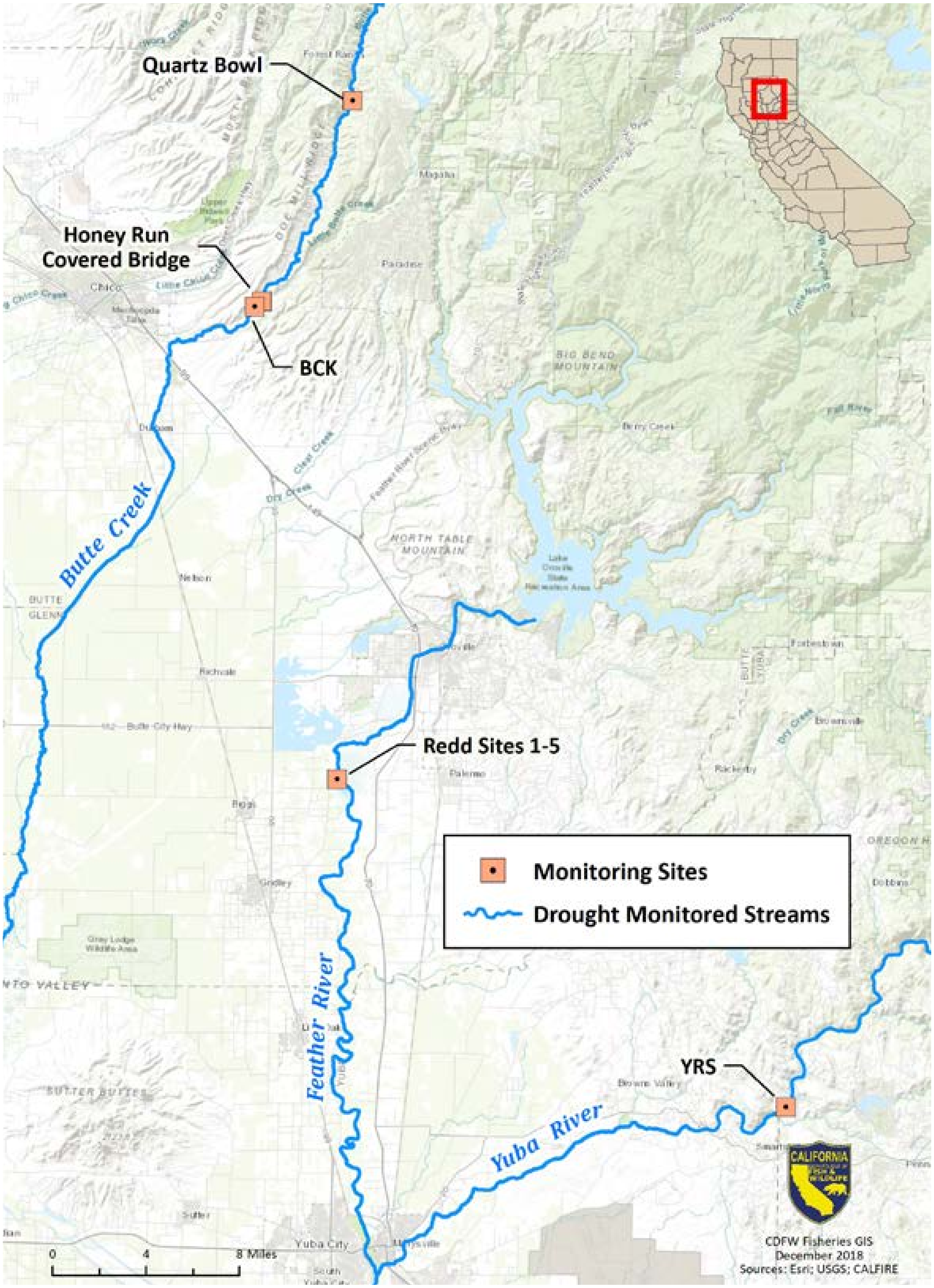
CHAPTER TWO

North Central Region

The North Central Region covers seventeen counties east of the San Francisco Bay area to the California-Nevada state line. These include Alpine, Amador, Butte, Calaveras, Colusa, El Dorado, Glenn, Lake, Nevada, Placer, Plumas, Sacramento, San Joaquin, Sierra, Sutter, Yolo and Yuba counties. The region includes rivers that drain from both the west and east sides of the Sierra Nevada mountain range. West-draining watersheds include the Feather, Yuba, American, Mokelumne, and Consumes rivers, which all flow into either the Sacramento or San Joaquin rivers. The west-draining rivers provide important habitat for salmon and steelhead.

The east-draining watersheds flow into the Lahontan Basin of Nevada and include the Truckee and Carson rivers. These rivers provide valuable habitat for Lahontan Cutthroat Trout and other native fishes. During the winter months, precipitation occurs as snow at higher elevations and rain at lower elevations. This gives way to hot and dry conditions during the summer months, resulting in cold, fast-moving rivers which flow down from the Sierra Nevada to the valleys below. Dam construction for agricultural and municipal uses has reduced the amount of salmon and steelhead habitat and altered the timing and quantity of streamflow. These activities have impacted both water quality and the ability of fish to migrate, spawn, and rear. The multi-year drought further affected the Region's fisheries resources through reduced streamflow and warmer water temperatures.

FIGURE 2.1.1.
Location of Drought Stressor Monitoring sites on Butte Creek, Feather River, and Yuba River. Efforts included California Data Exchange Center monitoring stations at Yuba River near Smartville (YRS) and Butte Creek (BCK).



2.1 CENTRAL VALLEY WATERSHEDS

Species Focus and Location Description

Monitoring in rivers which drain west from the Sierra Nevada focused on areas which contain populations of state and federal threatened spring-run Chinook Salmon and steelhead, as well as Central Valley fall-run Chinook Salmon. The watersheds monitored included Butte and Big Chico creeks and the Feather, Yuba, and American rivers (Figures 2.1.1 and 2.1.2).

Salmon and steelhead in these rivers require sufficient cold, clean water for spawning and rearing prior to migrating to the ocean to grow and mature. Fall-run Chinook Salmon migrate from the ocean into streams and rivers in autumn and spawn soon thereafter. In comparison, adult spring-run Chinook Salmon migrate to freshwater in spring, but spend more time "holding" in river habitat before spawning in early fall. Likewise, the duration of juvenile rearing is different between the two runs of Chinook Salmon. Juvenile spring-run Chinook Salmon spend more time (some more than one year) in freshwater compared to juvenile fall-run Chinook Salmon, which typically spend less than one year in freshwater prior to migrating to the ocean. This extended freshwater residency requires that both life stages of spring-run Chinook Salmon, especially adults, have access to deep, cool, highly oxygenated pools. Maintaining this habitat is critical during the hot summer months in the Central Valley, when human water demands are high.

Local Need for Drought Stressor Monitoring

The multi-year drought exacerbated the challenging conditions which already existed for salmon and steelhead in Central Valley rivers. Following sustained drought conditions, water levels in all large Central Valley reservoirs were very low. These conditions resulted in lower-than-normal river flows and higher-than-normal water temperatures. Increased water temperatures directly affect fish survival, growth rate, disease, distribution, and rate of development. To assess the potential impacts on salmonids in Central Valley watersheds, CDFW scientists conducted pre-spawning mortality surveys, spawning surveys, and water temperature monitoring.

Findings and Actions

Butte Creek

Historically, spring-run Chinook Salmon were widely distributed in most of the eastern tributaries of the Sacramento and San Joaquin rivers; however, large dams and water development projects have eliminated access to all but a few remaining tributaries (CDFG 1998). Butte Creek is one of only three Central Valley streams that continue to harbor a self-sustaining population of spring-run Chinook Salmon that is not dependent on support from a fish hatchery or another river system. The other two streams with self-sustaining populations of spring-run Chinook Salmon are Mill and Deer creeks.

CDFW scientists carried out surveys of pre-spawning Chinook Salmon mortality in Butte Creek during the summer holding period from 2014 to 2016. Thermographs were used to track stream temperatures during the hot summer holding period. As water temperatures increased during the summer months, spring-run Chinook Salmon tended to migrate farther upstream. Fish were seeking cooler refugia and avoided areas in the lower watershed with high water temperatures. Prolonged elevated water temperatures led to high pre-spawning mortalities (Figures 2.1.3 - 2.1.5). In 2014, there were a total of 232 Chinook Salmon mortalities in Butte Creek prior to spawning. Elevated water temperatures in Butte Creek in 2015 and 2016 caused the mortality of 432 and136 Chinook Salmon, respectively.

Big Chico Creek

CDFW scientists conducted multiple snorkel surveys of salmon in Big Chico Creek during the summer of 2016. In the entire creek, adult spring-run Chinook Salmon (20-25 in number) were observed holding in just one pool (Salmon Hole pool). However, by August, no live (or dead) spring-run Chinook Salmon were

FIGURE 2.1.2.
Locations of Drought Stressor Monitoring sites on the lower American River.

PLATE 2.1.1.
Summer spring-run Chinook Salmon holding habitat at Quartz Bowl Pool, Butte Creek. Photo: Clint Garman, CDFW.

seen. Water temperatures at Salmon Hole exceeded 20°C from late June to August, possibly resulting in fish kills or lack of spawning success.

Lower Yuba River

Redd surveys of Chinook Salmon were carried out during the 2014 spawning period. A total of 255 redds was observed in the lower Yuba River between the Narrows Pool and above Daguerre Point Dam. The first redd was observed on September 23, 2014. The majority of redds were observed during the week of October 10, 2014 (Table 2.1.1). Very few redds were constructed at the beginning of the survey.

As per the "Yuba River Accord"[10] flow schedule, streamflow was reduced by nearly 150 cfs on September 25, 2014. Shortly after, on September 27, 2014, streamflow and water surface elevation were incrementally increased through the remainder of the survey (Figure 2.1.6). Consequently, it was unlikely that any dewatering of spring-run Chinook Salmon redds occurred during the survey period. There was no sampling in the lower Yuba River in either 2015 or 2016, as resources were focused on other rivers and tributaries.

Lower American River

Before the construction of the Folsom and Nimbus dams in the mid-1950s, fall-run Chinook Salmon and steelhead were able to migrate and spawn in the upper reaches of the American River. In the upper reaches, streamflow was cooled by spring and summer snow melt. Following the construction of the dams, salmon and steelhead were restricted to a 10-mile section of the lower American River below Nimbus Dam, and as a result, the populations of both species have declined significantly in recent years.

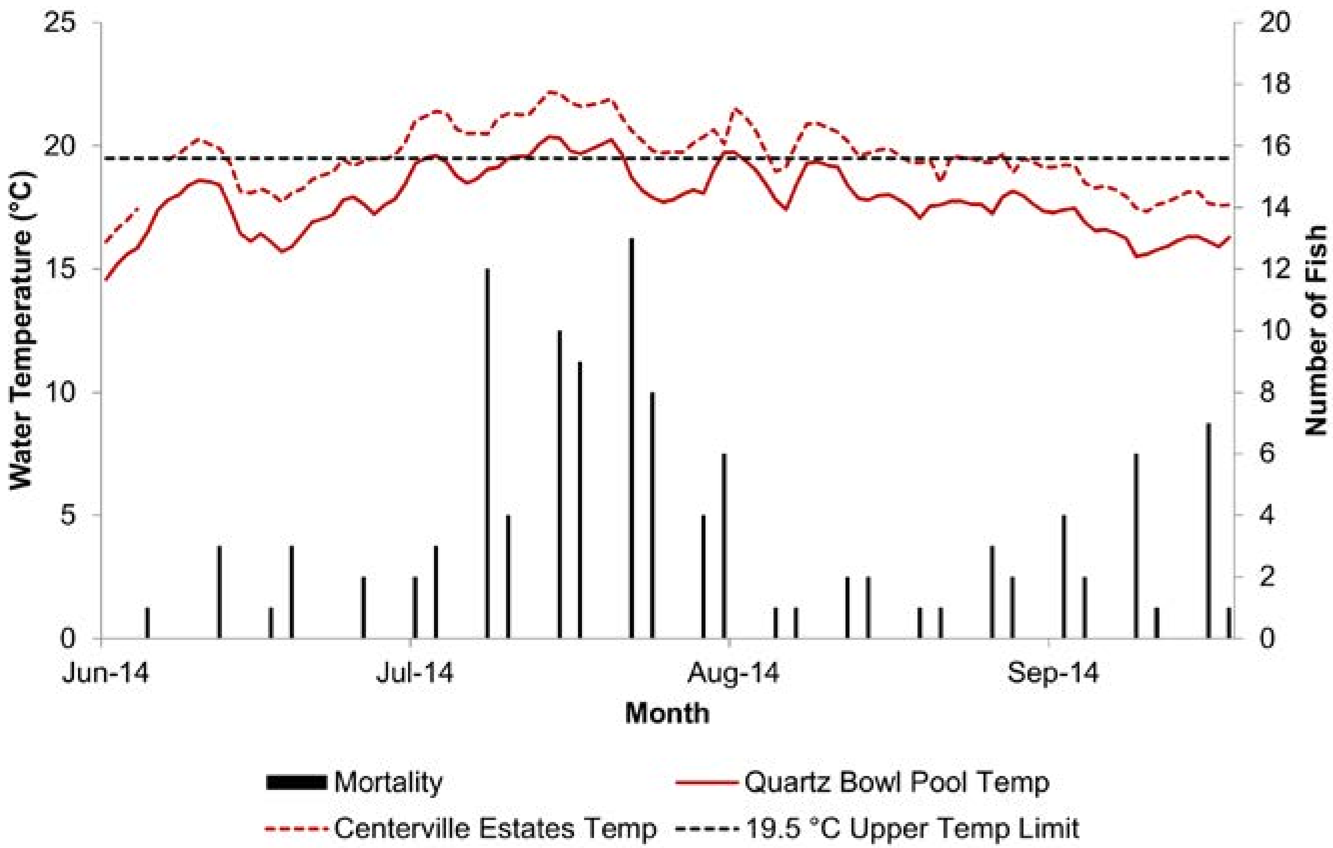


FIGURE 2.1.3.
Mean daily water temperature and daily observed pre-spawning mortality of spring-run Chinook Salmon in Butte Creek between 1 June and 17 September 2014.

Monitoring by CDFW scientists showed that water temperatures at all sites during the summers of 2014, 2015 and 2016 regularly exceeded the 18.3°C summer (May 15 – early October) target maximum for steelhead and 15.6 °C October target maximum for fall-run Chinook Salmon detailed in the Lower American River Flow Management Standard (Water Forum 2006). Water was consistently cooler at the uppermost sites near the dam and warmed as it moved downriver. Water temperatures at the confluence with the Sacramento River exceeded 22.8°C for several days in 2014 and reached a maximum of 23.9°C in 2015 (Figure 2.1.7). In 2016, monthly temperatures were lower than the previous two years; however, during the months of August and September, water temperatures at all sites were greater than the target maximum and the confluence with the Sacramento River exceeded 20.0°C. Due to high water temperatures at these critical times, it is possible that there were significant adverse drought related effects on salmon populations in the river.

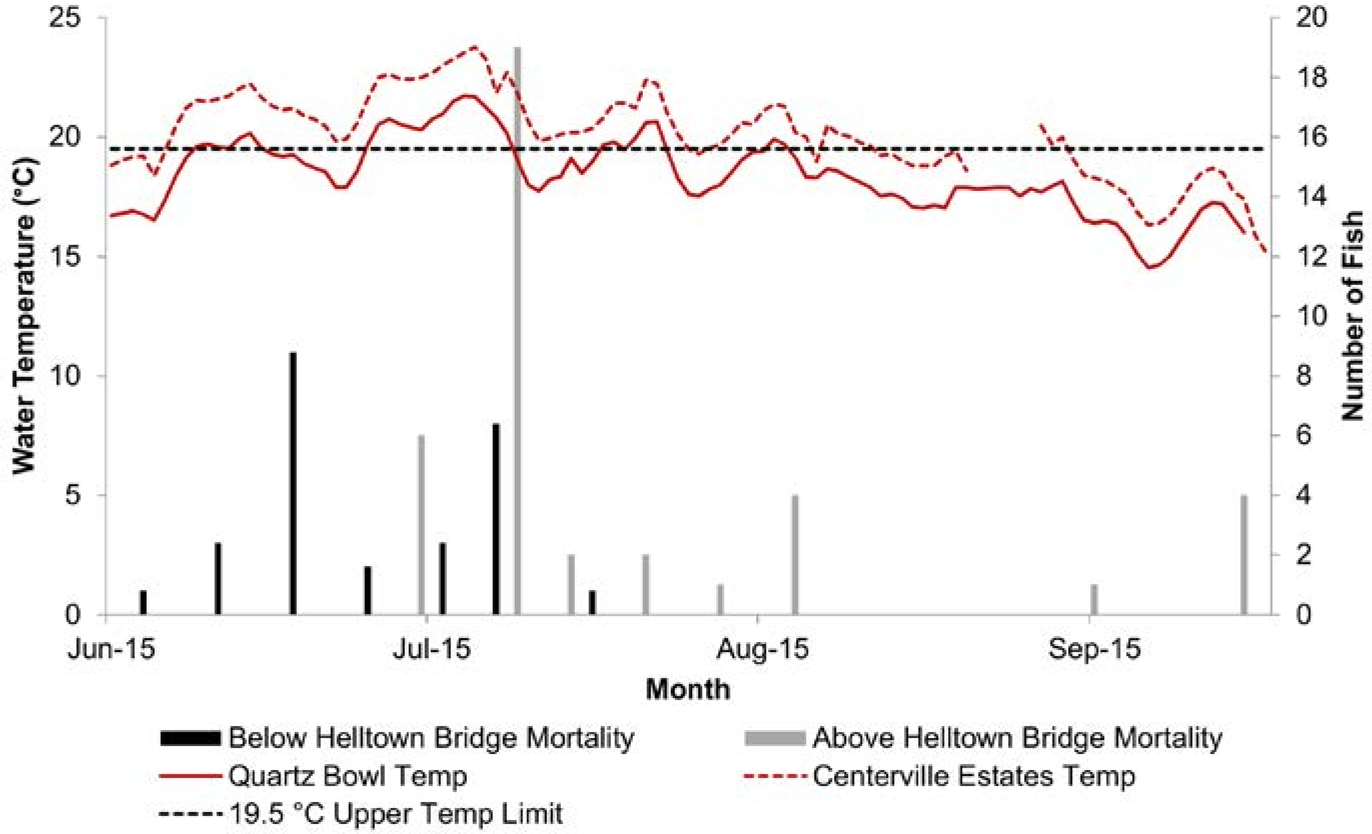


FIGURE 2.1.4.
Mean daily water temperature and daily observed pre-spawning mortality of spring-run Chinook Salmon in Butte Creek between 1 June and 17 September 2015.

TABLE 2.1.1.
Number of Chinook Salmon redds observed each week in the lower Yuba River.

Week of sampling	Number of Redds observed from Narrows Pool to Picnic Area	Number of Redds observed from Picnic Area to Daguerre Point Dam
9/23/2014	1	0
10/3/2014	14	6
10/10/2014	62	60
10/17/2014	17	N/A
10/24/2014	24	41
Total	**118**	**107**

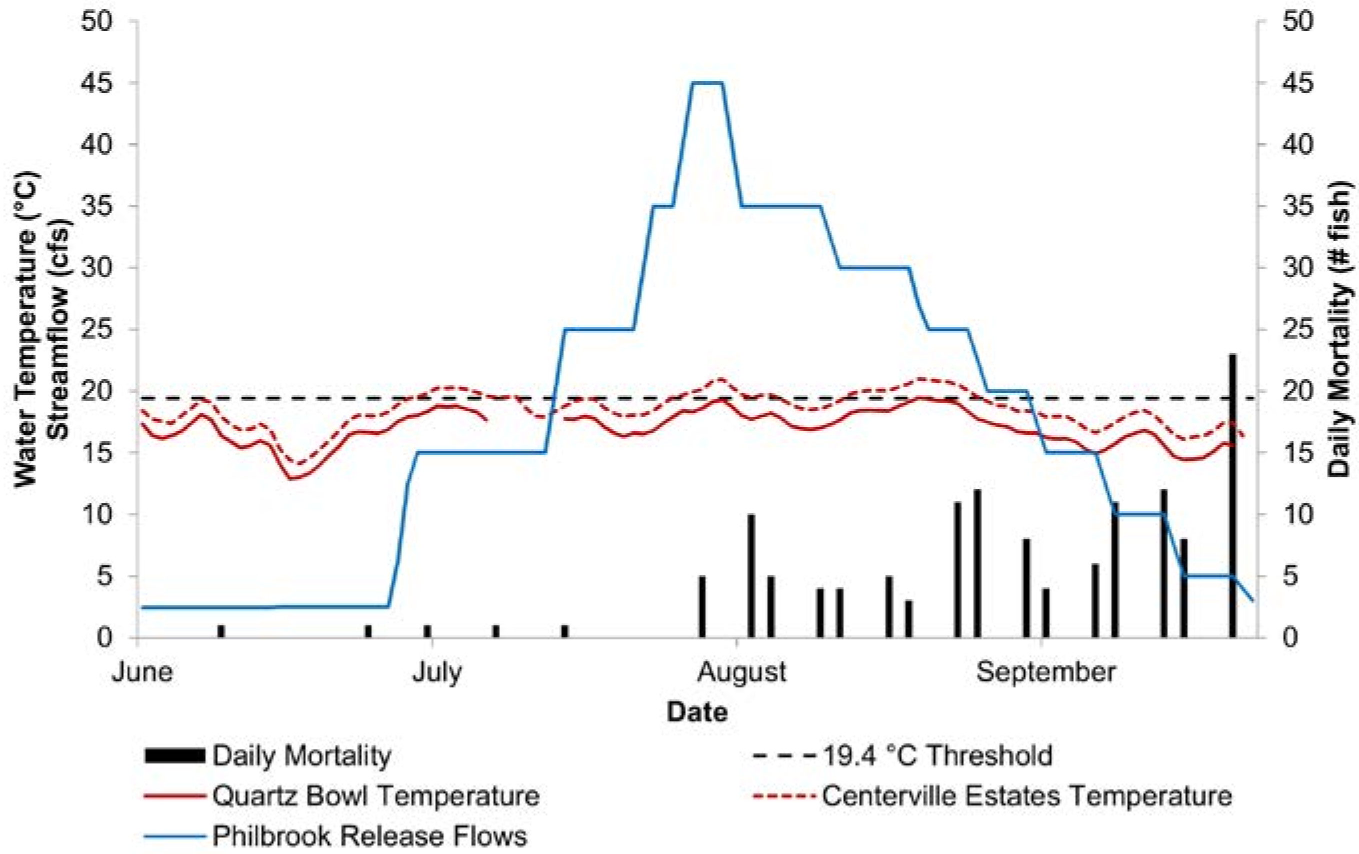
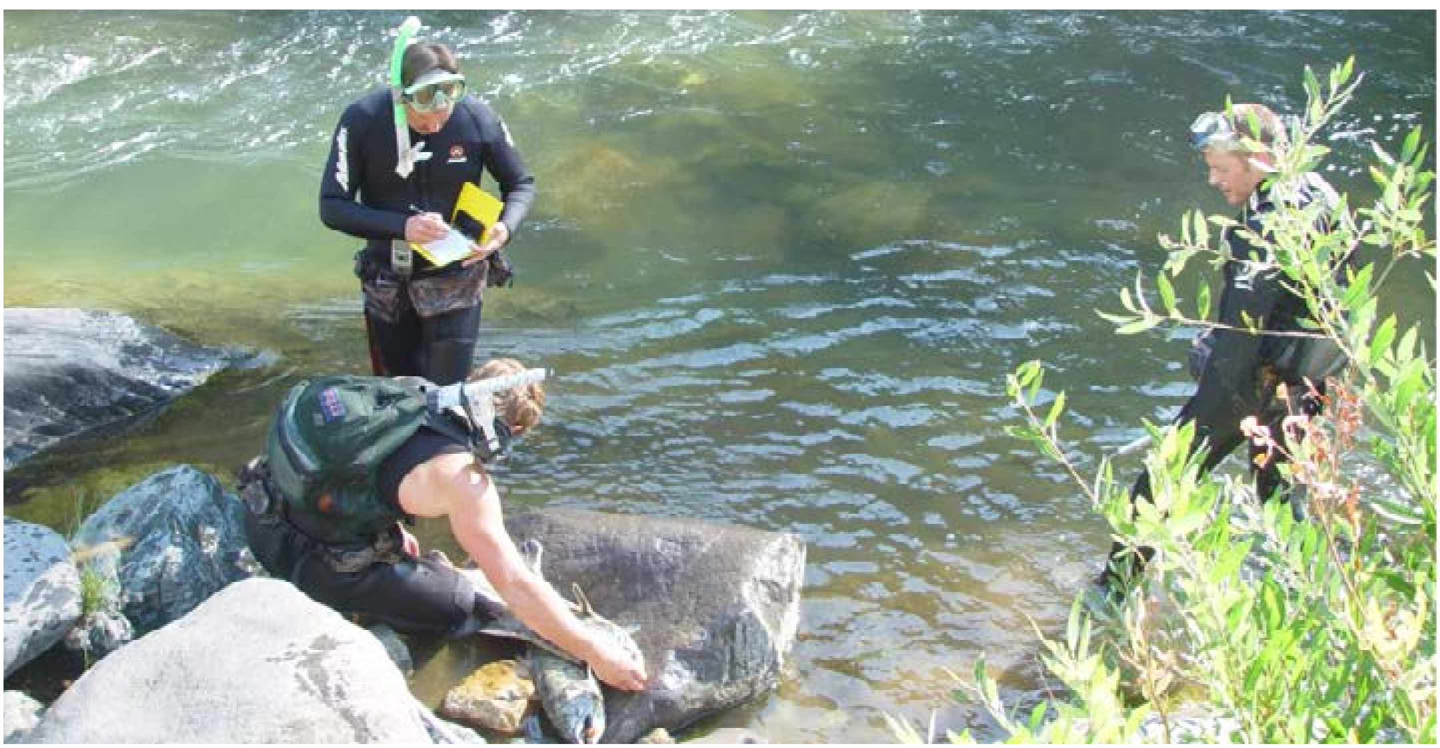
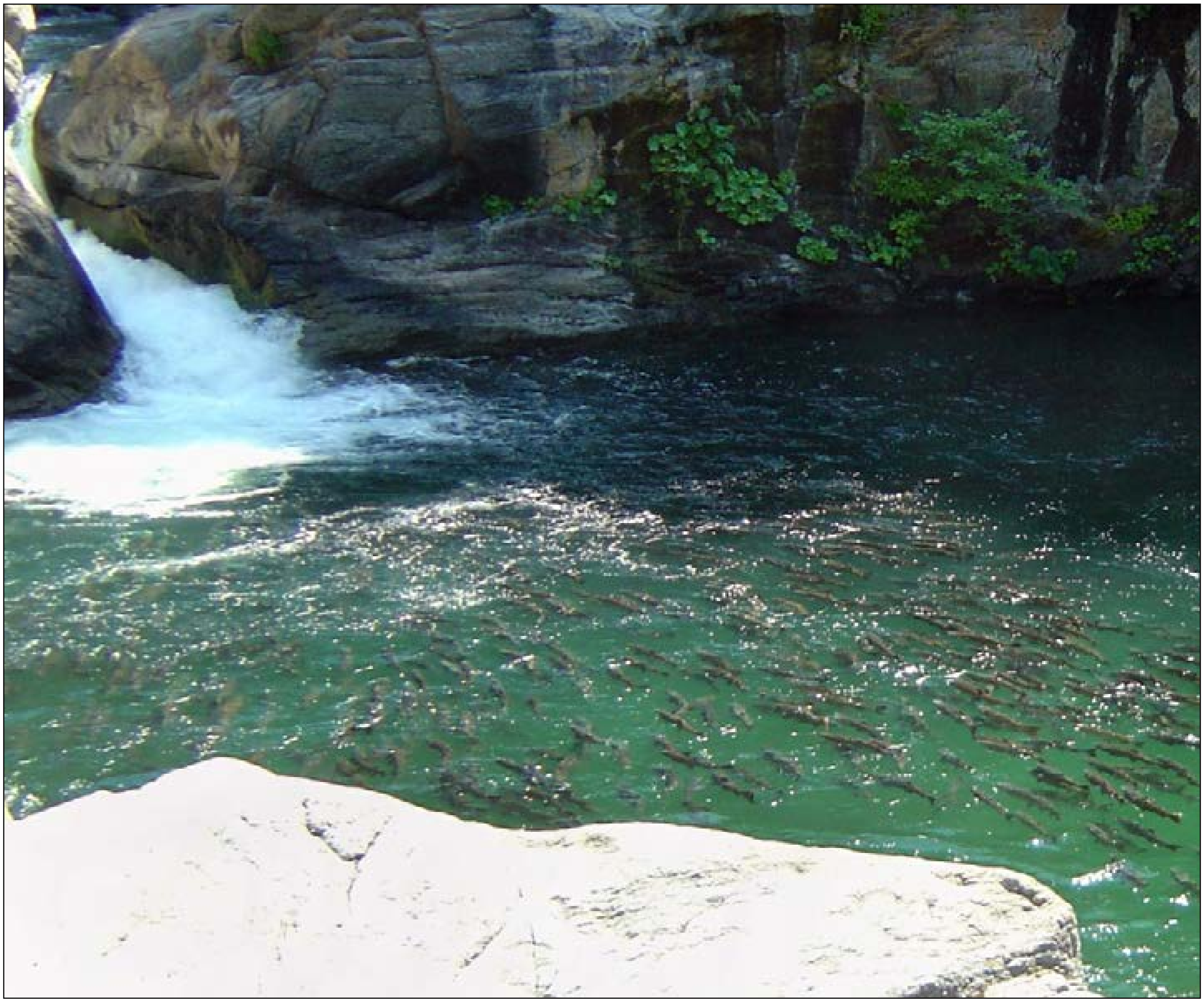


FIGURE 2.1.5.
Water temperature, flow, and daily observed pre-spawning mortality of spring-run Chinook Salmon in Butte Creek in summer of 2016.





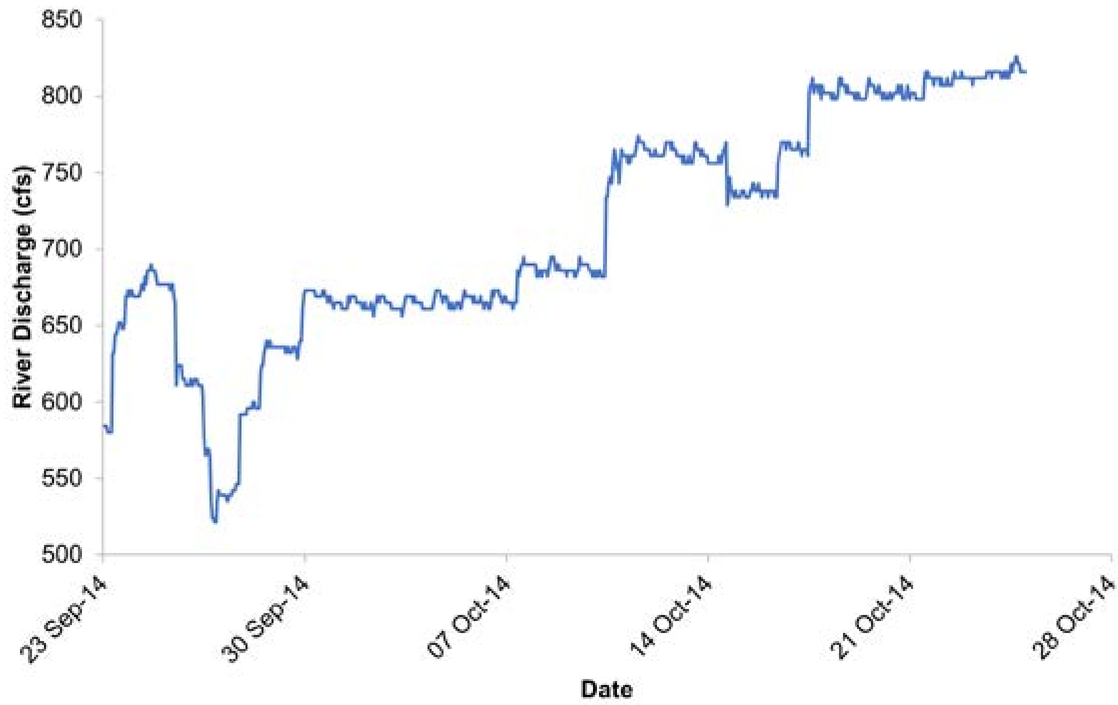


FIGURE 2.1.6.
River flow rate between 23 September and 25 October, 2014, at Smartville gauging station in lower Yuba River (YRS station, California Data Exchange Center).

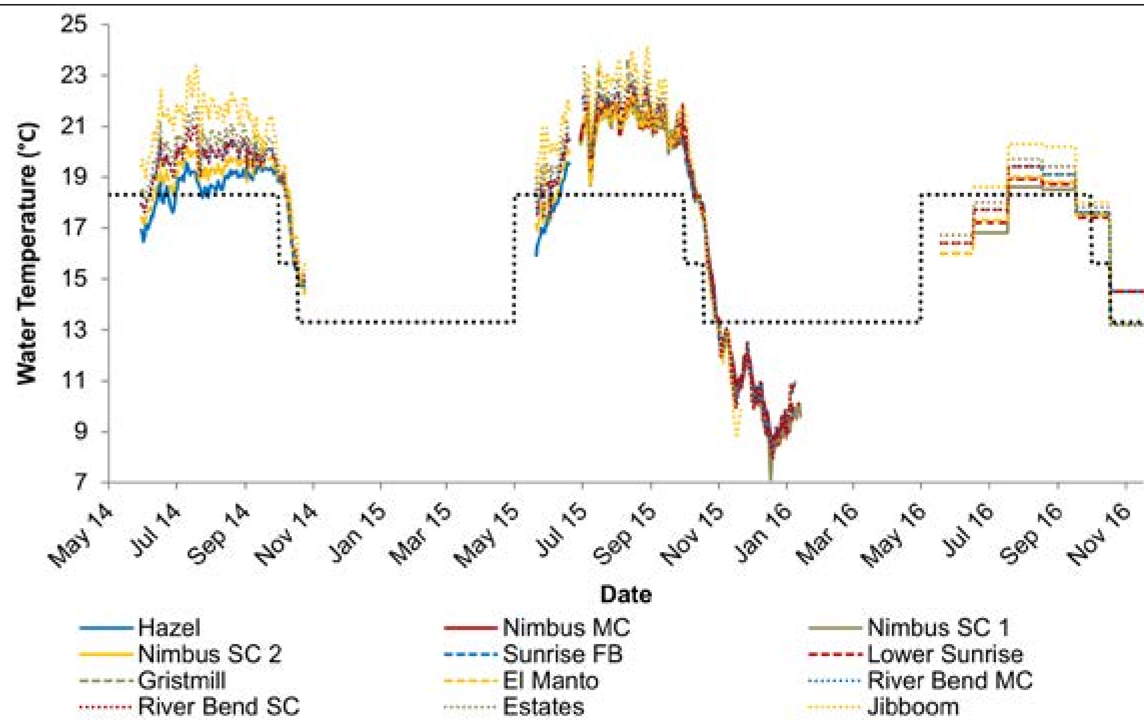


FIGURE 2.1.7.
Mean daily (2014, 2015) and monthly (2016) water temperature at monitoring sites on the lower American River. Black dotted line indicates the target temperatures at Watt Avenue Bridge (1.4 km downstream of "Estates" site) in summer (18.3 °C), October (15.6 °C), and late fall/winter (13.3 °C) for steelhead and fall-run Chinook Salmon spawning and rearing. MC = main channel, SC = side channel.

2.2 INLAND WATERSHEDS

Species Focus and Location Description

The Lahontan Cutthroat Trout is one of two endemic trout species on the eastern side of the Sierra Nevada. The geographic range of the species extends from northeastern California and northern Nevada into southern Oregon. Lahontan Cutthroat Trout are listed under the federal Endangered Species Act as threatened and are also a state-listed Species of Special Concern. Over the last century, populations have declined considerably, and efforts are now underway to recover and conserve the species.

CDFW scientists from the North Central Region carried out drought monitoring in eight high priority headwater streams across three counties. The streams monitored included Pole Creek, a tributary of the Truckee River in Placer County (Figure 2.2.1), Macklin Creek, East Fork Creek in Austin Meadow, and an unnamed tributary to East Fork Creek, located in Nevada County (Figures 2.2.2, 2.2.3). Streams monitored in Alpine County included an unnamed tributary of Pacific Creek in Marshall Canyon, and an unnamed tributary of the North Fork Mokelumne River in Milk Ranch Meadow (Figure 2.2.4). In addition, a one-day monitoring survey was carried out at a site in Pacific Creek, Alpine County.

Local Need for Drought Stressor Monitoring

The existing native trout populations in the monitored headwater streams are isolated from downstream non-native trout populations by natural waterfalls. The small size of the headwater habitats puts the native trout populations at risk, especially under drought conditions, when stream reaches can dry out completely.

Findings and Actions

Habitat and population monitoring

While all streams had flowing water throughout the

TABLE 2.2.1.
The total number Lahontan Cutthroat Trout observed at survey reaches in the North Central Region during the summer of 2015.

WATER	DATE(S) SURVEYED	NUMBER OF TROUT
Pole Creek	7/15/2015	200
Pole Creek	8/13/2015	230
Macklin Creek	7/14/2015	31
Macklin Creek	8/12/2015	209
East Fork Creek (Austin Meadow)	7/13/2015	86
East Fork Creek (Austin Meadow)	8/11/2015	52
East Fork Creek (Austin Meadow)	10/20/2015	44
Unnamed tributary to East Fork Creek	7/14/2015	75
Unnamed tributary to East Fork Creek	8/11/2015	90
Pacific Creek	7/7/2015	29
Unnamed Tributary in Milk Ranch Meadow	7/8/2015	36
Unnamed Tributary in Milk Ranch Meadow	7/21/2015	22
Unnamed Tributary in Marshall Canyon	7/22/2015	14

FIGURE 2.2.1.
Location of the reaches in which population surveys for Lahontan Cutthroat Trout were conducted in Pole Creek, Placer County, in 2015 and 2016.

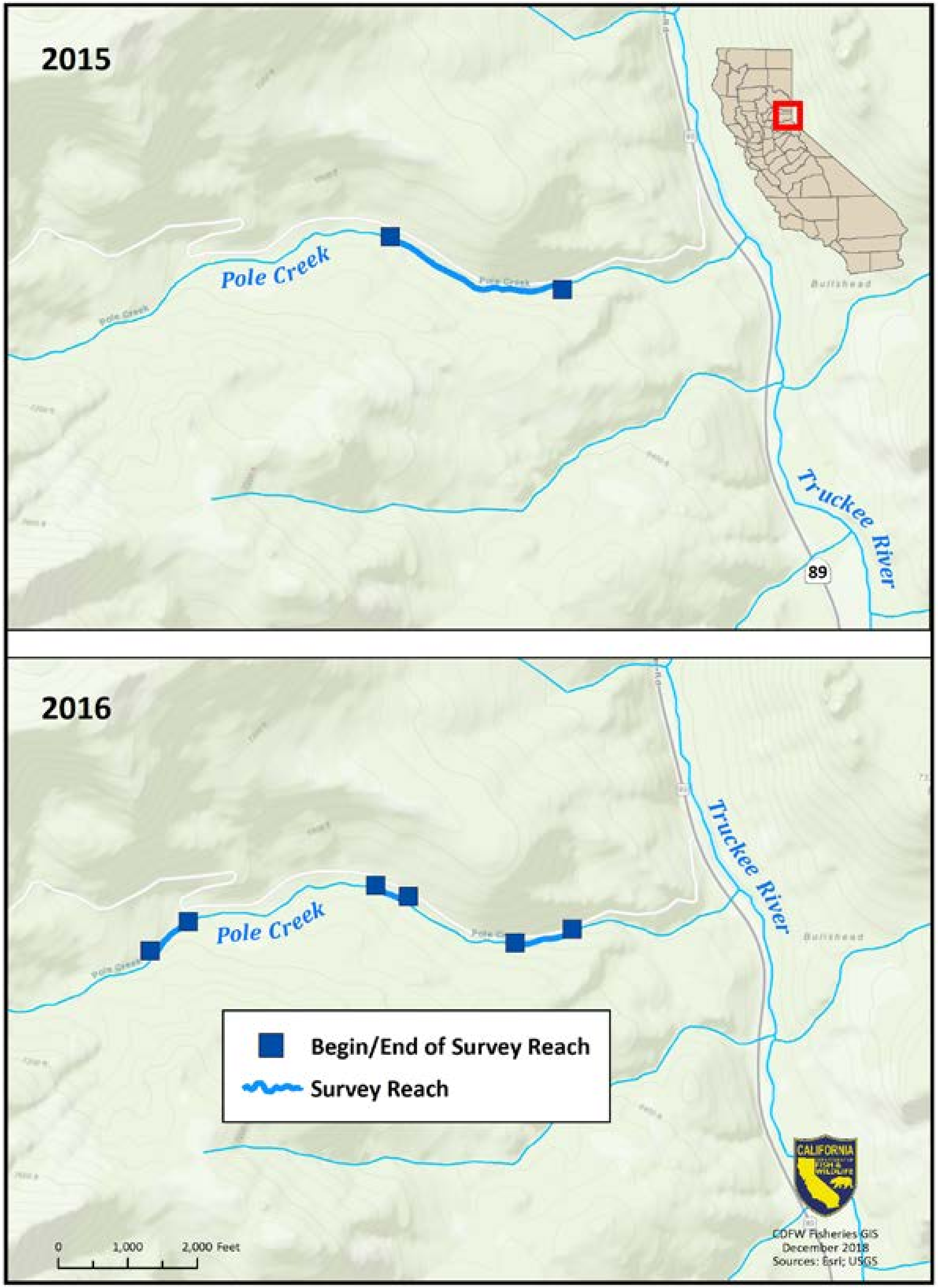


PLATE 2.2.1. **Monitored stream habitat at East Fork Creek, Austin Meadow, Nevada County, California October 20, 2015. Photo: John Hanson, CDFW.**

drought, approximately two-thirds of the available habitat in the streams went partially dry. This resulted in an overall decrease in trout numbers. As streamflow decreased over the summer, water temperatures generally increased, potentially increasing stress levels for fish and other aquatic life.

