Excerpts from:

SACRAMENTO RIVER FALL CHINOOK

(JULY 2019)

SALMON REBUILDING PLAN

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4.5 Recommendation 5: Habitat Committee (page 62)

This report has identified that habitat conditions appear to have contributed to escapement shortfalls and thus the overfished status determination. It is recommended that the Council direct the Habitat Committee to work with tribal, federal, state, and local habitat experts to review the status of the essential fish habitat affecting SRFC and, as appropriate, provide recommendations to the Council for restoration and enhancement measures within a suitable time frame, as described in the FMP.

4.7 Further recommendations (page 65)

5. There were several issues identified during the development of this Rebuilding Plan that have yet to be fully evaluated and formed into recommendations. The majority of these topics are habitat related, and include:
    a. Evaluate percent of unimpaired flow in February through June for major tributaries for years 2012 through 2015.
    b. Evaluate water quality of impaired flow reaches in major tributaries February through June for years 2012 through 2015. Determine to what extent water quality standards may have deviated from optimal conditions during the time period that the broods in question would have emigrated through those river reaches.
    c. Evaluate fall flow effects on redd de-watering.
    d. Evaluate fall Delta Cross Channel gate operations as they pertain to straying.
    e. Evaluate temperature control for SRFC spawning areas of the Feather, American, and upper Sacramento rivers. Dam operations do not cover all spawning habitat.
    f. Evaluate Delta water quality as it pertains to the requirements relative to optimal conditions for fish and how those water quality standards may have deviated during the time period that the broods in question would have emigrated through that part of the system.
    g. Examine changes in natural production over time in the Sacramento Basin. Recovery of natural populations is slower than hatchery stocks and impacts to natural production is likely to increase in the face of climate change.
    h. Incorporate age-2 river harvest in the forecasting of the SI.

3.0 Review of Potential Factors Leading to Overfished Status

3.1 Freshwater survival (page 7)

3.1.1 Review of freshwater conditions

3.1.1.1 <u>Sacramento River mainstem</u>

Temperature impacts on salmon can take the form of lethal and sub-lethal effects including adult pre-spawn mortality, reduced fecundity, egg and embryo mortality, and increased susceptibility to disease. Data from the U.S. Geological Survey (USGS) gauge located downstream of Keswick Dam on the Sacramento River was used to characterize water temperatures and flows during spawning (Figures 3.1.1.1.a and 3.1.1.1.b). In terms of incubation temperatures, Martin et al. (2017) identified 54° F (12° C) as the temperature below which there is no longer any temperature-induced mortality. Mortality rates are nearly 100 percent at temperatures of 62° F (16.7° C) or greater (Myrick and Cech 2001).

Water temperatures measured immediately downstream of Keswick Dam were above 54° F during the spawning period in 12 of 18 brood years from 1997 through 2014. Of note are the ‘critical’ broods of 2012-2014, which are the brood years that primarily contributed to escapement in 2015-2017. While water temperatures recorded below Keswick are reflective of habitat conditions in the immediate area, SRFC regularly utilize the mainstem Sacramento River for spawning from Keswick Dam downstream to Princeton Ferry (river mile 165) (Killam 2018).

In 2014 CDFW installed fifty water temperature loggers in the uppermost anadromous portion of the Sacramento River downstream of Keswick Dam to monitor drought-related water quality impacts (Killam and Thompson 2015). Water temperatures coming out of Keswick during 2014 approached the 62° F lethal limit and were the highest observed across brood years 1997-2014. Killam and Thompson (2015) recorded increasing water temperatures in SRFC spawning areas downstream of Keswick Dam. Water temperature monitoring in 2014 showed that water temperatures in the uppermost 83 river miles were above 56° F for a majority of the SRFC spawning period from late September to mid-November with temperatures peaking at 61° F in early October (the beginning of peak spawning for SRFC) (Killam and Thompson 2015). It was likely that nearly all SRFC in the Sacramento River deposited eggs in water temperatures considered to be lethal to all, or portions of, incubating eggs or pre-emergent fry in 2014. An estimated 15,923 female SRFC used the river in 2014. However, it was not possible to use rotary screw trap data to evaluate mainstem Sacramento River juvenile SRFC production in 2014 because SRFC juveniles captured in the traps could be from any number of tributaries upstream of trapping locations (Killam and Thompson 2015).

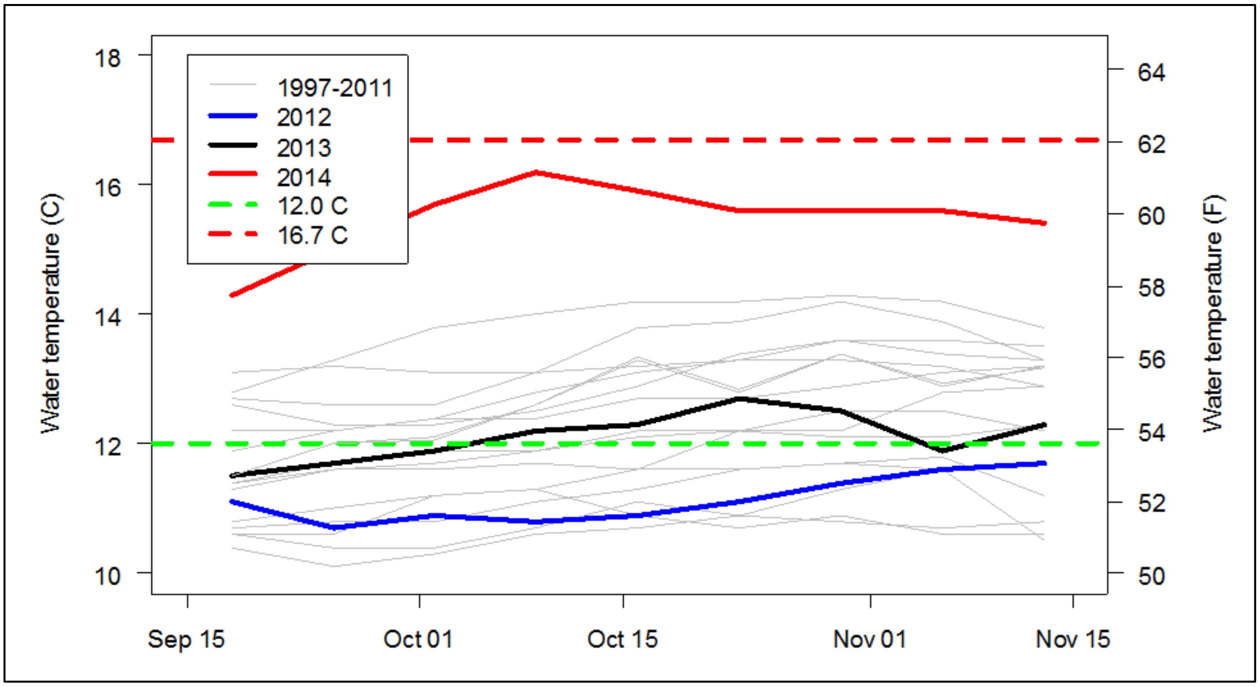

Figure 3.1.1.1.a. Water temperatures (°C on the left axis, °F on the right axis) in the Sacramento River below Keswick Dam during the spawning period for fall Chinook salmon across brood years 1997-2014 (data from Killam and Thompson 2015). The lower dashed line represents the temperature below which there is no mortality due to temperature (12˚°C/54°F) and the upper dashed line represents the temperature associated with nearly 100 percent temperature-induced mortality (16.7˚°C/62°F).

Flow levels influence the quantity and quality of spawning habitat. Sacramento River flow levels during the spawning period were relatively low during brood years 2012 and 2013 compared to previous years (Figure 3.1.1.1.b). Brood year 2014 experienced the lowest prolonged flow levels in the time series shown.

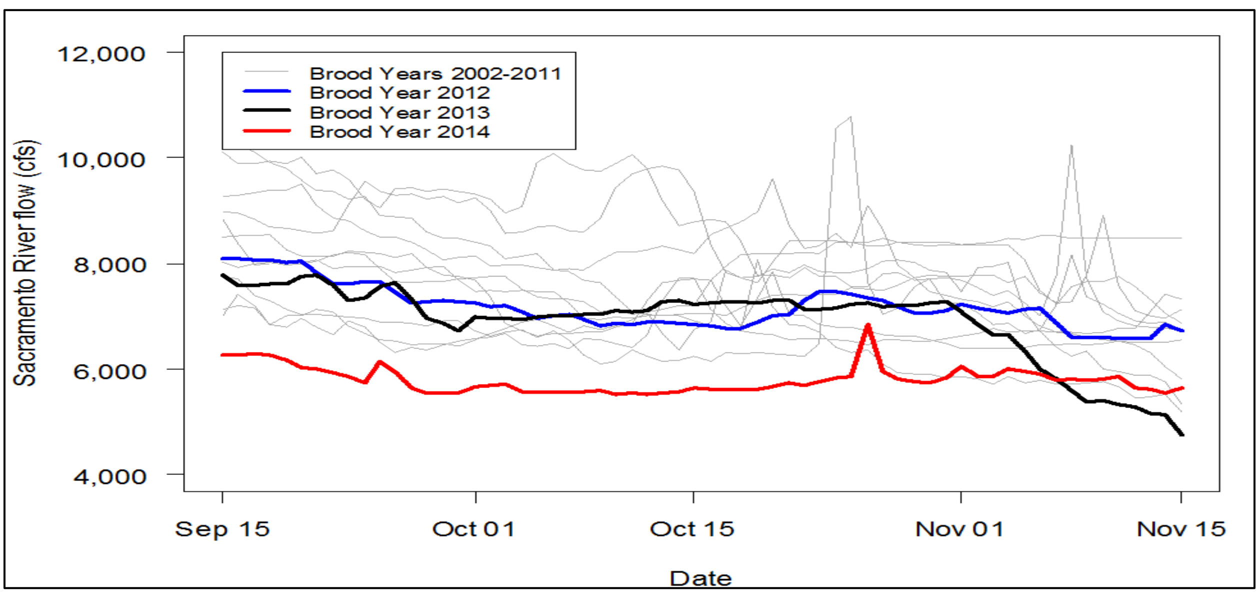

Figure 3.1.1.1.b. Sacramento River flow levels below Keswick Dam during the spawning period for brood years 2002-2014.

Water temperatures and flows experienced by juvenile SRFC were also indexed at the USGS gauge at Freeport, downstream of the city of Sacramento. Water temperatures were highest for brood year 2014 outmigrants (Figure 3.1.1.1.c). Flows were low for the 2012, 2013, and 2014 outmigrants (Figure 3.1.1.1.d).

