Lower Mokelumne River Salmonid Redd Survey Report:
October 2015 through March 2016

September 2016

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Key words: lower Mokelumne River, salmonid, fall-run Chinook salmon, steelhead, rainbow trout, redd survey, spawning, superimposition, gravel enhancement

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Abstract

Weekly fall-run Chinook salmon (*Oncorhynchus tshawytscha*) and winter-run steelhead/rainbow trout (*Oncorhynchus mykiss)* spawning surveys were conducted on the lower Mokelumne River from 21 October 2015 through 23 March 2016. Estimated total escapement during the 2015/2016 season was 12,879 Chinook salmon. The estimated number of in-river spawners was 4,581 Chinook salmon. The first salmon redd was detected on 21 October 2015. During the surveys, 1,359 salmon redds were identified. One hundred and ninety-four (14.3%) Chinook salmon redds were superimposed on other Chinook salmon redds and 824 (61%) redds were located within spawning habitat restoration sites. The reach from Camanche Dam to Mackville Road (reach 6) contained 1,120 (82%) salmon redds and the reach from Mackville Road to Elliott Road (reach 5) contained 239 (18%) salmon redds. The highest number of Chinook salmon redds (332) was detected during survey week 7 (1 and 2 December 2015) and survey week 8 (8 and 11 December 2015). Sixty-one *O. mykiss* redds were identified during the surveys. The first *O. mykiss* redd was found on 1 December 2015. Seventeen *O. mykiss* redds were superimposed on Chinook salmon redds. Fifteen (25%) *O. mykiss* redds were located within spawning habitat restoration sites. Reach 6 contained 37 (60.7%) *O. mykiss* redds and reach 5 contained 24 (39.3%) *O. mykiss* redds. The highest number of *O. mykiss* redds (10) was detected on 9 March 2016.

INTRODUCTION

The Mokelumne River is an east-Delta tributary that drains more than 1,642 square kilometers (600 square miles) of the western slope of the Sierra Nevada with headwaters at an elevation of 3,048 meters (10,000 feet) on the Sierra Nevada Crest (Jones and Stokes 1999). The Mokelumne River currently has 16 major water impoundments including Salt Springs Reservoir, Lower Bear River Reservoir, Pardee Reservoir and Camanche Reservoir. Water releases to the lower Mokelumne River (LMR) are controlled by Camanche Dam. The LMR is approximately 103 river kilometers (rkm) in length from the confluence with the San Joaquin River (rkm 0) and Camanche Dam (the first major impoundment and limit to anadromy, rkm 103). The construction of Camanche Dam was completed in 1963 and blocked upstream passage of Chinook salmon (*Oncorhynchus tshawytscha*) and steelhead (*Oncorhynchus mykiss*) to much of the available historical spawning habitat in the Mokelumne River. Most of the available

spawning habitat in the LMR is now limited to the 15.8 km (9.8 mile) section of river directly downstream of Camanche Dam (Setka and Bishop 2003).

Pardee and Camanche reservoirs and associated power generating facilities are owned and operated by the East Bay Municipal Utility District (EBMUD) and regulated by the Federal Regulatory Energy Commission (FERC Project P-2916), which provides water for approximately 1.3 million customers in Alameda and Contra Costa counties. Additional reservoirs and power generation facilities are located upstream of Pardee Reservoir and are owned and operated by Pacific Gas & Electric Company (PG&E). Downstream of Camanche Dam, Woodbridge Irrigation District (WID) operates Woodbridge Irrigation District Dam (WIDD) and an associated system of irrigation canals near Lodi, CA.

The LMR is utilized for spawning and rearing by fall-run Chinook salmon and both resident and anadromous forms of *O. mykiss*. Adult Chinook salmon ascend the LMR as early as August and may begin spawning in early September. Spawning activity usually peaks in November and tapers off through the month of December (Hartwell 1996; Marine and Vogel 1994; Setka 1997). The Mokelumne River Fish Installation (MRFI) was constructed in 1964 to mitigate for spawning habitat lost during the construction of Camanche Dam and receives approximately 63% of the total run per year (1990-2014 average). EBMUD has conducted annual spawning surveys on the LMR since 1990 (Hagar 1991; Hartwell 1996; Setka 1997). EBMUD conducts video monitoring at WIDD to assess the upstream passage of anadromous fishes. Video monitoring provides an escapement estimate of the total number of Chinook salmon and steelhead returning to the LMR each season.

OBJECTIVES

The primary objective of the 2015/2016 salmonid redd surveys (referred to as the 2015 season) was to enumerate Chinook salmon and *O. mykiss* redds in the LMR. Additional objectives of the redd surveys included:

- Determine the spatial and temporal distribution of redds in the LMR;
- Enumerate redds impacted by superimposition; and
- Determine use of spawning habitat restoration (SHR) sites.