The small numbers of trout that were observed were not substantially lower than typically found during an average or above average water year, so any adverse drought effects may not have been severe. Surveys carried out between 2013 and 2015 indicated that Lahontan Cutthroat Trout populations survived well in each of the monitored steams and were able to endure the severe drought conditions. The low number of Lahontan Cutthroat Trout collected in Unnamed Tributary to East Fork Creek was likely due to dense alder trees in the stream channel that inhibited access for electrofishing surveys.

All streams with suitable habitat for Lahontan Cutthroat Trout maintained adequate streamflow during summer 2015, although some habitat in Austin Meadow was eliminated by the effects of the drought. In Austin Meadow Creek, approximately one-third of the habitat available for Lahontan Cutthroat Trout went dry. Lahontan Cutthroat Trout were recorded in all the monitored streams, with the highest numbers being recorded in Pole, Macklin and Austin Meadow creeks (Table 2.2.1). The mean total length of trout captured in Pole Creek and Austin Meadow Creek was 179 mm and 141 mm, respectively.

FIGURE 2.2.2.
Location of Lahontan Cutthroat Trout observations and Drought Stressor Monitoring sites in East Fork Creek, Austin Meadow, Nevada County, 2015

FIGURE 2.2.3.
Location of the reaches in which population surveys for Lahontan Cutthroat Trout were conducted in Macklin Creek and in the Unnamed Tributary to East Fork Creek, Nevada County, in 2015 and 2016.

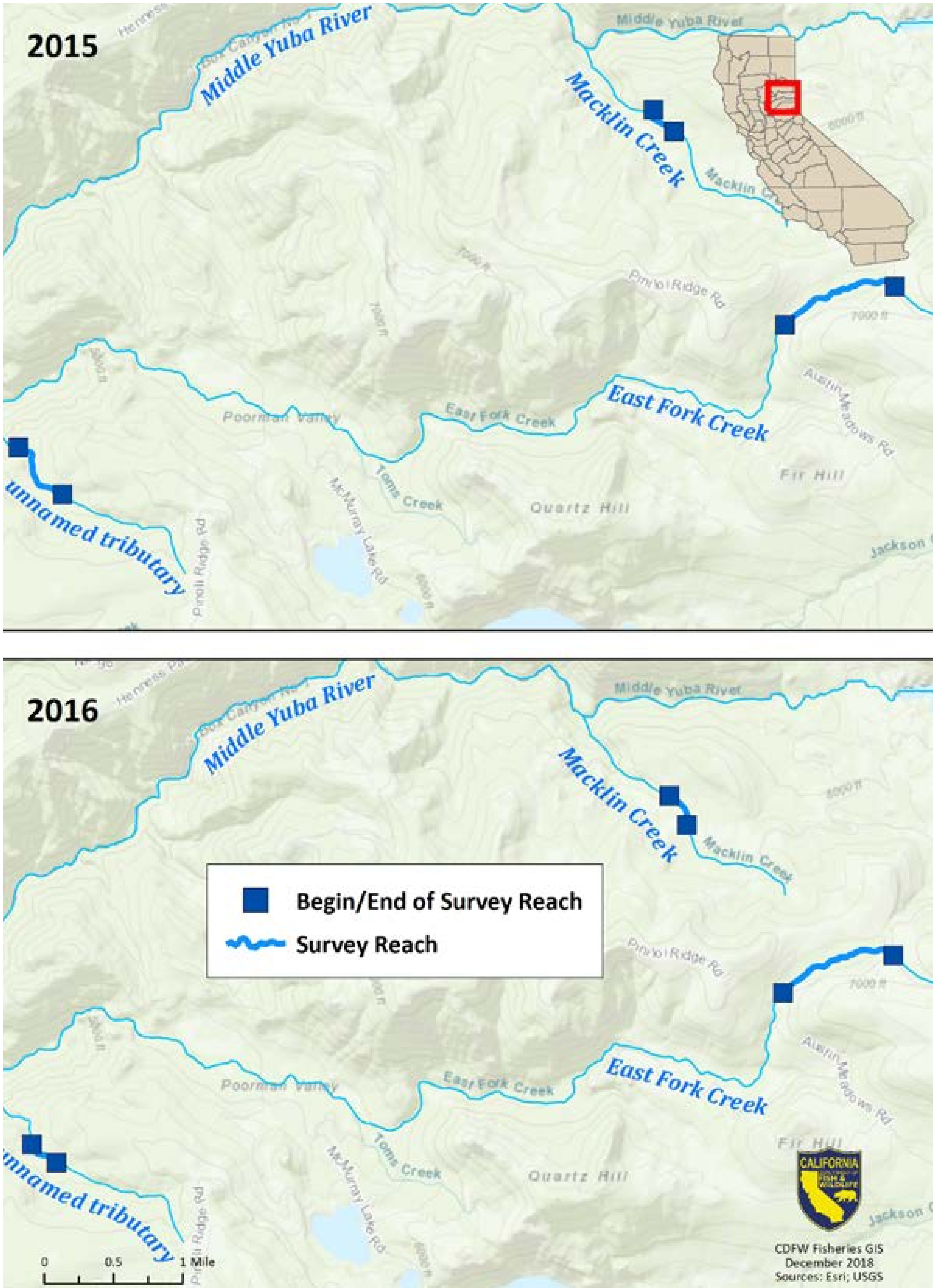


PLATE 2.2.2. CDFW scientist monitoring water quality in the unnamed tributary in Marshall Canyon, Alpine County on July 22, 2015. Photo: Nick Hood, CDFW.

PLATE 2.2.3. CDFW scientist monitoring water quality in the unnamed tributary Milk Ranch Meadow, Alpine County on July 21, 2015. Photo: Nick Hood, CDFW.

FIGURE 2.2.4.
Location of the reaches in which population surveys for Lahontan Cutthroat Trout were conducted in Pacific Creek, an unnamed tributary in Marshall Canyon, and an unnamed tributary of the North Fork Mokelumne River in Milk Ranch Meadow in Alpine County, California, in 2015 and 2016.

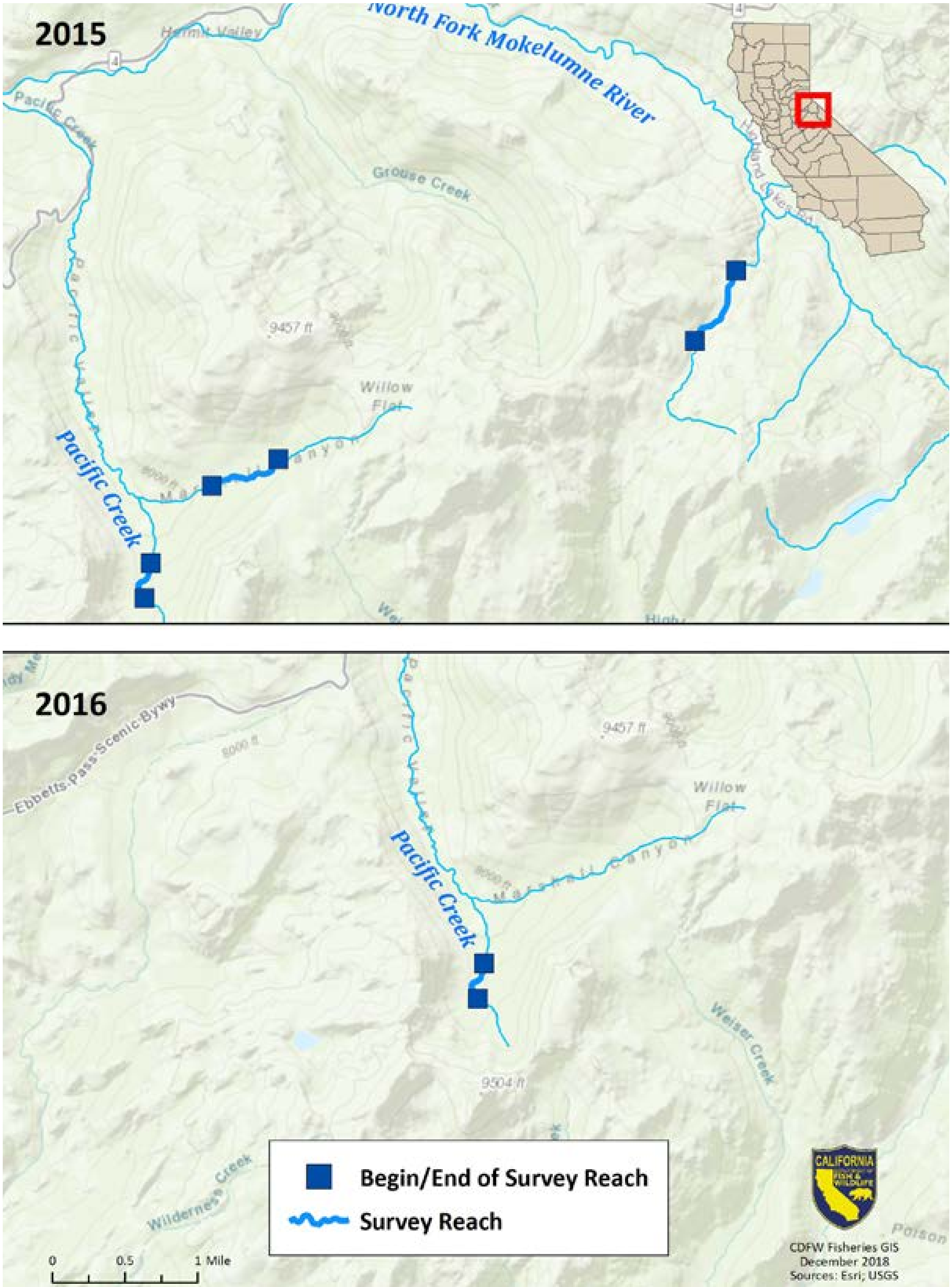


TABLE 2.2.1.
The number of total Lahontan Cutthroat Trout observed at survey reaches in the North Central Region during the summer of 2015.

WATER	DATE(S) SURVEYED	NUMBER OF TROUT
Pole Creek	7/15/2015	200
Pole Creek	8/13/2015	230
Macklin Creek	7/14/2015	31
Macklin Creek	8/12/2015	209
East Fork Creek (Austin Meadow)	7/13/2015	86
East Fork Creek (Austin Meadow)	8/11/2015	52
East Fork Creek (Austin Meadow)	10/20/2015	44
Unnamed tributary to East Fork Creek	7/14/2015	75
Unnamed tributary to East Fork Creek	8/11/2015	90
Pacific Creek	7/7/2015	29
Unnamed Tributary in Milk Ranch Meadow	7/8/2015	36
Unnamed Tributary in Milk Ranch Meadow	7/21/2015	22
Unnamed Tributary in Marshall Canyon	7/22/2015	14

CHAPTER THREE

Bay Delta Region

The Bay Delta Region consists of thirteen counties within the California Central Coast in the San Francisco Bay and Delta areas. These include the following counties: Alameda, Contra Costa, Marin, Napa, San Mateo, Santa Clara, Santa Cruz, San Francisco, Solano, Sonoma, as well as portions of counties located west of Interstate highway 5 (San Joaquin, Sacramento, and Yolo counties). Salmon and steelhead populations in all these areas have showed significant declines in recent years. Coho Salmon, Chinook Salmon, and steelhead in this region are all listed under the state and/or federal Endangered Species Acts.

3.1 NORTH OF SAN FRANCISCO BAY WATERSHEDS

Species Focus and Location Description

Drought Stressor Monitoring efforts north of San Francisco Bay focused on coastal watersheds in Marin, Sonoma, Mendocino, and Napa counties. Monitoring initially focused on the Russian River, Salmon Creek, Sonoma Creek, Napa River, Walker Creek, and Lagunitas Creek (Figure 3.1.1). These streams were selected because of pre-existing programs to restore habitat, monitor drought conditions, and recover salmon and steelhead

FIGURE 3.1.1.
Locations of priority streams for Chinook Salmon, Coho Salmon, and steelhead north of San Francisco during 2014-2015.

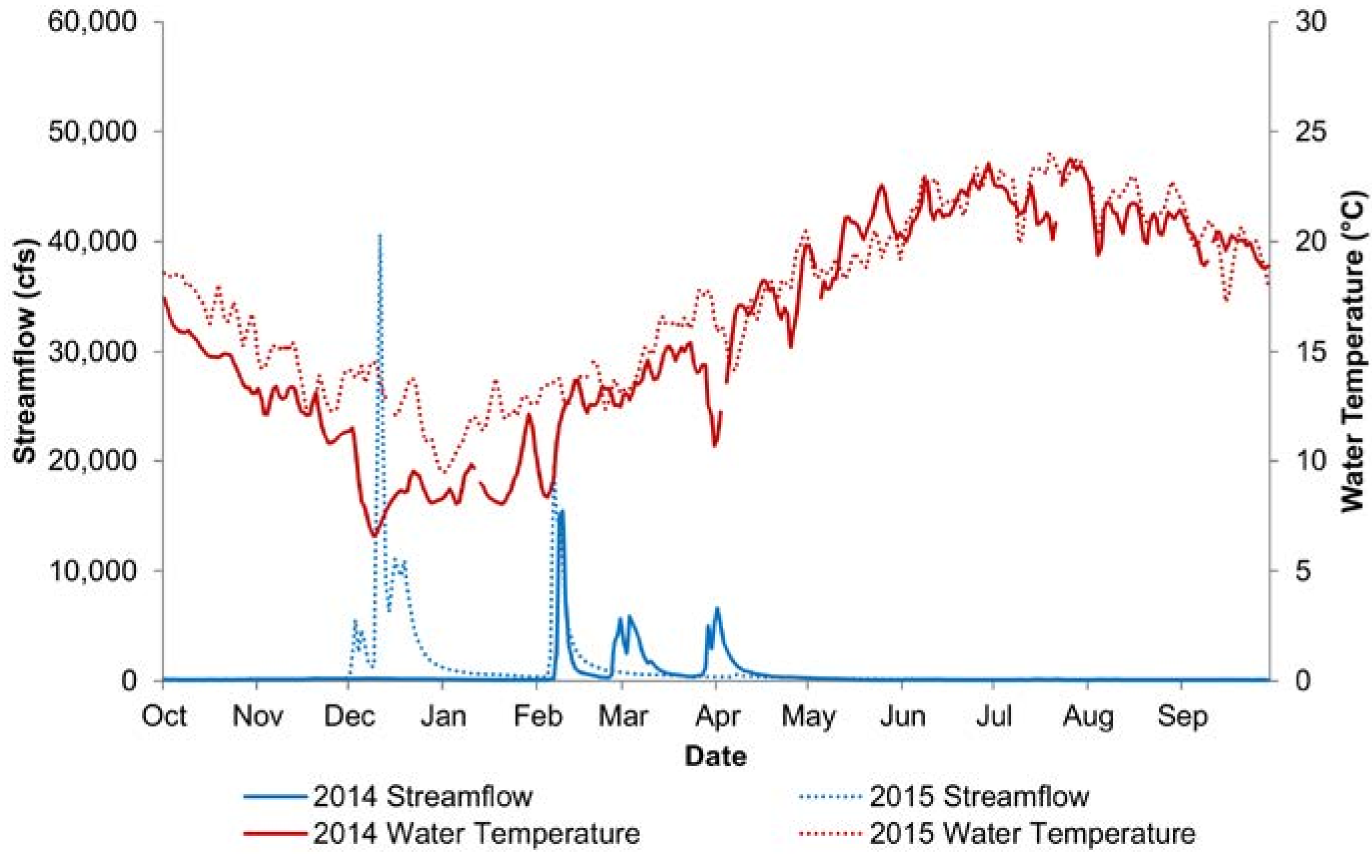


FIGURE 3.1.2.
Daily streamflow and water temperature on the Russian River, Sonoma County, as measured at the US Geological Survey stream gauge number 11467000 near Guerneville during water years 2014 and 2015. This information is depicted within the context of the sport fishery low flow closure time period (October through April).

populations. As monitoring continued into 2015 and 2016, efforts became more focused on streams that are habitat for Coho Salmon populations. The Russian River system was the highest priority watershed, not only due to the presence of Coho Salmon, but also due to its potential to produce high numbers of Chinook Salmon and steelhead as part of the California Coastal Chinook Salmon ESU, Northern California Steelhead Distinct Population Segment (DPS[11]) and Central California Coast Steelhead DPS.

Local Need for Drought Stressor Monitoring

Streamflow in many streams and rivers during the recent drought was reduced to levels that had not been recorded historically. The low flows added stress to aquatic systems that were already affected by a severely modified environment.

Federal and state recovery plans identify priority watersheds north of San Francisco as essential to the long-term region-wide recovery of Coho Salmon, Chinook Salmon, and steelhead (CDFG 2004; NMFS 2012). The Russian River Coho Salmon Captive Broodstock Program at Warm Springs Hatchery was first developed in 2001 in response to declining populations. The hatchery program is designed to prevent the extinction of Coho Salmon in the watershed and to restore overall population abundance and genetic diversity.

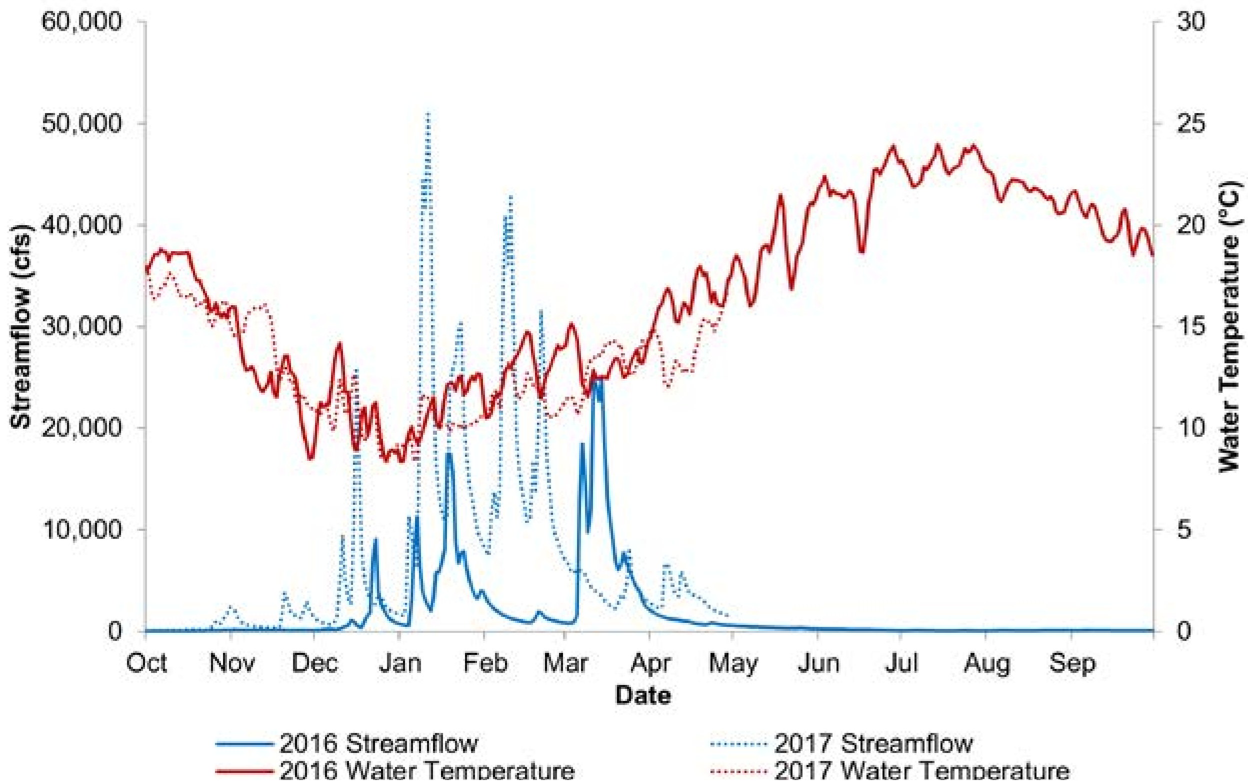


FIGURE 3.1.3.
Daily streamflow and water temperature on the Russian River, Sonoma County, as measured at the US Geological Survey stream gauge number 11467000 near Guerneville during 2016-2017. This information is depicted within the context of the sport fishery low flow closure time period (October through April).

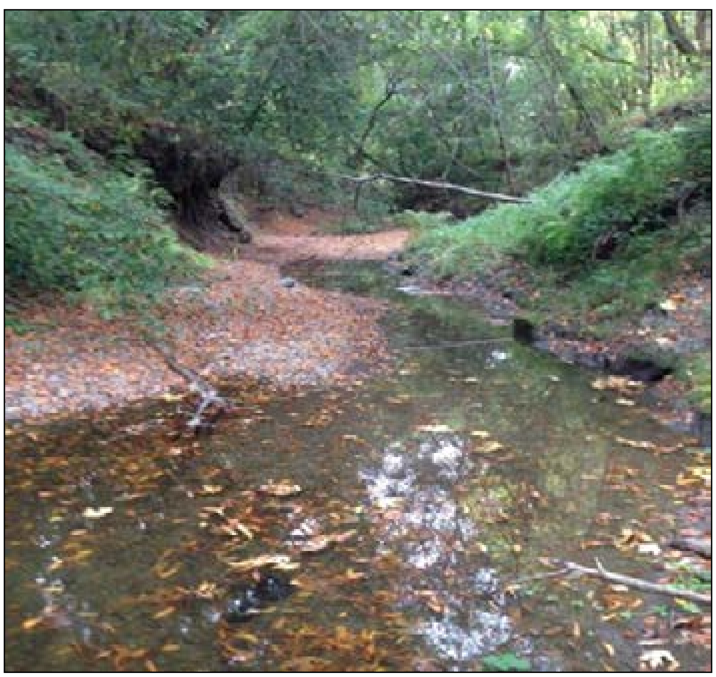



PLATE 3.1.1.
Reach of Green Valley Creek, a tributary of the Russian River in Sonoma County. The normally connected habitat (left) dried during summer 2015 resulting in isolated pools (right). Photo: CDFW.

PLATE 3.1.2.
Examples of Russian River tributary stream habitat that became fragmented. Clockwise from top left: upper Mark West Creek, Green Valley Creek, lower Mill Creek, Dutch Bill Creek. Photos: CDFW.

Since 2011, scientists from the California Sea Grant and the University of California San Diego, Scripps Institute of Oceanography, Extension Team (UC Extension Team) have undertaken population monitoring of Coho Salmon in several tributaries of the Russian River. The results of these studies have shown that low streamflow is a primary limiting factor for the survival of juvenile Coho Salmon populations (California Sea Grant 2016; Obedzinski et al. 2018). Under normal conditions, low streamflow in the Russian River and elsewhere in this region is usually associated with seasonal drying and/or water diversion during the summer months. The severe drought exacerbated these conditions and further reduced streamflow in most streams.

Monitoring stream conditions during the drought provided information on where and how salmon and steelhead survive during extremely dry periods. This information is necessary for planning, including determining the locations and timing of rescue efforts for salmon and steelhead populations, as well as identifying critical habitat for summer survival and prioritizing water conservation enhancement opportunities.

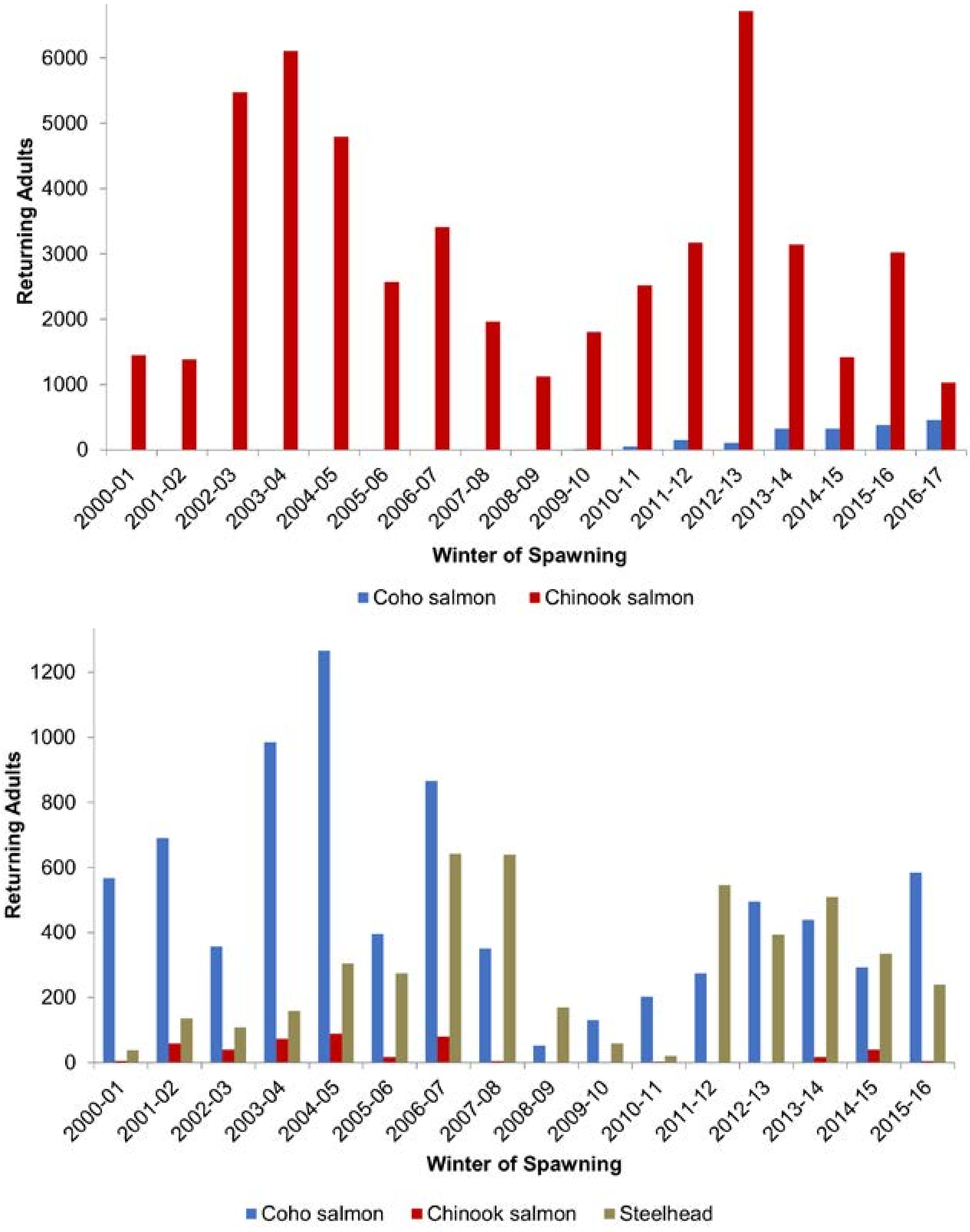


FIGURE 3.1.4.
Historical numbers of salmon and steelhead returning to spawn in the Russian River (top) and Lagunitas Creek (bottom) before and during the drought of 2013-2016. Source: Sonoma County Water Agency for Russian River populations and Marin Municipal Water District for Lagunitas Creek populations. Partial funding was through CDFW's Fisheries Restoration Grant Program.

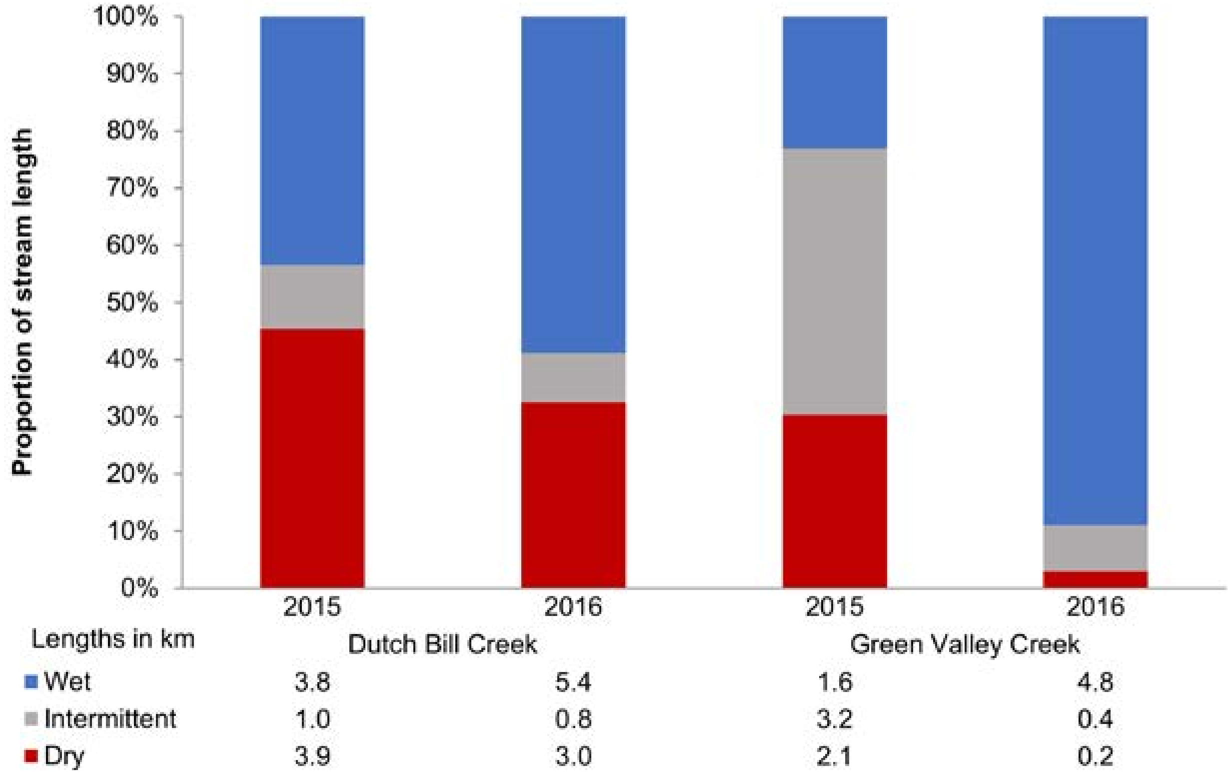


FIGURE 3.1.5.
Proportion of stream habitat that was wet, intermittent, and dry at Dutch Bill and Green Valley creeks in 2015 and 2016. Data were provided by University of California Cooperative Extension and California Sea Grant.

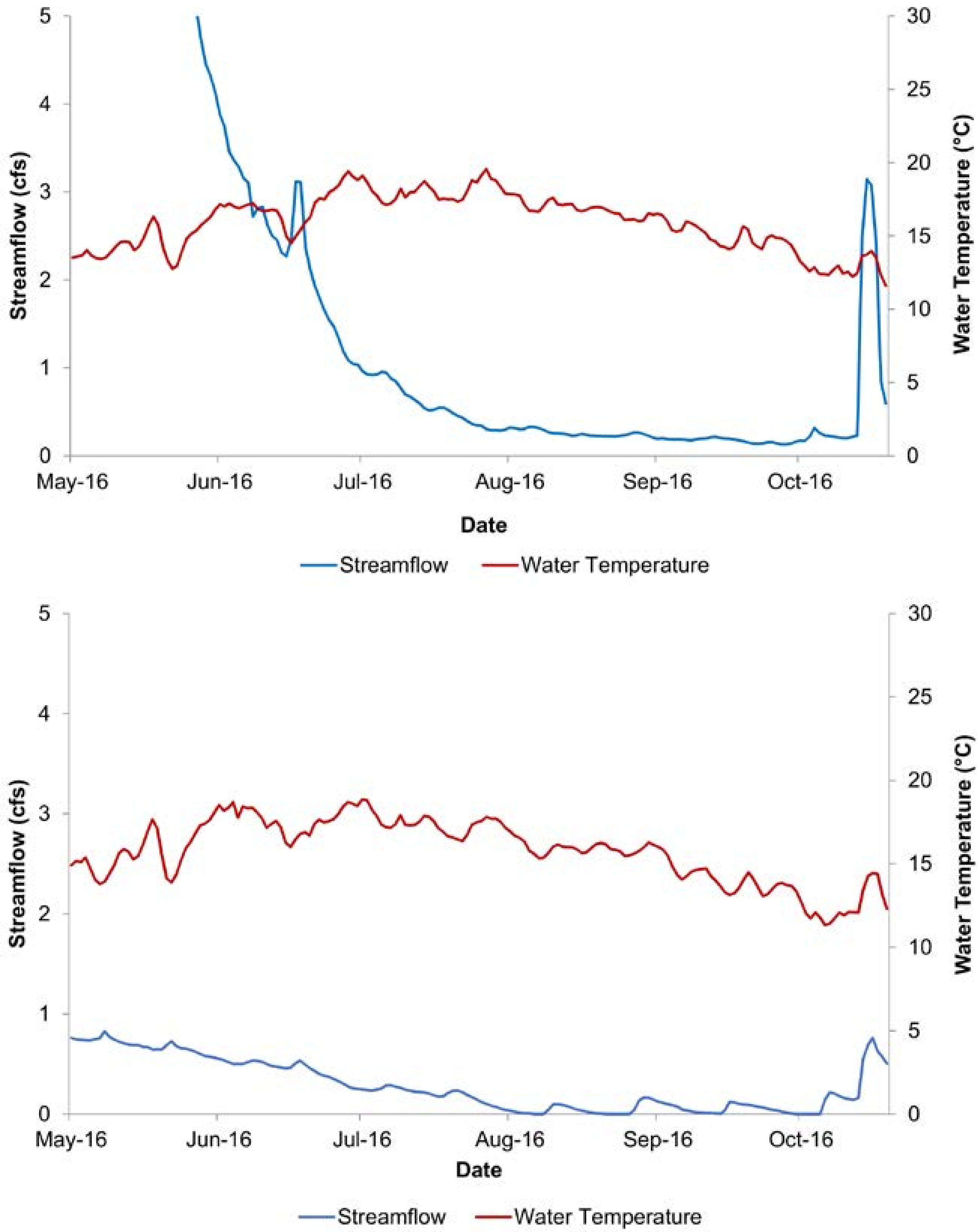


FIGURE 3.1.6.
Mean daily streamflow and water temperature in Mill (top) and Mark West (bottom) creeks, Sonoma County, as measured during 2016 low flow time period. Data were provided by Trout Unlimited.

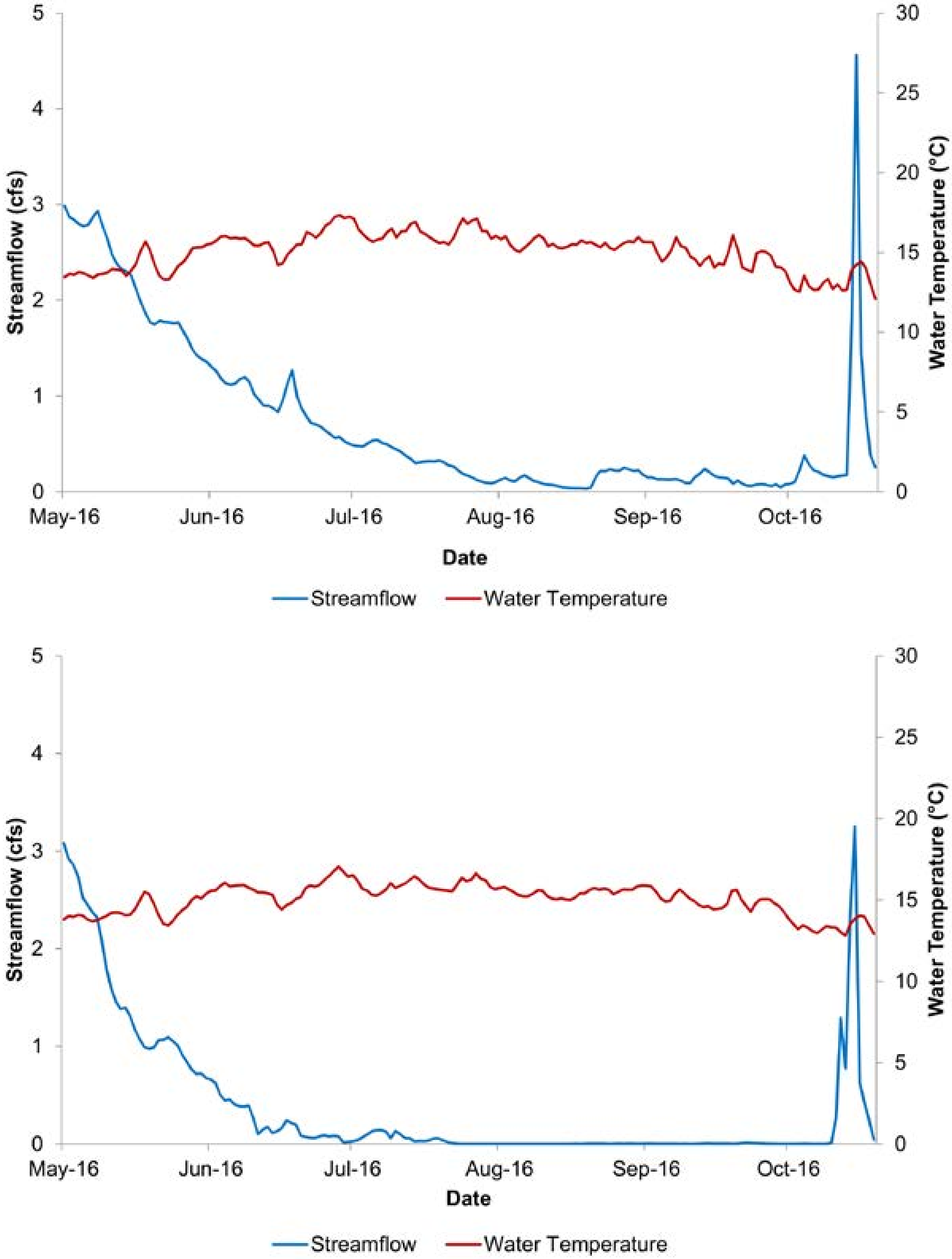


FIGURE 3.1.7.
Mean daily streamflow and water temperature in Dutch Bill (top) and Green Valley (bottom) creeks, Sonoma County, as measured during 2016 low flow time period. Data were provided by Trout Unlimited.

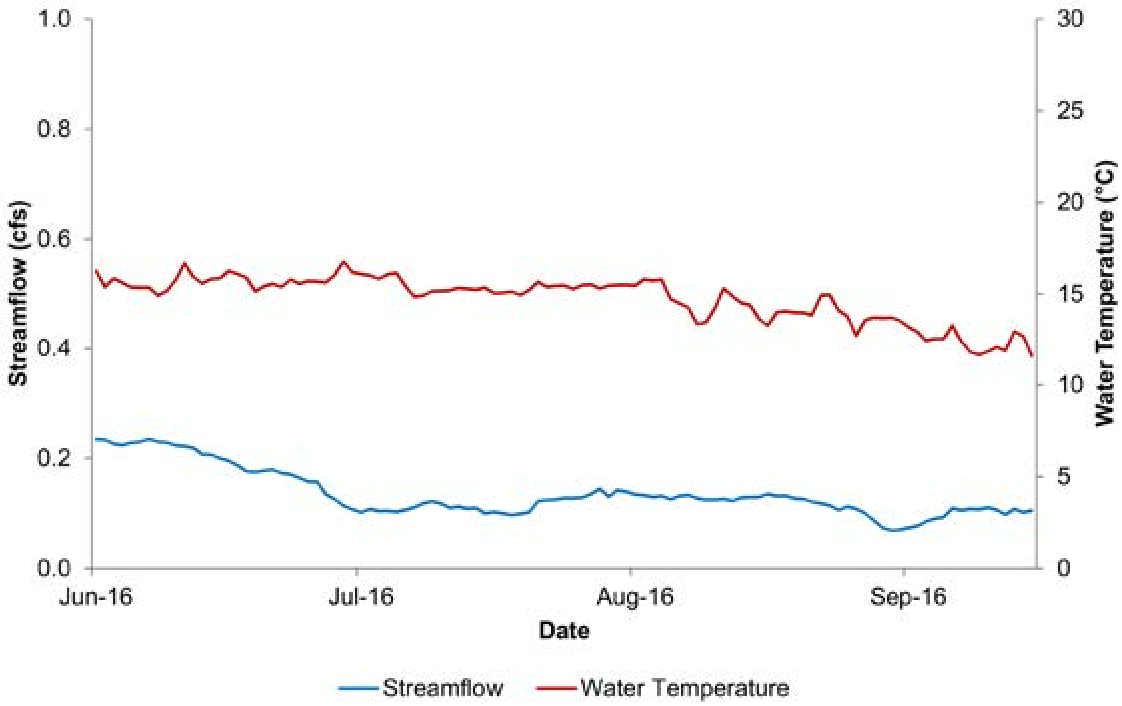


FIGURE 3.1.8.
Mean daily streamflow and water temperature in Walker Creek, Marin County, as measured during 2016 low flow time period.