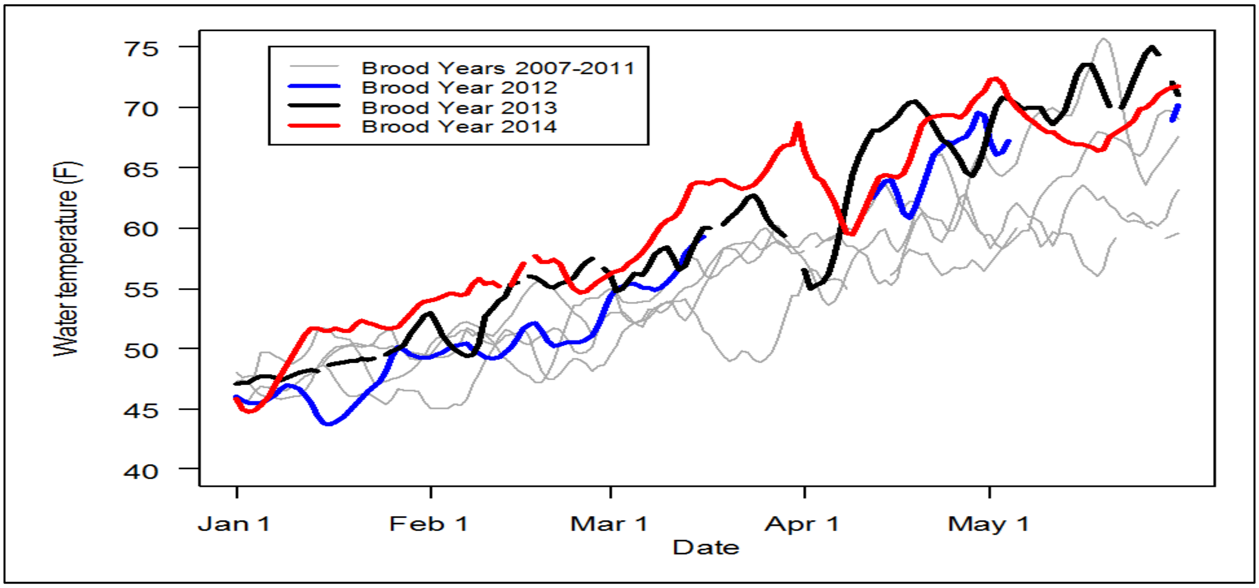

Figure 3.1.1.1.c. Sacramento River water temperature (°F) at Freeport (downstream of Sacramento) encountered by outmigrating fall Chinook juveniles from brood years 2007-2014.

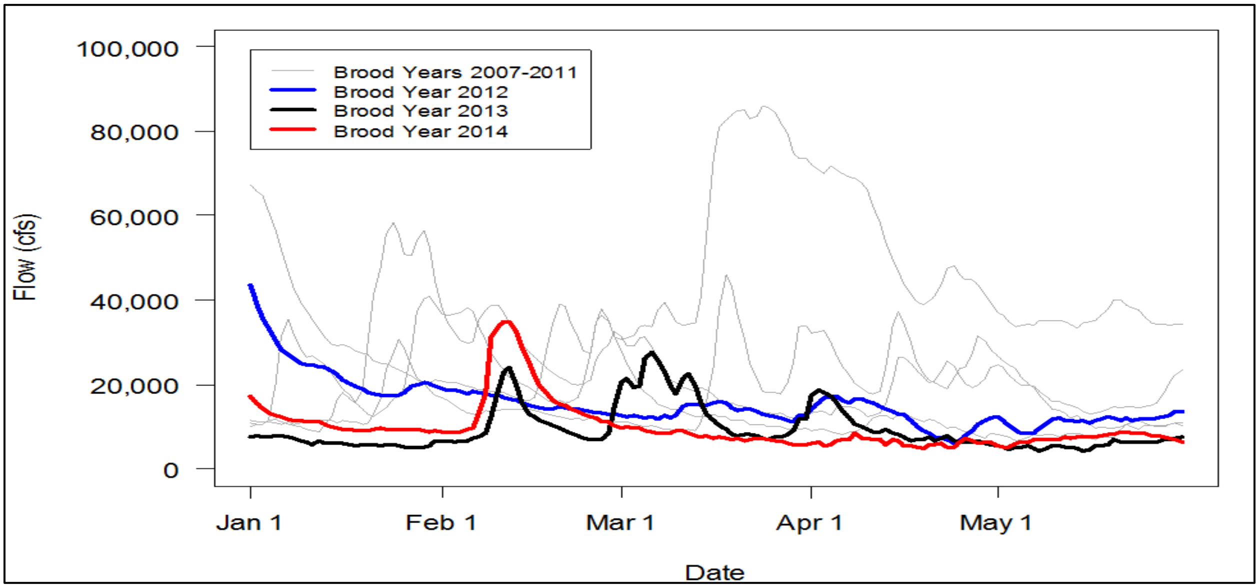

Figure 3.1.1.1.d. Sacramento River flow (cfs) at Freeport (downstream of Sacramento) encountered by outmigrating fall Chinook juveniles from brood years 2007-2014.

As previously mentioned, SRFC typically spawn from late September through mid-November, with the peak spawning occurring in October. Table 3.1.1.1.a presents the observed timing of

SRFC spawning by week, for the period September 3 through December 10. Data are based on observations of fresh female carcasses encountered during spawning seasons 2003 through 2017.

Table 3.1.1.1.a. Timing of Sacramento River fall-run Chinook spawning by week, for spawning seasons 2003 through 2017.

Week Beginning	Average Percent of Total Redds	Cumulative Percent of Total Redds
Sep 3	0.1%	0.1%
Sep 10	0.2%	0.3%
Sep 17	1.4%	1.7%
Sep 24	5.0%	6.7%
Oct 1	7.8%	14.5%
Oct 8	11.3%	25.8%
Oct 15	19.4%	45.2%
Oct 22	18.0%	63.3%
Oct 29	12.2%	75.5%
Nov 5	7.7%	83.2%
Nov 12	5.5%	88.7%
Nov 19	5.1%	93.7%
Nov 26	2.9%	96.7%
Dec 3	2.2%	98.9%
Dec 10	1.1%	100.0%

Reductions in flow during the spawning and egg incubation period can lead to redd dewatering. Since fall of 2013, the CDFW Red Bluff Field Office has actively monitored the fate of SRFC redds constructed in shallow water spawning habitat in the mainstem Sacramento River using funding through the Anadromous Fish Restoration Program. Newly constructed redds are marked with a unique marker and given a GPS waypoint, depth measurements are recorded, and current flow releases from Keswick Dam are noted. Field crews then return to these redds following scheduled flow reductions from Keswick Dam. The shallow water redd survey is conducted from Tehama Bridge at river mile (RM) 237 to Keswick Dam at RM 302. Table 3.1.1.b details the number of shallow redds identified and marked, and the number of those redds de-watered following flow reductions. While data do not exist for brood year 2012, there were generally low percentages of redds de-watered for brood years 2013 and 2014. It should be noted that these data only quantify redds that have been completely de-watered. It does not quantify redds partially de-watered nor changes in habitat associated with flow reductions, including velocity of water and dissolved oxygen in the egg pocket of shallow water redds.

Table 3.1.1.1.b. The number of shallow fall-run Chinook redds identified and marked, and the number of those redds de-watered following flow reductions on the main-stem Sacramento 2013 through 2017.

Year	Total Shallow Redds Identified	Percent De-watered
2013	515	2.7%
2014	43	0.3%
2015	291	2.1%
2016	0	NA
2017	15	1.5%

High river temperatures may contribute to pre-spawn mortality. As noted in Figure 3.1.1.1.a, temperatures during the spawning period were well above average for brood year 2014. CDFW provided estimates of pre-spawn mortality for brood years 2003-2017 based on sampling conducted in the Sacramento River mainstem (Figure 3.1.1.1.e). The average rate of pre-spawn mortality was 2.1 percent and in most years the rate was less than 4 percent. The notable exception was brood year 2014 where pre-spawn mortality was estimated to be 8.9 percent.

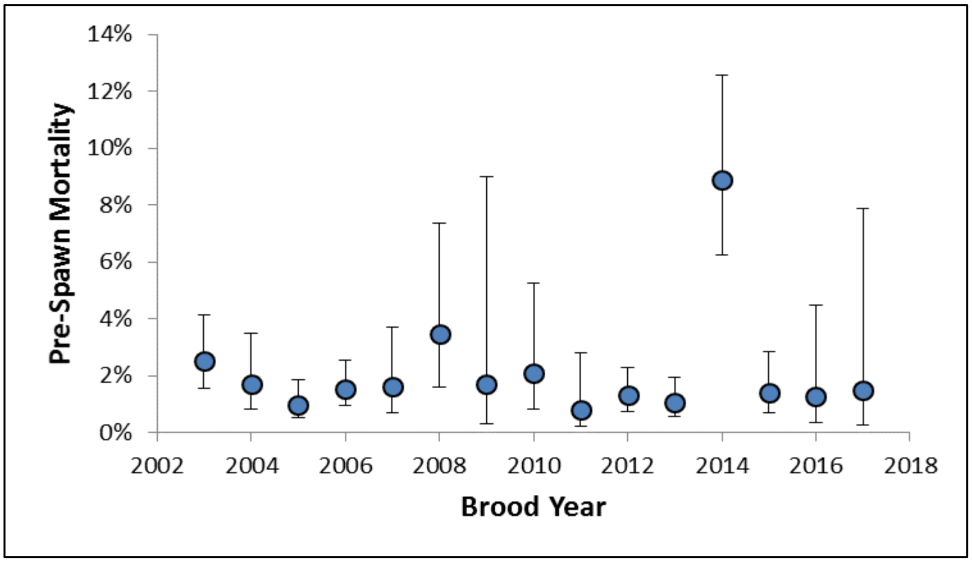

Figure 3.1.1.1.e. Estimates of pre-spawn mortality for Sacramento River fall Chinook (circles) along with 95 percent confidence intervals (whiskers) across brood years 2003-2017. Data source: CDFW.

Low flows and elevated water temperatures associated with exceptional drought conditions in the Sacramento River Basin were experienced by outmigrating juvenile SRFC beginning in spring 2013 and these conditions persisted through spring outmigration periods in 2014 and 2015. Acoustic telemetry studies in the Sacramento River have revealed low and variable survival during outmigration, suggesting marine mortality may not be the primary source of variability in cohort size as previously believed (Michel 2018). Recent investigations of juvenile Chinook survival in the Sacramento River mainstem using acoustic telemetry have shown that flow is strongly coupled with outmigration survival (Henderson 2018, Michel 2015, 2018, Notch 2017). Beginning in 2013, an investigation of juvenile survival of natural-origin Chinook emigrating from Mill Creek was initiated (Notch 2017). While this study focused on spring-run juveniles specifically, the location of the rotary screw trap (river mile 5) utilized to obtain juveniles was downstream of SRFC spawning habitat, and extensive Mill Creek juvenile Chinook life history investigations by CDFW show that young of the year spring-run closely mimic SRFC juveniles in emigration timing and length-at-date (Johnson and Merrick 2012). In this study juvenile Chinook smolts were captured in Mill Creek in April and May and implanted with miniaturized acoustic tags. The survival of tagged fish was then evaluated using over 140 acoustic receivers deployed each spring throughout the migration pathway of juvenile Chinook salmon from Mill Creek to the Pacific Ocean. In 2013, a total of 59 fish were tagged, and a single fish was detected surviving to the Golden Gate (Notch 2017). In 2014 and 2015, 36 and 186 fish were tagged, respectively, with zero fish either year surviving to the ocean (Notch 2017). The hydrograph of the Sacramento River is mostly unnatural and managed to store water in Shasta Reservoir for summer agricultural deliveries, maintaining delta water quality, and Sacramento

River temperature management. Generally, after April 15 water deliveries for agriculture increase and flows from Keswick Reservoir increase as a result. However, while the upper Sacramento River sees increasing flows, river levels downstream of Glenn Colusa Irrigation District and the numerous other large diversions along the Sacramento River are greatly reduced. This reduction in flow increases progressively downstream, and the Sacramento River reaches its lowest flows downstream of Tisdale in the vicinity of the Wilkins Slough USGS gauge. For brood year 2013, 38 percent of the CNFH-origin SRFC juveniles were released onsite, and these juveniles faced identical environmental conditions in the Sacramento River as the Mill Creek study fish. While all SRFC hatchery production was trucked for the 2014 brood, natural-origin SRFC juveniles were faced with extremely challenging conditions for survival in the Sacramento River mainstem.