METHODS

Surveys

The LMR is divided into six reaches between Camanche Dam and the confluence with the San Joaquin River. Reach delineations are based on gradient, substrate, and tidal influence. The majority of salmonid spawning habitat on the LMR is available in reaches 5 and 6. Therefore, redd surveys were conducted within reaches 5 and 6. Specifically, the surveys took place within a 16-rkm reach, from rkm 103 (the base of Camanche Dam) downstream to rkm 87.4 (Figure 1). Weekly redd surveys began on 21 October 2015 and were concluded on 23 March 2016. Both reaches were surveyed once per week during

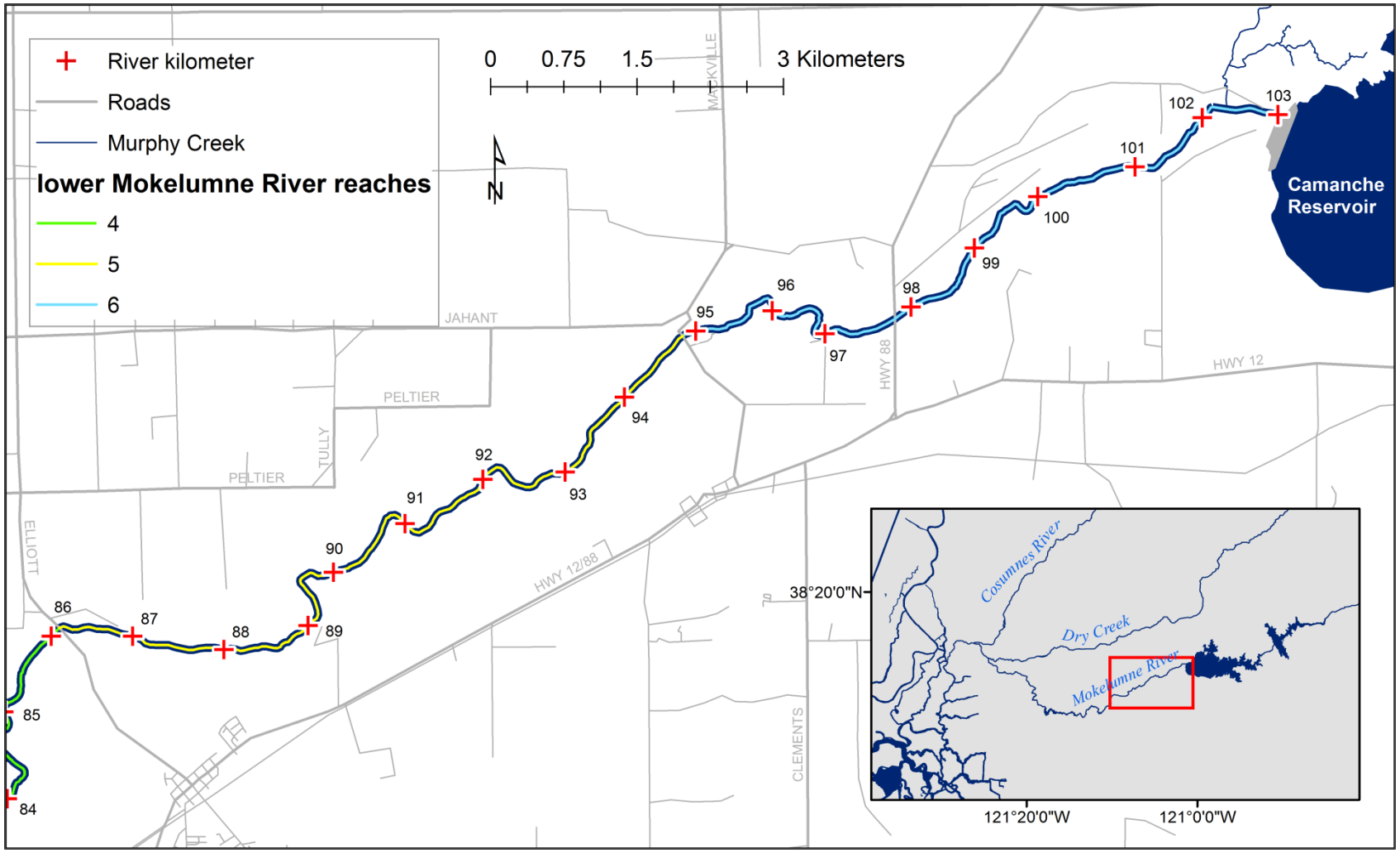

Figure 1. The location of river reaches 5 and 6 on the lower Mokelumne River, where salmonid redd surveys took place during the 2015 season.

this time frame. Surveys consisted of two to three individuals walking abreast downstream (water depths up to 1.1 meters) searching for redds. This method has been used in past LMR spawning surveys and in other rivers and streams (Keefe et al. 1994; Fritsch 1995; Hartwell 1996; Setka 1997). Kayaks were used to transport surveyors between spawning areas and were also used to search for redds in areas that were not wadeable.