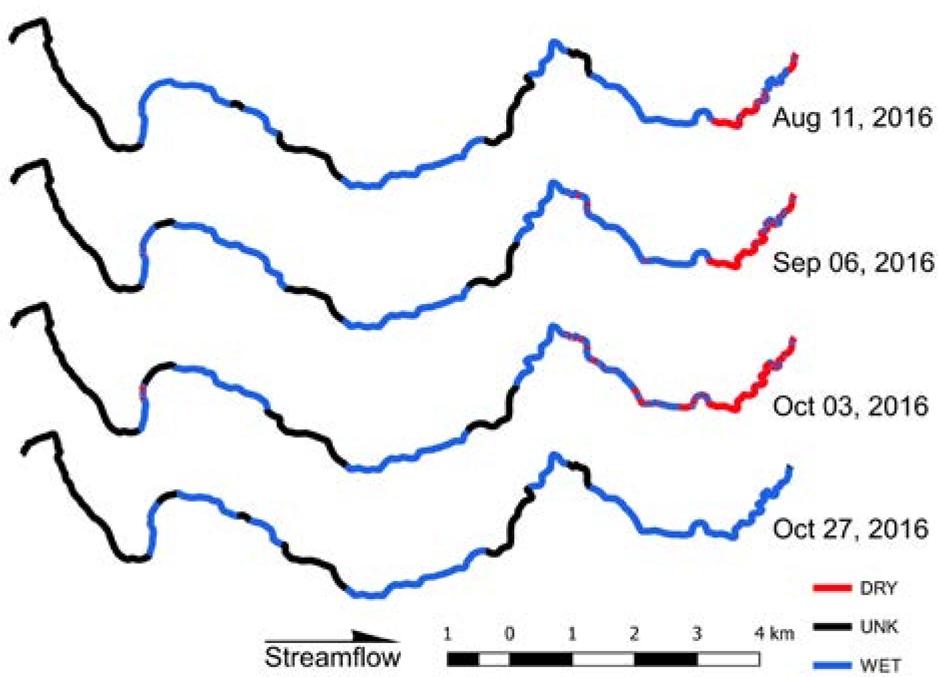


FIGURE 3.1.9.
Map of stream habitat that was wet, unknown (not surveyed), and dry in lower Mill Creek in summer and fall of 2016.

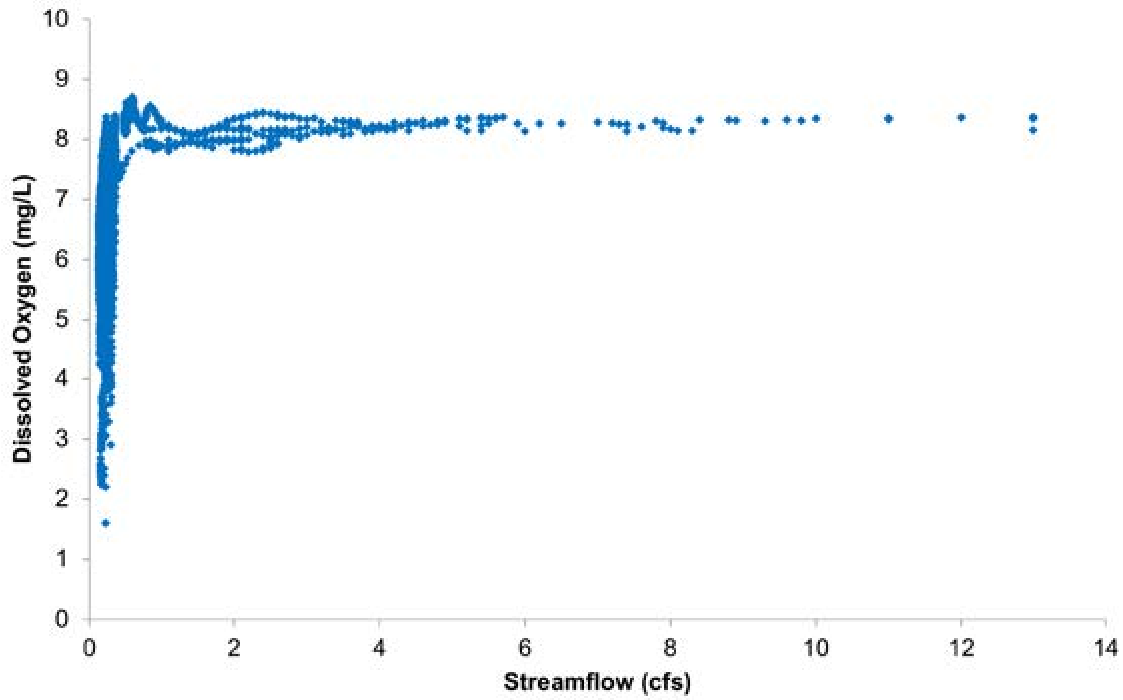


FIGURE 3.1.10.
Relationship between streamflow and dissolved oxygen in Mill Creek pool habitat. When streamflow drops to less than 0.1 cfs, dissolved oxygen quickly drops to levels lethal to rearing juvenile salmon and steelhead.

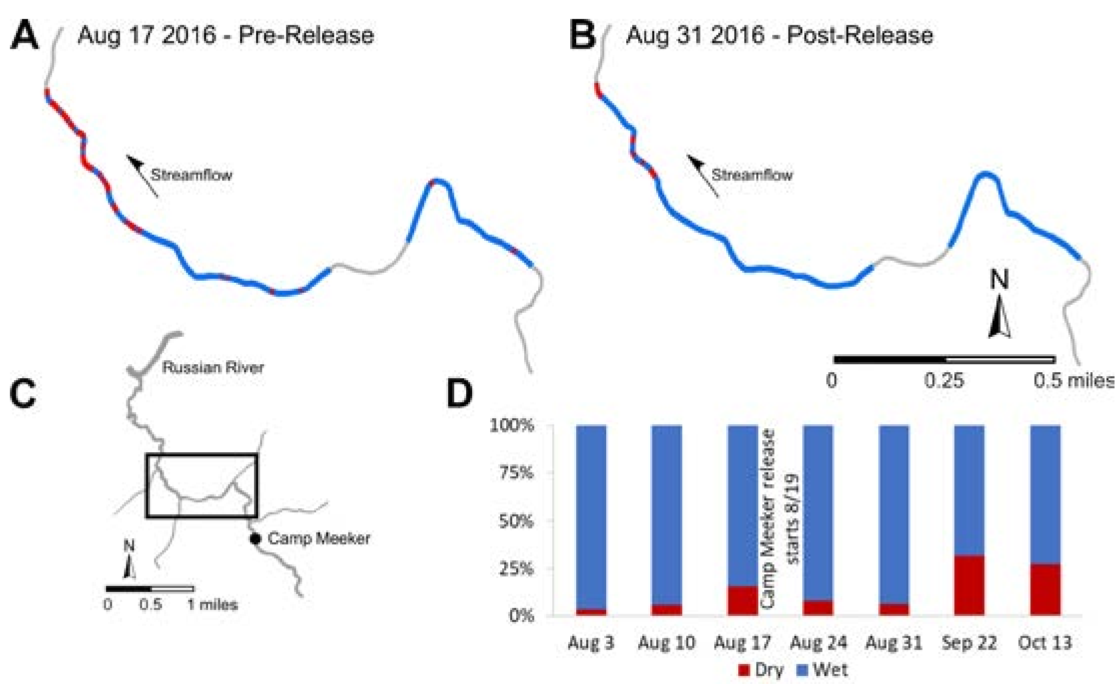


FIGURE 3.1.11.
Comparison of wet and dry sections before (A) and after (B) a voluntary flow release of Dutch Bill Creek (C) in 2016 (D). Data were provided by the University of California Cooperative Extension and California Sea Grant.

Findings and Actions

Russian River system and other California Central Coast streams

Monitoring by CDFW scientists showed that environmental conditions in the Russian River and other priority streams generally remained within an acceptable range for fish survival (Carter 2005). However, access to many tributary streams for spawning was limited for long periods of time due to lack of adequate streamflow. Water temperature during the migration and spawning seasons was found to be elevated (Figure 3.1.2).

After successive years of drought, tributaries generally dried out more quickly, became more fragmented, and had fewer reaches of wetted stream than in previous years. The major limiting factor for the successful rearing of juvenile salmon and steelhead was the quantity of instream flow available during the summer rearing period. Changes in streamflow patterns due to the drought likely impacted survival and abundance of Coho Salmon in the Russian River system.

Stream temperature during the summer generally remained within tolerable levels for salmon and steelhead. Summer periods of low streamflow created dry stream reaches and isolated pools, which often had reduced water quality. As streamflow declined, water temperature generally increased, and levels of dissolved oxygen decreased. This reduced the availability of suitable habitat to support sensitive fish species and prevented juvenile fish from moving to more suitable habitat. The lack of streamflow connectivity also likely reduced the number of aquatic insects available as food for juvenile salmon and steelhead, potentially affecting fish survival and abundance.

In the winter of 2015-16 some tributaries were sometimes limited in their connection with the mainstem river. Streams quickly returned to low flow during the winter migration and spawning seasons. In the Russian River in 2016, despite occasionally warmer water temperature during the migration and spawning seasons (Figure 3.1.3), water temperature was generally acceptable for all three salmonid species (Carter 2005).

The number of adult salmon and steelhead returning to most rivers was variable, but counts were generally lower than the long-term average, possibly due to adverse drought effects. However, returns of adult Coho Salmon increased in the Russian River, largely due to supplementation through the Coho Salmon Captive Broodstock Program at Warm Springs Hatchery (Figure 3.1.4).

In the spring of 2016, CDFW scientists coordinated their monitoring efforts with those of the California Sea Grant and UC Extension to monitor the four Voluntary Drought Initiative tributaries to the Russian River, including Dutch Bill, Green Valley, Mill, and Mark West creeks. CDFW scientists focused efforts primarily on Mill and Mark West creeks. Streamflow and water temperature conditions generally improved in 2016 compared to 2015 and large reaches of stream remained wetted during the summer (Figure 3.1.5).

Water temperature in creeks during the summer generally remained within tolerable levels for salmon and steelhead survival (Figures 3.1.6 - 3.1.8). Low flow periods in the summer often had reduced water quality, as exemplified by lower Mill Creek (Figure 3.1.9). Water temperature in these streams increased with reduced flows during the summer months, and the amount of dissolved oxygen levels declined markedly as streamflow slowed and the stream dried (Figure 3.1.10). The changes observed likely reduced the amount of suitable habitat available to support sensitive fish species, potentially impacting fish survival and abundance.

In 2016, lack of streamflow connectivity again likely reduced the number of aquatic insects available as a food source for juvenile salmon and steelhead. As a result, extreme drought conditions continued to impact the survival of fish during the summer low flow period. However, in late fall, streamflow in many streams increased and water temperatures decreased, largely due to regulated water releases and increased precipitation.

Management Actions

The establishment of the "Voluntary Drought Initiative" program in the Russian River watershed[12] during the drought encouraged the development of agreements between CDFW, NOAA Fisheries, and the public. This initiative helped conserve instream flows and habitat conditions for Coho Salmon and steelhead. It also helped determine the need for fish rescues. CDFW scientists worked with several landowners to provide enhanced flows to support summer rearing habitat critical for fish survival.

Studies by scientists from the California Sea Grant and UC Extension also provided further insight into changing habitat conditions during the drought. In addition, drought related emergency regulations were enacted by the State Water Resources Control Board. This required enhanced water conservation measures in four Russian River tributaries (Mark West, Mill, Green Valley, and Dutch Bill creeks) that were monitored by CDFW scientists. These management actions effectively reduced or influenced the extent to which these streams dried out during the drought. For example, additional water releases, such as in Dutch Bill Creek in August 2016, reduced dry stream reaches and restored connectivity, expanding and protecting existing fish habitat (Figure 3.1.11)

3.2 COASTAL STREAMS SOUTH OF SAN FRANCISCO

Species Focus and Location Description

Drought Stressor Monitoring in coastal watersheds south of San Francisco Bay focused on streams supporting populations of Coho Salmon and steelhead. Streams monitored included San Gregorio Creek, Pescadero Creek, and Gazos Creek, all located in San Mateo County, and Waddell Creek, Scott Creek, San Lorenzo River, Soquel Creek, and Aptos Creek, all in Santa Cruz County (Figure 3.2.1).

Monitoring in streams draining to South San Francisco Bay focused on steelhead and included Alameda Creek, Stevens Creek, Guadalupe River, and Coyote Creek. Additional monitoring in Santa Clara Valley focused on steelhead in Uvas Creek, a tributary to the Pajaro River. (Figure 3.2.2). In 2015-16, the list of monitored streams was reduced to focus efforts solely on the coastal streams of Pescadero Creek, Scott Creek, and the San Lorenzo River.

Loacal Need for Drought Stressor Monitoring

Coho Salmon and steelhead populations in streams south of San Francisco Bay were already substantially reduced prior to the onset of the drought, largely due to the adverse effects of human activities, including timber harvest, agriculture and urbanization. At the time of the drought, both species were already listed under state and federal Endangered Species Acts. The severe drought conditions raised concerns of possible extirpation of several populations as streams dried out. CDFW scientists conducted surveys to determine where and under what conditions salmon and steelhead survived under extreme drought conditions and whether emergency actions were warranted to prevent extirpation.

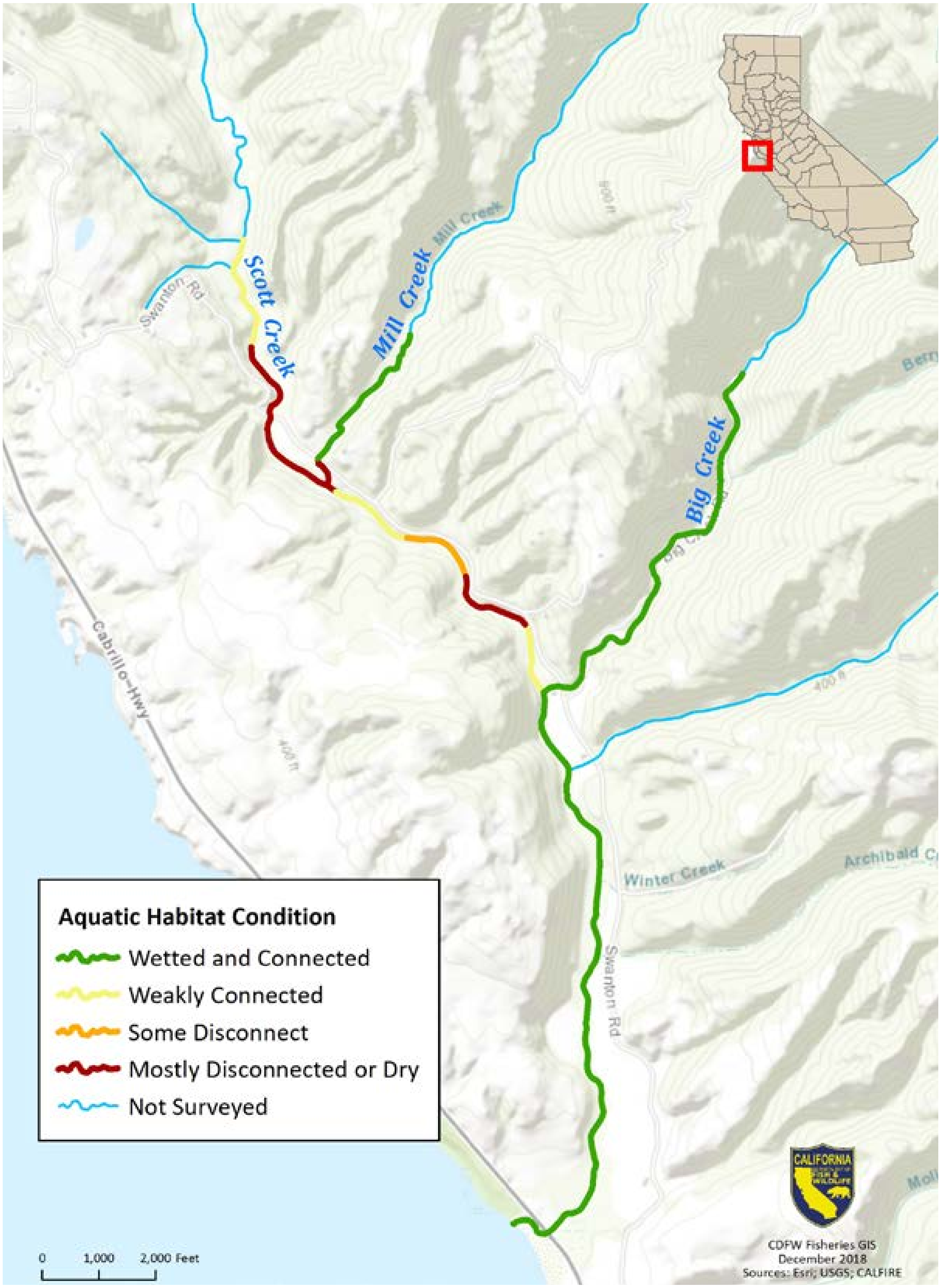
Findings and Actions

Monitoring by CDFW scientists showed that the environmental conditions associated with the severe drought were frequently harmful to the survival of aquatic species, especially Coho Salmon and steelhead. The drying of lower stream reaches

FIGURE 3.2.1.
Locations of priority coastal streams for Coho Salmon and steelhead south of San Francisco in 2014-2016.

FIGURE 3.2.2.
Map of priority South San Francisco Bay and Santa Clara Valley streams for steelhead in 2014-2015.

FIGURE 3.2.3.
Portions of lower Scott Creek that experienced varying levels of drying and habitat disconnection during summer 2015. Complete and prolonged stream drying results in aquatic habitat being eliminated.



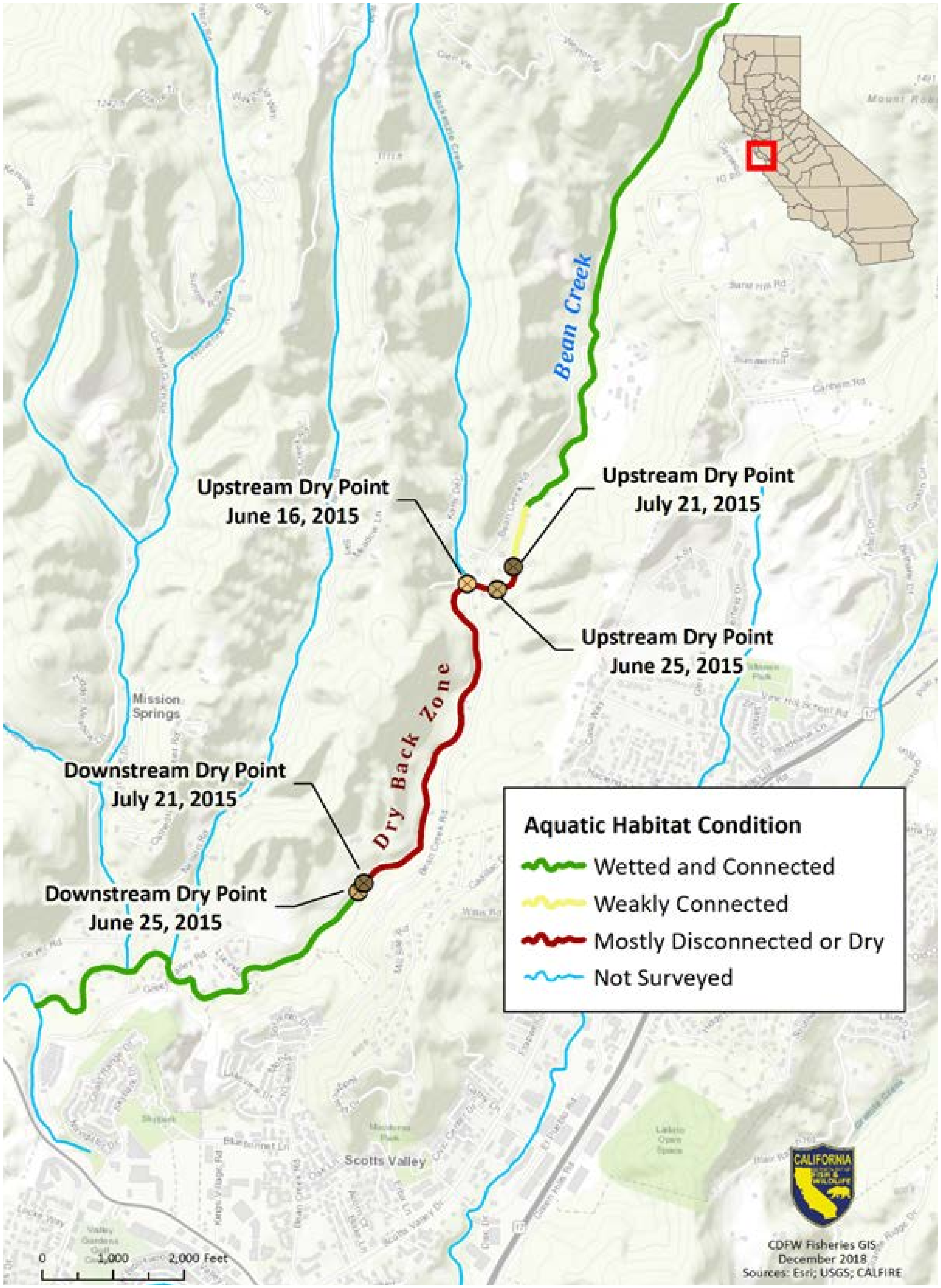
isolated juvenile salmon and steelhead from suitable habitat. Once water quality deteriorated, these fish were eliminated from these isolated sites. Juvenile rearing habitat for salmon and steelhead in the Central Coast is often naturally limited by low streamflow during the summer and fall; however, the prolonged drought extended this dry period into the rainy season. Drought conditions often resulted in poor or non-existent access for adult salmon and steelhead from the ocean to streams and prevented Coho Salmon and steelhead from spawning.

Many streams draining into San Francisco Bay and Santa Clara Valley tributaries to the Pajaro River typically receive reservoir water releases during the dry season to supplement their flows. These releases replenish aquifers through groundwater recharge and improve rearing habitat for juvenile steelhead; however, severe reductions in reservoir water storage during the drought, together with continued water consumption, meant that less water was available for downstream release. These factors led to the increased drying of streams and depletion of ground water recharge, reducing streamflow in most areas.

Coastal streams south of San Francisco Bay

Coastal streams in this region received approximately 69-82% of their average rainfall during the winter of 2014-15, with slightly over 50% of that coming during the month of December. There was almost no rainfall during January of that water year, preventing Coho Salmon and steelhead from accessing spawning areas. Many coastal streams south of San Francisco experienced adverse environmental conditions during the summer low flow period. Several streams went dry during summer and fall, and habitats became fragmented (Figures 3.2.3 and 3.2.4). CDFW scientists carried out weekly monitoring throughout the summer and fall periods.

FIGURE 3.2.4.
Portions of lower Bean Creek (San Lorenzo River watershed) that experienced varying levels of drying, including completely dry areas, and habitat disconnection during summer 2015.



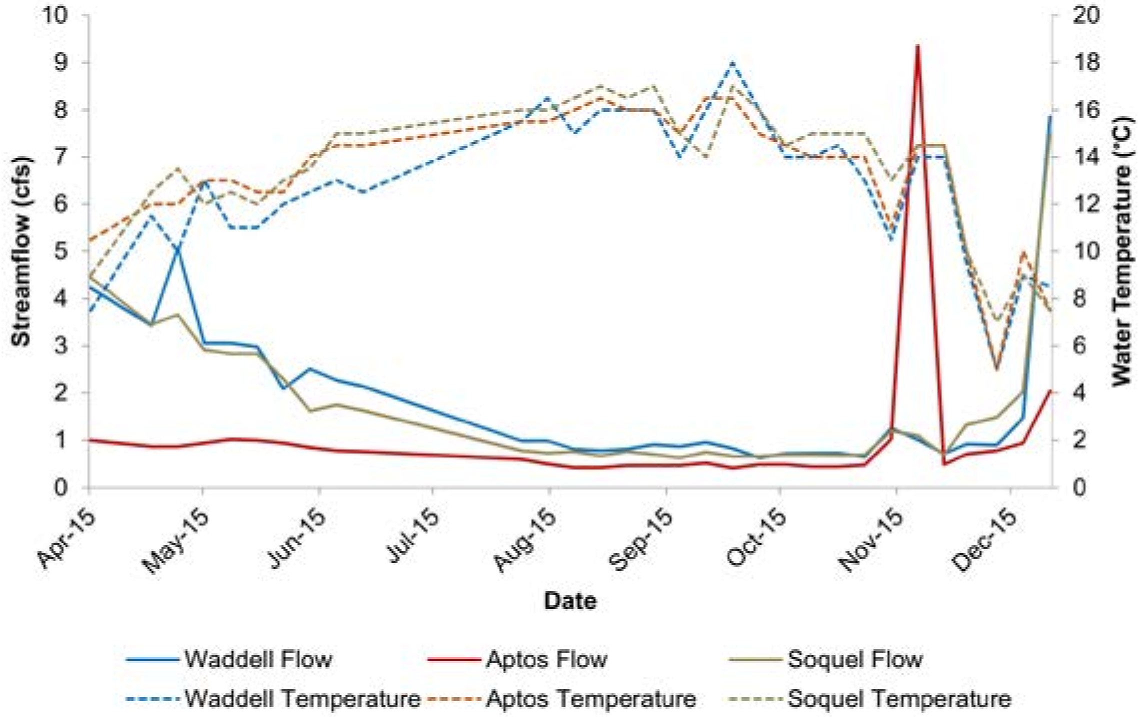


FIGURE 3.2.5.
Weekly streamflow and water temperature from April through December 2015 on Waddell, Soquel, and Aptos creeks.

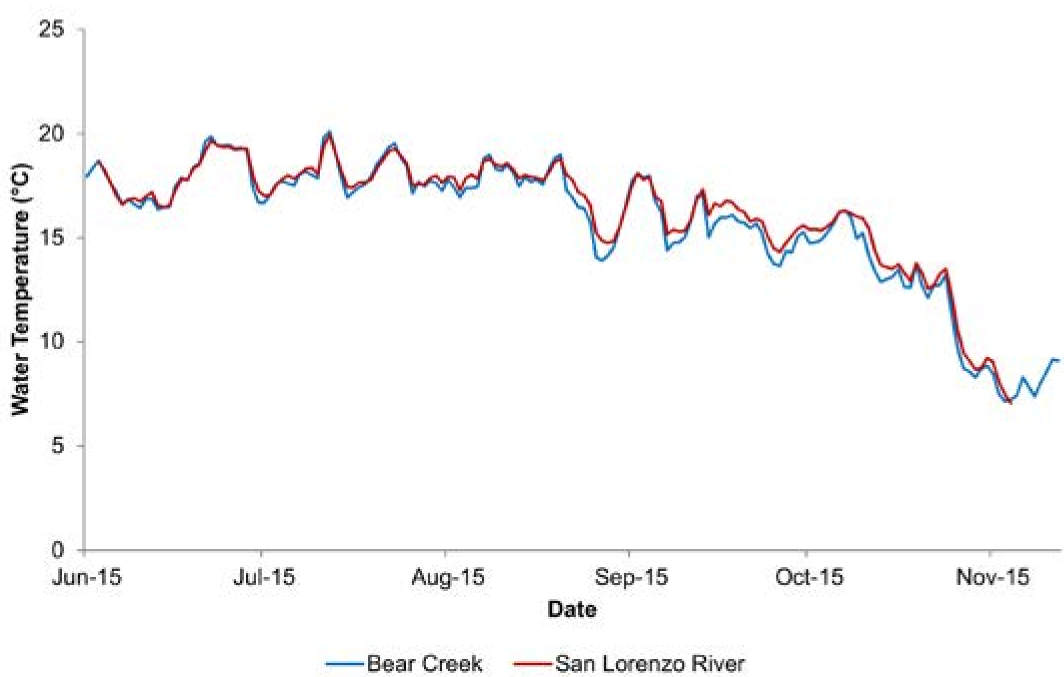


FIGURE 3.2.6.
Mean daily stream temperatures in the San Lorenzo River and Bear Creek, a tributary of the San Lorenzo River, Santa Cruz County, in 2015.

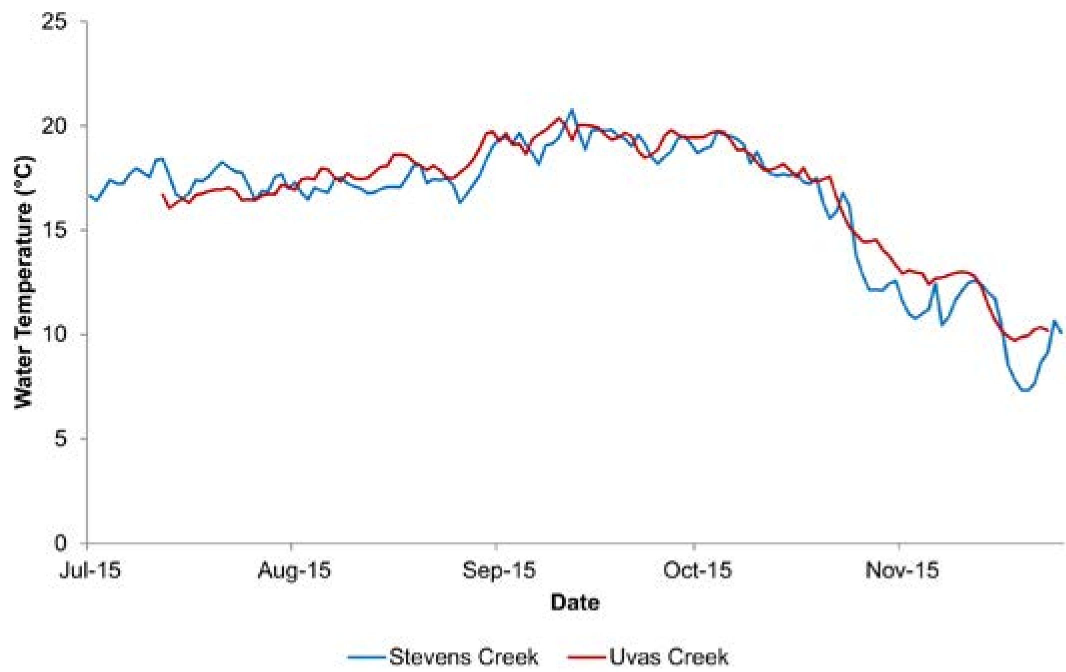


FIGURE 3.2.7.
Mean daily stream temperatures downstream of reservoir outlets during 2015 in Stevens and Uvas Creeks, Santa Clara County.

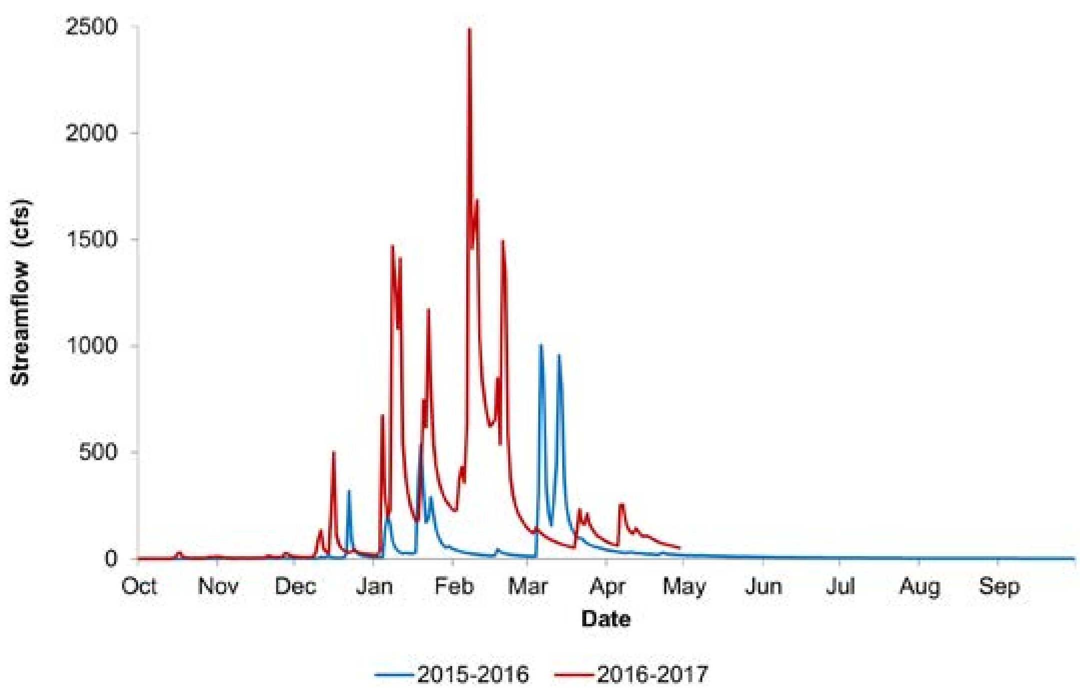


FIGURE 3.2.8.
Mean daily streamflow in Pescadero Creek as measured at the U. S. Geological Survey stream gauge number 11162500 near Pescadero, California, during 2015-2017.

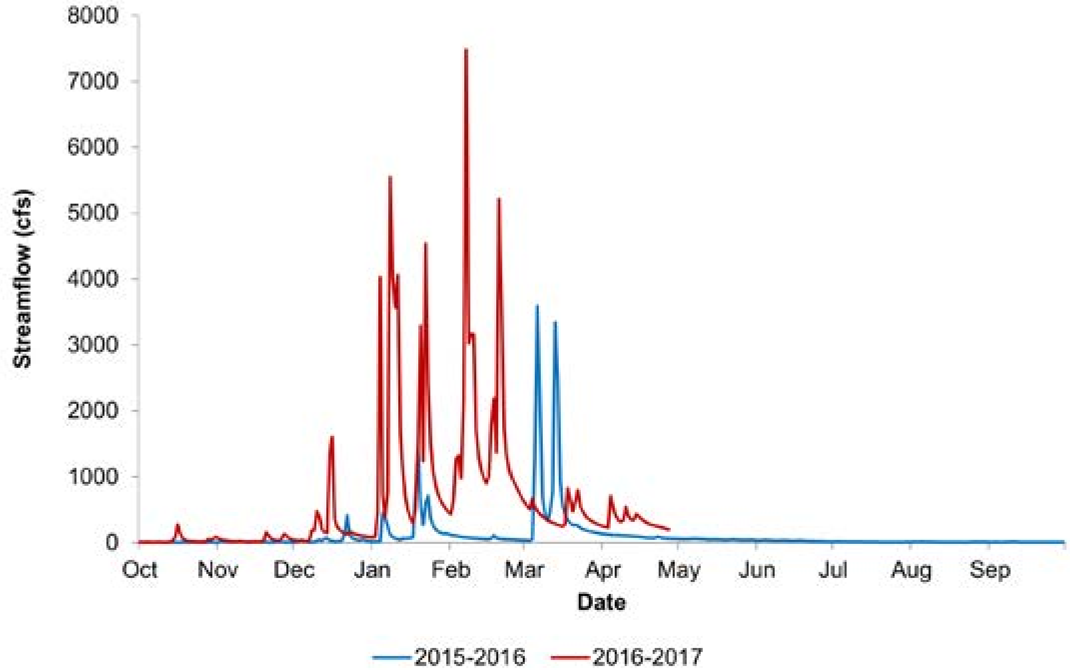


FIGURE 3.2.9.
Mean daily streamflow in the San Lorenzo River recorded at the U.S. Geological Survey stream gauge number 11161000 near Santa Cruz, California, during 2015-2017.

Streamflow in the monitored streams was extremely low during the summer months (Figure 3.2.5). Flow over shallow riffles was frequently too low to allow for movements by juvenile fish and likely decreased the supply of aquatic insects for food. The lack of reservoir water storage meant that downstream flow releases were severely reduced, resulting in stream reaches drying for longer periods than had been documented previously. For example, downstream of Uvas Reservoir, the lower reaches of Uvas Creek dried out in 2014 and 2015, reducing potential steelhead rearing habitat by approximately 75%. In addition, in 2015, for the first time in historical records, approximately two miles of Scott Creek experienced dry or near dry conditions. It is likely that these conditions were detrimental to one of the last remaining strongholds of Coho Salmon south of San Francisco Bay.

Water temperature in some of the headwater streams that were monitored, such as the San Lorenzo River, Bear, Stevens, Uvas creeks, showed periodic spikes (highs >20°C) and daily average temperatures around 20°C during the summer dry season (Figure 3.2.6 and 3.2.7). Lack of previous trend data, however, makes it unclear how these temperatures compared with other water years. Shallow riffle areas frequently made it difficult for juvenile fish to move to other stream reaches to seek refuge. As streamflow declined, water temperatures increased, further reducing the quality of aquatic habitat. In general, once pools became isolated from all surface flows, water temperatures quickly increased, and dissolved oxygen levels decreased. However, despite reductions in dissolved oxygen, water quality generally remained adequate in stream habitats that remained wetted throughout the season.

During the drought period, coastal watersheds and South San Francisco Bay area streams experienced extended dry periods into the rainy season, which restricted access from the ocean for Coho Salmon and steelhead and limited spawning in many central coast streams. In winter of 2015-16, area streams received rainfall and runoff more typical of an average year (e.g., 37.26 inches in Santa Cruz and 14.59 inches in San Jose). In early 2016, without any significant additional rainfall, these streams once again experienced dry conditions. Low streamflow (Figures 3.2.8 and 3.2.9) again reduced access for steelhead to streams in the middle of the spawning season.

CDFW scientists found that streamflow during the summer low flow period was slightly greater in 2016 than in previous years (Figure 3.2.10). For example, Scott Creek remained wetted throughout the period. However, streamflow reductions resulted in lower water quality and reduced food production, while reductions in water depth may have reduced juvenile fish movements.

Multiple years of drought depleted reservoir storage and limited water releases for steelhead. This was particularly problematic in Santa Clara Valley streams, limiting fish survival and access between the marine and freshwater environments. Following three years of drought, surveys in South San Francisco Bay streams showed that steelhead numbers remained low. Drought Stressor Monitoring helped CDFW scientists identify critical areas for the continued survival of juvenile salmon and steelhead. This helped prioritize management actions, including fish rescues, enforcement actions, and public outreach for voluntary water conservation measures.

Pescadero Creek and Gazos Creek

Surveys of spawning steelhead carried out by CDFW scientists in Gazos Creek during winter/spring 2014-2015 showed that adult access was delayed, likely due to low flow conditions. The first redd of the season was not observed until February 12, 2015, later than usually seen in this system, and a total of 37 redds were recorded by the end of the spawning season. In 2015-2016, adult fish appeared in Gazos Creek earlier in the season compared to 2014-2015. Steelhead redds were first observed in mid-December 2015, but the number of redds was reduced compared to previous years. CDFW scientists electrofished stream reaches in fall 2016 and found low densities of juvenile salmonids. Less than 4% of the steelhead captured were yearlings, while the remaining 96% were young-of-year fish. The low density of steelhead in the yearling class suggests low survival of steelhead in Pescadero Creek during drought conditions.

Coastal lagoon monitoring

In normal water years, coastal stream lagoons (i.e. bar-built estuaries) are important habitat for steelhead. In a number of watersheds along the Central California coast, sandbars form during the summer as streamflows decline. With adequate instream flow, the water columns of the lagoons can de-stratify and convert completely to freshwater. The de-stratified water column drives healthy water quality conditions and productive rearing habitat for steelhead which can grow to smolt size as young-of-the-year and yearlings.

During the drought, coastal stream lagoons also experienced periodic levels of high water temperature and low levels of dissolved oxygen during the summer. These levels were frequently within the lethal range for steelhead survival. Lower streamflow into the lagoons also produced salinity stratification, resulting in high water temperatures and low dissolved oxygen levels in the lower saltwater layer. For example, in a water profile taken at a location in Pescadero Creek lagoon in August 2015, both salinity and temperature increased over just 0.75 meters (by 21.9 ppt and 5.5°C, respectively) while the level of dissolved oxygen at depth was 59% lower than that recorded at the surface (Figure 3.2.11).