3.1.1.2 Feather River

The Feather River is 67 miles long from the fish barrier dam (anadromous fish barrier) down to the confluence with the Sacramento River (Figure 2.2.1.a), and is the largest tributary to the Sacramento River. Although the Yuba and Bear rivers are considered major tributaries to the Feather River, under most conditions, Oroville Reservoir releases dictate the vast majority of the river flows. SRFC spawning activity in the Feather River primarily occurs upstream of RM 53 to RM 67 (Figure 3.1.1.2.a).

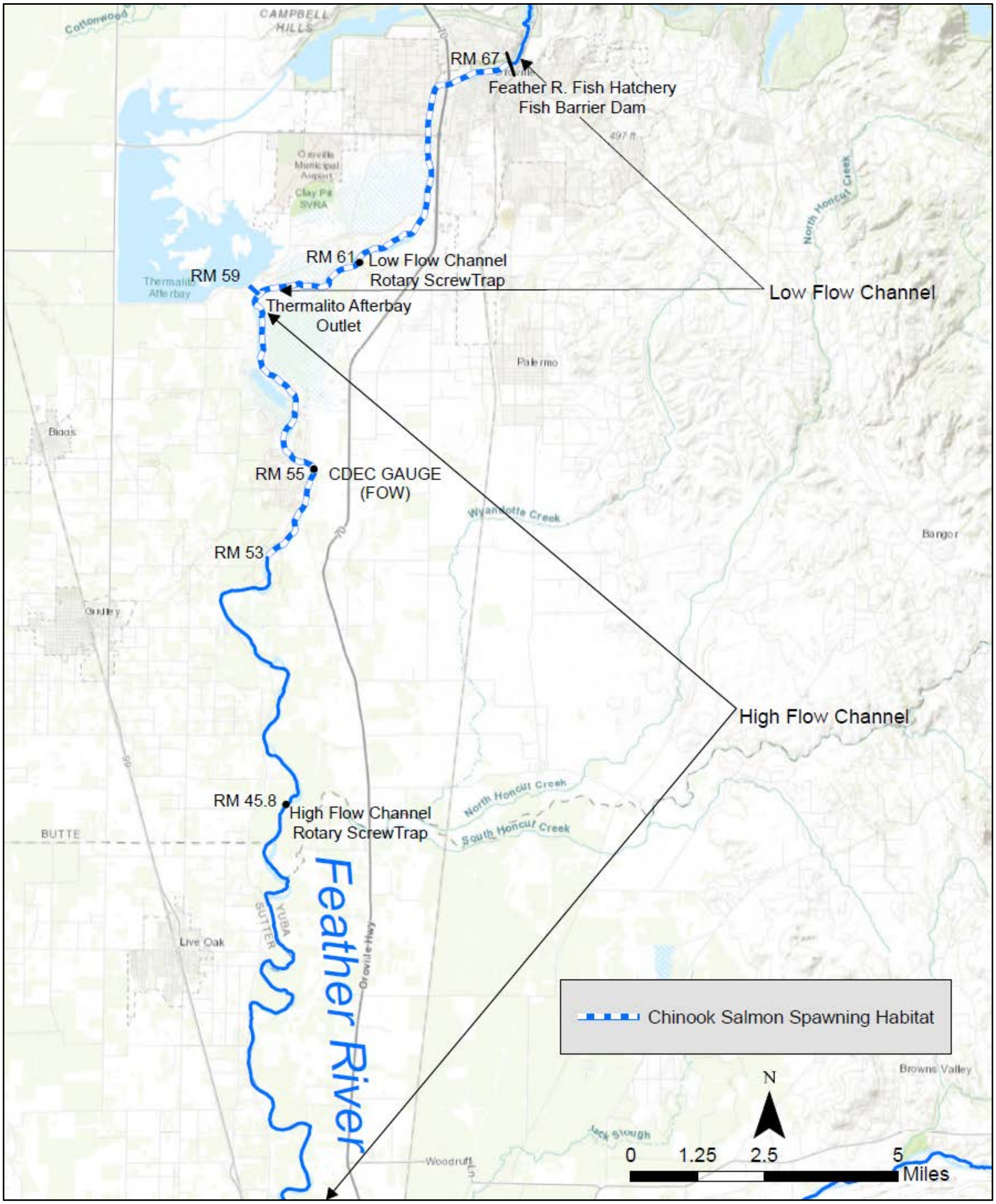

Figure 3.1.1.2.a. Map of the Feather River, including the fish barrier dam and the Thermalito Afterbay river outlet at RM 59.

Currently, an agreement between the California Department of Water Resources (CDWR) and CDFW (CDWR and CDFG 1983) regulates water temperature at FRH, located just below the barrier dam (see Figure 3.1.1.2.a). As a result, water temperatures in the low flow channel (between the fish barrier dam and the Thermalito Afterbay river outlet at RM 59) are often within a few degrees of required temperatures at the hatchery. In contrast, warm water releases from the Thermalito Afterbay river outlet (RM 59) frequently result in the exceedance of optimal spawning temperatures for SRFC during October downstream of RM 59. Temperature data in this portion of the Feather River were not available for 2012. In 2013, daily high temperatures were consistently over 56° F during October 1-28, with a high of 61° F on October 2. In 2014, daily high temperatures were consistently over 56° F during October 1-November 14, with a high of 64° F on October 2. (Figure 3.1.1.2.b). Water temperature data were collected by the CDWR at RM 55 using the Feather River Oroville Wildlife Area South Boundary Near Gridley gauge.

As referenced above, temperature impacts on salmon can take the form of lethal and sub-lethal effects including adult pre-spawn mortality, reduced fecundity, egg and embryo mortality, and include increased transmission or susceptibility to disease. It is likely that temperatures exceeding suitable spawning temperatures limited available spawning habitat for adult SRFC returning to the Feather River in the high flow channel over much of their spawning period between 2011 and 2017 resulting in direct and indirect effects including pre-spawn mortality. To evaluate pre-spawn mortality, female SRFC carcasses encountered during the escapement survey were qualitatively checked for the presence of eggs. Between 2011 and 2017, adult pre-spawn mortality ranged from a high of 30.3 percent in fall of 2013 to a low 1.2 percent in fall of 2017, with a mean of 17.2 percent (Table 3.1.1.2.a). High levels of pre-spawn mortality were observed for the critical broods and regardless of cause resulted in a reduction in potential juvenile production.

As population density, temperatures, habitat availability, and other factors can influence pre-spawn mortality, it is difficult to directly correlate observed pre-spawn mortality with water temperatures alone. Although density dependent and other factors may be influencing observed rates in pre-spawn mortality, these data suggest that adult pre-spawn mortality frequently decreases potential juvenile production in the Feather River. It is likely that reduction of temperature-suitable spawning habitat, and a consolidation of spawners returning to habitat in close proximity to the hatchery, contributed to the observed elevated annual pre-spawn mortality during the 2012-2014 spawning seasons.

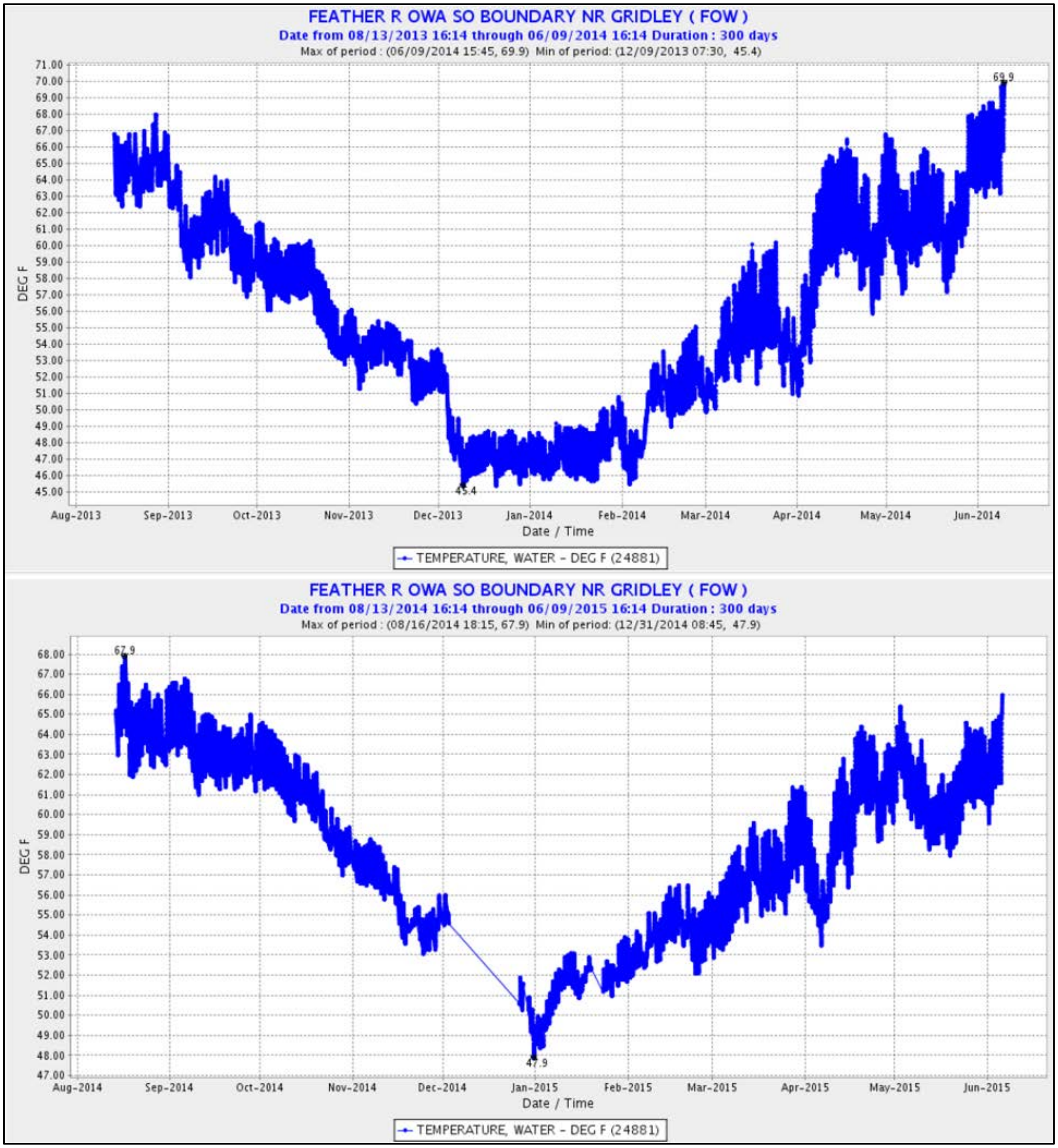

Figure 3.1.1.2.b. Feather River water temperatures (°F) downstream of the Thermalito Afterbay river outlet during the incubation, rearing, and outmigration periods for brood years 2013 and 2014. Temperatures affecting brood year 2012 were unavailable. Data was obtained from the CDWR gauge at the southern boundary of the Oroville Wildlife Area near Gridley, California.

Table 3.1.1.2.a. Total natural area escapement in the Feather River (including jacks) during 2011-2017, and the percentage of which that were estimated to have died prior to spawning.

Year	Feather River Natural Area Escapement[a/]	Percent Pre-spawn Mortality
2011	47,289	25.3%
2012	63,649	22.1%
2013	151,209	30.3%
2014	60,721	29.4%
2015	20,566	2.7%
2016	38,742	9.4%
2017	10,564	1.2%

a/ Spring-run Chinook are not distinguished from fall-run in the Feather River natural area spawning surveys, and thus are included in the escapement numbers reported here.

3.1.1.3 American River

The American River is the second largest tributary to the Sacramento River, a critical component of the San Francisco Bay/Sacramento-San Joaquin Delta ecosystem, and has historically contributed substantially to the overall SRFC stock. Folsom Reservoir on the American River is part of the Central Valley Project (CVP) and along with upstream diversions has altered flow and temperature regimes in the lower American River (LAR) from historical patterns and reduced available habitat (NMFS 2009a). During summer months, LAR water temperatures are controlled by blending warmer surface water in the reservoir with the reservoir's cold-water pool, utilizing temperature shutters at Folsom Dam. The timing and magnitude of reservoir releases affects how much cold-water pool is utilized to achieve LAR temperature targets throughout summer months. The disproportionate volume of reservoir cold-water pool needed to achieve summer temperature targets while releasing large volumes of stored water for CVP exports frequently exhausts cold-water pool storage prior to SRFC spawning, making it difficult to achieve suitable SRFC spawning temperatures. Over time, elevated water temperatures during the SRFC spawning period may be influencing spawn timing for American River-origin SRFC due to differential reproductive success of early versus late spawners.

As previously discussed, the effects of elevated water temperatures on Chinook salmon can be expressed in a variety of ways and direct measures of temperature impacts are often difficult to quantitatively assess. Bowerman et al. (2017) found that pre-spawn mortality increases with prolonged exposure to elevated water temperatures particularly in systems with high hatchery influence. Water temperatures in late October and early November are frequently over 60° F in the LAR and likely increase adult pre-spawn mortality. It is likely that adult pre-spawn mortality and direct egg and embryo mortality substantially decreased juvenile production in the LAR during 2012 through 2015. Additional flow-related impacts likely exacerbated temperature-related reductions in juvenile production (see section 3.1.9).

To evaluate pre-spawn mortality on the American River, female SRFC carcasses encountered during the escapement survey were qualitatively checked for the presence of eggs. The level of egg retention was determined by inspecting the abdominal cavity. Females are assumed to be unspawned if >70% of eggs are present, partially spawned if 30-70% of eggs are present, or spawned if <30% of eggs are present. Figure 3.1.1.3.a shows a trend from 2013 through 2015 where the majority of female carcasses encountered during the first 2-3 weeks of the survey (last two weeks of October and first week of November) were unspawned transitioning to fully spawned as the season progressed. As population density, temperatures, habitat availability, and other factors can influence pre-spawn mortality, it is difficult to correlate observed pre-spawn mortality with water temperatures alone. Regardless of cause, however, all years evaluated show a reduction in potential juvenile production due to pre-spawn mortality. As 2013 had the largest adult escapement to the LAR and 2014 had the warmest water temperatures during the time period in question (2013-2015), it is likely that these were contributing factors to the observed pre-spawn mortality during those years.

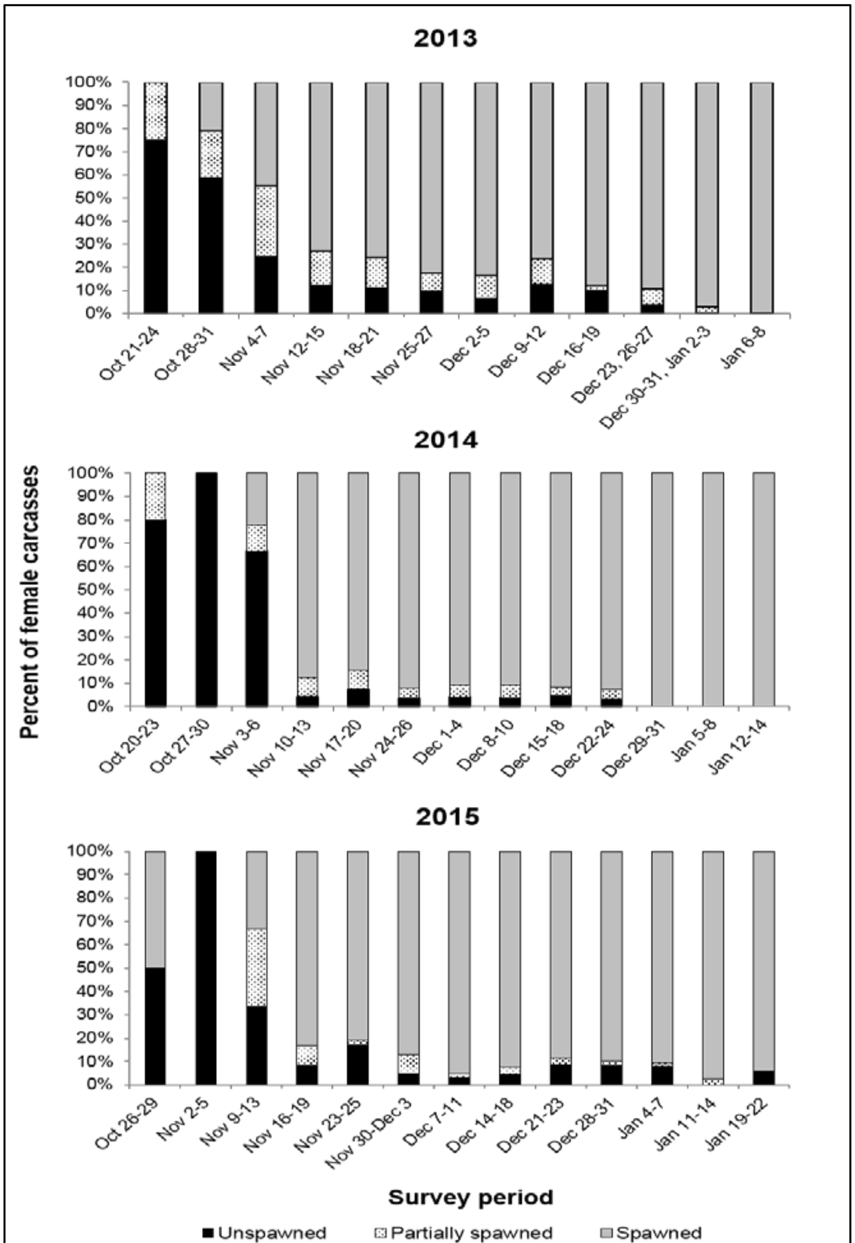

Figure 3.1.1.3.a. Estimated proportions of unspawned (>70% of eggs present), partially spawned (30-70% of eggs present), and spawned (<30% of eggs present) female SRFC carcasses in the American River natural area surveys during the 2013-2015 spawning seasons.

The American River has a long history of elevated water temperatures and from 2012 to 2016, water temperatures in excess of 56° F occurred during the SRFC spawning period (Figure 3.1.1.3.b), likely resulting in egg and embryo mortality. Chinook salmon spawning at 60° F is often associated with loss of eggs during these periods, caused by mortality in eggs and developing embryos (Snider and Vyverberg 1995). In the LAR, Chinook salmon eggs incubated in water temperatures above 62° F resulted in 100 percent mortality, eggs incubated in water at 60-62° F had 50 percent mortality to the eyed stage, and eggs incubated in 55-59° F experienced 20 percent mortality (Hinze 1959). When eggs were taken at water temperatures of 60-62° F and incubated at cooler temperatures of 55-56° F there was still a 30 percent loss by the eyed egg stage of development. In the Sacramento River, Chinook salmon eggs and fry exposed to water temperatures ranging from 43.5-63.0° F showed similar results. Mortalities of 80 percent or more were observed when fingerlings were incubated in water temperatures of 60-61° F (Healey 1979). Martin et al. (2017) showed that egg size in fish strongly influences oxygen uptake. As a consequence, lab-based assessments can underestimate temperature-related egg mortality, and salmon egg mortality in the natural environment may be occurring at temperatures as low as 53.6° F. Brood year 2014 experienced especially poor conditions as water temperatures were not consistently below 60° F until December 6. Temperatures in 2015 and 2016 did not contribute to the current overfished status since the progeny of those broods did not return as adults until 2018 and later, but high temperatures are likely to hinder rebuilding in the short term. Similar examples of poor freshwater conditions outside of the critical years are provided in other sections of this plan, and while they cannot be considered causative factors for the current status, they are still noteworthy and critical to rebuilding. Water temperature data were collected by the USGS at the William B. Pond gauging station.

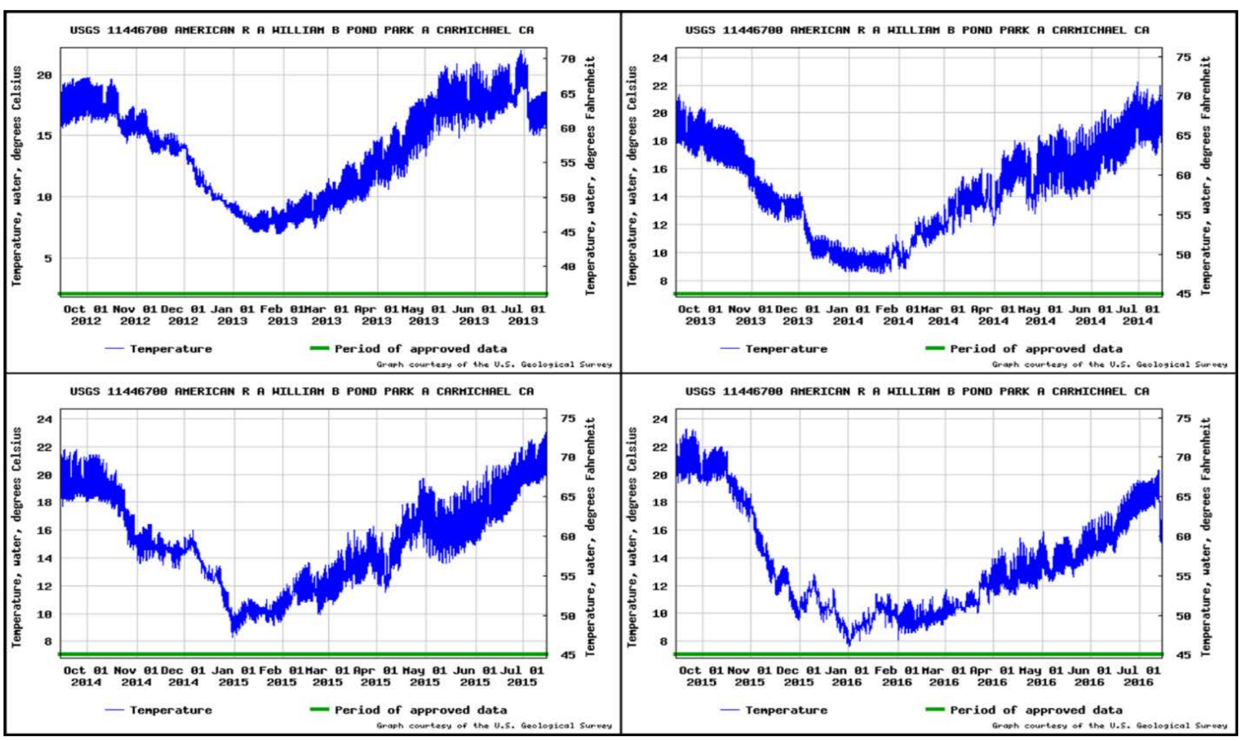

Figure 3.1.1.3.b. American River water temperatures (°C on the left axis, °F on the right axis) during the incubation, rearing, and outmigration periods for brood years 2012-2015. Data was obtained from the USGS gauge at William B. Pond Park near Carmichael, California.