Pescadero Creek lagoon experienced water temperatures between 19.7 – 30.9°C (average 25.7°C) for 35 days between July 28 and September 1, 2015. The high-water temperature in the lagoon helped drive the growth of dense aquatic vegetation throughout the lagoon complex. In late summer, 90% to 100% of the water column was filled with vegetation, further

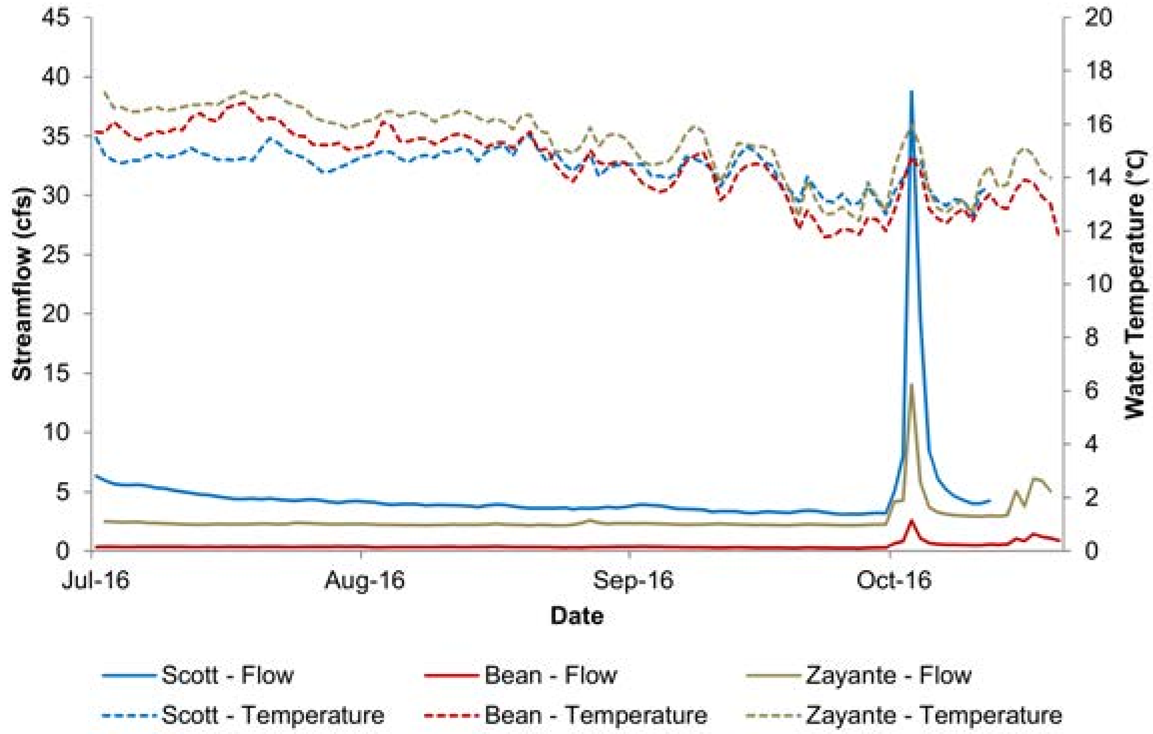


FIGURE 3.2.10.
Mean daily streamflow and water temperature in Bean and Zayante creeks (tributaries of the San Lorenzo River), and Scott Creek, in Santa Cruz County from July to October, 2016.

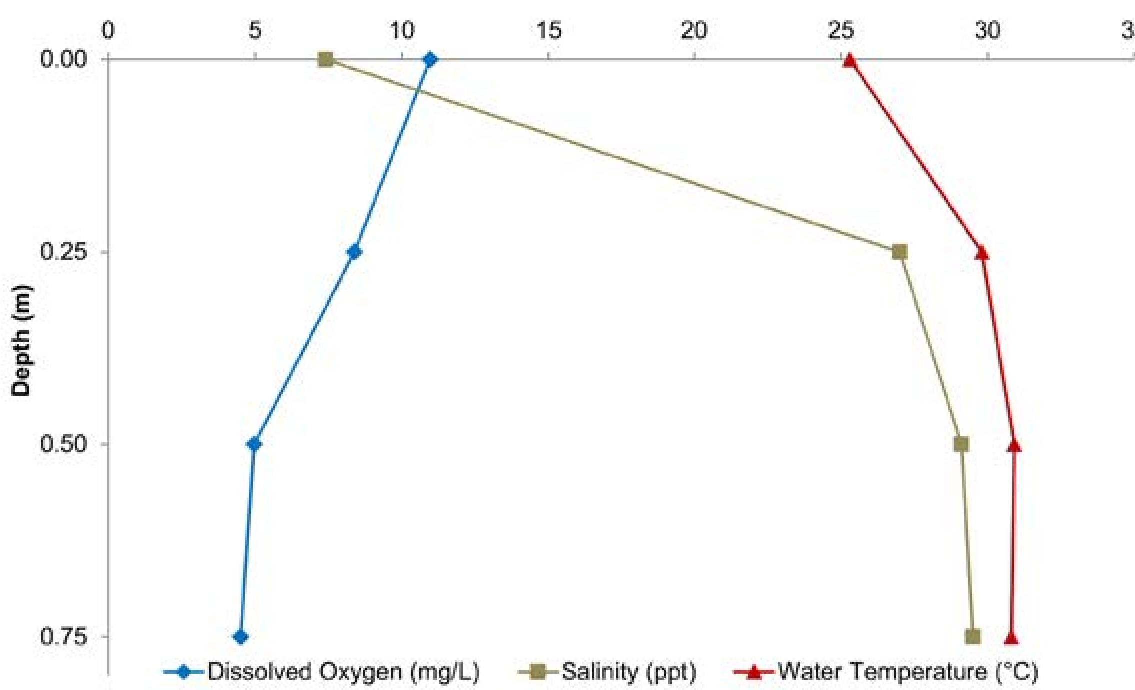


FIGURE 3.2.11.
Vertical water quality profile from one location in upper Pescadero Creek lagoon in August 2015.

reducing dissolved oxygen levels especially during the early mornings. This, in turn, reduced the amount of available habitat for steelhead, while low streamflow and persistence of the sandbar through the migratory periods effectively blocked steelhead migration between freshwater and marine environments. In mid-July 2015, the number of steelhead rearing in Pescadero Creek lagoon was estimated to be 2,345 (95% CI 1,841 to 3,478). By October, no steelhead were detected in the lagoon, suggesting a complete absence of lagoon rearing.

In 2016, following increased runoff, environmental conditions in coastal lagoons were improved, compared to 2015. Dissolved oxygen levels and water temperatures in Pescadero Creek lagoon in the summer remained suitable for rearing steelhead, and refuge areas were available. The numbers of juvenile steelhead in Pescadero Creek lagoon decreased over the summer period. In July and October 2016, the number of steelhead rearing in the lagoon was estimated to be 4,064 (95% CI 3,035 to 5,312) and 1,577 (95% CI 1,162 to 2,325), respectively. The reduction in steelhead numbers may have been partially due to the adverse effects of the drought.

CHAPTER FOUR

Central Region

The Central Region covers twelve geographically diverse counties, extending from the coast to the west slope of the Sierra Nevada, and includes Fresno, Kern, Kings, Madera, Mariposa, Merced, Monterey, San Benito, San Luis Obispo, Stanislaus, Tulare, and Tuolumne counties. Coastal streams drain from the coastal range directly into the ocean and provide important habitat for populations of coastal steelhead. In the southern Central Valley, the San Joaquin River and its anadromous fish bearing tributaries flow into the Bay-Delta, and thence San Francisco Bay, providing key habitat for both fall-run Chinook Salmon and steelhead. Streams draining the Sierra Nevada foothills provide habitat for a variety of fish and amphibian species, including Red Hills Roach at lower elevations, and the State Fish, Golden Trout, at higher altitudes. The multi-year drought affected the Region's fisheries resources through decreased streamflow and warmer water temperatures. Since it was not feasible to monitor all species in all streams, only fish species that were rare, and/or listed under the state and/or federal Endangered Species Acts, were chosen for drought impact evaluation.

4.1 COASTAL WATERSHEDS

Species Focus and Location Description

In the Central Region, five streams were selected for Drought Stressor Monitoring, including the Carmel, Big Sur, Salinas, and Arroyo Seco rivers in Monterey County (Figure 4.1.1) and Santa Rosa, Chorro, and San Luis Obispo creeks in San Luis Obispo County (Figure 4.1.2). These streams were chosen based primarily on

FIGURE 4.1.1.
Drought Stressor Monitoring locations and focus streams in Monterey County.

FIGURE 4.1.2.
Drought Stressor Monitoring locations and focus streams in San Luis Obispo County.

the known presence of persistent, though declining, steelhead populations and their importance to steelhead recovery in the region (NMFS 2013). All streams, except for Chorro Creek, are defined by NOAA Fisheries as "Core 1 streams" because they are relatively large producers of steelhead (NMFS 2013). Chorro Creek is defined by NOAA Fisheries as a Core 2 population as it is considered to be less productive although important for species recovery. Stream conditions were monitored to determine the extent to which extreme drought conditions impacted steelhead populations. This information enabled CDFW scientists to determine whether emergency management actions were warranted to prevent loss of steelhead populations.

Fish monitoring also provided information on Pacific Lamprey. As with salmon and steelhead, Pacific Lamprey are anadromous and transport marine nutrients into freshwater environments. In their larval "ammocete" form, Pacific Lamprey also provide ecosystem services such as filtering water and mixing bottom sediments. Although historic counts for the Big Sur River are not available, Pacific Lamprey reportedly enter coastal streams in large numbers in the spring (Reid and Goodman 2016). The Big Sur River provides habitat for an important source population that contributes spawning adults along the California coast. Drought conditions can impact Pacific Lamprey populations by fragmenting spawning habitat, reducing water quality, causing dry-backs that may kill developing ammocetes and prevent migration to and from the ocean.

Findings and Actions

CDFW scientists carried out weekly site visits from 2014 to 2016 to document habitat conditions and collect water quality data. Water temperatures were generally below the thresholds for southern steelhead as observed by Sloat and Osterback (2013) in their research in Santa Paula Creek (Figures 4.1.4-4.1.7). In that research, Sloan and Osterback (2013) found that steelhead activity dramatically decreased at temperatures greater than or equal to 25°C and that their persistence threshold was at 31.5°C. In the drought monitoring efforts on the Central Coast, there were short periods when water temperatures associated with low streamflow came close to the 25°C stress thresholds. Dissolved oxygen dropped to low levels as stream velocities reduced to near zero just before reaches completed dried. Reduced or no streamflow was documented for extended periods of time in all monitored streams on the Central Coast. Several streams that typically have year-round streamflow during average water years were intermittent during the drought, resulting in reduced habitat availability and increased habitat fragmentation.

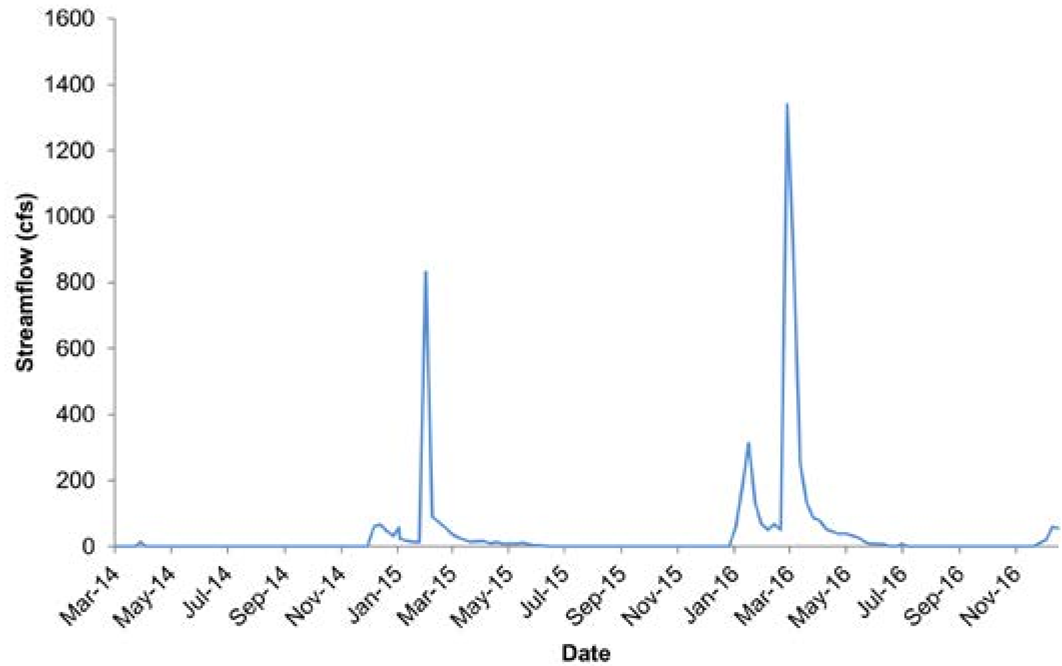


FIGURE 4.1.3.
Weekly streamflow measurement in the Carmel River, Monterey County, during Water Years 2014, 2015, and 2016 (October 1, 2013 – December 31, 2016).

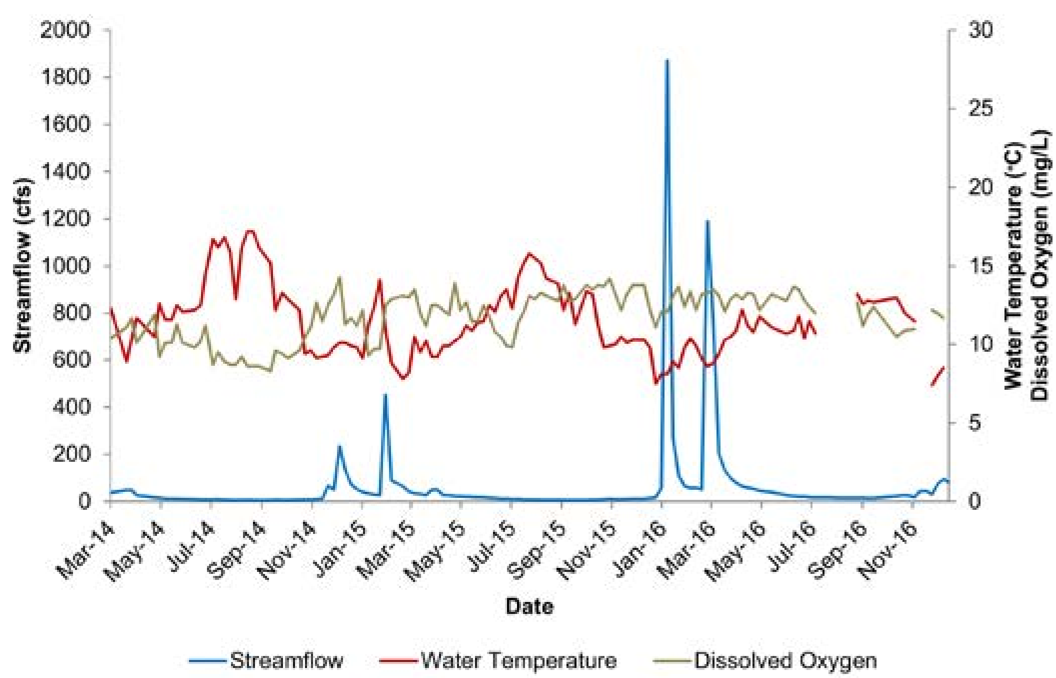


FIGURE 4.1.4.
Weekly measurements of streamflow, dissolved oxygen, and temperature in the Big Sur River, Monterey County, during Water Years 2014, 2015, and 2016 (October 1, 2013 – December 31, 2016). Breaks in data represent times when water temperature and dissolved oxygen were not measured.

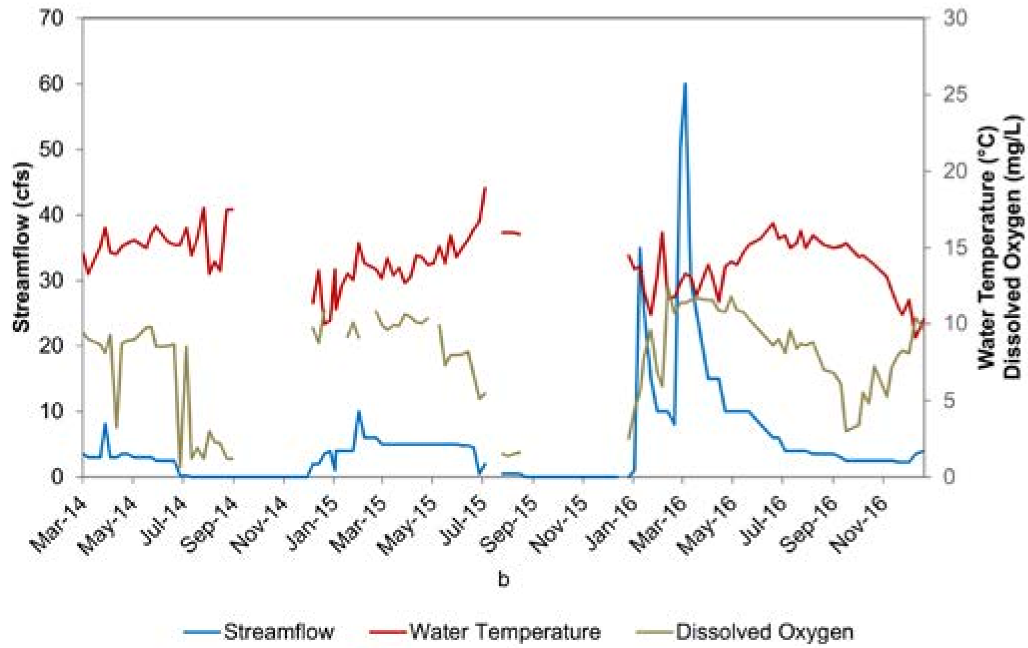


FIGURE 4.1.5.
Weekly visual estimates of streamflow and measurements of dissolved oxygen and temperature in Santa Rosa Creek, San Luis Obispo County, during Water Years 2014, 2015, and 2016 (October 1, 2013 – December 31, 2016). Breaks in data represent times when sampling locations dried completely.

Storms associated with the return of a strong El Niño in 2016 increased rainfall in Monterey and San Luis Obispo counties above levels recorded in 2014 and 2015, although the total rainfall was still below average.

Carmel River and Big Sur River

The Carmel River experienced earlier and more extensive stream drying during Water Years 2014 and 2015. In typical water years, the Carmel River is regularly open to the ocean during the winter and spring seasons due to high streamflow. In Water Year 2014, the lagoon was closed all year, but opened intermittently in Water Year 2015 (Figure 4.1.3); however, the open periods were over shorter durations compared to past years of average rainfall. At the Big Sur River, temperature and dissolved oxygen levels were determined to be below stress-thresholds (4.1.4). Without similar data collection previously for comparison, however, it is difficult to determine how these parameters were affected by drought conditions. Streamflow in Big Sur River from spring through fall was below the critically dry levels required for both steelhead spawning and rearing (22 to 25 cubic feet per second) (Holmes and Cowan 2014) (Figure 4.1.4). The Big Sur River lagoon typically remains open to the ocean throughout the year but closes during extremely low flows. Approximately 0.65 km of the lower river immediately upstream of the lagoon dried out in 2014 between August and November, necessitating a steelhead rescue effort in that reach. This closure and drying event was unprecedented and had never been documented during average and above-average water years. The Salinas River and Arroyo Seco sites were only monitored occasionally and provided limited data.

CDFW scientists monitored the connectivity of the Carmel and Big Sur rivers with the ocean. Both rivers saw increased periods of connectivity in 2016 compared to 2014 and 2015. In 2016, the Carmel

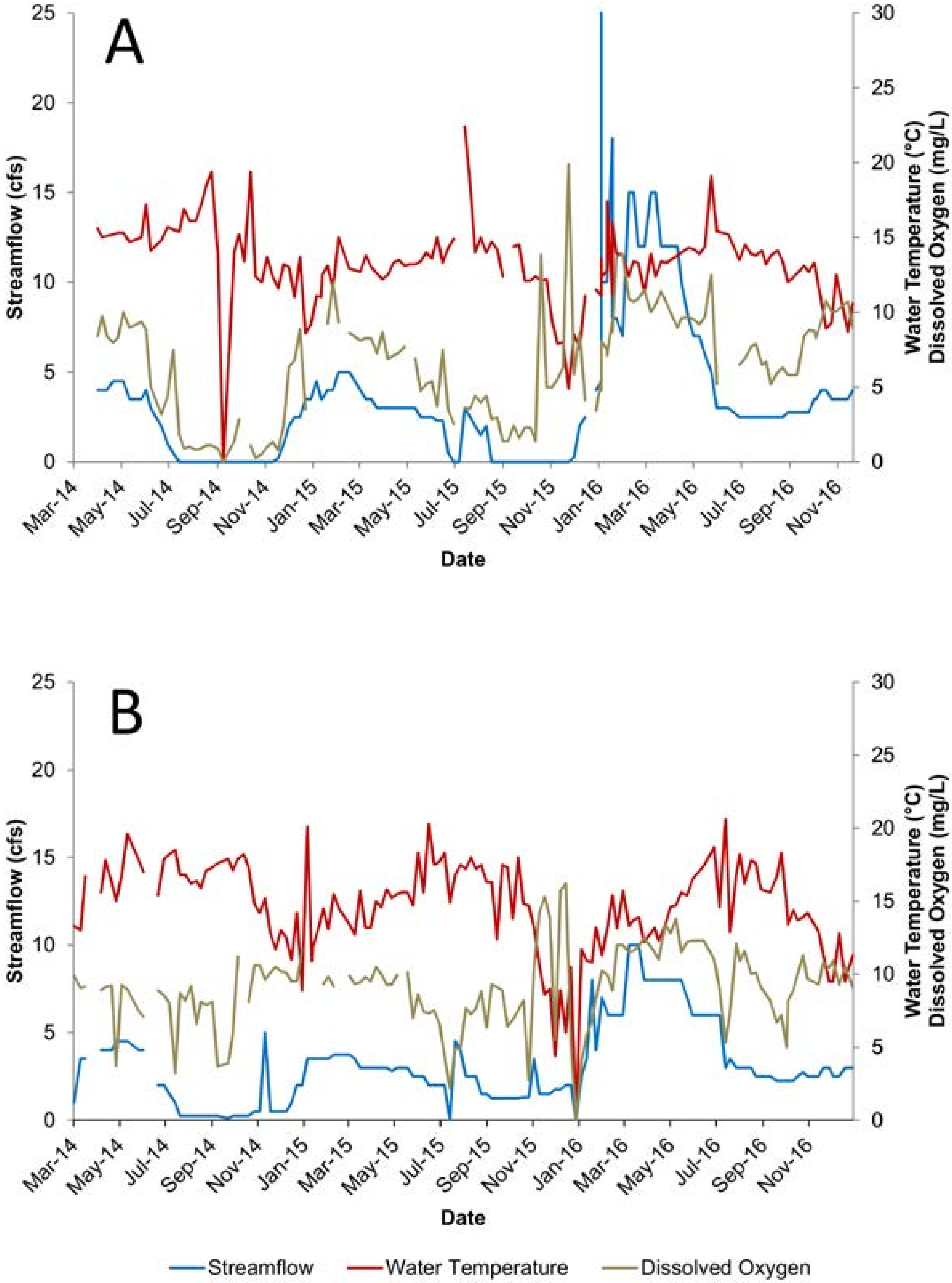


FIGURE 4.1.6.

Weekly visual estimates of streamflow and measurements of dissolved oxygen and temperature in (a) lower Chorro Creek and (b) upper Chorro Creek, San Luis Obispo County, during Water Years 2014, 2015, and 2016 (October 1, 2013 – December 31, 2016). Breaks in data represent times when sampling locations dried completely.

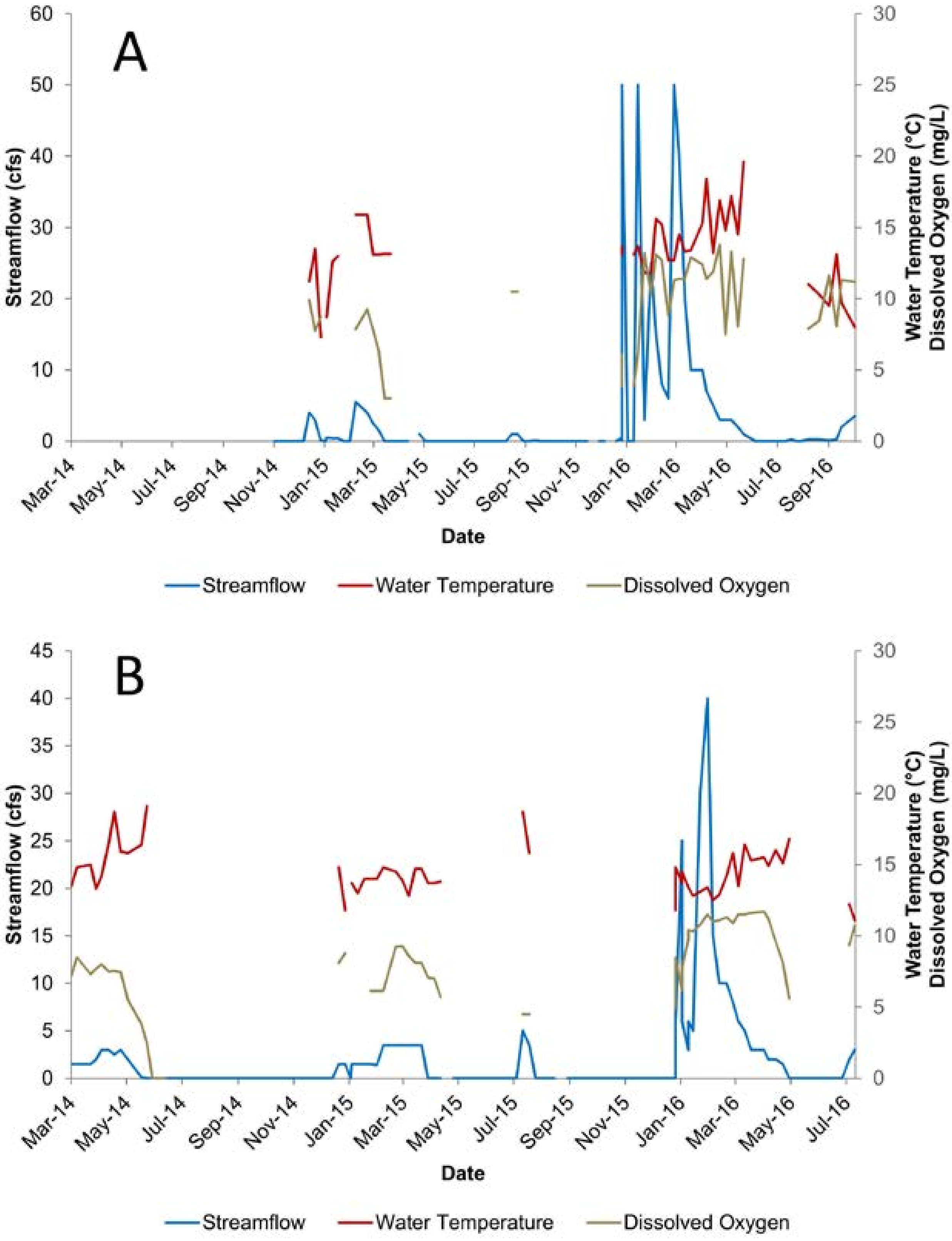


FIGURE 4.1.7.
Weekly visual estimates of streamflow and measurements of dissolved oxygen and temperature at sites on (a) lower- (Margarita Ave) and (b) upper- (Cuesta Ave) San Luis Obispo Creek, San Luis Obispo County, during Water Years 2014, 2015, and 2016 (October 1, 2013 – December 31, 2016). Breaks in data represent times when sampling locations dried completely.

PLATE 4.1.1.
Pacific Lamprey in Big Sur River, Monterey County, during 2016. Photo: CDFW.

FIGURE 4.1.2.
Big Sur River, Monterey County, fish rescue and dry back site downstream of Andrew Molera State Park in October 2015. Photo: CDFW.

River lagoon opened to the ocean in early January and remained open for five months, providing access for steelhead and lamprey between freshwater and marine environments. Throughout 2016, the Big Sur River flowed year-round to the ocean and there was no habitat fragmentation. This marked increase in connectivity for both rivers corresponded with increased spawning activity compared to conditions in 2014-2015.

In 2016, CDFW scientists observed 39 steelhead redds and 75 Pacific Lamprey redds in a 25-mile reach of the Carmel River. This was a large improvement compared to results in 2015, when scientists observed only one steelhead redd and no Pacific Lamprey redds. In the Big Sur River, CDFW scientists conducted spawning surveys in the entire lower 9-mile section downstream of the "gorge" in Pfeiffer Big Sur State Park. As with the Carmel River, spawning survey results showed an increased number of redds (15 steelhead and 271 Pacific Lamprey) compared to results in 2015 (only eight steelhead redds).

Santa Rosa Creek, Chorro Creek, San Luis Obispo Creek

In normal years, the monitoring site on Santa Rosa Creek and adjacent areas typically maintains perennial flows; however, the site dried out completely in both May 2014 and in April 2015 (Figures 4.1.5). This period coincides with when juvenile steelhead (smolts) and post-spawned adults (kelts) typically migrate from freshwater to the ocean. In 2016, CDFW scientists recorded streamflow of 10 cfs or more during the months of January through May in Santa Rosa Creek, which maintained perennial flow as is typical for a normal water year in this river system (Figure 4.1.5). The lagoon also remained open to the sea from January through June. The improved streamflow conditions in Santa Rosa Creek during 2016 allowed for continuous steelhead passage and access to rearing and spawning habitats. Water temperatures in Santa Rosa Creek remained below stress thresholds for steelhead year-round, but dissolved oxygen levels reached critically low levels during the summers of 2014 (1.2 mg/L) and 2015 (1.4 mg/L) when stream velocity approached zero and reaches completely dried. In summer 2016, dissolved oxygen improved to normal levels. These low levels documented are known to be potentially lethal for the survival of adult and juvenile steelhead (Matthews and Berg 1996).

The lower Chorro Creek sampling location became an isolated pool from August 2014 through 2015 (Figure 4.1.6.a). In contrast, the sampling site at upper Chorro Creek during both years maintained adequate streamflow and connectivity (Figure 4.1.6.b), demonstrating the importance of upper Chorro Creek as summer refuge habitat, particularly during drought conditions. Water temperatures in Chorro Creek remained below stress thresholds for steelhead year-round, reaching a maximum 22.4°C at lower Chorro Creek on July 22, 2015. Dissolved oxygen levels reached critically low levels only at lower Chorro Creek (July through early December 2014) when the stream velocity went to zero and stream reaches dried. At upper Chorro Creek, the dissolved oxygen level hit its lowest measured value (2.15 mg/L) on July 15, 2015 when the stream reach monitored nearly dried. In summer 2016, dissolved oxygen levels improved to normal levels. Throughout 2016, monitoring sites in lower and upper Chorro Creek maintained continuous and steady streamflow (Figures 4.1.6). This allowed for improved fish passage and created spawning opportunities, providing habitat and ocean access for steelhead.

During an average water year, approximately one mile of the upper San Luis Obispo Creek typically goes dry, whereas the lower sections of the creek typically flows year-round. Data collected at the monitoring locations at Cuesta Park, in the upper watershed, show that there was no stream flow at this location for 7.5 months in 2014 (from end of May through beginning of December) (Figures 4.1.7). In 2015, this location was dry for 9.5 months

(from April through mid-January) with a short-lived flow for about a week in July 2015. In 2016, this site was dry for about five months (from the end of June through the beginning of December). Water temperature and dissolved oxygen at the Cuesta Park sampling site never reached levels that surpassed aforementioned stress thresholds for steelhead. The water temperature peaked at 19.1°C on May 28, 2014 just before the reach dried. At the Margarita Avenue site, temperatures peaked at their highest values on two days in 2014 (18.7°C in April and 19.1°C on May 28, 2014).

Results of electrofishing in 2016 (45 steelhead) compared to 2014 (eight steelhead) showed a greater abundance of juvenile steelhead at index reaches, indicated improved spawning and/or rearing conditions for steelhead.

4.2 WILD TROUT AND INLAND WATERSHEDS

Species Focus and Location Description

In Central Region's inland waters, CDFW scientists monitored conditions for Golden Trout and Red Hills Roach. Both species are listed as Species of Special Concern. Golden Trout is native to the South Fork Kern River and Golden Trout Creek watersheds, located on the western slope of the Sierra Nevada in Tulare County (Figures 4.2.1 and 4.2.2). The Red Hills Roach is a highly distinctive form of California Roach, and is found in only a few small streams within the Red Hills Area of Critical Environmental Concern of Tuolumne County (Moyle 2002).

Local Need for Drought Stressor Monitoring

The Golden Trout population in Volcanic Creek (Figure 4.2.1) is one of the few remaining genetically distinct populations found within the native range of this species. Volcanic Creek is a small watershed with a spring-fed water supply. The volcanic nature of the soil means that this stream typically goes dry at the surface before reaching Golden Trout Creek. The lack of connectivity to other trout populations, in combination with its small population size, poses significant risks to long-term survival of the species and the potential impacts of the drought.

FIGURE 4.2.1.

Locations of trail cameras, temperature loggers, and visual encounter surveys along Volcanic Creek, Tulare County during the summers of 2014, 2015, and 2016.

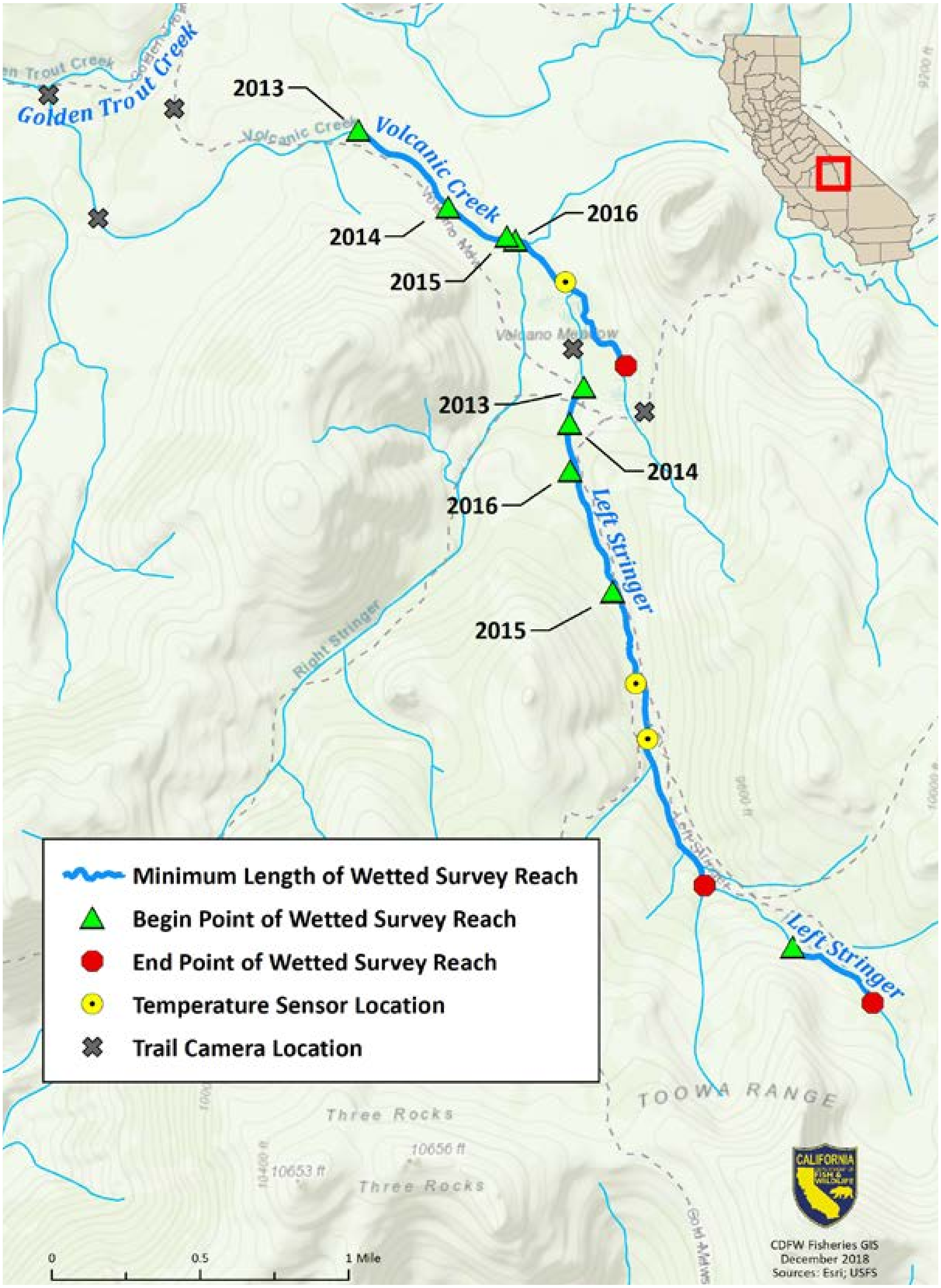
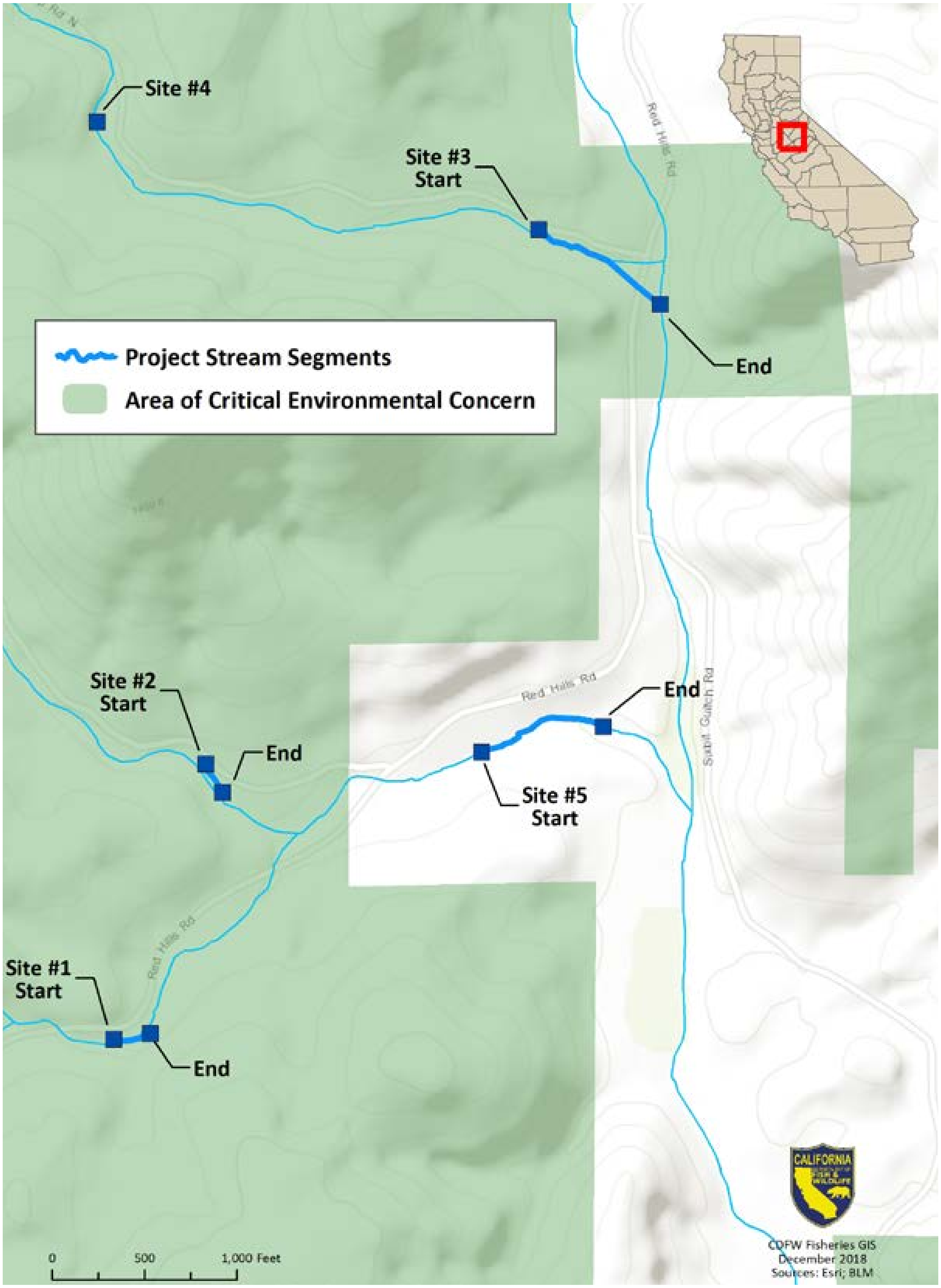


FIGURE 4.2.2.
Locations of Red Hills Roach monitoring surveys within the Red Hills Area of Critical Environmental Concern, Tuolumne County.



Red Hills Roach only occur within the Red Hills Area of Critical Environmental Concern (Figure 4.2.2), an area managed by the US Bureau of Land Management. Five spring-fed habitats are core locations for this species (Figure 4.2.2). When the aquifer is depleted after long periods of drought, the stream habitat between springs may go completely dry, fragmenting surface water flows. As with the risks faced by Golden Trout, the drying of springs may isolate existing Red Hills Roach populations. The species may be at risk should the spring water source completely cease, or the water quality conditions deteriorate.

The drought years of 2013, 2014 and 2015 were critically dry years in this region, resulting in lower than normal snowpack at high elevations. This factor, combined with less rainfall at lower elevations, reduced the available water supply on which the survival of Golden Trout and Red Hills Roach depends. CDFW scientists responded by monitoring population status and habitat quality. This information helped determine whether emergency actions were necessary to rescue populations.

Findings and Actions

Golden Trout in Volcanic Creek

CDFW scientists monitored the status of Golden Trout by conducting visual encounter surveys in Volcanic and Left Stringer creeks. The extent of wetted stream reaches was determined and water temperature sensors installed in several creeks, including Volcanic Creek, Left Stringer Creek, and in other nearby Golden Trout waters (Salt Lick Meadow, Groundhog Meadow, and Golden Trout

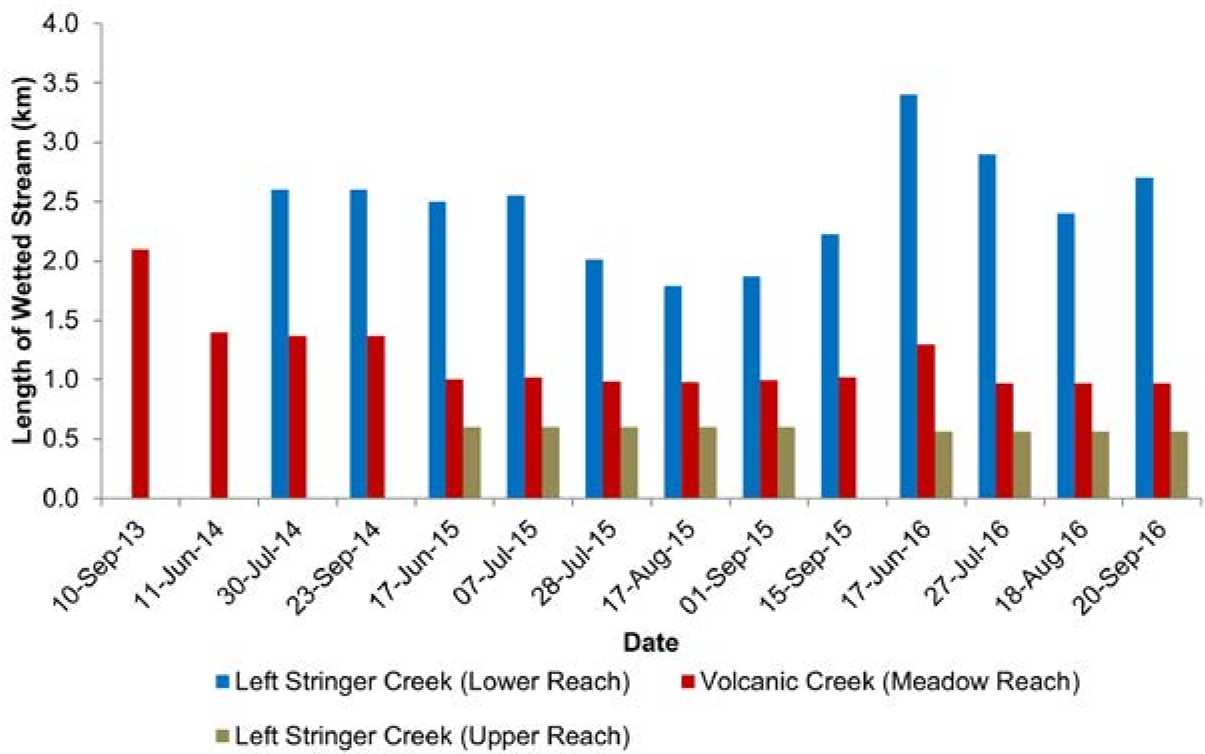


FIGURE 4.2.3.
Length of wetted habitat from 2013 to 2016 in Volcanic Creek and two reaches in Left Stringer Creek. Only data from reaches that were surveyed are included.

creeks). CDFW scientists also deployed digital trail cameras to document the drying of streams and to determine the extent of surface water connectivity with Golden Trout Creek (Figure 4.2.1). These assessments collectively provided important information to inform resource management decisions.

In Volcanic Creek there was a 54% loss in wetted habitat since 2013 (Figure 4.2.3). Volcanic Creek visual encounter surveys in June 2016 counted 48 Golden Trout, an 81% reduction in count compared to the 2014 survey (Figure 4.2.4). Additional counts in July and August 2016 saw a further reduction in the number of Golden Trout. Heavy vegetative growth limited viewing conditions during this period and may have contributed to the decreased counts.

The lower reach of Left Stringer Creek experienced a 41% reduction in wetted habitat from 2013 to 2015. Visual encounter surveys in the lower reach of Left Stringer Creek showed a 71% reduction in fish abundance from 2014 to 2016. The upper reach of Left Stringer Creek had stable wetted habitat and the fluctuations in visual counts can most likely be attributed to changes in viewing conditions (Figure 4.2.3).

Water temperature in Volcanic Creek (Meadow Reach) during the winter dropped to a minimum 0.1 °C. Reductions in available wetted habitat and the presence of anchor ice, driven by drought conditions from 2013 to 2015, are likely to be the primary causes of declines in Golden Trout populations in the surveyed reaches (Figure 4.2.4).

Although habitat conditions improved in 2016 through increased precipitation and runoff, populations of Golden Trout continued to shrink in both creeks from fall 2015 to spring 2016 (Figure 4.2.4). To preserve the genetic diversity of Golden Trout and prevent loss of the local population, CDFW scientists rescued a total of 52 fish in 2016 from the three reaches of Left Stringer and Volcanic creeks. The rescued fish were transported to the American River Hatchery located in eastern Sacramento County. At the hatchery, the rescued fish were held in tanks until conditions improved in Left Stringer and Volcanic creeks so that fish could be safely reintroduced.

During next winter of 2016-2017, there was near record precipitation, bringing much-needed rain and snowpack to the high elevations of the Sierra Nevada. June 2017 surveys documented connectivity of Volcanic Creek to Left Stringer and Golden Trout creeks. Water levels were extremely high during the June survey, making for difficult conditions for population assessments using the visual encounter method. Under these conditions, the amount of wetted habitat was at a maximum and the fish density was believed to be at a minimum. This combination made for the ideal conditions to reintroduce the trout held at the American River hatchery, and in July 2017, CDFW scientists successfully reintroduced Golden Trout back into Left Stringer and Volcanic creeks.

Red Hills Roach within the Red Hills Area of Critical Environmental Concern

The abundance of Red Hills Roach in the Red Hills Area of Critical Environmental Concern was evaluated in 2014 by visual encounter surveys (Figure 4.2.5). Habitat conditions were monitored by photographing habitat locations over time to track changes in hydrological conditions, including habitat connectivity. CDFW scientists also surveyed stream depth and channel width, as well as the total length of the wetted area (Figure 4.2.6). Water temperature was monitored with data loggers deployed at two locations and also recorded manually during stream surveys. Other water quality information collected included pH, dissolved oxygen, specific conductivity, salinity, and total dissolved solids.

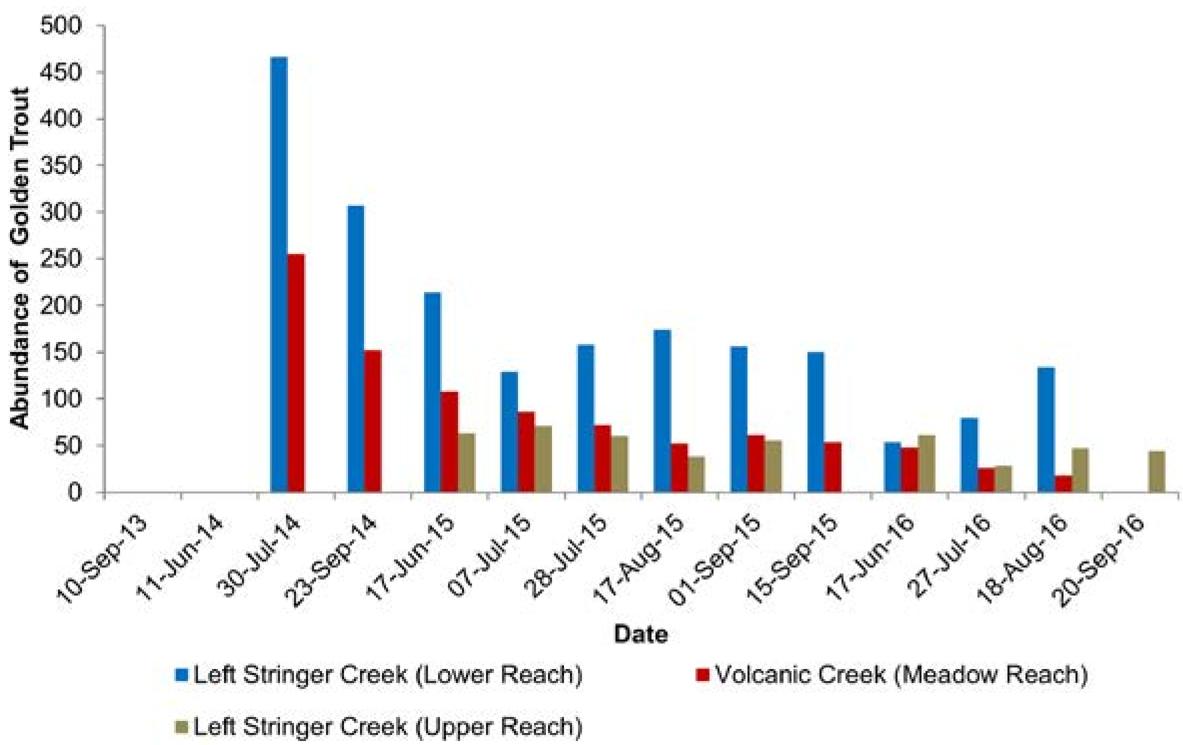


FIGURE 4.2.4.
Total number of Golden Trout as determined from visual estimation surveys in three reaches of Volcanic Creek. Only data from reaches that were surveyed are included.

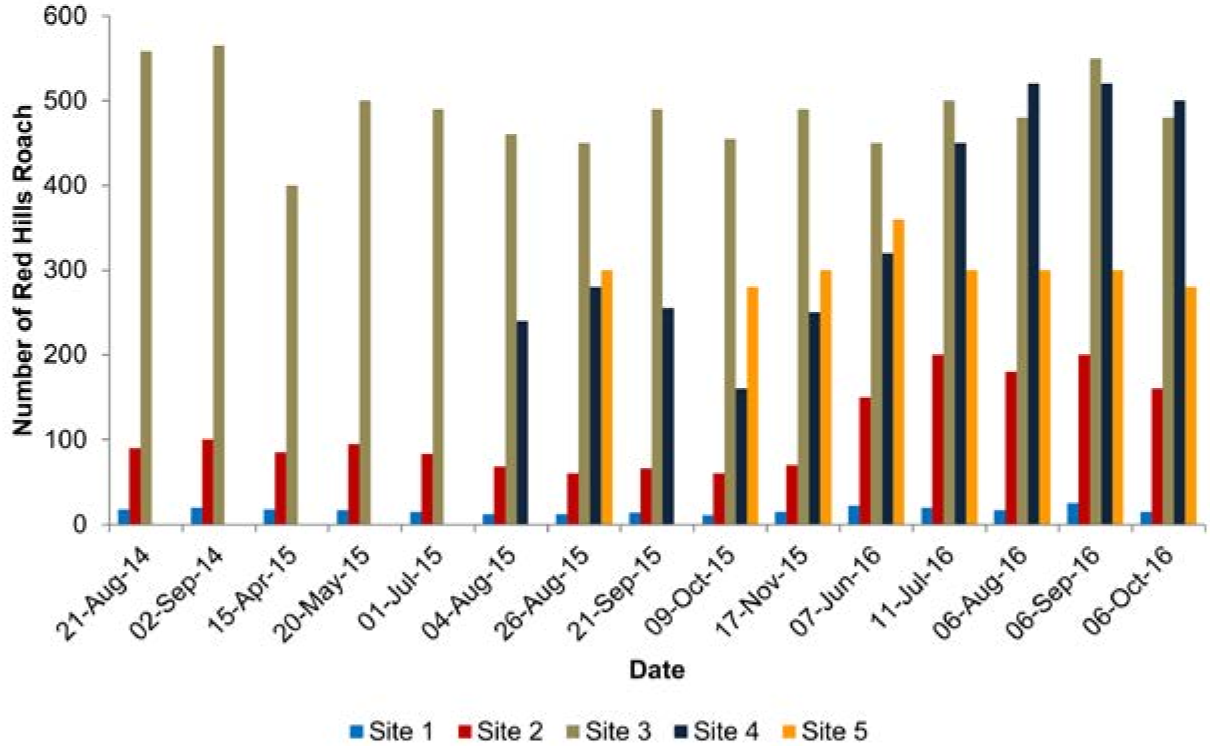


FIGURE 4.2.5.
Total number of Red Hills Roach as determined from visual estimation surveys at five locations within the Red Hills Area of Critical Environmental Concern. Only data from reaches that were surveyed are included.

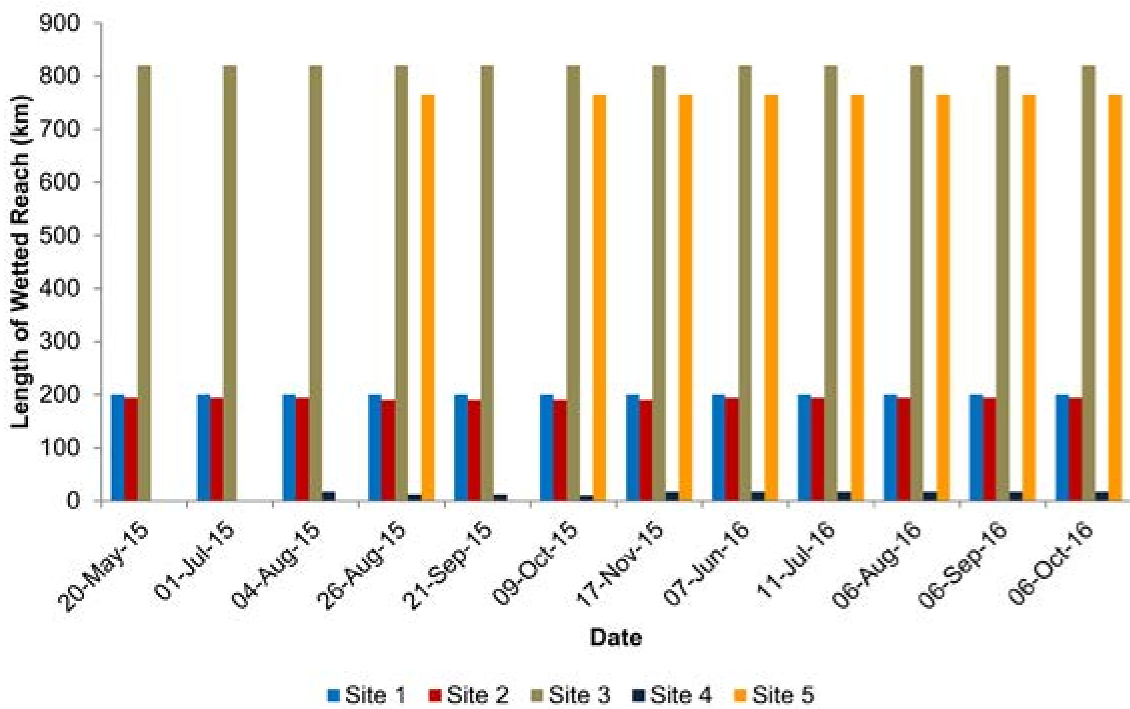


FIGURE 4.2.6.
Length of wetted habitat at five locations within the Red Hills Area of Critical Environmental Concern. Only data from reaches that were surveyed are included.

CDFW scientists developed a fish rescue plan based on monitoring information to help guide fish rescues if populations were endangered, and a threshold for management actions, such as adding water or conducting a fish rescue, was established. The threshold was met if either (1) the abundance of Red Hills Roach, or (2) the quantity of wetted stream, was reduced by 40% or more at any of the five monitoring locations. This threshold was reached on October 05, 2015 when the spring water supply to Location 4 ceased and loss of streamflow to downstream habitat caused a 40% reduction in the available surface water habitat.

CDFW scientists acted to alleviate the loss of habitat by transporting water from Moccasin Hatchery, located in Tuolumne County, to two 300-gallon plastic cylindrical tanks located on-site in a concealed area. These tanks delivered water to the stream though irrigation hoses to supplement the available aquatic habitat and to prevent further stream drying. Water quality was monitored to ensure that fish were not stressed. The first two water deliveries occurred on October 09, 2015. Water deliveries continued through October 27, 2015 until the spring was recharged by rainfall and the aquatic habitat was resupplied. A total of five water deliveries, supplying approximately 2,800 gallons of water, succeeded in retaining Red Hills Roach habitat at stable levels.

In 2016, all springs that supplied water to aquatic habitats supporting Red Hills Roach were flowing again and water quality was suitable for fish survival. The condition of aquatic habitat and numbers of Red Hills Roach both improved in 2016. During the final visual encounter surveys of the year, CDFW scientists documented approximately 1,435 Red Hills Roach, all in good condition, at the five monitoring locations (Figure 4.2.5).

4.3 SAN JOAQUIN RIVER BASIN

Species Focus and Location Description

CDFW scientists carried out Drought Stressor Monitoring in the San Joaquin River basin, located in Fresno, Madera, Merced, Stanislaus, and San Joaquin counties (Figure 4.3.1). The San Joaquin River basin provides habitat for both Chinook Salmon and steelhead (Moyle 2002, Yoshiyama et al. 1998, NMFS 2014). Monitoring in the Stanislaus, Tuolumne and Merced rivers focused on Chinook Salmon, steelhead and also on general water quality.

Local Need for Drought Stressor Monitoring

The extended drought conditions reduced the amount of cold water stored within all the major reservoirs in the region. Reservoir water releases with elevated water temperatures raised concern about increased downstream mortality of salmon and steelhead. Water temperature monitoring and snorkel surveys were carried out to better understand the status and health of salmon and steelhead populations and their habitat. This allowed CDFW scientists to make informed science-based decisions to determine whether emergency management actions were warranted.

To minimize the adverse impacts to fish populations caused by unfavorable drought conditions, CDFW scientists supported continued investment in the San Joaquin River Restoration Program (SJRRP), a comprehensive effort to restore water flow and healthy fish populations to the San Joaquin River between Friant Dam and the confluence with the Merced River (SJRRP 2010)[13]. The efforts to support Chinook Salmon survival included: 1) using water conservation and chiller equipment to maintain water quality and supply at the SJRRP salmon conservation facility; 2) purchasing equipment for fish rescues; and 3) monitoring water quality conditions in-river and at the SJRRP salmon conservation facility.

TABLE 4.3.1.
Estimates of the number of adult fall-run Chinook Salmon returning to San Joaquin River tributaries: Stanislaus, Tuolumne, and Merced rivers in 2014 and 2015.

Year	Stanislaus River (Number of Adult Chinook Salmon)	Tuolumne River (Number of Adult Chinook Salmon)	Merced River (Number of Adult Chinook Salmon)
2014	3060	438	1733
2015	6136	113	2453

TABLE 4.3.2.
Snorkel survey summary counts for Chinook Salmon and steelhead in Stanislaus and Merced rivers in 2014 and 2015.

Species (Age class)	Stanislaus River 2014	Stanislaus River 2015	Merced River 2014	Merced River 2015
Steelhead (Adult and Juvenile)	1753	612	742	59
Chinook Salmon (Adult)	3	0	14	1
Chinook Salmon (Juvenile)	24	3	9046	34

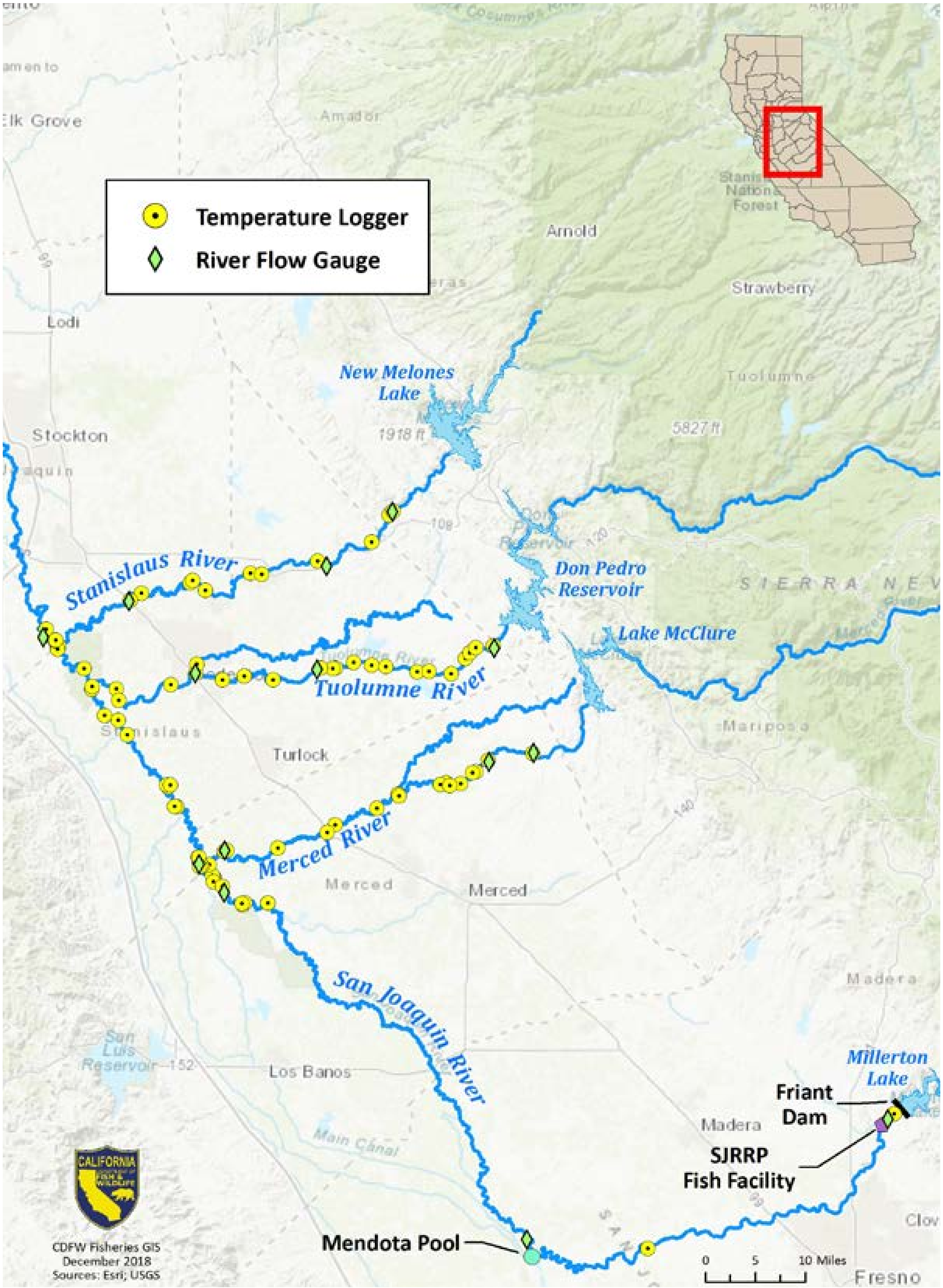
TABLE 4.3.3.
Total number of fish by species determined through snorkel surveys on the Merced River in 2014, 2015, and 2016.

Fish Species	Total Counts of Fish by Species		
	2014	2015	2016
American Shad	3	0	0
Black Bass (unidentified)	1017	1363	137
Common Carp	201	114	8
catfish (unidentified)	1	1	0
Chinook Salmon juvenile)	9046	34	33
Chinook Salmon (adult)	14	1	0
Golden Shiner	231	79	1
Goldfish	2	0	0
lamprey (unidentified)	0	0	1
minnow (unidentified)	195761	41073	5064
Sacramento Sucker	61163	14455	4869
sculpin (unidentified)	17	3	7
steelhead (untagged)	742	59	80
steelhead (tagged)	0	0	7
sunfish (unidentified)	257	190	6
Tule Perch	0	1	0
White Catfish	1	0	0

TABLE 4.3.4.
Total number of fish by species determined through snorkel surveys on the Stanislaus River in 2014, 2015, and 2016.

Fish Species	Total Counts of Fish by Species		
	2014	2015	2016
Brown Bullhead	0	0	19
Bluegill	0	1	1
Chinook Salmon (juvenile)	24	3	145
Chinook Salmon (adult)	3	0	1
minnow (unidentified)	0	70	1360
Sacramento Pikeminnow	0	3	136
Sacramento Sucker	0	72	2687
sculpin (unidentified)	0	0	1
steelhead (juvenile)	1753	612	2508
steelhead (adult)	0	0	238
Threespine Stickleback	0	0	1

FIGURE 4.3.1.
Locations of Drought Stressor Monitoring survey reaches and monitoring installations in San Joaquin River Basin.



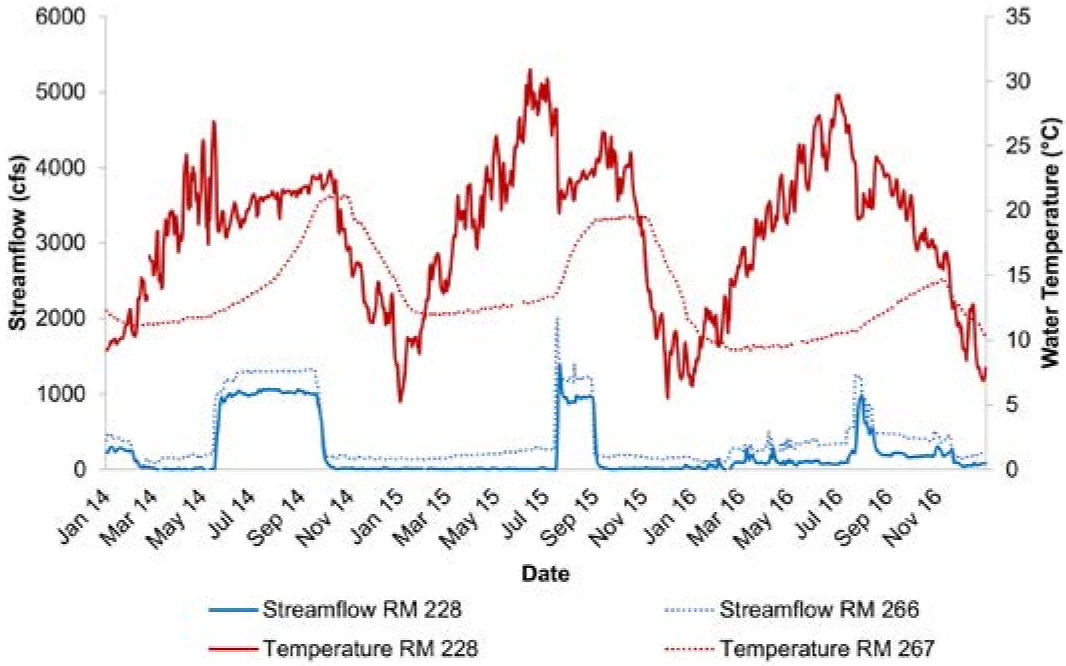


FIGURE 4.3.2.
Mean daily streamflow (cfs) and water temperature (°C) from 2014 through 2016 at downstream (RM 228) and upstream [RM 266 and 267 (Friant Dam)] locations in the upper San Joaquin River. Note that temperature and streamflow at the upstream site were not recorded at the same location.

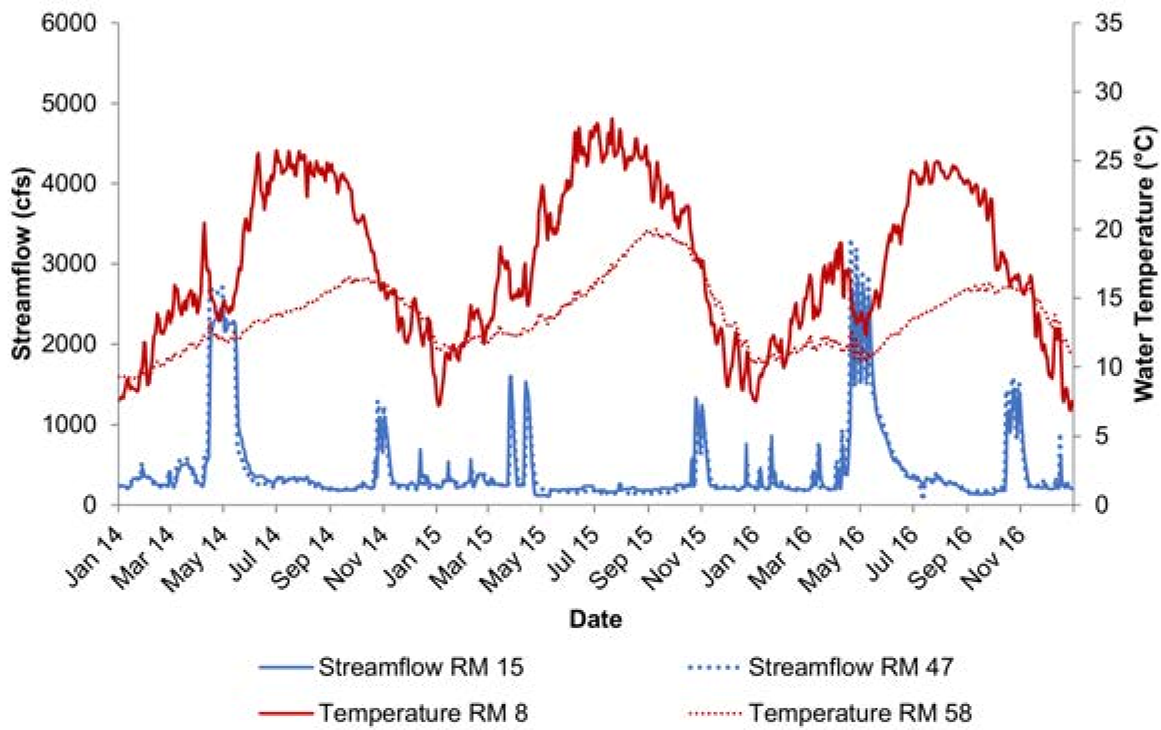


FIGURE 4.3.3.
Mean daily streamflow (cfs) and water temperature (°C) from 2014 through 2016 at downstream (RM 8 and 15) and upstream (RM 47 and 58) locations in the Stanislaus River. Note that temperature and streamflow were not measured at the same locations.

Findings and Actions

Salmon and steelhead

CDFW scientists conducted snorkel surveys of steelhead and Chinook Salmon populations in the lower San Joaquin, Merced and Stanislaus rivers. The number of adult fall-run Chinook Salmon recorded in the lower San Joaquin River basin in 2014 was substantially lower than in 2015 (Table 4.3.1). Snorkel surveys in the Stanislaus and Merced rivers recorded a higher number of steelhead in the Stanislaus River than in the Merced River. In both the Stanislaus and Merced rivers, higher numbers of steelhead were documented in 2014 compared to 2015 (Table 4.3.2). The number of Chinook Salmon and steelhead recorded in the Merced River in 2016 was the lowest since monitoring began (Table 4.3.3). Conversely, in the same year, the count of juvenile Chinook Salmon, juvenile and adult steelhead, and total fish in the Stanislaus River was the highest since monitoring began (Table 4.3.4). The positive changes in the Stanislaus River are thought to be a response to improved water temperatures and increased fish survival. Likewise, the declining fish population trends in the Merced River may have been the result of reduced fish survival associated with elevated water temperatures compounded over multiple summers.

Water quality and flow

Water temperature was monitored hourly in the lower San Joaquin River and the Stanislaus, Tuolumne, and Merced rivers. All thermographs were checked and downloaded monthly, except at 'critical' locations where, during spring and summer of 2014 and 2015, they were downloaded every other day. Water temperature records from the upper San Joaquin River showed an unprecedented increase from May through mid-September 2014, and from mid-July through September 2015 (Figures

4.3.2). The warmer water temperatures were likely a result of agricultural water releases to Mendota Pool, which were made to satisfy the commitments of the US Bureau of Reclamation to the Exchange Contractors Water Authority.

Based on historical records, the water temperature of the San Joaquin River below Friant Dam, River Mile (RM) 267, prior to 2014 ranged between 7°C and 13°C year-round, with occasional peaks above 14°C. In October 2014, water temperature below Friant Dam peaked above 21°C, while in September 2015 temperatures peaked above 20°C. Following the end of water deliveries, water temperatures leveled off through to the end of the year (CDFW 2016).

In 2014 and 2015, the Stanislaus, Tuolumne, Merced, and the lower San Joaquin rivers all experienced elevated summer water temperatures, with maxima ranging from 25°C to 30°C (Figures 4.3.2 - 4.3.6). The Stanislaus and Merced rivers exhibited similar temperature and flow patterns, with both recording higher summer water temperatures and lower river flows in 2015 than in 2014 (Figures 4.3.3 and Figure 4.3.5). The higher summer water temperatures and lower river flow patterns in the Tuolumne, Merced and the lower San Joaquin rivers were similar in both 2014 and 2015 (Figures 4.3.3 – 4.3.5).

Many water temperature loggers were lost in 2016, either due to vandalism or damage from high flows or fallen trees. These losses left large gaps in the collected data, especially in the lower San Joaquin River, where only seven days of data were preserved at three locations. As in previous years, the Stanislaus, Tuolumne, and Merced rivers all experienced elevated summer water temperatures in 2016 (Figures 4.3.3 – 4.3.5); however, maximum summer temperatures were lower in the two tributaries compared to 2014 and 2015 despite similar flow patterns.

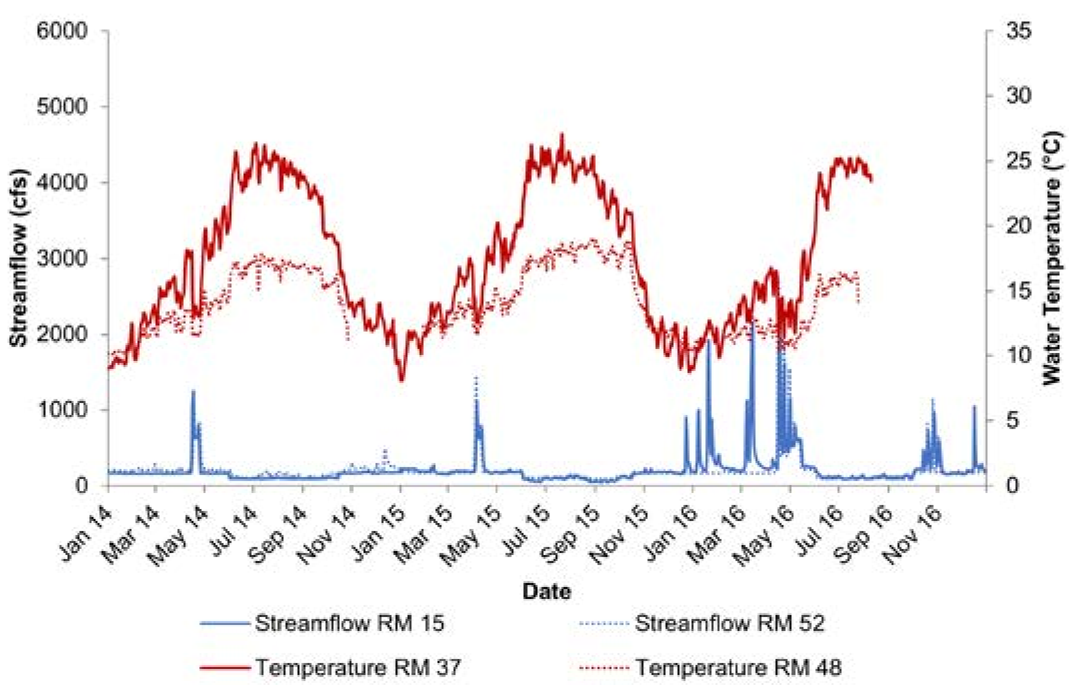


FIGURE 4.3.4.
Mean daily streamflow (cfs) and water temperature (°C) from 2014 through 2016 at downstream (RM 15 and 37) and upstream (RM 48 and 52) locations in the Tuolumne River. Note that temperature and streamflow were not measured at the same locations.

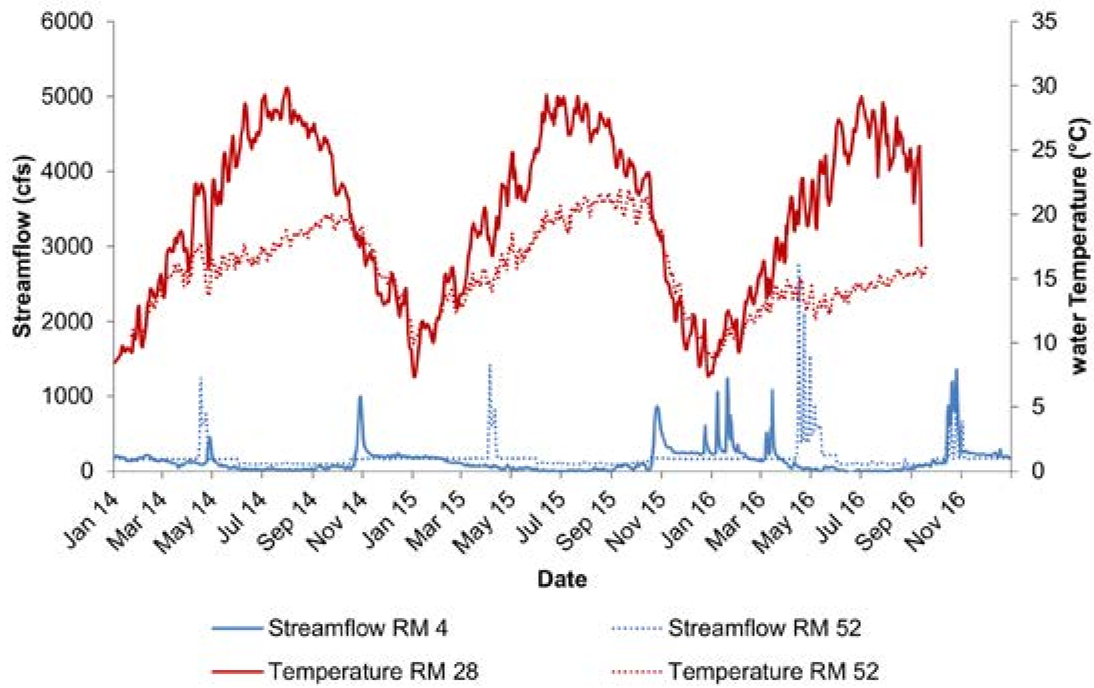


FIGURE 4.3.5.
Mean daily streamflow (cfs) and water temperature (°C) from 2014 through 2016 at downstream (RM 4 and 28) and upstream (RM 52) locations in the Merced River. Note that temperature and streamflow were not measured at the same locations.

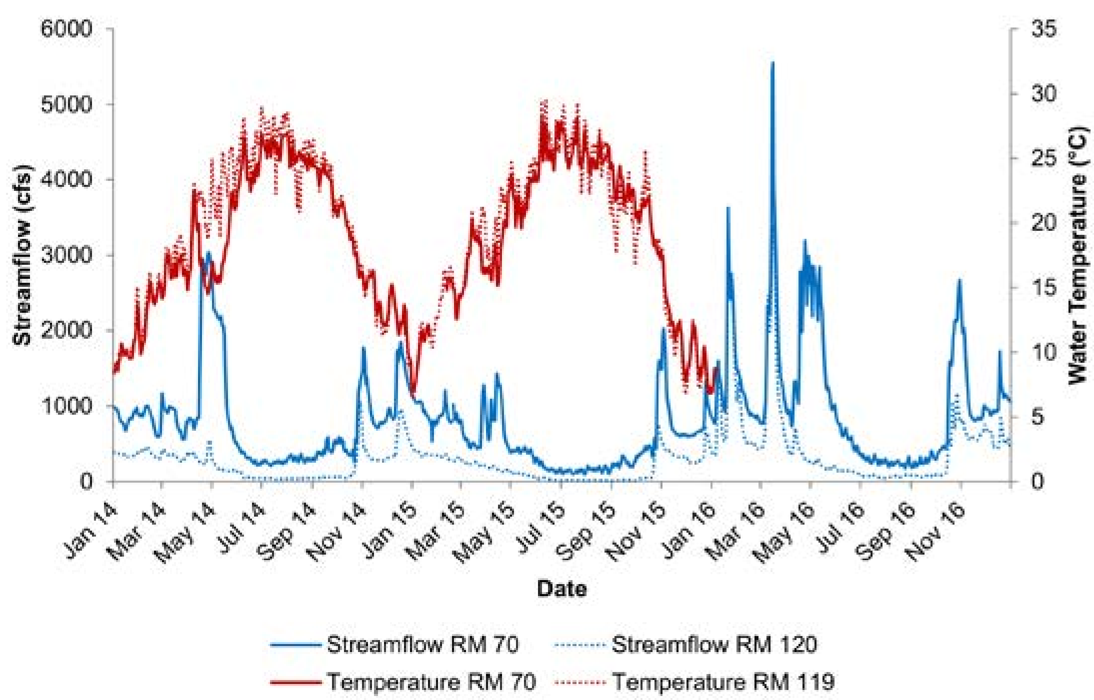


FIGURE 4.3.6.
Mean daily streamflow (cfs) and water temperature (°C) from 2014 through 2016 at downstream (RM 70) and upstream (RM 119 and 120) locations in the lower San Joaquin River. Note that temperature and streamflow from upstream were not measured at the same location.