Estimates of egg-to-fry survival in the LAR highlight how poor natural production has been. From 2012 through 2016, egg-to-fry survival estimates in the LAR have ranged from 1.3 to 7.3 percent (PSMFC 2014a, 2014b, Silva and Bouton 2015) (Table 3.1.1.3.a). Based on scientific literature review, at least 10 percent freshwater survival was needed to stabilize or recover Chinook salmon to viable population levels in North American west coast rivers (Anchor QEA 2016, BDCP 2012, Quinn 2005).

Table 3.1.1.3.a. Lower American River SRFC egg-to-fry survival estimates from rotary screw traps for brood years 2012-2016.

Brood Year	Survival Rate	Number of Female Spawners
2012	6.8%	23,383
2013	1.3%	28,215
2014	2.2%	12,429
2015	7.3%	6,153
2016	4.4%	3,580

Adult SRFC returns to LAR natural areas have dropped precipitously between 2013 and 2017 from a high of 52,631 in 2013 to a low of 5,742 in 2017. This concerning trend is likely a response to pre-spawn mortality and poor egg-to-fry survival. When returns of hatchery-produced SRFC and stray salmon from other tributaries are factored in using CWT recovery data, it becomes quite clear that poor natural production in the LAR is dramatically affecting adult returns and is decreasing LAR contributions to the ocean sport and commercial fisheries, a considerable economic impact to the fishing industry. Low adult returns to the LAR and few naturally-produced fish are also influencing the ability of Nimbus Fish Hatchery to produce SRFC associated with mitigation for Folsom Dam. As an integrated hatchery, naturally-produced fish must be incorporated into broodstock at acceptable levels to prevent hatchery operations from genetically influencing the natural population and allow for local area adaptation (CA HSRG 2012).

3.1.2 Parental spawner abundance

For the 2012-2014 critical broods, parental spawner escapement to hatcheries and natural areas was near or above the average over years 1970-2017 and well above the S_{MSY} of 122,000 adults (see Table B-1 in PFMC 2018b).

Estimates of the number of female spawners above Red Bluff Diversion Dam (RBDD) are reported in Voss and Poytress (2017). Excluding the 2002 and 2003 high escapement years, the average number of female spawners above RBDD has been 24,400 fish (Figure 3.1.2.a). The number of female spawners in brood years 2012-2014 were above this average, ranging from 32,600 to 39,400 across these brood years.

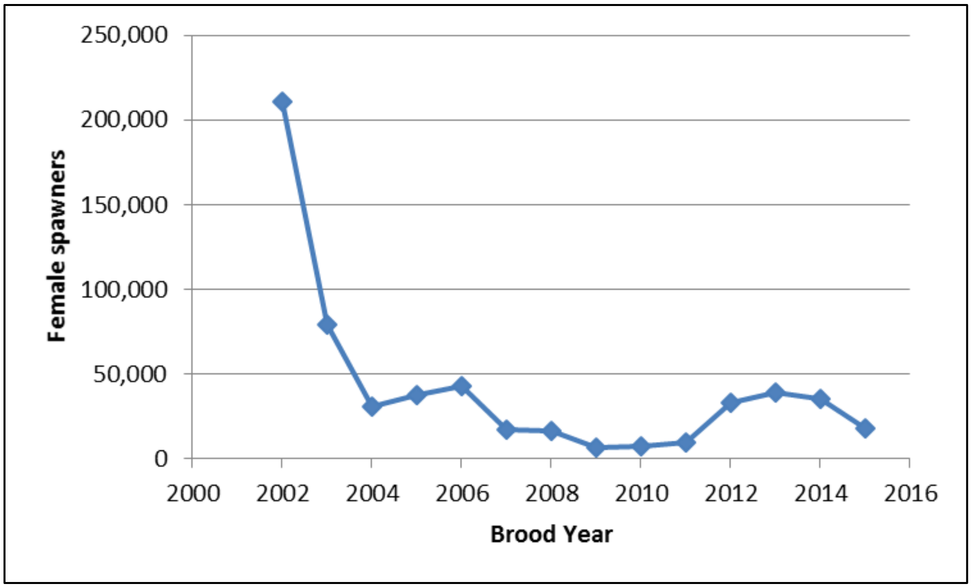

Figure 3.1.2.a. Estimates of the number of female spawners above Red Bluff Diversion Dam (from Voss and Poytress 2017).

3.1.3 Juvenile Production Estimates

Since 2002, USFWS has used screw traps attached to RBDD to estimate juvenile SRFC passage (Voss and Poytress 2017). These estimates represent a fry-equivalent juvenile production index (JPI) that provides a useful measure of juvenile productivity above RBDD (Figure 3.1.3.a). Across brood years 2002-2015, the average JPI has been 18.5 million fry. Brood years 2012 and 2013 were well-above average, but brood year 2014 was the lowest value recorded for the JPI.

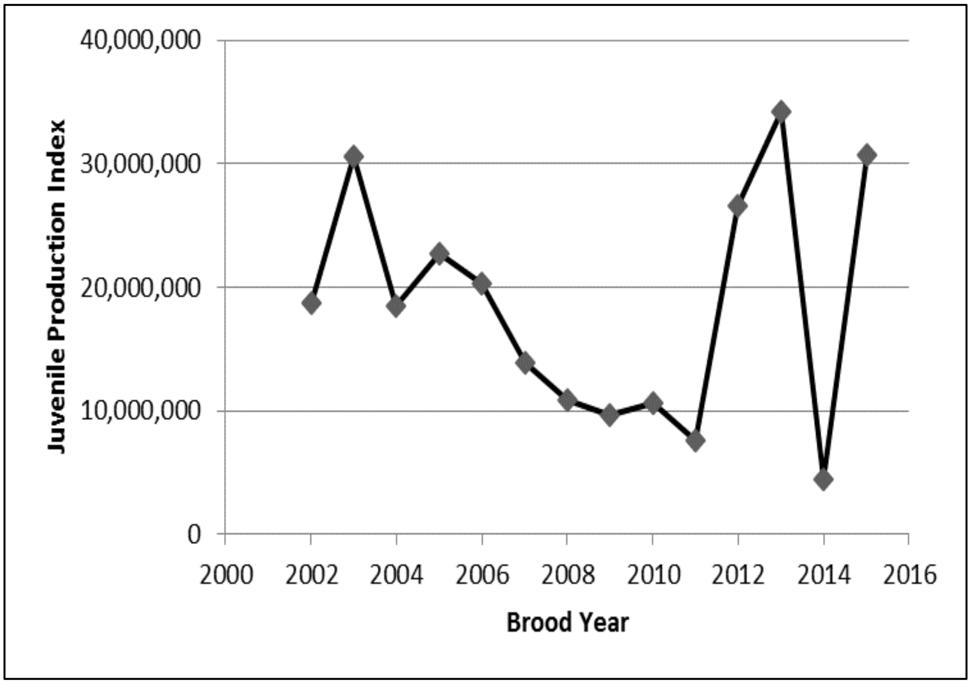

Figure 3.1.3.a. Fry-equivalent Juvenile Production Index estimates of SRFC production above RBDD across brood years 2002-2015 (Voss and Poytress 2017).

Since 1995, CDFW has used rotary screw traps at Knights Landing to track emigrating juvenile SRFC passage into the Sacramento-San Joaquin Delta. Passage estimates for the Knights Landing screw traps followed similar trends to those observed at RBDD for brood year 2013 through 2016 outmigrants, with a substantial reduction in passage observed for brood year 2014 (Table 3.1.3.a). Data for brood year 2012 were not available.

Table 3.1.3.a. Juvenile SRFC passage estimates at Knights Landing for brood years 2013 -2016.

Brood Year	Smolts (in millions)
2013	25.8
2014	3.2
2015	19.7
2016	11.4

3.1.4 Disease

In addition to influencing pre-spawn mortality and available suitable spawning habitat, elevated temperatures and stable low reservoir releases in the Feather River have likely contributed to disease infectivity and disease contraction in juvenile SRFC. Since 2012, pathogens *Ceratonova shasta* (*C. shasta*) and *Parvicapsula minibicornis* (*P. minibicornis*) have been monitored by USFWS in collaboration with CDWR and CDFW. Between 2012 and 2016 (January-May), a pattern of *C. shasta* and *P. minibicornis* infectivity was observed and likely affected a large proportion of the emigrating population. *C. shasta* was detected in 35 percent, 58 percent, and 46 percent of the juveniles collected in spring of 2014, 2015, and 2016, respectively (Foott 2014, Foott et el. 2016, Foott and Imrie 2016). Pathogen monitoring was also conducted on the Sacramento River in spring of 2013 and 2014 (Foott 2013, 2014). In 2013, asymptomatic infections of *C. shasta* and *P. minibicornis* were observed in 62 natural Sacramento River Chinook juveniles collected from Red Bluff to Tisdale (Foott 2013). In 2014, *C. shasta* infection was detected in juvenile Chinook salmon collected from the lower Sacramento River at a rate of 74 percent (Foott 2014). It is therefore likely that infectivity in the Sacramento River was high for natural-origin SRFC juveniles during drought conditions in 2013, 2014, and likely 2015, leading to reduced fitness and outmigration success for juvenile SRFC.

As referenced above, warm water releases from the Thermalito Afterbay river outlet (RM 59) on the Feather River frequently result in temperatures that exceed optimal spawning temperatures for SRFC in October downstream of the outlet. This likely compresses adult spawners into available temperature suitable spawning habitat upstream of the outlet at least for a portion of the spawning window. Pathology data suggested a zone of high infectivity was likely present in the high flow channel downstream of the Afterbay river outlet (Foott 2014). In both 2015 and 2016 a zone of high *C. shasta* infectivity was present beginning near the confluence of RM 59 and extended downstream to at least RM 45, according to reports provided by the USFWS California-Nevada Fish Health Center (Foott et al. 2016, Foott and Imrie 2016).

It is reasonable to assume that if a majority of adults spawn in the low flow channel (upstream of RM 59), and their progeny must emigrate through a zone of high *C. shasta* infectivity, then in-river juvenile production would be severely reduced. For brood years 2012 through 2015, passage estimates within the high flow channel (RM 45.8) were substantially lower than estimates of passage at the low flow channel rotary screw trap at RM 61 (Table 3.1.4.a). These data suggest that the emigrating juvenile populations of brood years 2012-2015 were reduced by an average of 48 percent in only 15 miles of habitat. While some loss due to predation and other causes would be expected between the two sampling locations, the magnitude of loss suggests that disease severely reduced in-river production in the Feather River and that there was no appreciable spawning downstream of RM 61. If successful spawning occurred downstream of RM 61 during 2012 through 2015, it did not occur in sufficient magnitude to offset the observed losses. It is worthwhile noting that in spring of 2018 (brood year 2017), only 1.9 million juveniles were estimated to have passed the low flow channel rotary screw trap (RM 61). This is the lowest passage estimate during the 2012-2018 period and suggests that short-term stock rebuilding may need to rely more heavily on hatchery production than natural production from the Feather River.

It is generally accepted that in order to develop an infectious zone the following factors need to coincide: low velocity, unvaried flows in close proximity to spawning areas (myxospore input), and temperatures above 54-59° F (12-15° C). It is also worth noting that due to reoccurring pathogen issues documented on the Feather River, pulse flows similar to those mandated on the Klamath River (*HVT v. NMFS* 2017) may be prudent to help with stock rebuilding and maintenance.

Table 3.1.4.a. Sacramento River fall Chinook juvenile passage estimates in the Feather River and the estimated mortality during downstream migration, brood years 2011-2015.

Brood Year	Juvenile Passage Estimate at River Mile 61.0	Juvenile Passage Estimate at River Mile 45.8	Percent Reduction
2011	9,902,393	9,271,622	6%
2012	26,254,553	13,871,128	47%
2013	27,645,796	23,888,112	14%
2014	19,087,391	7,516,495	61%
2015	10,025,589	2,994,935	70%

3.1.5 Stock and recruitment

Stock-recruitment relationships are used to characterize the relationship between the number of parental spawners and their progeny. The number of progeny produced per spawner is typically highest at low spawner abundances and declines with increasing spawner abundance due to density-dependent effects (e.g., redd superimposition at high spawner densities). In addition to quantifying density-dependent effects, stock-recruitment relationships are also useful for quantifying density-independent effects (e.g., water temperature during egg incubation). Density-independent effects can be indexed by examining the residuals[1] from a stock-recruitment relationship, with negative residuals representing lower than expected recruitment given the number of parental spawners, and positive residuals representing higher than expected recruitment given the number of parental spawners. For these reasons, stock-recruitment relationships provide a useful framework for characterizing the levels of density-dependence alongside density-independent effects in a population.

[1] Residuals are the differences between the observed $\log_e$ (recruits/spawners) and the predicted $\log_e$ (recruits/spawners) from the stock-recruitment relationship. In this application, recruits are the Juvenile Production Index and spawners are the number of female spawners.

The estimated number of spawners upstream of RBDD and the JPI estimates calculated from RBDD passage provide the necessary components for examining the stock-recruitment relationship for the Sacramento River and its tributaries upstream of RBDD (Figure 3.1.5.a). The Ricker stock-recruitment function that was fit to these data indicated that the juvenile production index increases with increased spawner abundance with maximum average juvenile production at approximately 80,000 female spawners, that there was a moderate amount of density-dependence at higher spawner abundances, and that there was a relatively low amount of density-independent variation.

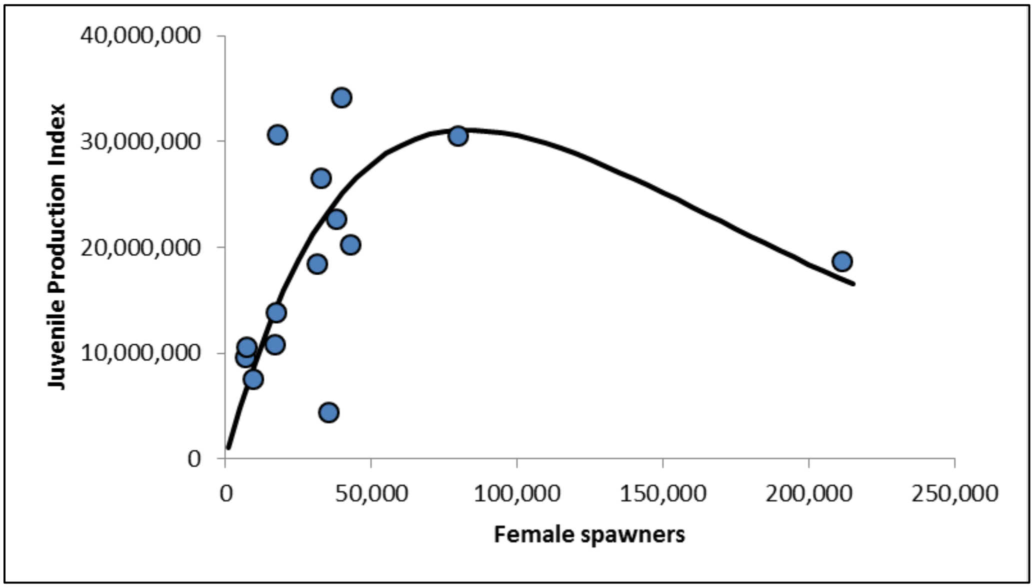

Figure 3.1.5.a. Estimates of the number of the total number of female spawners above RBDD and the fry-equivalent juvenile production index for brood years 2002-2015. The line represents the Ricker stock-recruitment function that was fit to the data.

As mentioned above, the residuals from the fitted stock-recruitment relationship characterize the density-independent factors influencing productivity, with negative residuals indicating lower-than-expected recruitment given spawner abundance and positive residuals indicating higher-than-expected recruitment given spawner abundance. Examining the residuals for the fitted stock-recruitment function for SRFC data indicated that brood years 2012 and 2013 had slightly higher-than-expected recruitment given female spawner abundance, but brood year 2014 had dramatically lower-than-expected recruitment given the number of female spawners that year (Figure 3.1.5.b).

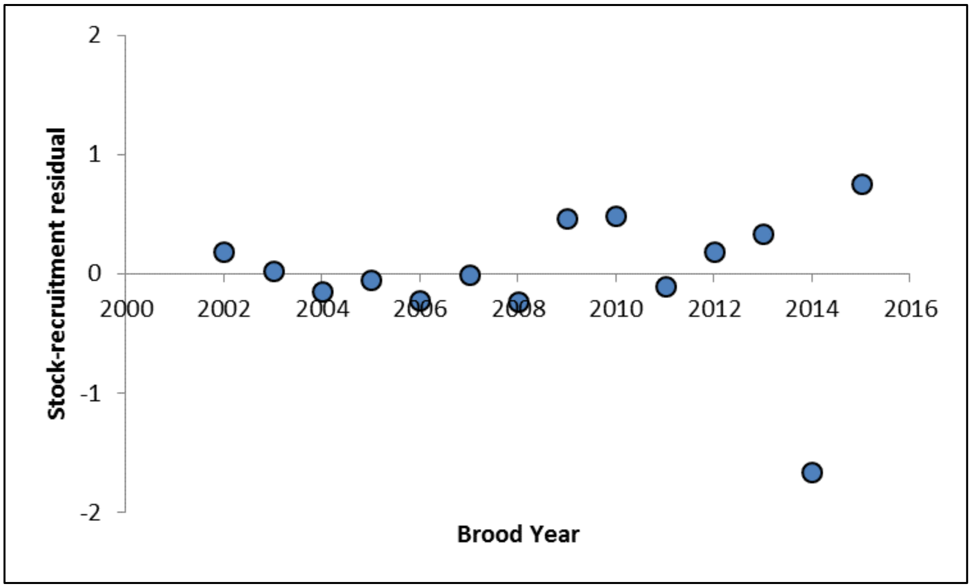

Figure 3.1.5.b Residuals from the fitted stock-recruitment relationship by brood year for the Sacramento River above RBDD.

3.1.6 Hatchery production

As described earlier, hatchery production of SRFC comes from Coleman National Fish Hatchery (CNFH), operated by USFWS, and from Feather River Hatchery (FRH) and Nimbus Fish Hatchery (NFH), operated by CDFW. CNFH is located on Battle Creek, a tributary near the upper limit of anadromy in the mainstem, and smolts are typically released directly into the creek. However, in response to severe drought conditions in the Sacramento River, brood years 2013 and 2014 had 62 percent and 100 percent of their smolts, respectively, trucked to the delta and released into net pens. At FRH, all of the fall-run production is trucked (or sometimes barged) and released into net pens in the delta and San Pablo/San Francisco Bay, as well as coastal net pens located in Half Moon Bay and Santa Cruz. NFH is located on the American River, upstream of the city of Sacramento. A portion of the production at NFH is always trucked to the delta or bay and released into net pens, although in most of the recent years the majority of smolts have been released into the American River. However, the 2013 and 2014 broods were entirely trucked to San Pablo Bay for release, again due to extreme drought conditions in-river. Figure 3.1.6.a shows the percentages of the total annual SRFC hatchery releases (all three hatcheries combined) that were trucked offsite prior to release for the 2006-2014 broods. Offsite releases have returned to more standard levels since the 2014 brood. The effects of these offsite releases for CNFH and NFH are discussed in Section 3.1.7.

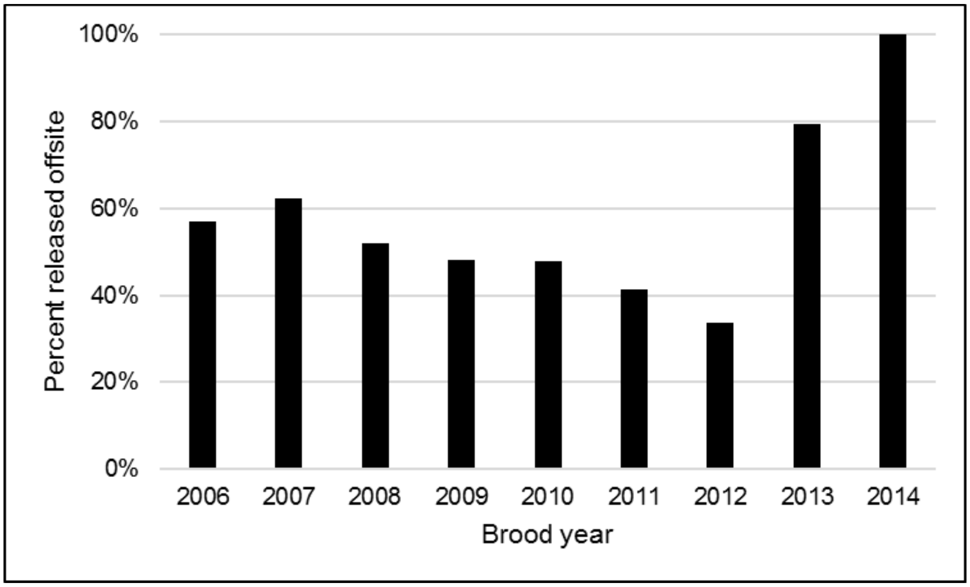

Figure 3.1.6.a. Percentages of the total annual SRFC hatchery releases that were transported offsite via truck prior to release, brood years 2006-2014.

Table 3.1.6.a shows the total number of SRFC smolts released annually from each hatchery for brood years 2000-2014. For all three facilities, annual release numbers during the brood years that contributed to the overfished status were lower than the 2000-2011 averages. While CNFH and NFH released on average 800-900 thousand fewer smolts during the critical years, the difference was even greater at FRH with an average of 2.8 million fewer smolts released. There was increased mortality at FRH for the 2013 and 2014 broods due to an egg fungus, and this reduced production during those years, especially for the 2014 brood. Variability in enhancement releases, which are separate from mitigation release targets, also factored into the reduced production at FRH as compared to earlier broods. Across years, enhancement release targets have shifted between FRH and the Mokelumne River Hatchery, which is outside of the Sacramento Basin and thus not included as a component of the SRFC stock. FRH enhancement releases have been as high as 4 million SRFC smolts, but the release target at FRH was only 2 million during the critical years. Additionally, FRH did not come close to meeting that target for any of those broods, especially 2013 and 2014 due to the egg fungus issue previously mentioned. Across the three hatcheries in Table 3.1.6.a, the combined reduction in SRFC production during the critical years was substantial. On average, approximately 4.5 million fewer smolts were released annually for the 2012-2014 broods as compared to the 2000-2011 broods, which is a 17 percent reduction.