The Stanislaus and Tuolumne rivers both recorded maximum summer temperatures of 25°C in 2016, down from the maximum of 30°C recorded in the previous two years (Figures 4.3.3 and 4.3.4). The Merced River followed a similar temperature pattern as in previous years, with maximum summer water temperatures reaching 30°C (Figure 4.3.5). Water temperatures decreased as a result of increased local precipitation associated with the 2015/2016 El Niño, reducing water temperatures to the extent that by the end of June, the temperature was at a six-year low for that time of year (CDFW 2016).

Streamflow in the lower Merced River dried out completely from May to early September 2016 (Figure 4.3.5). In comparison, the San Joaquin, Stanislaus, Tuolumne Rivers remained flowing throughout the year (Figures 4.3.2 - 4.3.6).

Management actions undertaken included fish rescues and a temporary closure of the lower Merced River to angling in 2014 and 2015.

PLATE 4.3.1.
Merced River habitat conditions during surveys conducted in 2016. On July 27 (top), the channel had narrowed noticeably. On August 24 (middle), the channel had become disconnected, forming isolated pools. On September 28 (bottom), flow increased, causing the channel to become reconnected. Photo: CDFW.

CHAPTER FIVE

South Coast Region

The South Coast Region includes Santa Barbara, Ventura, Los Angeles, Orange, and San Diego counties. Southern California coastal streams have been greatly modified through the effects of urbanization and water development. These alterations have modified the streamflow regime and decreased the amount of suitable habitat available for fish species listed as Endangered under state and federal ESA, listed as a California Fully Protected Species, or categorized as a California Species of Special Concern. These species include steelhead, Unarmored Threespine Stickleback, Santa Ana Sucker, Santa Ana Speckled Dace, and Arroyo Chub.

During normal water years, many streams in the South Coast Region are perennial in the headwaters but become intermittent in the lower sections, especially in areas of high urbanization or agriculture. The drought exacerbated these conditions, leading to increased rates of stream drying. CDFW scientists monitored these effects across seven major watersheds in the South Coast Region.

5.1 COASTAL WATERSHEDS

Species Focus and Location Description

Steelhead populations from Santa Barbara County south to the Mexican border are listed as Endangered under the federal Endangered Species Act (NMFS 2012). High priority watersheds monitored for steelhead in this area included the Santa Ynez, Ventura, and Santa Clara rivers and Arroyo Hondo Creek (Figure 5.1.1). These watersheds provide habitat for both anadromous and resident life history forms of Rainbow Trout, which can interbreed and change forms. This flexibility in life history strategy is an especially important adaptation for survival of this species at the southern limit of its geographic range, where streamflow conditions are often highly variable.

Local Need for Drought Monitoring

Monitoring steelhead populations during the drought provided a means to determine which locations maintain cold-water refugia when most of the watershed dries. Documenting these locations helps CDFW scientists understand locations that need to be protected and be made accessible. During times of drought, these are important fish release locations when rescues are needed.

Findings and Actions

To record the extent of wet and dry reaches of streams throughout the year, CDFW scientists surveyed streams with Global Positioning System (GPS) units. This information was mapped to determine the extent of stream drying over time (Figure 5.1.2).

PLATE 5.1.1.
Arroyo Hondo Creek, Ventura County, in spring (left) and summer (right) 2014. Streamflow declined in summer, resulting in isolated pool habitats. Photo: CDFW.

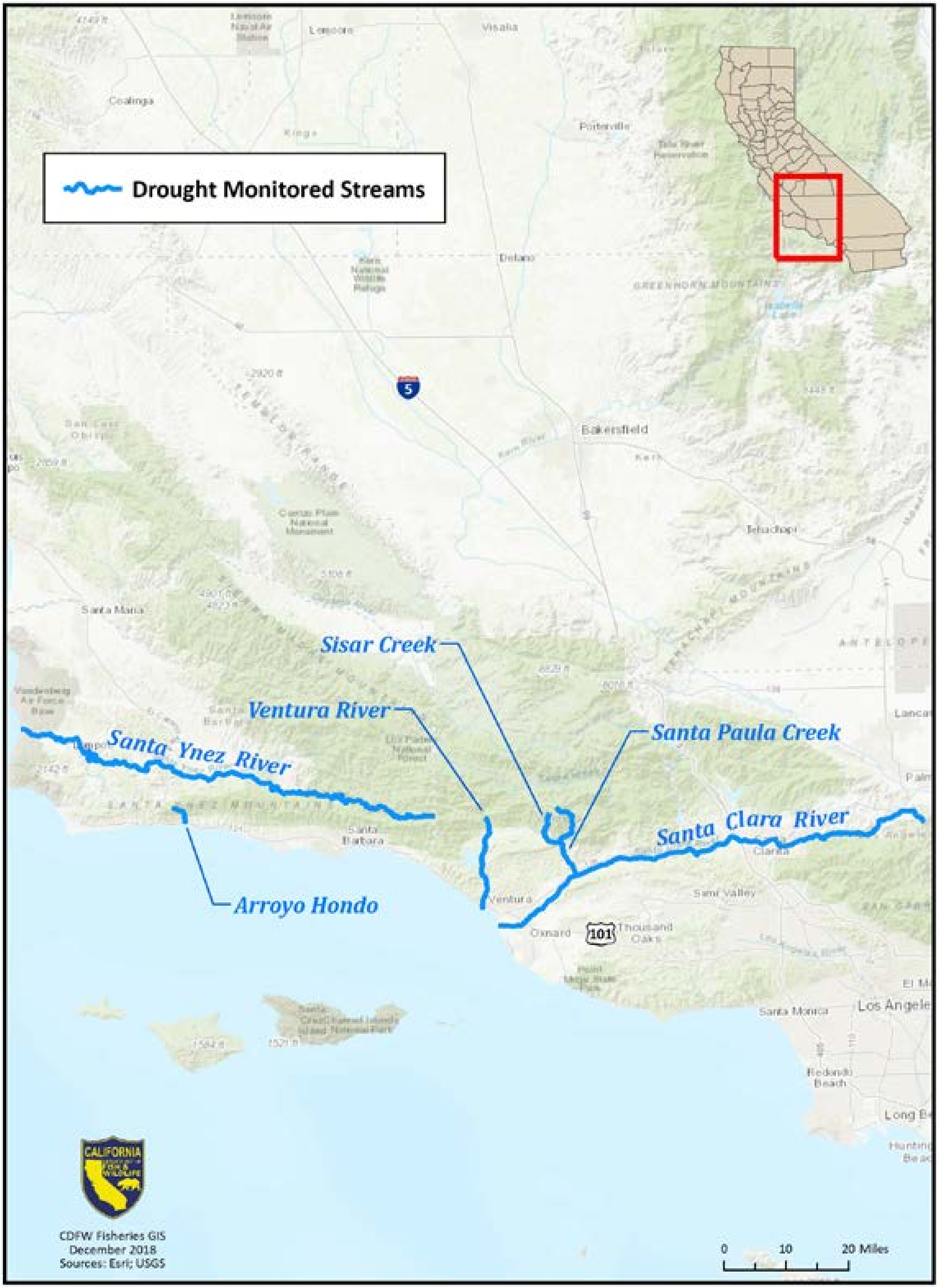


FIGURE 5.1.1.
Locations of Drought Stressor Monitoring priority watersheds for the South Coast Region Coastal Fisheries Program.

PLATE 5.1.2.
Stream conditions in Matilija Creek, tributary to the Ventura River, before (left) and after (right) three trout were rescued in April 2015. Photo: CDFW

CDFW scientists also conducted spawning surveys during winter and spring to estimate the number of adult steelhead in the watershed. This information was collected to determine the status of the population and to document the extent of changes in spawning habitat during the drought. CDFW scientists used information on refugia locations along with fish population information to prioritize drought responses.

Streamflow and drying patterns corresponded closely with rainfall. Wetted extent of some streams varied dramatically during the drought, ranging from 100% to less than 1% wetted. In 2015, the extent of wetted stream at Arroyo Hondo Creek varied from a high of 98% in February to a low of 38% in October during the same year. The upper North Fork Matilija Creek was 98% wetted in August 2014, but only 85% wetted in August 2015 (Figure 5.1.3). When streamflow declined, wetted habitat became fragmented and prevented fish migration. Isolated pools also became stagnant over time, resulting in increased water temperatures and decreased concentrations of dissolved oxygen. In San Antonio Creek, extreme seasonal drying reduced the flowing wetted length from 57% in January 2015 to only 6% in early October 2015 (Figure 5.1.4).

The two most common causes of fish kills were stream drying and reductions in amounts of dissolved oxygen in the water. As streams dried, more stagnant flow conditions combined with cellular respiration and decomposition processes reduced dissolved oxygen levels. During 2014 and 2015, a total of 16 fish rescues occurred due to loss of water depth and six rescues occurred due to low levels of dissolved oxygen. During this time, CDFW scientists and partners rescued 196 steelhead in 2014 and 308 steelhead in 2015. All fish rescue operations followed CDFW protocol to preserve local genetic diversity and fish were released into cold-water refugia within the same watersheds.

In March 2016, despite one storm early in the year, the Ventura River basin was only 70% wetted. By November and December 2016, the basin was 43%

wetted (Figure 5.1.5). The extensive dry sections of the river meant that during the spring of 2016, adult steelhead could not return from the ocean and smolts could not travel downstream to the ocean. The upper portion of Matilija Creek in the Ventura River watershed was reduced to 70% wetted in July 2016 (Figures 5.1.6). CDFW scientists had never observed such extensive drying of Matilija Creek prior to the drought. In October, Sisar Creek in the Santa Clara watershed was reduced to 18% of its average wetted length, triggering a fish rescue. The Santa Clara watershed was not affected as dramatically, and Santa Paula Creek was still 90% wetted during the driest period of 2016.

In the Santa Ynez River, low streamflow in 2016 led to critically low water levels in Lake Cachuma, preventing the United States Bureau of Reclamation from delivering flows into Hilton Creek. As a consequence, parts of Hilton Creek went dry (US Bureau of Reclamation 2016, personal communication). At the request of the US Bureau of Reclamation, NOAA Fisheries, and the Cachuma Operations and Maintenance Board, CDFW scientists rescued 34 juvenile steelhead before they were stranded. The rescued steelhead were later returned into wetted portions of Hilton Creek.

During winter of 2016 and spring of 2017, CDFW scientists conducted spawning surveys in the Ventura, Santa Clara and Arroyo Hondo watersheds. No steelhead redds were observed; however, CDFW scientists were able to document the presence of resident rainbow trout redds. Reproduction of this resident life history form can help sustain the anadromous population when environmental conditions do not allow hydrologic connectivity with the ocean. Also, the anadromous form, if trapped by dry stream channel, could remain in-river until future rains again allow for hydrologic connectivity.

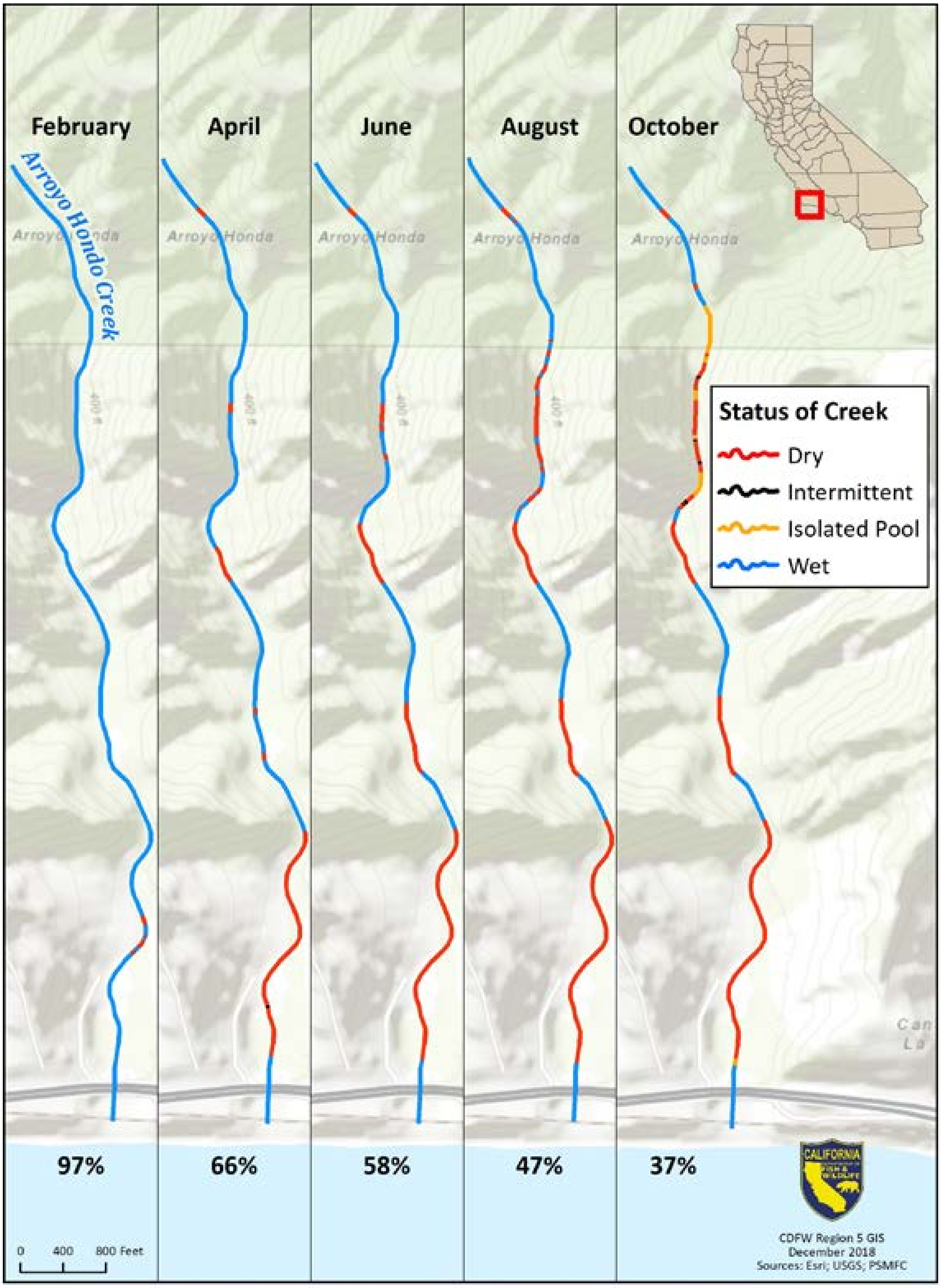


FIGURE 5.1.2.
Bimonthly changes in percent of wetted streambed in Arroyo Hondo Creek, Ventura County, in 2015.

PLATE 5.1.3.
During March 2016 spawning surveys, the lower Ventura River was reduced to isolated puddles for several miles and was impassable to returning adult steelhead. Photo: CDFW.

PLATE 5.1.4.
During December of 2016, the Ventura River suffered from low flows and dried out sections in the middle of the river. Invasive water primrose (*Ludwigia grandiflora subspecies*) in the lower river choked the channel during low flow and prevented any early season adult steelhead from returning to the headwaters to spawn. Photo: CDFW.

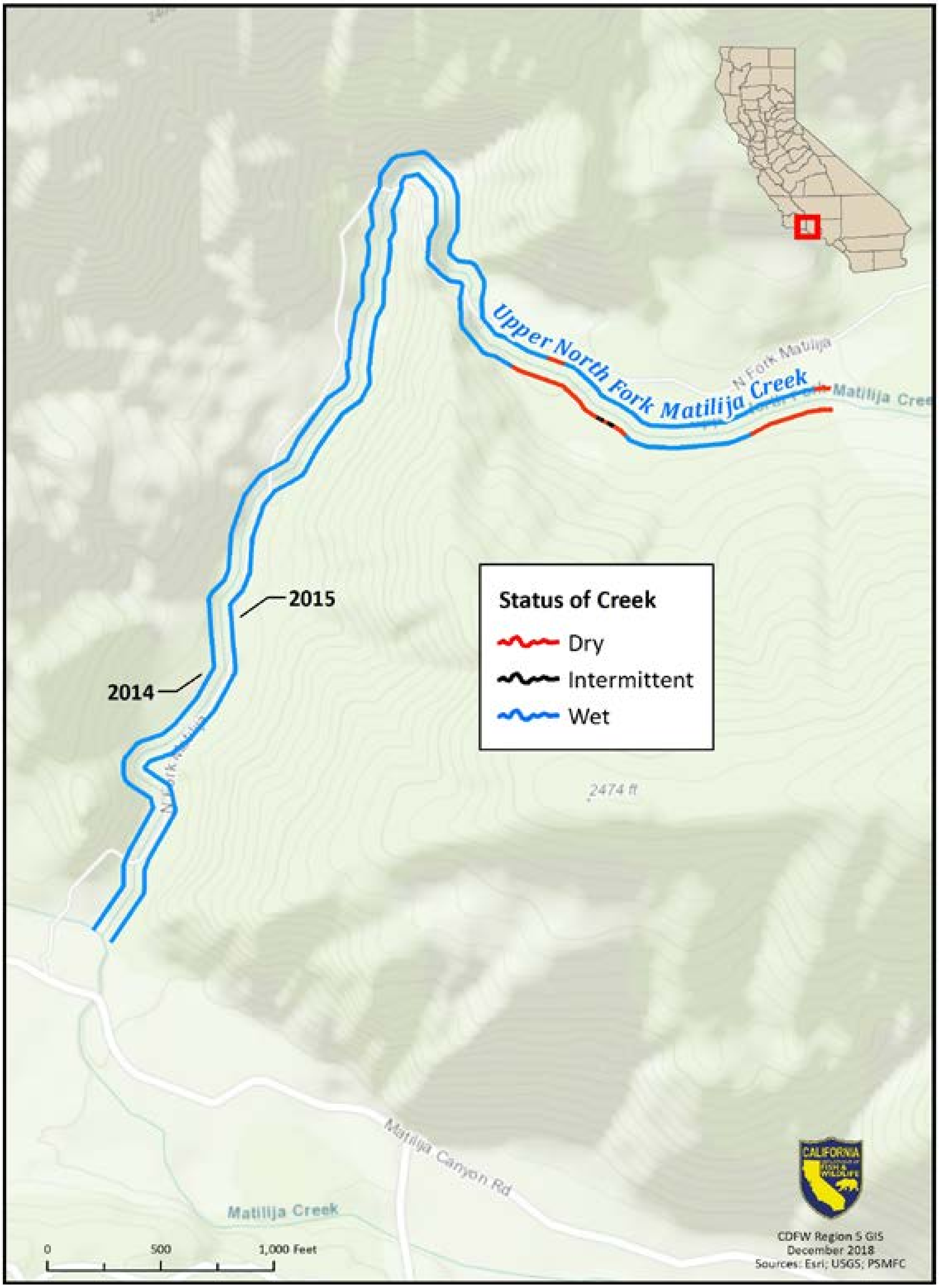


FIGURE 5.1.3.
August percent wetted channel in 2014 (98%, left line) and 2015 (85%, right line) in upper North Fork Matilija Creek, Ventura County.

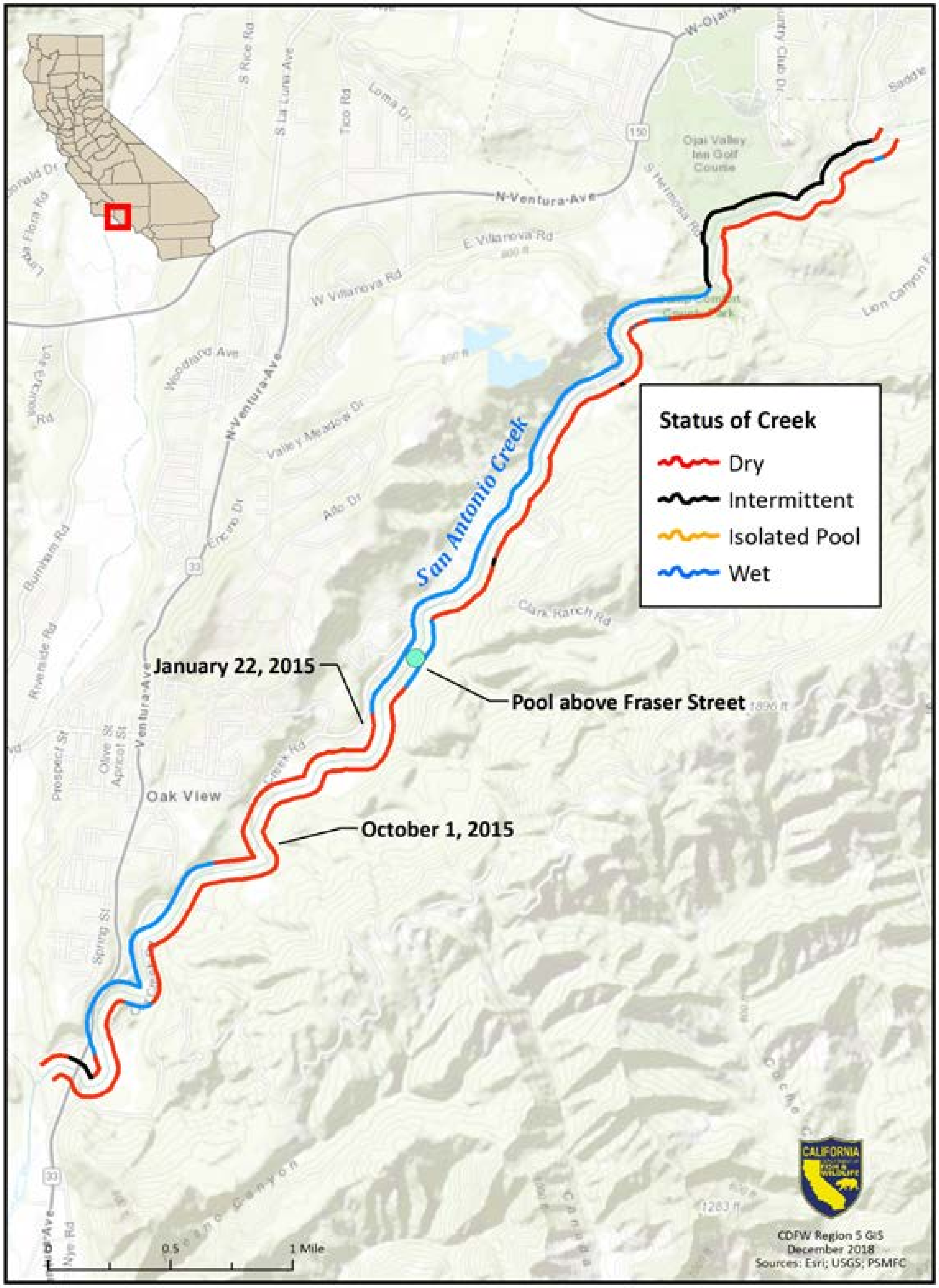


FIGURE 5.1.4.
Streamflow conditions in San Antonio Creek, Ventura County, during January (the left line), and the beginning of October 2015 (the right line).

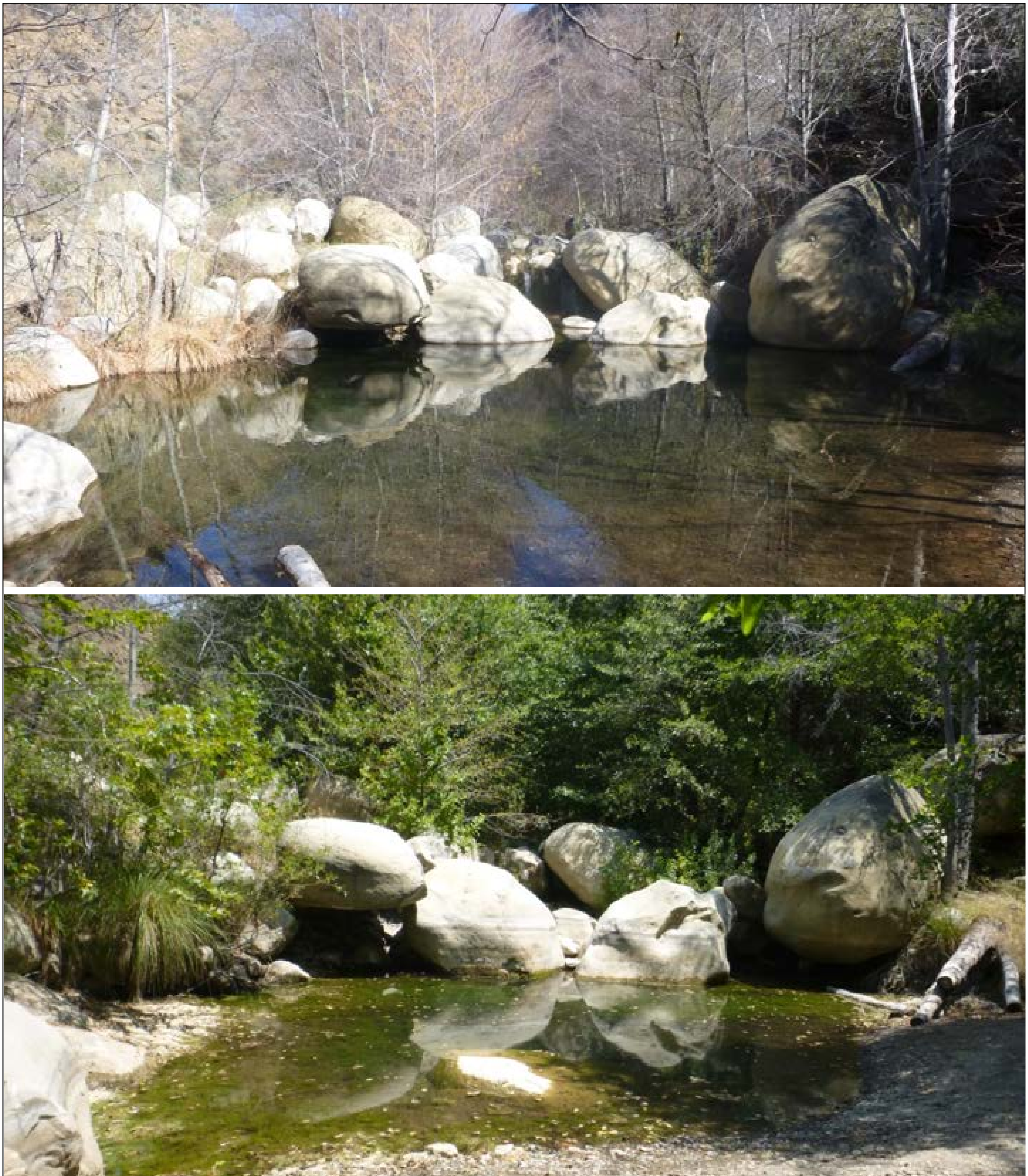


PLATE 5.1.5.
Matilija Creek in the upper Ventura River watershed during February (top photo) and July (bottom photo) of 2016. Large portions of this previously flowing creek were intermittent or dry during the summer. Photo: CDFW.

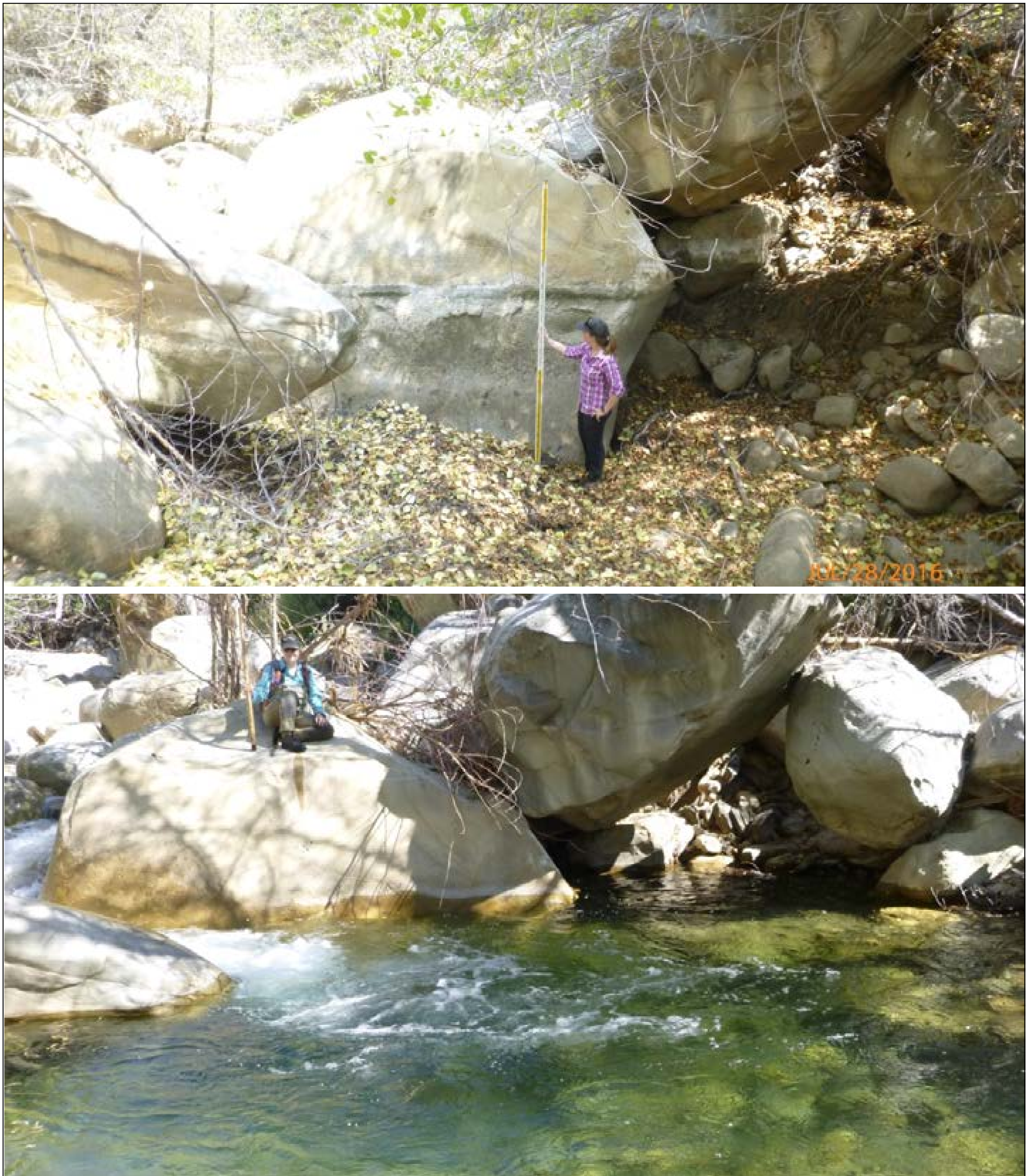


PLATE 5.1.6.
In July 2016, this usually perennial pool on Matilija Creek in the Ventura River watershed went dry (top picture), killing several juvenile steelhead. In 2017, the pool was restored to normal winter flow by recent rains (bottom picture). Photo: CDFW.

PLATE 5.1.7.
A CDFW scientist monitors water quality of a relocation pool following a fish rescue on Sisar Creek in the Santa Clara watershed. Photo: CDFW.

PLATE 5.1.8.
Critically low reservoir levels reduced flows and partially dewatered Hilton Creek in the Santa Ynez River watershed. In July 2016, CDFW scientists translocated 34 juvenile steelhead before their habitat completely dried. Photo: CDFW.

FIGURE 5.1.5.
Critical steelhead stream reaches of the Ventura watershed indicating dry and wet sections during the March 2016 (left) and November/December 2016 (right).

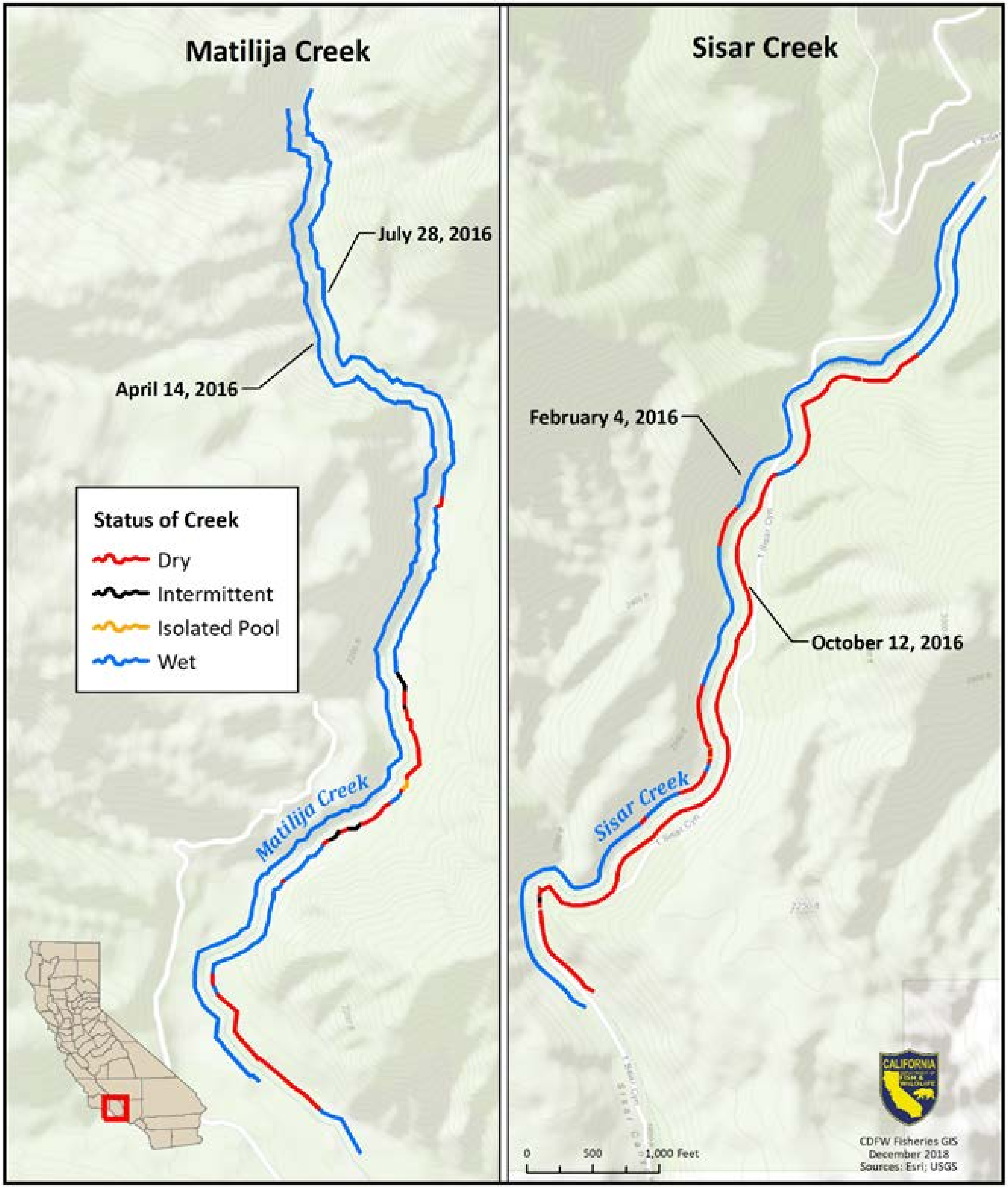
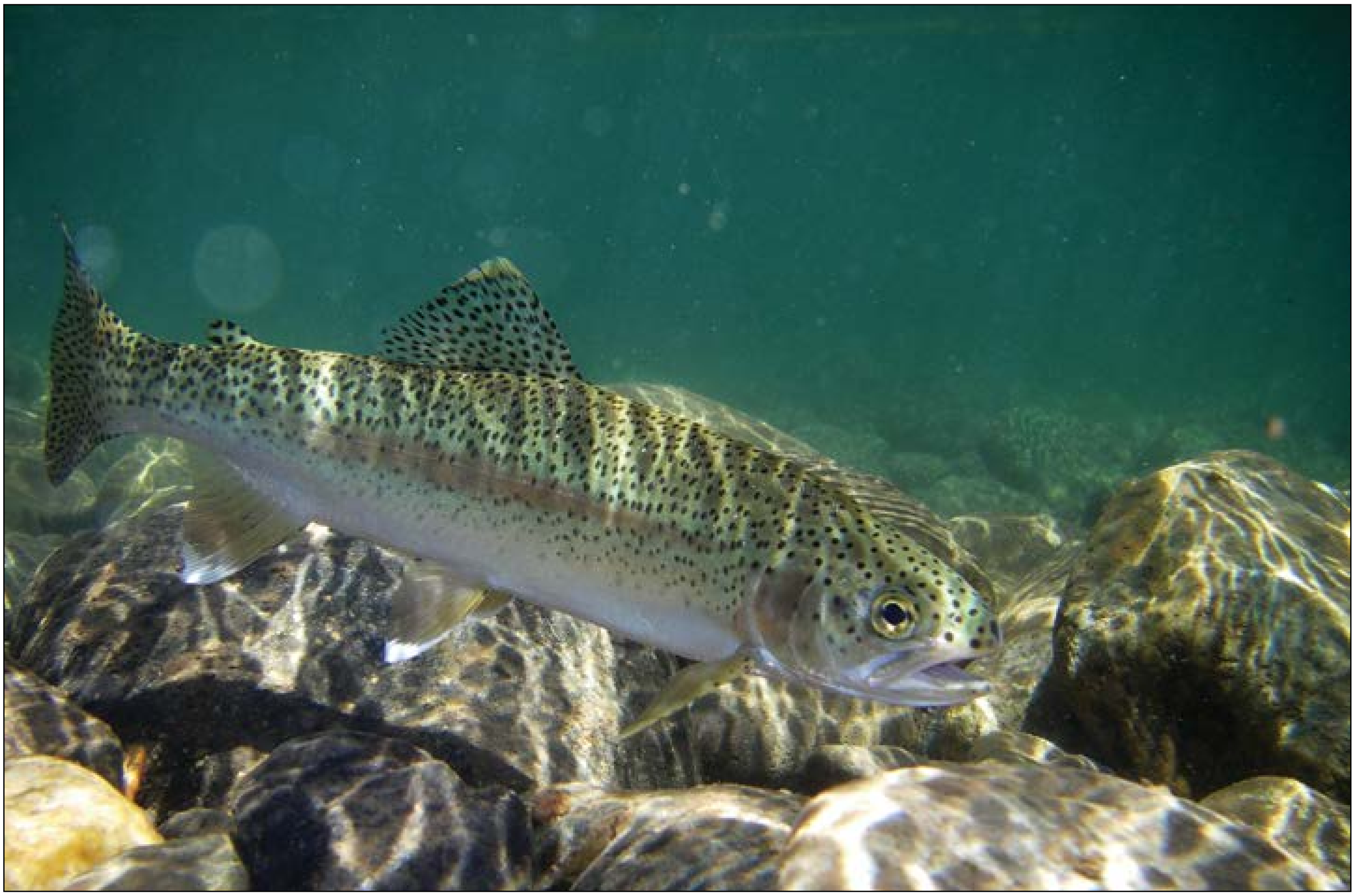


FIGURE 5.1.6.
Comparisons of wetted lengths of Matilija Creek, tributary of the Ventura River, from May to July 2016 (left) and Sisar Creek, tributary of the Santa Clara River, from February to October 2016 (right).



5.2 INLAND WATERSHEDS

Species Focus and Location Description

CDFW scientists focused Drought Stressor Monitoring on habitat conditions for the following native fish species: federal and state Endangered, and California Fully Protected Unarmored Threespine Stickleback (stickleback); federal Threatened Santa Ana Sucker; California Species of Special Concern Santa Ana Speckled Dace; California Species of Special Concern Arroyo Chub; and resident rainbow trout.

Four inland watersheds in Southern California were monitored for drought conditions, including the Santa Clara River, Big Tujunga Creek, San Gabriel River, and San Felipe Creek (Figure 5.2.1). Two of these, the Santa Clara River and San Felipe Creek, currently support stickleback populations. The other two watersheds, the upper San Gabriel River and Big Tujunga Creek, provide habitat for populations of Santa Ana Sucker, Santa Ana Speckled Dace, Arroyo Chub, and rainbow trout.

Local Need for Drought Stressor Monitoring

Severe drought conditions in southern California altered and reduced the available habitat for stickleback in the Santa Clara River and San Felipe Creek. These streams have relatively large and apparently stable populations of native fish (O'Brien et al. 2011). The San Gabriel River is one of the last remaining river basins in southern California where Santa Ana Sucker, Santa Ana Speckled Dace, and Arroyo Chub co-exist.