Table 3.1.6.a. Numbers of SRFC smolts released from Coleman National Fish Hatchery (on Battle Creek), Feather River Hatchery, and Nimbus Fish Hatchery (on the American River) for the 2000-2014 broods.

Brood Year	Coleman National Fish Hatchery	Feather River Hatchery	Nimbus Fish Hatchery	Total SRFC Smolts Released
2000	12,664,580	5,036,622	4,375,806	22,077,008
2001	11,318,028	6,743,911	4,222,082	22,284,021
2002	14,018,806	8,137,445	4,361,300	26,517,551
2003	13,101,565	8,549,876	4,578,400	26,229,841
2004	11,854,153	8,996,680	4,570,000	25,420,833
2005	13,355,345	10,347,148	3,002,600	26,705,093
2006	12,316,193	9,785,968	6,130,383	28,232,544
2007	12,699,100	10,148,313	6,931,264	29,778,677
2008	14,021,126	8,351,309	4,194,887	26,567,322
2009	11,569,461	9,719,123	4,612,769	25,901,353
2010	12,709,391	10,552,142	4,855,599	28,117,132
2011	12,508,161	10,012,097	4,805,043	27,325,301
2012	**11,875,014**	**6,952,929**	**4,012,500**	**22,840,443**
2013	**11,780,007**	**6,632,534**	**3,587,565**	**22,000,106**
2014	**11,846,951**	**4,578,358**	**3,932,549**	**20,357,858**
2000-2011 avg.	12,677,992	8,865,053	4,720,011	26,263,056
2012-2014 avg.	11,833,991	6,054,607	3,844,205	21,732,802

3.1.7 Effects of offsite hatchery releases on straying and in-river harvest

As discussed in the previous section, all SRFC hatchery production for brood year 2014, and most of the brood year 2013 production, was trucked offsite and released into delta, bay, or coastal net pens. For CNFH specifically, there was much concern over the decision to truck their smolts to the delta during those years. Returning spawners from offsite CNFH releases have been shown to stray at high rates, more so than the other two Sacramento Basin hatcheries. SRFC released onsite at CNFH have a high tendency to return to the upper Sacramento Basin, where they originated, with minimal straying (estimated between 0 and 6 percent). In contrast, SRFC produced at CNFH but trucked to downstream release sites have been found spawning in every accessible sub-basin within the Central Valley, with observed stray rates ranging from 73 to 98 percent. Trucked releases from FRH and NFH have not been observed straying nearly to the extent of trucked CNFH releases, with stray rates typically in the vicinity of 5-25 percent (Kormos et al. 2012, Palmer-Zwahlen and Kormos 2013, Palmer-Zwahlen and Kormos 2015, Palmer-Zwahlen et al. 2018). Still, even with the substantial straying risk, particularly for CNFH releases, trucking smolts was deemed necessary during those drought years due to the highly degraded in-river conditions.

Straying has traditionally been defined for SRFC as fish spawning outside of their respective hatchery's sub-basin (i.e., outside of the upper Sacramento, Feather, and American basins for CNFH, FRH, and NFH, respectively), and the stray rates reported above were calculated in this manner (Kormos et al. 2012, Palmer-Zwahlen and Kormos 2013, Palmer-Zwahlen and Kormos 2015, Palmer-Zwahlen et al. 2018). However, MSST for SRFC is based on the pooled adult escapement to the entire Sacramento Basin. Therefore, straying spawners do not necessarily contribute to an overfished status unless they stray to the San Joaquin Basin or outside of the

Central Valley altogether. For example, SRFC produced at CNFH that spawn in the Feather or American basins, while technically straying, are still counted toward total SRFC escapement. However, if straying affects their migratory behavior and increases their susceptibility to in-river harvest, it could affect overall escapement and thus contribute to an overfished status. Table 3.1.7.a presents preliminary estimates for numbers of adult SRFC from each hatchery (with CNFH and NFH broken out into onsite and offsite releases) that returned to the Central Valley, strayed into the San Joaquin Basin, were harvested in-river, and ultimately escaped to Sacramento Basin spawning areas (hatchery and natural) during 2015-2017. Brood year 2014, which was entirely released offsite for all three hatcheries, contributed to adult escapement in 2017 as age-3 spawners. Brood year 2013, which was mostly released offsite (38 percent of the CNFH production was still released at the hatchery), contributed to adult escapement in 2016 (age-3) and 2017 (age-4). Neither of these broods were old enough to be considered adults in 2015.

Table 3.1.7.a. Preliminary estimates for numbers of hatchery-origin adult SRFC from Coleman National Fish Hatchery, Nimbus Fish Hatchery, and Feather River Hatchery that returned to the Central Valley, strayed into the San Joaquin Basin, were harvested in-river, and escaped to Sacramento Basin spawning areas (hatchery and natural) during 2015-2017. Estimates for Coleman and Nimbus are further broken out into onsite and offsite releases.

2015	Total Central Valley Run	Strays into San Joaquin Basin	*% of total Central Valley run that strayed into San Joaquin Basin*	Total Sacramento Basin Run	Sacramento Basin In-river Harvest	*% of total Sacramento Basin run that was harvested in-river*	Sacramento Basin Escapement
Coleman - onsite	16,890	0	*0%*	16,890	2,806	*17%*	14,084
Coleman - offsite[a/]	38	0	*0%*	38	0	*0%*	38
Nimbus - onsite	6,957	0	*0%*	6,957	796	*11%*	6,161
Nimbus - offsite	4,423	420	*9%*	4,003	1,082	*27%*	2,921
Feather River[b/]	53,012	514	*1%*	52,498	5,683	*11%*	46,815
2016							
Coleman - onsite	9,815	0	*0%*	9,815	1,931	*20%*	7,884
Coleman - offsite	19,879	767	*4%*	19,112	8,513	*45%*	10,599
Nimbus - onsite	1,031	0	*0%*	1,031	127	*12%*	904
Nimbus - offsite	11,411	1,442	*13%*	9,969	3,065	*31%*	6,904
Feather River[b/]	39,598	110	*0%*	39,488	5,012	*13%*	34,476
2017							
Coleman - onsite	434	0	*0%*	434	43	*10%*	391
Coleman - offsite	16,263	2,832	*17%*	13,431	5,954	*44%*	7,477
Nimbus - onsite[c/]	14	0	*0%*	14	0	*0%*	14
Nimbus - offsite	12,830	4,350	*34%*	8,480	2,838	*33%*	5,642
Feather River[b/]	29,780	912	*3%*	28,868	8,827	*31%*	20,041

a/ Brood year 2010 (age-5) was the only brood with offsite Coleman releases that contributed to adult escapement in 2015.

b/ All Feather River Hatchery releases were conducted offsite.

c/ Brood year 2012 (age-5) was the only brood with onsite Nimbus releases that contributed to adult escapement in 2017.

During the three years that contributed to the overfished status, no adults from onsite-releases were estimated to have strayed into the San Joaquin Basin. It was markedly different for offsite releases, however, and adults returning from offsite NFH releases actually strayed into the San Joaquin Basin at higher rates than those returning from offsite CNFH releases. Stray rates generally increased each year during 2015-2017, and they were particularly high in 2017. That year, approximately one third of the adults returning from offsite NFH releases strayed into the San Joaquin Basin. It was also high for offsite CNFH releases at 17 percent, and between all three hatcheries in 2017, over 8,000 adults strayed into the San Joaquin Basin and were lost from SRFC escapement. In 2016, 13 percent and 4 percent of the adult spawners returning from offsite NFH and CNFH releases, respectively, strayed into the San Joaquin Basin. Adults returning from FRH, where all releases were offsite, did not stray into the San Joaquin Basin at particularly high rates during any of the critical years.

Offsite-released fish were noticeably more prone to harvest once inside the Sacramento Basin. Adults returning from offsite CNFH releases were harvested at especially high rates in 2016 and 2017, at slightly less than half. During those same years, approximately one third of the adults returning from offsite NFH releases were harvested in-river, and FRH-origin adults had a similarly high harvest rate in 2017. Prior to 2016, the basin-wide harvest rate in the river sport fishery averaged 14 percent annually. Although the high harvest rates in Table 3.1.7.a only pertain to hatchery-origin SRFC, they are symptomatic of a larger problem as the entire SRFC stock experienced elevated in-river harvest rates during 2016 and 2017, largely due to the migratory behavior of spawners returning from offsite hatchery releases. While the salmon being discussed here did return to the greater Sacramento Basin, and thus had the possibility of contributing to SRFC escapement, there was a great deal of sub-basin straying, particularly with CNFH-origin salmon straying into the Feather and American basins. The data aren't presented here, but preliminary results indicate that straying outside of the upper Sacramento Basin was greater than 90 percent for offsite-released CNFH adults returning in 2016 and 2017, in line with the rates reported for earlier return years (Kormos et al. 2012, Palmer-Zwahlen and Kormos 2013, Palmer-Zwahlen and Kormos 2015, Palmer-Zwahlen et al. 2018). Since the majority of CNFH-origin SRFC returning during those two years were from offsite releases, this created a large shift in sport fishing effort away from the upper Sacramento Basin and into the Feather and American basins, due to a severe lack of fish returning to upper Sacramento areas. Focusing fishing pressure in the areas where most of the fish were returning likely resulted in increased harvest rates on all SRFC regardless of origin, and basin-wide harvest rates did exceed historical rates in 2016 (21 percent), and even more so in 2017 (36 percent). SRFC adult escapement was sharply reduced during those two years as a result of these increased harvest rates. Section 3.3.2 provides more details on in-river harvest, and specifically the shift in fishing effort during 2016 and 2017.

3.1.8 Hatchery-origin contributions to natural area escapement and inland harvest

Since hatchery production of SRFC has remained relatively constant, comparing the annual proportions of hatchery-origin fish in natural spawning areas and inland harvest can help elucidate the relative strength of the natural component of the stock. For example, if a particular sub-basin's natural area escapement is almost entirely comprised of hatchery-origin fish, it may indicate very low survival among the natural component of those broods due to conditions that the hatchery component was able to avoid. Table 3.1.8.a provides preliminary estimates of hatchery-origin contributions to SRFC natural area escapement and harvest in the upper Sacramento River mainstem, Feather River, and American River, as well as harvest in the lower

Sacramento River mainstem (no escapement data available for this sector) during 2015-2017. Tributary data is not included in this analysis due to inconsistences in available data between years. CDFW has been analyzing hatchery-origin contributions to Central Valley escapement and harvest since return year 2010, and reports are currently available for 2010-2013 which offer a means of comparison (see Kormos et al. 2012, Palmer-Zwahlen and Kormos 2013, Palmer-Zwahlen and Kormos 2015, Palmer-Zwahlen et al. 2018). Table 3.1.8.b summarizes the hatchery- and natural-origin contributions from those reports, for the same sectors that were analyzed for 2015-2017. A common result across the CDFW reports is that hatchery-origin fish routinely make up the majority of natural area escapement and harvest, and at various levels of escapement. SRFC escapement was higher during 2010-2013 than during the years that contributed to the overfished status, although it was not incredibly high during 2010 and 2011 when 124,270 and 119,342 adults, respectively, returned to Sacramento Basin hatcheries and natural areas. Escapement increased significantly in 2012 and even more so in 2013 when 285,429 and 406,200 adults returned, respectively (PFMC 2018b). It is important to note that adults were not analyzed separately in the CDFW reports, so the hatchery-origin proportions reported in Table 3.1.8.b include age-2 fish unlike the values presented below for 2015-2017.