The perennial waters of the three forks of the San Gabriel River provide year-round habitat for native fish. The East Fork, North Fork, and West Fork were not thought to be in jeopardy of going dry; however, drought conditions contributed to stream

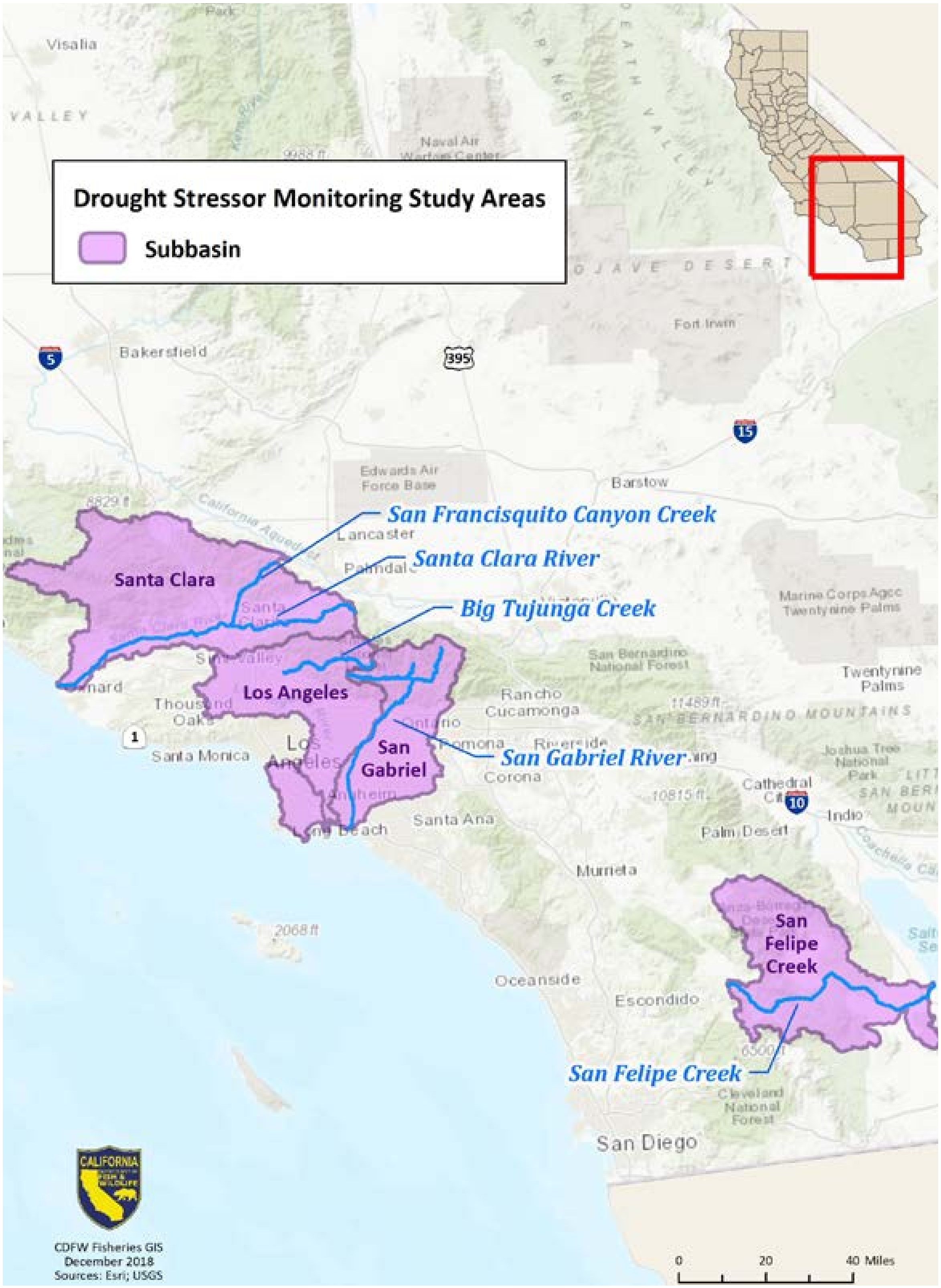


FIGURE 5.2.1.
Locations of Drought Stressor Monitoring priority watersheds for the South Coast Region Inland Fisheries Program.

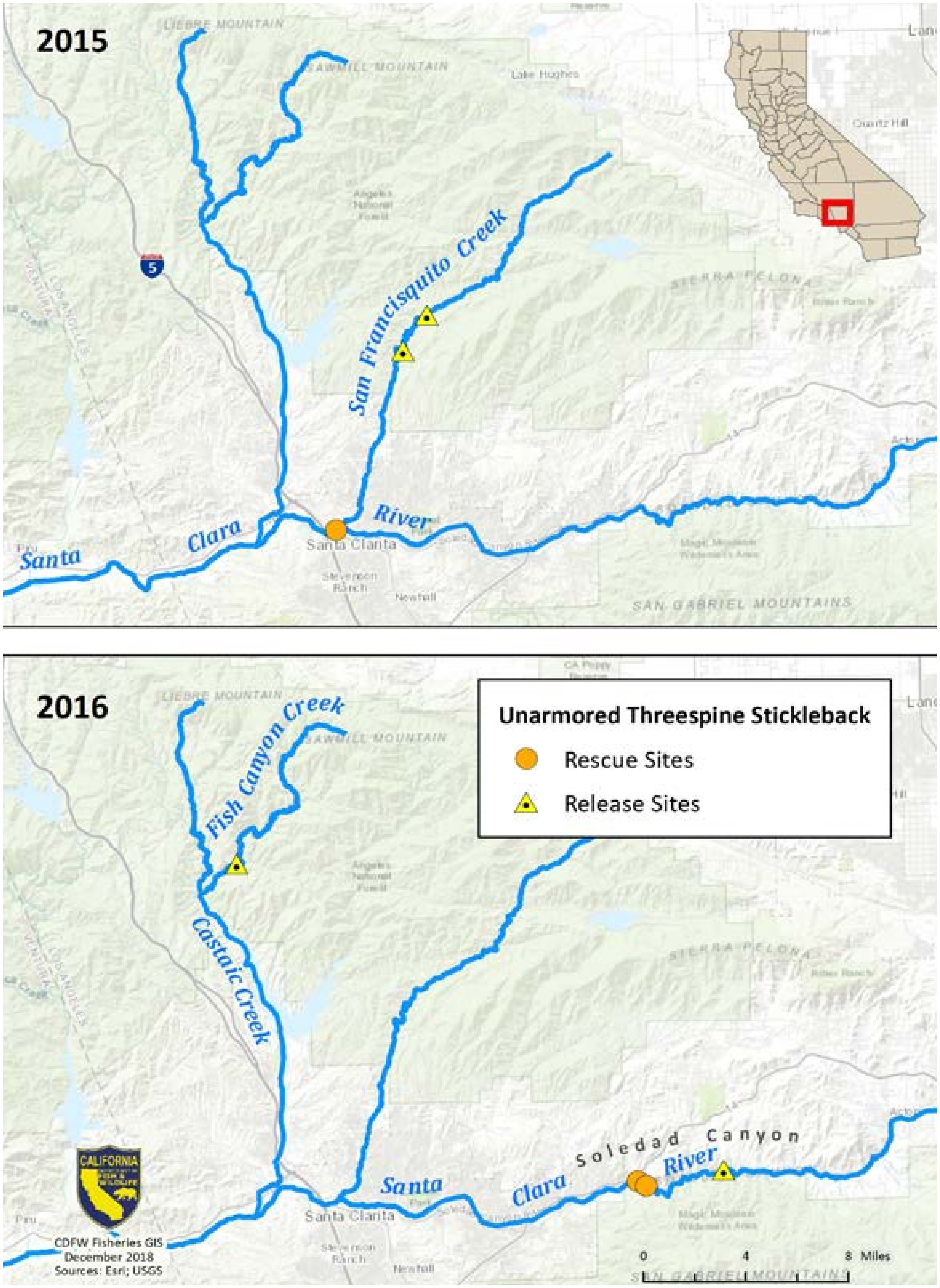


FIGURE 5.2.2.
Locations of Unarmored Threespine Stickleback rescue and release sites on Santa Clara River, Los Angeles County, in 2015 and 2016.

FIGURE 5.2.3.
Locations of Drought Stressor Monitoring sites on San Felipe Creek, San Diego County.

habitat changes, which can impact fish populations. The lack of flushing winter storm flows had the potential to lead to an increase in sedimentation and decreased the available pool habitat. Lack of flushing flows can also increase the amount of silt in the streambed, reducing habitat complexity and aquatic insect production.

Findings and Actions

Santa Clara River

CDFW scientists carried out biweekly monitoring of the mainstem Santa Clara River, beginning in spring 2014. Visual monitoring surveys were used to identify available wetted stream reaches and water quality conditions. Monitoring indicated that the number of available stickleback-occupied pools was severely reduced during the drought, triggering the implementation of a stickleback rescue in 2014. CDFW scientists rescued stickleback from drying habitat of the Santa Clara River in April, May, and August of 2014, releasing captured fish at two sites in a nearby tributary (San Francisquito Creek) (Figure 5.2.2).

The stream pools at the rescue site dried out completely in the fall of 2014 which would have resulted in the loss of this stickleback population without the implementation of drought monitoring and fish rescue. During follow-up monitoring in 2015 and early 2016, CDFW scientists found lower numbers of fish than previously encountered. These observations underscored the fact that although the population managed to persist through the drought period, there is still a need for population monitoring to ensure that the species is not extirpated.

Monitoring in 2016 focused on three creek sections known to hold stickleback populations, including Soledad Canyon, San Francisquito Creek, and a wetted section of the upper Santa Clara River. All three streams had similar water temperatures and dissolved oxygen levels throughout most of the monitoring period, though low streamflow during the summer months resulted in higher water temperatures and reduced levels of dissolved oxygen. By late summer, sections of some survey areas began to go completely dry, but San Francisquito Creek continued to receive steady water releases from the upstream reservoir. These releases helped maintain consistent water temperatures and dissolved oxygen levels throughout the monitoring period.

In May 2016, CDFW scientists were alerted to the stranding and possible mortality of stickleback in the lower portion of Soledad Canyon (Figure 5.2.2). Over the following weeks, scientists from ECORP Consulting, Inc., US Fish and Wildlife Service, US Forest Service, and CDFW rescued 1,600 juveniles from the lower portion of Soledad Canyon and transported them to a release site located approximately four miles upstream. Less than a week after the final Soledad Canyon rescue, the Sand Fire severely burned the surrounding area of Soledad Canyon. During post-fire monitoring, CDFW scientists determined that the upland vegetation surrounding the creek had been destroyed and that the stream was at risk of heavy sedimentation.

Anticipating a catastrophic event, scientists from CDFW, US Fish and Wildlife Service and US Forest Service began planning a stickleback rescue in Soledad Canyon. In October 2016, CDFW scientists collected 171 stickleback from Soledad Canyon and transported them to the state production hatchery in Fillmore, California, for temporary holding. This rescue proved to be very timely, occurring just prior to the heavy rain events in January 2017. At that time, the rain washed a large amount of sediment, ash and debris into the creek at Soledad Canyon, burying the collection site under seven feet of ash and sediment. Without the rescue, CDFW scientists believe that the stickleback population would have been buried and lost. When flows subsided in the spring after heavy rainfall, CDFW scientists successfully released the rescued stickleback from the hatchery into Fish Canyon Creek, a tributary to Castaic Creek.

San Felipe Creek

CDFW scientists monitored environmental conditions and stickleback populations in San Felipe Creek at two study sites covering approximately one mile of perennially flowing spring-fed water (Figure 5.2.3). Surveys were conducted biweekly to monthly from summer 2015 through early 2016. Water temperature, dissolved oxygen and streamflow were measured at each study site (Figures 5.2.4 and 5.2.5). Dissolved oxygen levels at both sites remained relatively constant, while water temperatures fluctuated. Stream discharge was similar at both sites over the study period, ranging from 0.1 cfs to just below 1.0 cfs (Figure 5.2.5). In early 2017, San Felipe Creek experienced a high flow event and overtopped its banks. CDFW scientists documented extensive scouring of the river bed at several locations within the creek which created large pools.

San Gabriel River

The three forks of the upper San Gabriel River, located above San Gabriel Dam, are important areas for the conservation of endemic populations of Santa Ana Sucker, Santa Ana Speckled Dace, Arroyo Chub and rainbow trout (Swift et al. 1993, O'Brien et al. 2011, Moyle et al. 1995). CDFW scientists measured water quality and streamflow at four study sites at a weekly to biweekly frequency from 2014 to early 2016. Two sites were located on the East Fork, one site on the North Fork and another site was located on the West Fork San Gabriel River (Figure 5.2.6).

CDFW scientists found that while water temperature at times exceeded 20°C, dissolved oxygen levels were generally within healthy concentrations for fishes (Figures 5.2.7 - 5.2.9). In 2015, water temperatures reached peak levels in June, much earlier than in 2008, when water temperatures were found to peak in

August (O'Brien et al. 2011). Peak water temperatures in the East Fork San Gabriel River were higher in 2015 (21 °C) than over the period of 2001 to 2004 (16 °C to 18 °C) (Ally 2004).

Reduced rainfall into the San Gabriel River watershed resulted in a lack of flushing winter storm flows. This contributed to increased sedimentation, decreased pool habitat, and increased embeddedness of cobbles within the streambed. However, significant rains in early 2017, together with water releases from Cogswell Dam, substantially increased streamflow in the San Gabriel River. The flushing flows improved fish habitat conditions through the re-distribution of fine sediment, sand and cobbles throughout the watershed.

Big Tujunga Creek

Located in the San Gabriel Mountains, Big Tujunga Creek provides important habitat for the conservation of endemic populations of Santa Ana Sucker, Santa Ana Speckled Dace, Arroyo Chub and rainbow trout (Moyle et al. 1995, Psomas 2017, Swift et al. 1993, USFWS 2014). Two dams located in Big Tujunga Creek for the purposes of flood control and water conservation have modified stream habitat conditions through the attenuation of storm flows. In 2016, to conserve water supply during the drought, minimal flows were released from Big Tujunga Dam (Psomas 2017).

From 2015 to 2017, CDFW scientists carried out monthly monitoring of water temperature and streamflow at three study sites along Big Tujunga Creek, including sites at Delta Flat, Wildwood, and Vogel Recreation Areas. These surveys recorded decreased stream widths and water depths during the drought, as well as reduced streamflow. Additionally, fewer fish were observed in 2016 compared to pre-drought years. Delta Flat, the most downstream study site, dried out in August 2016. The stream was wetted again by November, and scientists determined that stream width was approximately 25% of pre-drought conditions. Vogel Recreation Area, the most upstream study site, also experienced reduced flows and increased fine sediment in pool habitats during the drought.

Water temperatures at the Wildwood Study Site reached 20 °C by July 2016 and peaked at 25 °C in September. By November 2016, water temperatures had decreased to 10 °C at all three study sites. Heavy rains in January and February 2017, as well as large releases from Big Tujunga Dam, increased stream discharge at all study sites. During the heavy rains, silt was flushed out of the mainstem and was replaced with cobble and sand, improving habitat quality. CDFW scientists expect that these habitat changes will improve conditions for fish due to enhanced production of the macroinvertebrates on which fish feed, as well as improved spawning conditions.

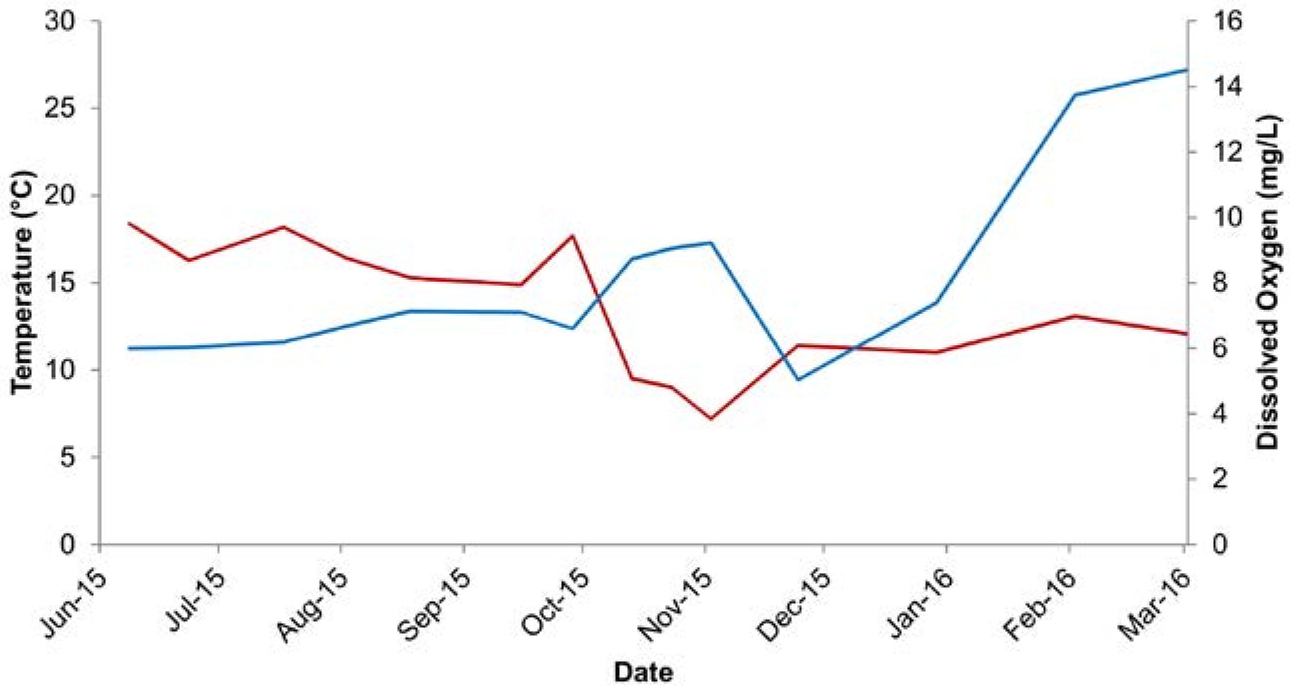


FIGURE 5.2.4.
Biweekly water temperature and dissolved oxygen data from June 25, 2015 through March 18, 2016 at Study Site 1 in San Felipe Creek, San Diego County.

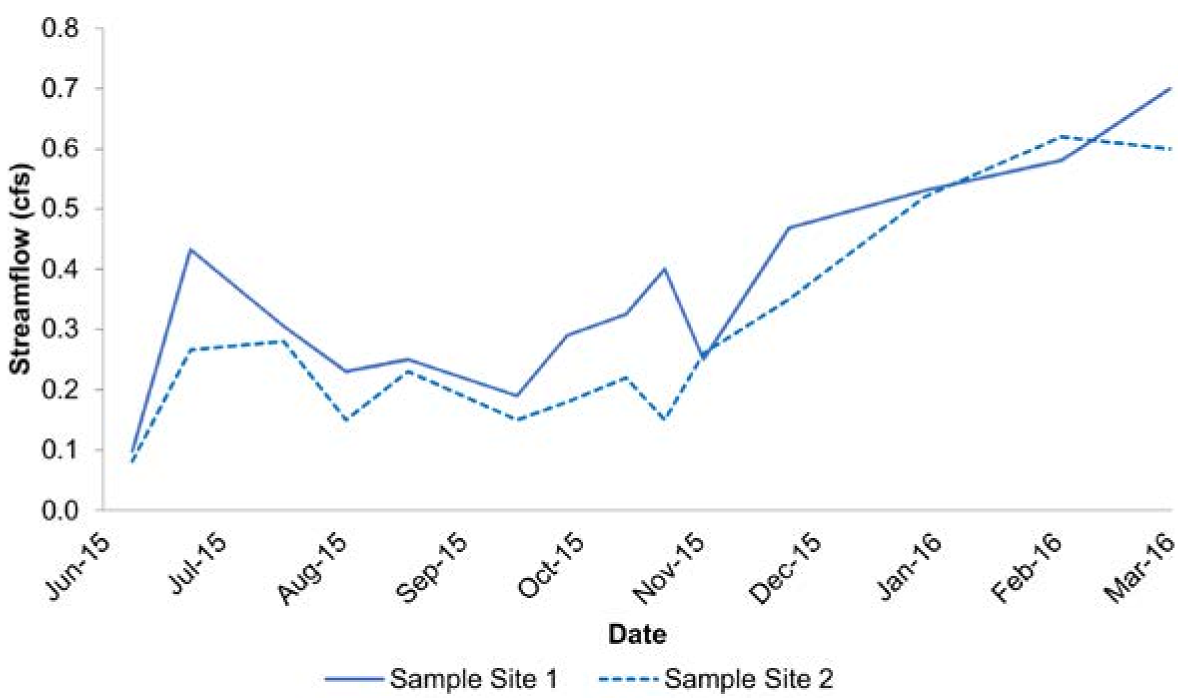


FIGURE 5.2.5.
Biweekly streamflow data from June 25, 2015 through March 18, 2016 at Study Sites 1 and 2 in San Felipe Creek, San Diego County.

FIGURE 5.2.6.
Locations of Drought Stressor Monitoring study sites on the San Gabriel River, Los Angeles County.

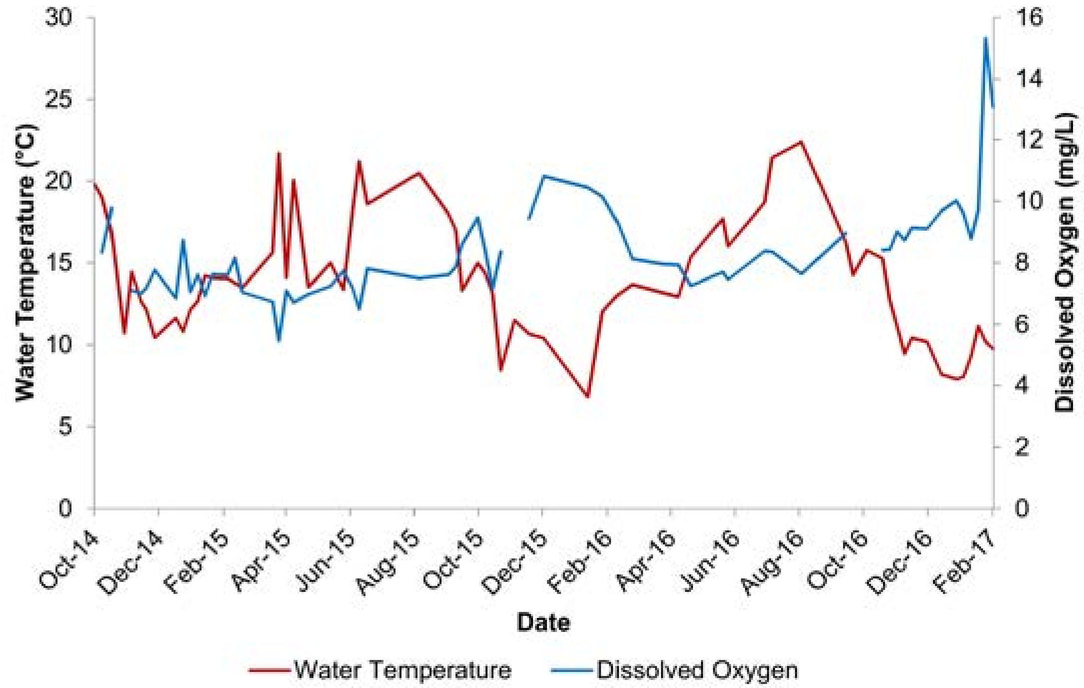


FIGURE 5.2.7.
Biweekly water temperature and dissolved oxygen data from October 22, 2014 to February 22, 2017 at an upstream study site on the East Fork San Gabriel River, Los Angeles County.

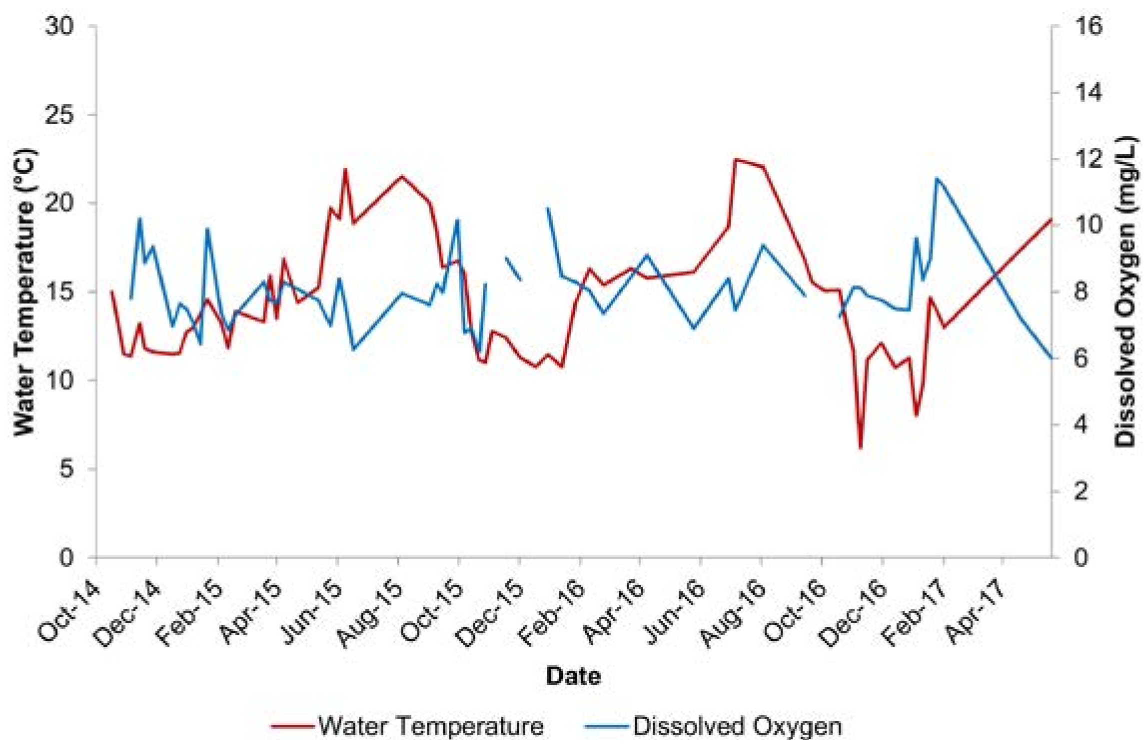


FIGURE 5.2.8.
Weekly water temperature and dissolved oxygen data from October 22, 2014 to February 22, 2017 at the upstream study site located on the North Fork San Gabriel Creek, San Diego County.

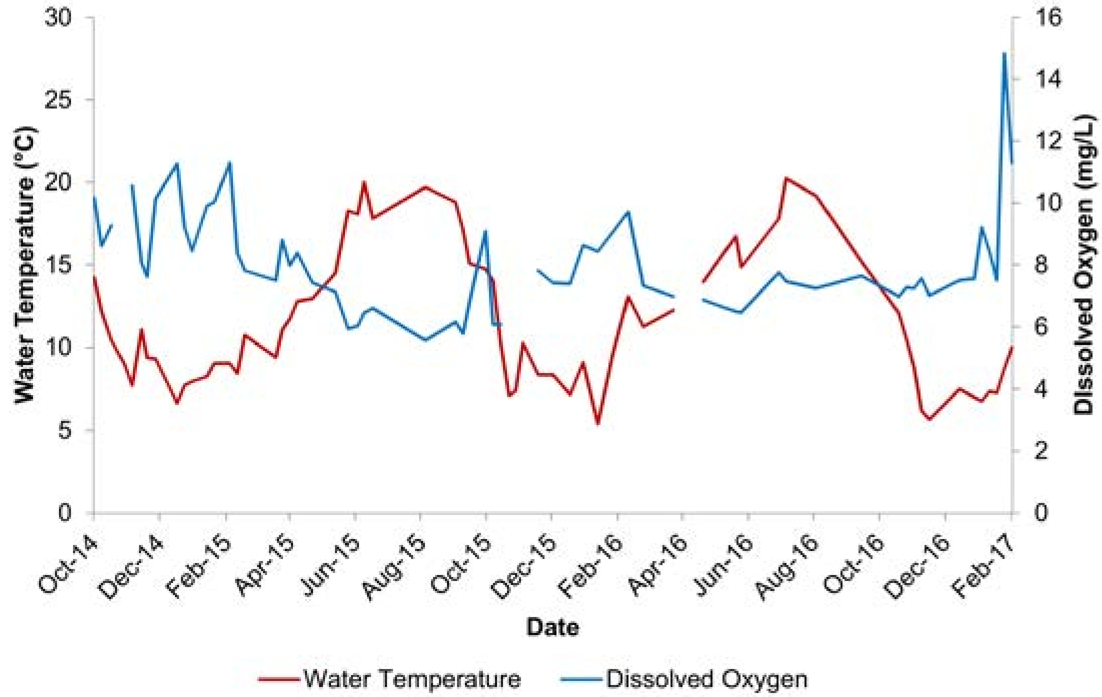


FIGURE 5.2.9.
Weekly to biweekly water temperature and dissolved oxygen data from October 22, 2014 to February 22, 2017 at the upstream study site located on the West Fork San Gabriel Creek, San Diego County.

PLATE 5.2.1.
Unarmored Threespine Stickleback captured from Soledad Canyon Creek, tributary to the Santa Clara River, Los Angeles County. Photo: Tim Hovey, CDFW, 2015.

PLATE 5.2.2.
Increased sediment accumulation in East Fork San Gabriel River, Los Angeles County, as observed from upstream of the study site. Photo: Hans Hansen, CDFW, September 23, 2015.

PLATE 5.2.3.
Santa Clara River rescue site showing isolated, drying stickleback habitat in the Santa Clara River, Los Angeles County. Photo: Tim Hovey, CDFW, 2014.

PLATE 5.2.4.
CDFW scientist collecting stickleback from the Santa Clara River rescue site, Los Angeles County. Photo: Tim Hovey, CDFW, April 30, 2014.

PLATE 5.2.5.
CDFW scientist collects water quality data at Study Site 2 on San Felipe Creek, San Diego County. Photo: Dylan Nickerson, CDFW, October 15, 2015.

PLATE 5.2.6.
CDFW scientist collecting Unarmored Threespine Stickleback from Soledad Canyon prior to the winter of 2016/2017 which brought heavy rain, streamflow, and post-fire sedimentation. Note the black arrow denoting a reference mark on the retaining wall and compare this to its location in Plate 5.2.7. Photo: CDFW.

PLATE 5.2.7.
Accumulation of sediment from the winter storms of 2016/2017 which brought heavy rain, high streamflow, and post-fire sedimentation in Soledad Canyon. CDFW scientists rescued Unarmored Threespine Stickleback from this location before the habitat was buried. Note the black arrow denoting the same reference mark from Plate 5.2.6. Photo: CDFW.

PLATE 5.2.8.
A male Unarmored Threespine Stickleback immediately after being released into Fish Canyon Creek. A total of 151 Unarmored Threespine Stickleback were transported and released into the creek in April 2017. Photo: CDFW.

PLATE 5.2.9.
The Fish Canyon Creek release site. A total of 151 Unarmored Threespine Stickleback were transported and released into this section of the creek in April 2017. Photo: CDFW.

CHAPTER SIX

Inland Deserts Region

The Inland Deserts Region contains both the highest and lowest elevations in the state (Mount Whitney in the Sierra Nevada Mountains and Badwater Basin in Death Valley, respectively). The region spans 500 miles from north-to-south and comprises 70% of the latitudinal range of California. Climate in the region is highly variable. Summer temperatures can exceed 49°C (120°F) and winter temperatures can drop below -17°C (0°F). The northernmost county, Mono, is comprised of grassland dominated by sagebrush, and is known as the "Great Basin steppe". The area is in the steep eastern side of the Sierra Nevada.

CDFW scientists monitored three aquatic species listed under the federal Endangered Species Act, located within eleven waters of Mono County. The choice of species was based on the potential risk to habitats under a drought scenario. The list of species monitored included Lahontan Cutthroat Trout and Paiute Cutthroat Trout, which occur in eight isolated headwater streams. These streams can be high risk habitat for populations, especially during catastrophic events such as wildfire and flash floods. CDFW scientists also monitored Whitmore Hot Springs, the last remaining habitat of Long Valley Speckled Dace.

The southern portion of the region includes San Bernardino, Imperial, and Riverside counties, and encompasses a large area with high mountain peaks and vast deserts. Monitoring efforts in this area focused on the impacts of drought on rainbow trout populations in Coldwater Canyon Creek, Riverside County.

6.1 NORTH

Species Focus and Location Description

CDFW scientists monitored habitat for Lahontan Cutthroat Trout, Paiute Cutthroat Trout, Long Valley Speckled Dace, and Sierra Nevada Yellow-legged Frog. The monitored Lahontan Cutthroat Trout habitat included five streams in Mono County: O'Harrel Canyon, Slinkard, By-Day, Silver, and Wolf creeks (Figure 6.1.1). O'Harrel Canyon Creek is a tributary to the Owens River, with headwaters in the Glass Mountain range. The other four streams are located within the Walker Basin. Three streams on the eastern slope of the White Mountains in southern Mono County were monitored for Paiute Cutthroat Trout, including Leidy Creek and its tributary, Cabin Creek, and North Fork Cottonwood Creek (Figure 6.1.1, note: some sources continue the name Cottonwood Creek for the reach above the confluence with South Fork Cottonwood Creek). All streams in the White Mountains are out-of-basin populations that provide critical refuge habitat for Paiute Cutthroat Trout. The Paiute Cutthroat Trout subspecies is native only to Silver King Creek, located in Alpine County.

Whitmore Hot Springs and the associated wetland host the sole surviving relictual[14] population of the Long Valley Speckled Dace. This fish is the most genetically distinct of five subspecies of speckled dace in the Inland Deserts Region, and perhaps in California. However, introduced fishes have eliminated the formerly widespread speckled dace from all sites except Whitmore Hot Springs, which is a threatened and isolated single habitat. A second site, Little Alkali Spring, was a relictual habitat for speckled dace until the unauthorized introduction of Mosquitofish (*Gambusia affinis*) occurred in 1999. Since 2014 the area has been the subject of a species recovery project. Whitmore and Little Alkali hot springs are both located in Long Valley Caldera, within the Owens Basin in central Mono County.

Local Need for Drought Stressor Monitoring

All monitored streams, except for Silver and Wolf creeks, typically have relatively low streamflow (less than 2 cfs), even during years of average rainfall. Consequently, any further reduction of streamflow

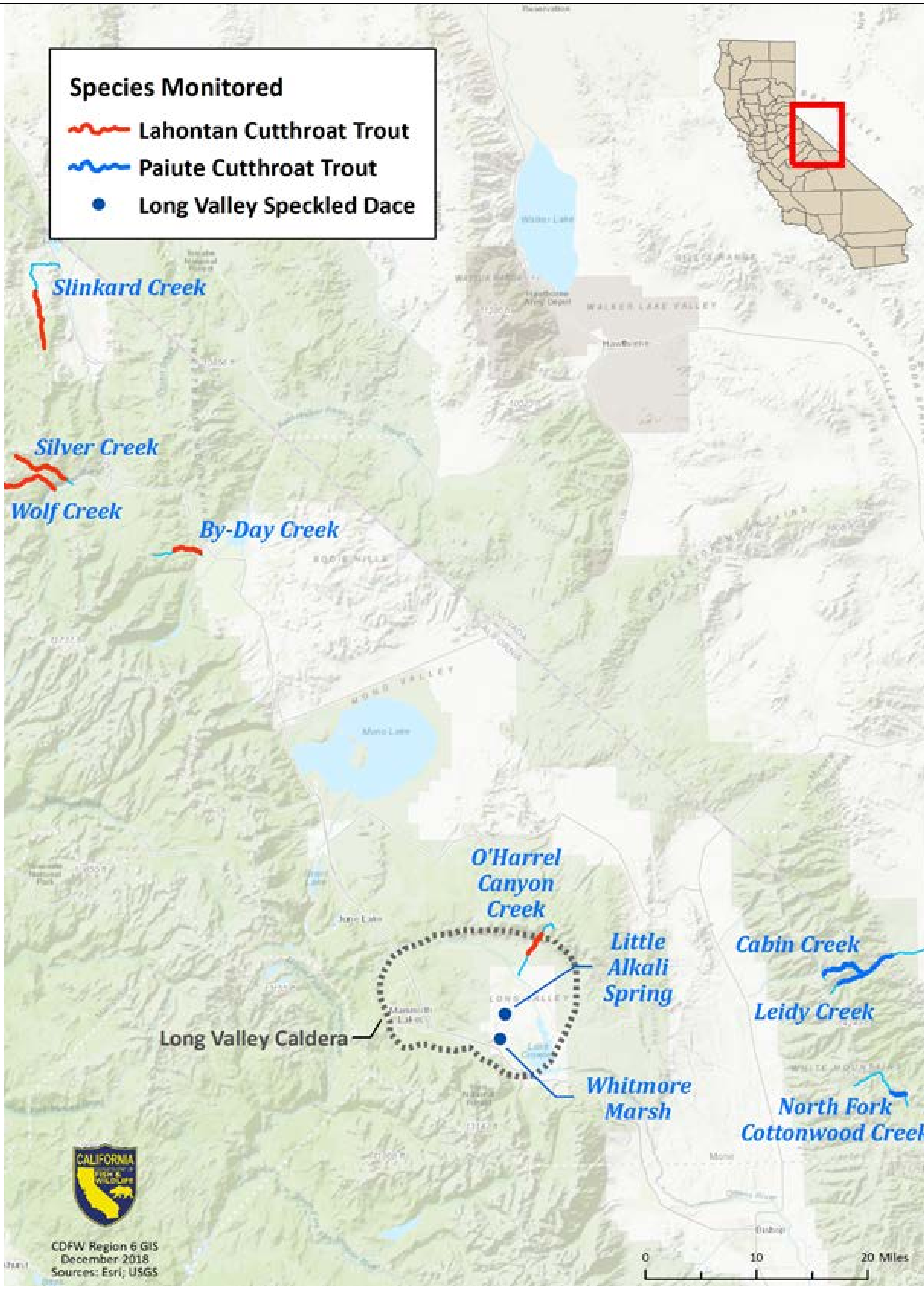


FIGURE 6.1.1.
Locations of Drought Stressor Monitoring study sites within the northern portion of the Inland Deserts Region.

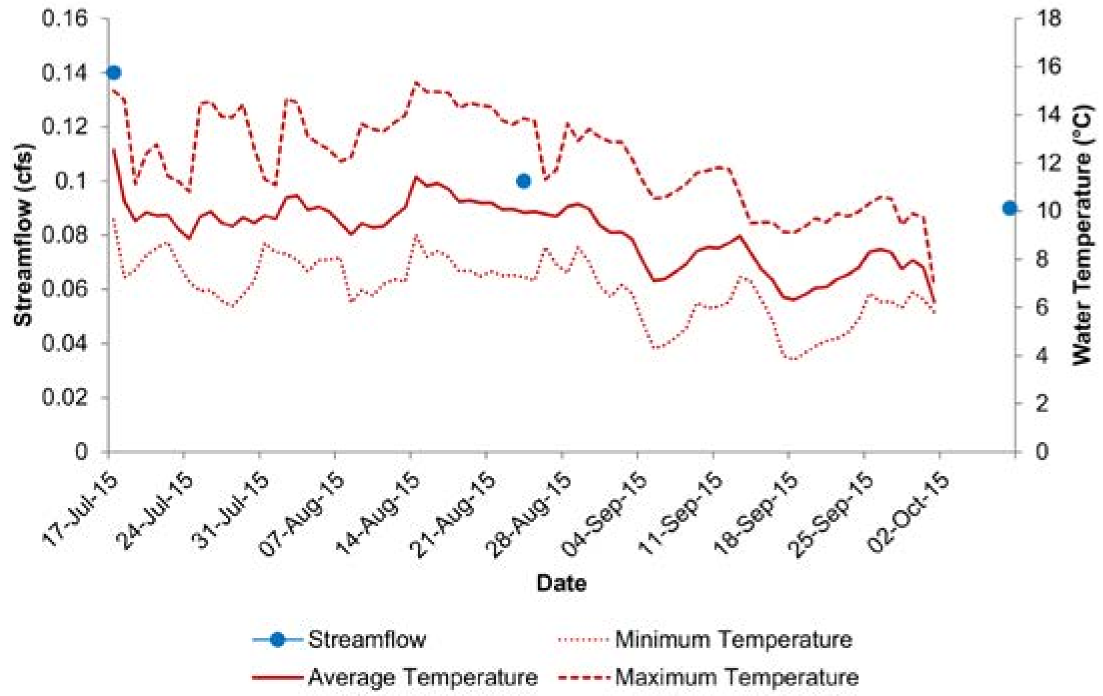


FIGURE 6.1.2.
Daily average, maximum, and minimum of water temperatures and three measurements of streamflow in the North Fork Cottonwood Creek, Mono County, during summer 2015.