Table 3.1.8.a. Preliminary estimates of natural- and hatchery-origin adults that contributed to natural area escapement and harvest in the upper Sacramento River mainstem, Feather River, and American River, and harvest in the lower Sacramento River mainstem (no escapement data available for this sector) during 2015-2017.

	Natural-origin Adults	Hatchery-origin Adults	Total Adults	Percent Hatchery-origin
Upper Sacramento River				
Natural Area Escapement				
2015	8,629	18,246	26,875	68%
2016	2,652	1,709	4,361	39%
2017	444	381	825	46%
In-river Harvest				
2015	1,807	5,258	7,065	74%
2016	1,091	1,696	2,787	61%
2017	1,496	97	1,593	6%
Feather River				
Natural Area Escapement				
2015	2,786	15,283	18,069	85%
2016	5,578	28,476	34,054	84%
2017	754	7,366	8,120	91%
In-river Harvest				
2015	0	1,839	1,839	100%
2016	763	3,456	4,219	82%
2017	93	6,673	6,766	99%
American River				
Natural Area Escapement				
2015	4,084	7,364	11,448	64%
2016	1,735	5,394	7,129	76%
2017	1,336	4,406	5,742	77%
In-river Harvest				
2015	657	3,573	4,230	84%
2016	2,413	10,101	12,514	81%
2017	0	8,166	8,166	100%
Lower Sacramento River				
In-river Harvest				
2015	1,302	2,432	3,734	65%
2016	92	4,243	4,335	98%
2017	2,083	3,458	5,541	62%

Table 3.1.8.b. Estimates of natural- and hatchery-origin SRFC that contributed to natural area escapement and harvest in the upper Sacramento River mainstem, Feather River, and American River, and harvest in the lower Sacramento River mainstem (no escapement data available for this sector) during 2010-2013. Values reported here are total numbers, not just adults, so they include age-2 SRFC. Data was obtained from Kormos et al. 2012, Palmer-Zwahlen and Kormos 2013, Palmer-Zwahlen and Kormos 2015, and Palmer-Zwahlen et al. 2018.

	Natural-origin Adults	Hatchery-origin Adults	Total Adults	Percent Hatchery-origin
Upper Sacramento River				
Natural Area Escapement				
2010	13,146	3,226	16,372	20%
2011	7,735	2,848	10,583	27%
2012	7,314	15,121	22,435	67%
2013	21,375	11,140	32,515	34%
In-river Harvest				
2010	1,310	770	2,080	37%
2011	5,059	14,912	19,971	75%
2012	7,883	17,642	25,525	69%
2013	7,018	13,929	20,947	66%
Feather River				
Natural Area Escapement				
2010	9,933	34,981	44,914	78%
2011	4,883	42,406	47,289	90%
2012	6,530	57,119	63,649	90%
2013	23,603	127,606	151,209	84%
In-river Harvest				
2010	326	868	1,194	73%
2011	703	3,515	4,218	83%
2012	2,551	9,760	12,311	79%
2013	3,591	9,058	12,649	72%
American River				
Natural Area Escapement				
2010	5,134	2,439	7,573	32%
2011	7,150	14,170	21,320	66%
2012	9,347	25,553	34,900	73%
2013	19,096	35,163	54,259	65%
In-river Harvest				
2010	0	375	375	100%
2011	1,118	20,293	21,411	95%
2012	5,128	18,435	23,563	78%
2013	3,663	6,304	9,967	63%
Lower Sacramento River				
In-river Harvest				
2010	61	1,947	2,008	97%
2011	2,806	12,094	14,900	81%
2012	3,142	16,674	19,816	84%
2013	7,615	12,874	20,489	63%

During 2015-2017, hatchery-origin fish contributed to natural area escapement in these sectors in proportions that were generally in line with what was presented in the CDFW reports (see Kormos et al. 2012, Palmer-Zwahlen and Kormos 2013, Palmer-Zwahlen and Kormos 2015, Palmer-Zwahlen et al. 2018). In the upper Sacramento River, hatchery-origin contributions to natural area escapement ranged from 20 to 67 percent during 2010-2013, and the percentages during the overfished years were mostly within this range (2015 was just outside at 68 percent). Given that offsite-released CNFH-origin SRFC are estimated to have strayed outside of the upper Sacramento Basin at greater than 90 percent during 2016 and 2017 as described in the previous section, it is not surprising that hatchery-origin fish composed much lower proportions of the natural area escapement in this sector during those two years as compared to 2015. Natural area spawners in the Feather River contained the highest proportions of hatchery-origin fish among the three sectors in each year, and this is also what was reported in the CDFW reports. During 2010-2013, hatchery-origin spawners composed between 78 and 90 percent of the Feather River's natural area escapement, and the percentages during 2015-2017 were mostly within this range (2017 was just outside at 91 percent). Natural area spawners in the American River displayed the largest deviation from the hatchery-origin contributions reported for 2010-2013, although the differences were still minimal. In the CDFW reports, hatchery-origin fish were present in American River natural spawning areas at rates between 32 and 73 percent. The hatchery-origin contribution in 2015 was within this range, but it was slightly higher during 2016 and 2017 at 76 and 77 percent, respectively.

Hatchery-origin contributions to inland harvest are more variable between years and sectors. The upper Sacramento River sport fishery adult harvest was comprised of relatively lower proportions of hatchery-origin fish as compared to the other sectors, and this was also observed during 2010-2013 (Kormos et al. 2012, Palmer-Zwahlen and Kormos 2013, Palmer-Zwahlen and Kormos 2015, Palmer-Zwahlen et al. 2018). During those years, hatchery-origin fish composed between 37 and 75 percent of the upper Sacramento River harvest, and the proportions during 2015 and 2016 were within this range. In 2017, however, the proportion decreased precipitously to 6 percent. This was, again, likely due to the extensive straying outside of the upper Sacramento Basin estimated for offsite-released CNFH-origin SRFC as described above. The primary brood contributing to the 2017 run was brood year 2014, which was the year CNFH trucked 100 percent of their production to the delta for release. In the Feather River, hatchery-origin contributions to inland adult harvest were at or near 100 percent during 2015 and 2017. This is well above the 2010-2013 range reported by CDFW of 72 to 83 percent, however the 2016 proportion was within this range. The 2017 American River adult sport harvest was also estimated to be comprised entirely of hatchery-origin fish, although this has been observed in the past as CDFW reported a range of 63 to 100 percent during 2010-2013. The hatchery-origin contributions to the 2015 and 2016 American River adult sport harvests were much lower and within the range observed by CDFW. The influx of offsite-released CNFH-origin SRFC into the Feather and American rivers, combined with the large shift in fishing effort to these sub-basins, likely contributed to the considerably high hatchery-origin contributions to sport harvest in these sectors during 2017. Section 3.3.2 provides more background on the effort shift observed in the Central Valley sport fishery during the overfished years. In the lower Sacramento River sport fishery, hatchery-origin fish composed only 65 and 62 percent of the adult harvest, respectively, in 2015 and 2017, near the bottom of the 2010-2013 range reported by CDFW of 63 to 97 percent. The 2016 sport harvest, however, was just above this range as 98 percent of the adults harvested were estimated to be of hatchery-origin. An important feature of the lower Sacramento River sport fishery is that anglers intercept SRFC returning to all three of the other sub-basins, since all fish entering the Sacramento Basin have to traverse through the lower Sacramento River. Thus, harvest and hatchery-origin contributions in this sector are highly influenced by the relative strengths of these different sub-stocks, making it difficult to interpret differences observed between years.

Although hatchery-origin contributions to adult harvest were elevated over previously reported proportions in select years and sectors, the same was not observed to any great extent among natural area spawners. While production as a whole was clearly weak for the broods that contributed to the overfished status, there is insufficient evidence to suggest that the relative contribution of natural production was any weaker than for the broods that contributed to the 2010-2013 escapements. However, what occurred during 2010-2013 may not be representative of other years, so this analysis could be strengthened in the future once additional years of data are available for comparison.

3.1.9 Other relevant factors

Drought actions and regulatory oversight of state and federal water project operations
On January 17, 2014, California Governor Jerry Brown issued a Drought Emergency Proclamation that directed the State Water Resources Control Board (Water Board) to consider petitions to modify established requirements for diversion and water quality including requirements relating to water quality objectives for the San Francisco Bay/Sacramento-San Joaquin Delta Estuary as was establish by Water Rights Decision-1641 for the State and Central Valley Water Projects. As a result, Temporary Urgency Change Petitions (TUCPs) and other associated actions were filed by CDWR and the U.S. Bureau of Reclamation (USBR) in 2014, 2015, and 2016
(see https://www.waterboards.ca.gov/waterrights/water_issues/programs/drought/tucp/).

CDWR and USBR requested that the Water Board consider modifying requirements of USBR's and CDWR's water right permits to enable changes in operations, and requested concurrence under federal biological opinions for the state and federal water projects. Petitions requested reduced delta outflow requirements to increase reservoir storage, along with associated modifications to delta water quality standards. In addition, TUCPs requested greater flexibility in CDWR and USBR operations of the Delta Cross Channel (DCC) gates to ensure freshwater supplies were maintained and to minimize salinity intrusion from San Francisco Bay. It was widely recognized that some of the requested modifications to standards and requirements could pose risks to fisheries resources. In response to these concerns, a drought operations plan was developed in 2014 to maximize regulatory flexibility to allow for swift adjustments in response to changes in the weather and environment to help bolster water supplies when possible while minimizing impacts to fish and wildlife (USBR and CDWR 2014). The 2014 plan called for increased monitoring in order to respond to the needs of state and federally listed fish species, and included a matrix of triggers for DCC gate operations to prevent entrainment of ESA-listed Sacramento River winter Chinook (SRWC) and Central Valley spring Chinook into the interior delta. Entrainment into the interior delta has been shown to slow emigration and increase loss rates of salmonids (USBR and CDWR 2014).

SRFC have evolved with and are adapted to high spring flows associated with snow melt. Drought conditions in 2013 through 2015 resulted in reduced reservoir releases affecting fall temperatures and spawning habitat availability, and also influenced conditions during juvenile outmigration. Reduced winter and spring flows resulted in elevated temperatures within emigration corridors, decreased food availability, increased energetic expenditure during emigration associated with slow water velocities, and increased risk of predation and disease contraction. The 2013-2015 drought likely impacted juvenile SRFC in several ways resulting in decreased recruitment to ocean fisheries and subsequent adult escapement. As SRFC are not state or federally listed, drought operations plans and triggers were not designed to be particularly protective of this stock. This extended to SRFC hatchery production and resulted in altered release strategies. For example, USFWS developed an alternate release plan for CNFH fall-run production which modified standard release strategies if downstream temperatures exceed certain thresholds and the DCC gates are open (USFWS 2014). Similar drought release strategies were developed for NFH. In both cases, thresholds were met in 2014 and all fall-run production was released into net pens in the delta or San Francisco Bay. While these actions may have improved survival of juveniles to ocean entry and increased recruitment to the ocean fisheries, they also drastically increased straying of returning adults. In the case of CNFH fall-run production, the rate of adult straying in fall of 2017 was high and the hatchery was unable to meet its production goal. This will likely influence the SRFC stock rebuilding timeline.