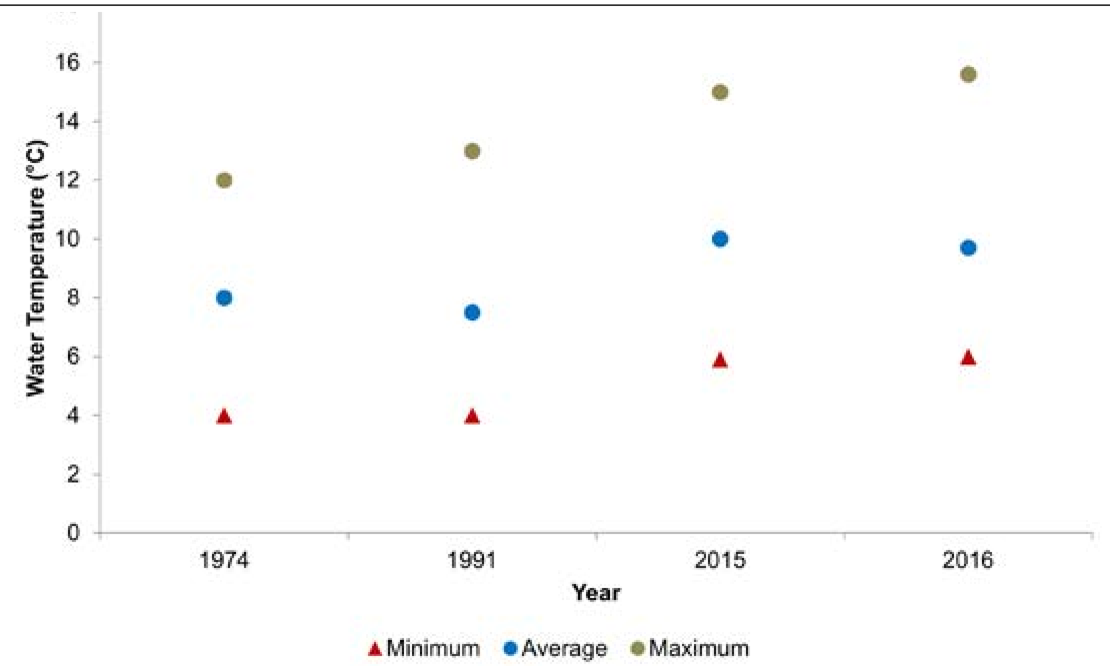


FIGURE 6.1.3.
Comparison of water temperatures during normal (1974) and drought (1991, 2015, and 2016) years at the North Fork Cottonwood Creek, Mono County.

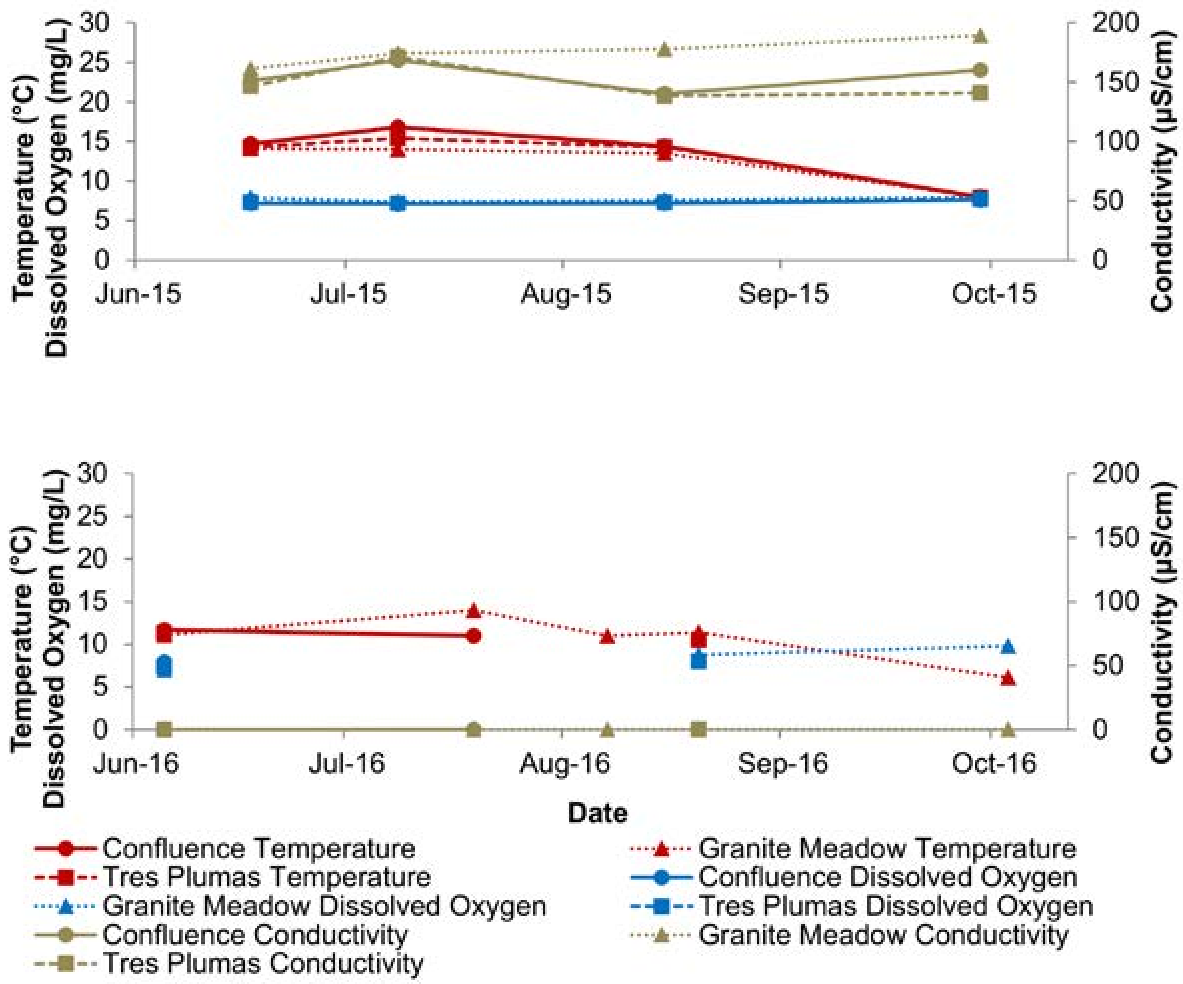


FIGURE 6.1.4.
Temperature, conductivity, and dissolved oxygen concentrations at North Fork Cottonwood Creek, Mono County, for the 2015 and 2016 monitoring periods.

due to drought has the potential to impact resident fish populations. Low streamflow can result in fish stranding, habitat fragmentation, reduction in available habitat, and poor water quality. In winter, areas of low flow and shallow water depth are also at risk of freezing when there is not enough snow pack to insulate pool and channel surfaces. Based on these habitat characteristics, CDFW scientists were concerned about the potential adverse impacts of drought to the survival of cutthroat trout populations.

CDFW scientists were also concerned about impacts of reduced spring flows to the relict populations of Long Valley Speckled Dace. Discharge from springs supplying the nearby Hot Creek Hatchery declined more than 70% during the drought; however, since no baseline flow data was available, it was difficult to determine the extent of drought impacts on streamflow. CDFW scientists monitored the springs during the drought to detect any changes in water outflows that supply both the extant habitat

(Whitmore Hot Springs) and a recently restored habitat (Little Alkali Spring). It was determined that if spring flows were to decline, it would be necessary to carry out a fish rescue and take fish into captivity.

Findings and Actions

Lahontan Cutthroat Trout

Streamflow at all sites during the drought was greatly reduced compared to baseline flows. Temporary habitat fragmentation was observed in By-Day and O'Harrel Canyon creeks, where riffles were less than 0.5 inches in depth; however, despite low stream flows, water quality remained within the known tolerances of Lahontan Cutthroat Trout. CDFW scientists installed water temperature loggers to enable analysis of long-term stream temperature trends.

Stream sedimentation increased greatly in Wolf Creek which experienced up to 16 inches of deposition in some locations, as well as in areas of Silver, Slinkard, and O'Harrel Canyon creeks. The increased sedimentation in Slinkard Creek was due to low flows that caused sediment to be deposited in the creek rather than carried to lower in the watershed by flowing water. The increased sedimentation in lower By-Day, upper Wolf, and O'Harrel Canyon creeks was caused by the deposition of debris flows. The cause of the debris flows may have been the inflow of drought-dried soils which followed summer thunderstorms. It is likely that these events resulted in increased mortality of Lahontan Cutthroat Trout populations. One reach with Lahontan Cutthroat Trout, lower By-day Creek, also dried out completely in July and August 2015 because the alluvial aquifer was depleted.

By early August in By-Day Creek only a short 800-meter long stretch of stream remained wetted. As the area of wetted stream contracted during the drought, rescue operations for Lahontan Cutthroat Trout became increasingly necessary. During a visual survey in 2016, CDFW scientists detected low numbers of trout in the stream, even though water quality remained within known tolerances. The population of Lahontan Cutthroat Trout in By-Day Creek is currently thought to be at risk.

Paiute Cutthroat Trout

CDFW scientists carried out visual fish surveys along 1.3 miles of North Fork Cottonwood Creek and 1.0 mile of Cabin Creek (Figures 6.1.1). A comparison of streamflow in 2015 to historical data (1991-2000) showed that streamflow was extremely low during summer, although the streams did not go dry. However, most riffle habitats became impassible by July (water depth <0.5 inches), restricting trout movement. Historical data shows that streamflow

PLATE 6.1.1. **A rescued Lahontan Cutthroat Trout prior to relocation into Wolf Creek, Mono County. Photo: CDFW.**

PLATE 6.1.2.
CDFW scientist conducts Lahontan Cutthroat Trout rescue operations on By-Day Creek, Mono County. Photo: CDFW.

in North Fork Cottonwood Creek in 1991 followed a similar pattern to that in 2015, although in 2015 the base-flow was lower (Wong 1993; Figure 6.1.2). At some sites, water temperature showed large daily variations of up to 12°C (Figure 6.1.3). Such wide variations limit any conclusions that can be drawn from comparisons with historical point data. Water temperatures and levels of dissolved oxygen during the monitoring period remained within the tolerances of Paiute Cutthroat Trout (Moyle 2002).

Previous fish surveys carried out in North Fork Cottonwood Creek have recorded high numbers of Paiute Cutthroat Trout (Wong and Becker 1994–1998). The numbers recorded in the 2015 surveys in the same reach were lower than recorded historically. This decline may be due to many factors, including the effects of the lengthy drought and lack of recruitment (no young-of-year trout were observed in 2015), as well as the adverse effects of increased gravel siltation on fish spawning (Buckmaster and Emery 2015). Few fish were observed in Cabin Creek, likely due to dense riparian growth which inhibited access to the stream. A massive debris flow occurred in Leidy Creek downstream of the Cabin Creek confluence; however, any impacts from the debris flow to Paiute Cutthroat Trout caused by the debris flow are unclear. The status of Paiute Cutthroat Trout in Leidy Creek remains unknown and will be investigated during future surveys.

CDFW scientists conducted visual fish surveys along 1.3 miles of North Fork Cottonwood Creek and 1.0 mile of Cabin Creek, a tributary to Leidy Creek. Streamflow was extremely low during the summer, and isolated portions of the North Fork Cottonwood Creek went dry. Streamflow data from North Fork Cottonwood Creek during the 1991 drought showed a similar pattern to that seen in 2016. However, base-flows in 2016 were lower than in previous years (Wong 1993). Water temperature and dissolved oxygen levels during the monitoring period remained suitable for Paiute Cutthroat Trout (Figure 6.1.4), with large daily temperature variations. The North Fork Cottonwood Creek recorded a higher maximum temperature in both 2015 and 2016 than was recorded in historical droughts (Figure 6.1.3).

Long Valley Speckled Dace

The discharge of Whitmore Hot Springs during August-December 2015 averaged 0.72 cfs and 0.47 cfs during the 2016 monitoring period. Flow at the much smaller Little Alkali Spring varied between 0.0185 and 0.0196 cfs in 2015 and averaged 0.015 cfs in 2016. While low streamflow and water quality remained adequate for the survival of Long Valley Speckled Dace. CDFW suspended monitoring at both Whitmore and Little Alkali hot springs in November 2016 due to snow coverage which restricted access to the sites.

Non-native Mosquitofish were removed from Little Alkali Spring in winter 2015 by a combination of diverting flow from the channel habitat with irrigation pipe and natural winter freezing. Observations over the following year confirmed the absence of Mosquitofish so Long Valley Speckled Dace were reintroduced in 2016.

PLATE 6.1.3. CDFW scientists inspecting deteriorating barrier on Slinkard Creek, May 2016. Photo: CDFW.

6.2 SOUTH

Species Focus and Location Description

Coldwater Canyon Creek supports a small resident population of wild resident rainbow trout (Jacobson et al. 2014). The creek originates within the Cleveland National Forest and flows through both private property and public property owned and maintained by the Riverside-Corona Resource Conservation District (District) (Figure 6.2.1).

Local Need for Drought Stressor Monitoring

Coldwater Canyon Creek is home to one of only two populations of resident rainbow trout of steelhead lineage remaining in San Diego, Orange, and Riverside counties. There is an urgent need to protect, manage, and plan for the conservation and recovery of this population. Maintaining cold, clean water and adequate streamflow is crucial to protecting this population.

Findings and Actions

Coldwater Canyon Creek

CDFW and District scientists characterized available trout habitat in Coldwater Canyon Creek from June to August 2014. The protocols used are described in the California Salmonid Stream Habitat Restoration Manual (Flosi et al. 2010). In summer 2014, District staff also began recording water quality in the creek. Water temperature loggers were installed within the available rainbow trout habitat to measure long-term fluctuations.

In April 2015, CDFW scientists recorded rainbow trout spawning in the creek, and by May, young-of-

FIGURE 6.2.1.
Location of Drought Stressor Monitoring study reach on Coldwater Canyon Creek, Riverside County.

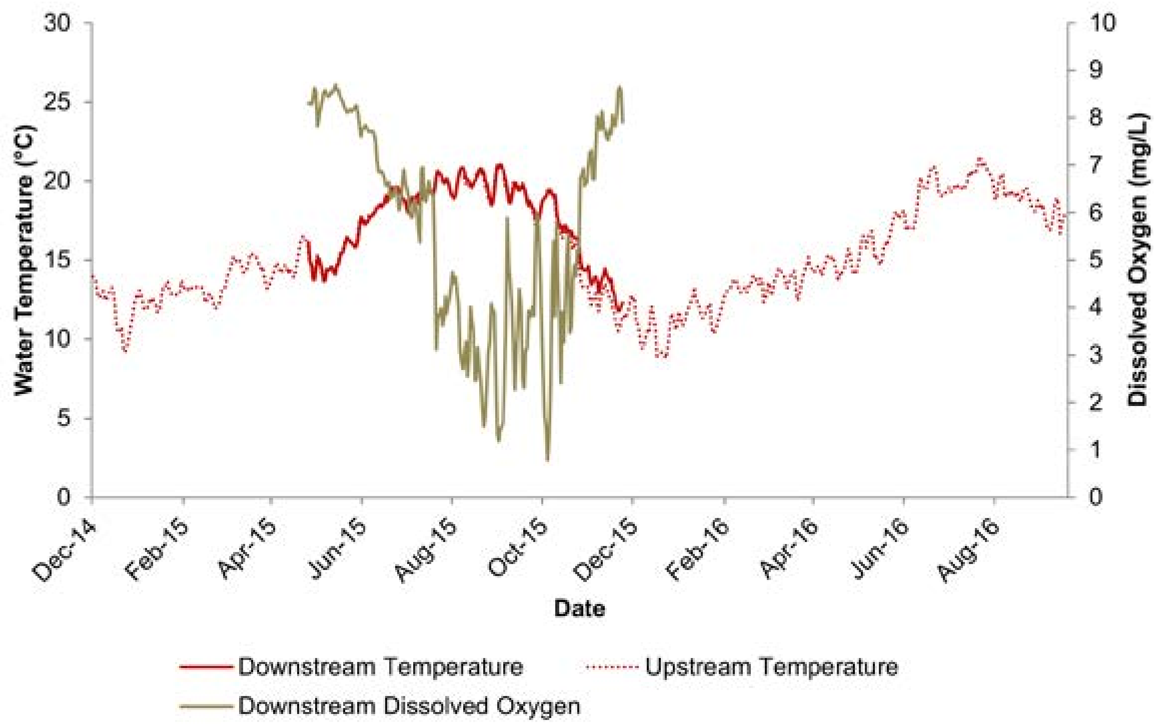


FIGURE 6.2.2.
Daily average temperature at the upstream site on Coldwater Canyon Creek, Riverside County, from December 2014 to September 2016. Daily average temperature and dissolved oxygen at the downstream site was collected from May 2015 to December 2015.

PLATE 6.2.1.
A Coldwater Canyon Creek rainbow trout. Photo: Riverside-Corona Resource Conservation District.

PLATE 6.2.2.
CDFW scientists from the Mojave River Hatchery, the South Coast Region, and Inland Deserts Region, in partnership with Riverside-Corona Resource Conservation District staff, rescue native rainbow trout in the lower reach of Coldwater Canyon Creek. Photo: District. Photo: CDFW.

the-year rainbow trout were observed throughout the wetted area.

Water temperatures remained below 20°C through July 2015 (Figure 6.2.2); however, over the period August 12-20, 2015, water levels and dissolved oxygen concentrations in the lower 0.5 miles of habitat decreased rapidly, adversely affecting habitat conditions in the refuge pools. Based on this information, CDFW scientists performed a fish rescue operation on August 26, 2015. A total of 14 rainbow trout were removed from the lower portion of Coldwater Creek and relocated to the Mojave River Hatchery for holding. The rescued fish were later returned to Coldwater Canyon Creek on March 3, 2016, after CDFW scientists determined that conditions had improved. Based on information collected during monthly monitoring intervals, scientists found that streamflow had increased to 0.4 cfs and water temperature and dissolved oxygen were within tolerable levels.

On March 31, 2016, CDFW scientists found young-of-the-year trout throughout the creek, indicating that the trout had successfully reproduced. From June through October, however, CDFW scientists found that temperatures were again at stressful levels, reaching daily averages over 20° C (Figure 6.2.2). As occurred in 2015, CDFW scientists conducted a fish rescue operation in June 2016, rescuing total of 145 rainbow trout to be held at the Mojave River Hatchery until habitat conditions at Coldwater Canyon Creek improved. Rainbow trout were released back into Coldwater Canyon Creek during the onset of winter season rainfall.

CHAPTER SEVEN
Discussion

The years from 2012-2016 were a time of record-breaking drought in many parts of California, especially in the southern Central Valley and coastal areas (Williams et al. 2015). Although the amount of rainfall is the principal driver of drought variability, ongoing climate change increases the likelihood of extreme droughts (Seager et al 2015, Williams et al. 2015). Recent studies suggest that "mega-droughts" lasting many decades, which have occurred in the past, particularly during the 12th and 13th Centuries, have the potential to recur in the future (Cook et al. 2009).

The implementation of Drought Stressor Monitoring in watersheds throughout the state provided valuable information on the status of aquatic life and the environment. The monitoring data provided important documentation of the environmental changes associated with the severe drought conditions, and how the changes affected aquatic habitats and fish populations throughout the state. This information also helped scientists address the major questions associated with the drought, including changes in habitat conditions, population responses to drought conditions and how best to ameliorate the adverse effects.

The following patterns of drought-related ecosystem change were recorded throughout the state: (1) streams dried earlier than usual and for longer periods of time; (2) estuaries and bar-built lagoons exhibited degraded water quality, including reduced levels of

dissolved oxygen and elevated water temperatures; (3) water temperatures sometimes rose to critical levels for the survival of salmon and steelhead; (4) wild trout populations in high elevation streams were threatened by the formation of winter anchor ice; and (5) fish were often stranded by low streamflow and adversely affected by poor water quality. These changes often adversely affected fish survival and required emergency fish rescues to be undertaken.

There were many examples of streams drying during the drought due to low streamflow. Because of reduced freshwater streamflow, scientists found that estuaries and bar-built lagoons were more affected by tidal influence, exhibiting increased salinity stratification. The marine influence often extended farther into streams and lasted longer than usual. The lower saltwater layer, during summer and early fall, often had higher temperatures and lower levels of dissolved oxygen than the upper freshwater layers. This caused increased levels of stress to juvenile salmon and steelhead residing in the bar-built lagoons.

Above tidal influence, the drought often made habitat conditions within streams detrimental to aquatic species survival. Streams characterized as perennial dried out and formed isolated pools, while streams that are typically intermittent during the dry summer months dried out earlier in the year. Isolated pools often provided temporary safe havens for many aquatic species. However, as the drought persisted, the water quality in many of these pools quickly deteriorated, with elevated water temperatures and decreased levels of dissolved oxygen. The drying of streams and increased habitat fragmentation resulted in less suitable habitat for native species. In several areas of the state, and especially in South Central and Southern California, the lack of hydrological connectivity meant that salmon and steelhead were often unable to access their upstream spawning areas or emigrate to the ocean.

Reduced streamflow and elevated water temperature increased stress levels for salmon and steelhead. A number of native fish species in California outside of the salmon family, however, can withstand relatively high water temperatures. These species included Arroyo Chub and Unarmored Threespine Stickleback (tolerance up to 24°C [75°F]) as well as Speckled Dace (tolerance up to 31°C [88°F]; Moyle 2002). As with fish in the salmon family, these fish also have their water quality limit. Extended periods of time spent at these higher temperatures may have had adverse effects on feeding, reproductive behavior, and defense mechanisms, which may affect survival.

Wild trout populations in high elevation streams were at high risk throughout the year. In summer, trout faced reduced streamflow and warming water temperatures similar to the threats faced by salmon and steelhead. During the winter, trout populations were often at risk of freezing due to the formation of anchor ice along the stream bed. This prevented fish from reaching refuge habitat where they could better survive the winter conditions. Snowpack during the winter typically insulates streams and prevents freezing. The reduced or absent snowpack, combined with lower streamflow, may have been a major factor contributing to increased trout mortalities at high elevations during the winter months.

Drought stressor monitoring was integral to management actions and was particularly critical to the process of aquatic species rescue. Fish rescues were only undertaken after Drought Stressor Monitoring information showed that populations were at high risk of becoming locally extinct in the immediate future. CDFW scientists developed special criteria and guidelines to assess the threat of drought and when to initiate rescue operations. When suitable habitat was available, fish were relocated to nearby habitat within the same stream or watershed to ensure the genetic health of the population and to maintain local adaptations. In cases where habitat was not available, fish were relocated to nearby hatcheries for temporary holding.

In addition to informing fish rescue actions, CDFW scientists used monitoring information to help maintain adequate streamflow and water temperatures for fish, while at the same time allowing adequate water supplies and hydroelectric energy for human needs. On May 14, 2014, CDFW and NOAA Fisheries developed a Voluntary Drought Initiative between the two agencies that provides the framework for collaborative actions with water users to protect aquatic species. These actions included fish rescue, relocation, monitoring, and habitat restoration. Other actions taken by CDFW to protect aquatic resources include petitioning the Fish and Game Commission in 2014, 2015, and 2016 to enact emergency closures of recreational fisheries on several rivers in California.

Near-record levels of rainfall which fell across the majority of California during the winter of 2016-2017 caused Governor Jerry Brown to issue a proclamation on April 7, 2017, ending the drought state of emergency. However, the Governor at that time maintained a drought emergency in Fresno, Kings, Tulare, and Tuolumne counties, and instructed state agencies to continue to manage the impacts of drought on wildlife through improved monitoring of native fish populations. In January 2019, Gavin Newsom became the next California Governor, and as of February 2019, the status of the percentage of the state suffering from drought is currently 55% "abnormally dry", 8.6% "moderate drought", 1.9% "severe drought", and 0% at "extreme" or "exceptional drought"[15].

The end of extreme drought conditions may however present new threats to California's vulnerable fish populations and their habitat. These include such impacts as wildfires, mud slides, flash flooding, and debris flows. Monitoring these and other emerging environmental conditions will allow CDFW to gain a more complete understanding of the environmental effects of drought. Furthermore, the knowledge and data gained through Drought Stressor Monitoring can guide CDFW and other resource managers during future droughts. It can also allow agencies to forecast and target regions and streams that are most likely to experience the most severe impacts of drought and take preventative measures.

Recommendations for the Future

Climate change is expected to increase the duration, intensity, and frequency of future droughts. Therefore, obtaining actionable information through monitoring and research programs, such as Drought Stressor Monitoring, is crucial to the long-term survival and recovery of special status fish populations in California (Diffenbaugh et al. 2015, Mann and Gleick 2015). Continued involvement in monitoring programs and partnerships is therefore necessary to protect California's natural resources, both now and in the future.

One unexpected beneficial outcome of Drought Stressor Monitoring is that it generated an assessment of Departmental stream monitoring efforts throughout the state, identifying both watersheds where robust, routine, detailed monitoring efforts were already ongoing and watersheds where monitoring was needed but either underprioritized or lacking. Routine, reliable data collecting during non-drought conditions are invaluable for helping managers and scientists set priorities and direct resources during extreme events. We recommend that stream and habitat monitoring efforts conducted by CDFW be standardized and organized into a statewide stream monitoring program, using common protocols for data collection, analysis, and reporting.

As the human population of California continues to increase, the demands on its natural resources will continue to expand. To effectively balance resources for people and to recover populations listed under the state and federal Endangered Species Acts, collaborative monitoring efforts need to be continued and expanded into the future to effectively manage California's natural resources. Information gained through monitoring helps to ensure that we maintain a healthy environment. Several statewide monitoring programs that, when fully-funded and implemented, will provide the necessary information to meet critical management needs. These include:

- DFW Klamath–Trinity River Program and tribal and federal agency monitoring programs – anadromous salmonids, including the Yurok, Karuk, and Hoop Klamath River Coho Ecology Study, and Lower Klamath River Sub-basin Restoration Plan and the Yurok's Pacific Lamprey Monitoring Program;
- CDFW-NOAA FISHERIES California Coastal Salmon and Steelhead Monitoring Program;
- Federal Central Valley Anadromous Fisheries Restoration Program – all species (primarily Chinook Salmon);
- CDFW San Joaquin River Restoration Program – anadromous salmonids;
- CDFW Delta Investigation and Monitoring Program – smelt and sturgeon species;
- CDFW Ocean Salmon Program;
- Central Valley Steelhead Trout Monitoring Pilot Project – interagency plan piloted starting in 2015 by CDFW;
- Central Valley Chinook Salmon Monitoring Program – interagency plan yet to be implemented;
- Central Valley Sturgeon Monitoring Projects – three integrated pilot projects to be implemented by CDFW, SWFRC, NOAA FISHERIES, and the University of California;
- North Coast Smelt Monitoring – needed for longfin smelt and eulachon in targeted rivers and estuaries on the north-central and north-coast ecoregions;
- Pacific Lamprey Monitoring Programs – needed in both the Klamath-Trinity and Central Valley ecoregions;
- CDFW Coded Wire Tagging / Recovery Program – anadromous salmonds;
- CDFW Hatchery Operation – anadromous salmonids; and
- CDFW Heritage and Wild Trout Program.

The continuation of stream monitoring is essential to determine the impacts of drought conditions and ongoing climate change on aquatic communities and their habitat. While immediate drought conditions have been relieved by the wet winter of 2016-2017, longer term climate change in California is likely to continue to cause continued variability in rainfall patterns and temperature regimes (Stocker 2013). This underscores the need to better understand how these processes interact with and impact the aquatic environment.

Better science and information-based decisions can help mitigate the environmental changes impacting aquatic habitats. Management efforts such as Drought Stressor Monitoring, the California Coastal Monitoring Program, and other programs currently being implemented across the state, play a vital role in ensuring California's valuable fisheries resources remain in place for future generations to enjoy.

Endnotes

[1] A Species of Special Concern is a species, subspecies, or distinct population of an animal native to California that has shown signs that it is at risk and may qualify, currently or in the future, for state listing as endangered or threatened, or is already listed federally but not yet at the state level.

[2] An ecotone is a transitional zone between two ecological communities.

[3] A biome is a major ecological community or organisms adapted to a particular climatic or environmental condition on a large geographic area in which they occur.

[4] A salmon or steelhead smolt is a stage in the juvenile life-cycle when a fish undergoes physiological, morphological, and behavioral changes and then migrates from freshwater to the marine environment.

[5] A salmon redd is a nest, a shallow depression scooped in the gravel where eggs are deposited.

[6] Salmon fry are juveniles that have absorbed their yolk sac and emerged from the gravel so they can feed.

[7] Cubic Feet per Second (cfs) is a unit of flow rate describing the volume of water passing a given location per second. This is the standard unit used in the United States and is used throughout this report.

[8] Escapement is the term used to describe the number of adults returning from the ocean to a spawning stream each year.

[9] Passive Integrated Transponder tags (PIT) use Radio-Frequency Identification (RFID) technology to uniquely mark fish. PIT tags are detected when fish either pass antennas deployed in the watershed, or when fish are captured and scanned by researchers.

[10] See: http://www.yubaaccordrmt.com/default.htm

[11] DPS – under the Endangered Species Act, a Distinct Population Segment (DPS) is a population or group of populations that is discrete and significant in relation to the entire species.

[12] See: https://www.wildlife.ca.gov/Drought/Projects/Russian-River-Coho

[13] See: http://www.restoresjr.net/

[14] A relictual population is one that occurs in a small portion of its historically occupied range.

[15] See: https://www.drought.gov/drought/states/California

Literature Cited

ADAMS, P., 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. Fish Bulletin No. 180. California Department of Fish and Wildlife.

ALLY, J. R. 2004. Inland fisheries survey report: survey of selected stream parameters in the East Fork San Gabriel River and its tributary Cattle Canyon, and in the North Fork San Gabriel River. California Department of Fish and Game, Inland Fisheries Files, Region 5, Los Alamitos, USA.

ANDERSON C. W., SCHEER G., AND D. WARD. 2015. Results of Freshwater Creek salmonid life cycle monitoring station 2014-2015. Scientific Report. Fisheries Restoration Grant Agreement Number P1210323. 50 p.

BEHNKE, R. J. 1992. Native trout of western North America. AFS Monograph 6. American Fisheries Society, Bethesda, Maryland.

BJORN, T.C. AND D.W. REISER. 1991. Habitat requirements of salmonids in streams. In: Influences of Forest and Rangeland Management on Salmonid Fishes and their Habitats (Meehan, W.R., ed.), Vol. 19, pp. 83-138. Bethesda, MD: American Fisheries Society Special Publication.

BUCKMASTER, N. AND D. EMERY. 2015. CDFG memo report on flows and Paiute Cutthroat Trout distribution and abundance in the North Fork of Cottonwood Creek, Mono County in July 2015. California Department of Fish and Wildlife.

CALIFORNIA DEPARTMENT OF FISH AND GAME (CDFG). 1998. A status review of the spring-run Chinook Salmon (Oncorhynchus tshawytscha) in the Sacramento River drainage. California Department of Fish and Game.

CALIFORNIA DEPARTMENT OF FISH AND GAME (CDFG). 2004. Recovery Strategy for California Coho Salmon. Report to the Fish and Game Commission. 594 pp.

CALIFORNIA DEPARTMENT OF FISH AND WILDLIFE (CDFW). 2014. McCloud River Redband Trout Rescues [Internet]. California Department of Fish and Wildlife [cited 2016 June 1].

CALIFORNIA DEPARTMENT OF FISH AND WILDLIFE (CDFW). 2016. San Joaquin River restoration program fiscal year 2014/2015 annual report. Final Draft. April 8, 2016. California Department of Fish and Wildlife.

CALIFORNIA SEA GRANT. 2016. Flow and survival study [Internet]. California Sea Grant; [cited 2016 June 8].

CARTER, K. 2005.The effects of temperature on steelhead trout, Coho Salmon, and Chinook Salmon biology and function by life stage implications for Klamath Basin TMDLs. North Coast Regional Water Quality Control Board Report.

COOK, E. R, R. SEAGER; R. R. HEIM, JR., R. S. VOSE, C. HERWEIJER, AND C. WOODHOUSE. 2009. Megadroughts in North America: placing IPCC projections of hydroclimatic change in a long-term paleoclimate context. Lamont–Doherty Earth Observatory of Columbia University Journal of Quaternary Science. DOI: 10.1002/jqs.1303.

DIFFENBAUGH, N. S., D.L. SWAIN, AND D. TOUMA. 2015. Anthropogenic warming has increased drought risk in California. Proceedings of the National Academy of Sciences, 112: 3931-3936.

FLOSI, G., S. DOWNIE, J. HOPELAIN, M. BIRD, R. COEY, AND B. COLLINS. 2010. California salmonid stream habitat restoration manual, Fourth Edition. Fisheries Division, California Department of Fish and Wildlife.

GARWOOD, J. AND S. RICKER. 2013 (Revised 2015). Juvenile Coho Salmon spatial structure monitoring protocol: Summer survey methods. California Department of Fish and Wildlife. Arcata, CA.

HOLLOWAY, W., GALLAGHER, S. P., THOMPSON, S., D. WRIGHT, AND E. LANG. 2014. Coastal Mendocino County salmonid life cycle and regional monitoring: monitoring status and trends for 2014. 2013-14 Administrative Report. Pacific States Marine Fisheries Commission and the California State Department of Fish and Wildlife, Coastal Watershed Planning and Assessment Program. 54pp.

HOLMES, R. W. AND W. COWAN. 2014. Instream flow evaluation steelhead spawning and rearing Big Sur River, Monterey County. Water Branch, California Department of Fish and Wildlife.

ISAAC, D.J., S.J. WENGER, E.E. PERTERSON, J. M. VER HOEF, S. HOSTETLER, C.H. LUCE, J.B. DUNHAM, J. KERSHNER, B.B. ROPER, D. NAGEL, D. HORAN, G. CHANDLER, S. PARKES, AND S. WOLLRAB. 2011. NORWEST: An interagency stream temperature database and model for the Northwest United States. U.S. Fish and Wildlife Service, Great Northern Landscape Conservation Cooperative Grant.

JACOBSON, S., J. MARSHALL, D. DALRYMPLE, F. KAWASKI, D. PEARSE, A. ABADÍA-CARDOSO, AND J. C. GARZA. 2014. Genetic analysis of trout (Oncorhynchus mykiss) in Southern California coastal rivers and streams. California Department of Fish and Wildlife, Fisheries Restoration Grant Program Report. Project No. 0950015.

MANN, M. E. AND P.H. GLEICK. 2015. Climate change and California drought in the 21st century. Proceedings of the National Academy of Sciences, 112: 3858-3859.

MATTHEWS, K.R. AND N.H. BERG. 1996. Rainbow trout responses to water temperature and dissolved oxygen stress in two southern California stream pools. Journal of Fish Biology 50: 50-67.

MOYLE, P.B. 2002. Inland fishes of California. University of California Press. Berkeley, Los Angles, California.

MOYLE, P.B., R.M. YOSHIYAMA, J.E. WILLIAMS, AND E.D. WIKRAMANAYAKE. 1995. Fish species of special concern in California. Second edition. California Department of Fish and Game.

NATIONAL MARINE FISHERIES SERVICE (NMFS). 2012. Southern California steelhead recovery plan. Southwest Region, Protected Resources Division, Long Beach, California.

NATIONAL MARINE FISHERIES SERVICE (NMFS). 2013. South-Central California coast steelhead recovery plan. West Coast Region, California Coastal Area Office, Long Beach, California.

NATIONAL MARINE FISHERIES SERVICE (NMFS). 2014. Recovery plan for the evolutionarily significant units of Sacramento River winter-run Chinook Salmon and Central Valley Spring-run Chinook Salmon and the Distinct Population Segment of California Central Valley steelhead. California Central Valley Area Office. Sacramento, California.

OBEDZINSKI, M., S.N. PIERCE, G.E. HORTON, AND M.J. DEITCH. 2018. Effects of flow-related variables on oversummer survival of juvenile Coho Salmon in intermittent streams. Transactions of the American fisheries Society. 147: 588-605.

O'BRIEN, J.W., H.K. HANSEN, AND M.E. STEPHENS. 2011. Status of fishes in the Upper San Gabriel River Basin, Los Angeles County, California. California Fish and Game 97:149-163.

OSTERBACK, A. 2013. Maximum stream temperature and the occurrence, abundance, and behavior of steelhead trout (Oncorhynchus mykiss) in a Southern California stream. Canadian Journal of Fisheries and Aquatic Sciences. 70. 10.1139.

PAGE, L.M., H. ESPINOSA-PEREZ, L.T. FINDLEY, C.R. GILBERT, R.N. LEA, N.E. MANDRAK, R.L. MAYDEN, AND J.S. NELSON. 2013. Common and scientific names of fishes from the United States, Canada, and Mexico, 7th edition. American Fisheries Society, special publication 34, Bethesda, Maryland.

PSOMAS. 2017. DRAFT Santa Ana Sucker Habitat Suitability Survey Results and Eighth Annual Santa Ana Sucker and Benthic Macroinvertebrate Survey Results, Big Tujunga Creek, Los Angeles County, California. Santa Ana, California. Prepared for Los Angeles County Department of Public Works, Water Resources Division-Dams. Alhambra, California.

REID, S.B. 2008. Conservation review - Modoc Sucker, Catostomus microps. Final Report submitted to U.S. Fish and Wildlife Service – Klamath Falls Field Office. Version date: December 31, 2008.

REID, S.B. AND D.H. GOODMAN. 2016. Pacific Lamprey in coastal drainages of California: occupancy patterns and contraction of the southern range. Transactions of the American Fisheries Society 145: 703-711.

SEAGER, R., M. HOERLING, S. SCHUBERT, H. WANG, B. LYON, A. KUMAR, J. NAKAMURA, AND N. HENDERSON. 2015. Causes of the 2011-2014 California drought. Journal of Climate 28: 6997-7024.

SAN JOAQUIN RIVER RESTORATION PROGRAM (SJRRP). 2010. Fisheries Management Plan (FMP): a framework for adaptive management in the San Joaquin River Restoration Program. November 2010. 164p.

SPARKMAN, M.D., P. BAIRRINGTON, M. METHANY, AND D. VITALI. 2015. Drought, streamflow, adult Chinook Salmon migration and smolt production within the Redwood Creek Basin. PowerPoint presentation for the American Fisheries Society National Meeting, Portland, Portland, Oregon.

STENHOUSE, T.F., C. E. BEAN, W. R. CHESNEY, AND M. S. PISANO. 2012. Water temperature thresholds for Coho Salmon in a spring-fed river, Siskiyou County, California. California Fish and Game 98:19-37.

STOCKER, S.A., ed. Climate Change. 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge Univ. Press, New York, 2013.

SWIFT, C.C., T.R. HAGLUND, M. RUIZ, AND R.N. FISHER. 1993. The status and distribution of freshwater fish in Southern California. Bull. Southern California Academy of Science 92: 101-167.

TATE, K.W., D.F. LILE, D.L. LANCASTER, M.L. PORATH, J.A. MORRISON, AND Y. SADO. 2005. Graphical Analysis Facilitates Evaluation of Stream Temperature Monitoring Data. California Agriculture, Volume 59, Number 3.

UNITED STATES DEPARTMENT OF AGRICULTURE (USDA). 1998. Conservation agreement for upper McCloud River Redband Trout (Oncorhynchus mykiss stonei): Shasta Trinity National Forest. 68p.

UNITED STATES FISH AND WILDLIFE SERVICE (USFWS). 2009. Modoc Sucker (Catostomus microps), 5-year review: summary and evaluation. U.S. Fish and Wildlife Service, Klamath Falls Fish and Wildlife Office, Klamath Falls, Oregon.

UNITED STATES FISH AND WILDLIFE SERVICE (USFWS). 2014 (November 24). Draft Recovery Plan for the Santa Ana Sucker. Sacramento, CA: USFWS, Pacific Southwest Region.

WATER FORUM. 2006. Lower American flow management standard, Draft Report, July 31, 2006. Sacramento, California.

WILLIAMS, A. P., R. SEAGER, J. T. ABATZOGLOU, B. I. COOK, J. E. SMERDON, AND E. R. COOK. 2015. Contribution of anthropogenic warming to California drought during 2014-2015. Geophysical Research Letters 42: 6819-6828.

WONG, D. 1993. CDFG memo report on flows and Paiute Cutthroat Trout abundance in Cottonwood Creek, Mono County in 1993. California Department of Fish and Game, Bishop, California.

WONG, D. AND D. BECKER. 1994. CDFG memo report on flows and Paiute Cutthroat Trout abundance in Cottonwood Creek, Mono County in 1994. California Department of Fish and Game, Bishop, California.

WONG, D. AND D. BECKER. 1995. CDFG memo report on flows and Paiute Cutthroat Trout abundance in Cottonwood Creek, Mono County in 1995. California Department of Fish and Game, Bishop, California.

WONG, D. AND D. BECKER. 1996. CDFG memo report on flows and Paiute Cutthroat Trout abundance in Cottonwood Creek, Mono County in 1996. California Department of Fish and Game, Bishop, California.

WONG, D. AND D. BECKER. 1997. CDFG memo report on flows and Paiute Cutthroat Trout abundance in Cottonwood Creek, Mono County in 1997. California Department of Fish and Game, Bishop, California.

WONG, D. AND D. BECKER. 1998a. CDFG memo report on flows and Paiute Cutthroat Trout abundance in Cottonwood Creek, Mono County in 1998. California Department of Fish and Game, Bishop, California.

WONG, D. AND D. BECKER. 1998b. CDFG memo report on flows and Cutthroat Trout abundance in O'Harrel Canyon Creek, Mono County in 1998. California Department of Fish and Game, Bishop, California.

YOSHIYAMA, R.M., E.R. GERSTUNG, F.W. FISHER, AND P.B. MOYLE. 1998. Historical and present distribution of Chinook Salmon in the Central Valley drainage of California. Fish Bulletin 179, Volume 1