In previous years, redd locations were marked with numbered cattle ear tags and/or colored bricks. More recently, however, Global Navigation Satellite Systems (GNSS) have been used to mark salmonid redd locations. The Trimble Geo XH GNSS units record more accurate positions (<1 meter real-time) and have the capability to display previously recorded data in the field. The ability to see data from previous surveys eliminated the need to physically mark redds and reduced the potential of counting a redd more than once. Surveyors positioned themselves directly downstream of each redd and recorded the position of the tailspill. Care was taken to avoid impacting redds during the surveys.

Surveyors determined if previously detected redds were superimposed based on the amount of time that had elapsed since a redd was first detected. A 3-week (21 days) filter was used to help distinguish older redds from newly constructed redds. The filter was based on the estimated life of fall-run Chinook salmon redds (Gallagher et al. 2007). All visible occurrences of redd superimposition were recorded.

Throughout the 2015 salmonid redd surveys, a subset of water depth and velocity measurements was recorded just above the nose of Chinook salmon and *O. mykiss* redds. To assess spatial and temporal variability, a subsample of water depth and velocity data were recorded from one of every nine Chinook salmon redds detected throughout the survey period. Because fewer *O. mykiss* redds are detected on an annual basis, water depths and velocities were measured at nearly half of the *O. mykiss* redds detected during the survey period. Water depth measurements were recorded to the nearest centimeter (cm) using a top-setting rod. Velocity measurements were taken using a Flo-Mate™ portable velocity meter (Marsh McBirney, Inc.) at 60% of the depth and were recorded in meters per second (m/s).

Surface water temperature and flow data were obtained from EBMUD gauging stations at Camanche Dam (rkm 103), McIntire (rkm 101), and Elliot Road (rkm 86). In addition, a total of sixteen HOBO TidbiT© waterproof temperature loggers were buried below the gravel surface on 7 and 14 October 2015 to record subsurface water temperatures on an hourly basis. Two temperature loggers were buried at depths of 25 cm and 40 cm within eight spawning sites between Camanche Dam (rkm 103) and Elliot Road (rkm 86). A Trimble Geo XH™ GNSS unit was used to mark the burial locations of the temperature loggers. The temperature loggers were recovered from the gravel on 12 April 2016, after the majority of Chinook salmon fry were predicted to have emerged from their redds according to an egg model developed by Vogel (1993).

Data Collection and Analysis

A minimum of ten points were recorded on the GNSS unit at each redd location and point data files were stored using Terrasync 5.21 software. After field data were collected, the data files were downloaded and processed using GPS Pathfinder Office 5.30 software. Once downloaded, geographic positions were corrected using the nearest base data providers. The data files were then imported to an ArcMap 10.2 (ESRI) database.

Data analyses were performed using ArcMap 10.2 (Arc/Info (ESRI) systems), JMPIN 9.0.0 (Academic), Microsoft (MS) Access 2010 and MS Excel 2010. A P-value ≤ 0.05 was considered statistically significant.

RESULTS

Environmental Data

In 2015, a series of pulse flows were released throughout October, November, and the beginning of December (Figure 2). Average daily flow from Camanche Dam peaked near 400 cubic feet per second (cfs) during the first three pulses and peaked near 250 cfs during the following four pulses.

During the redd survey period (21 October 2015 – 23 March 2016) average daily discharge from Camanche Dam ranged from 161 to 416 cfs (Figure 2). The average daily flow during this time period was 195 cfs. The average daily flow when Chinook salmon redds were detected (21 October 2015 through 9 February 2016) ranged from 161 to 416 cfs and averaged 192 cfs. The average daily flow when *O. mykiss* redds were detected (1 December 2015 through 23 March 2016) ranged from 161 cfs to 361 cfs and averaged 189 cfs.

Average daily surface water temperatures at the McIntire gauging station (rkm 101, reach 6) ranged from 9.6°C to 17.6°C during the survey period (Figure 2). The average temperature during this time frame was 11.9°C. The average daily water temperatures during the time period salmon redds were detected (21 October 2015 through 9 February 2016) ranged from 9.6°C to 17.6°C and averaged 12.6°C. The average daily water temperatures during the time period when *O. mykiss* redds were detected (1 December 2015 through 23 March 2016) ranged from 9.6°C to 13.4°C and averaged 10.5°C.

Twelve of the sixteen temperature loggers were recovered from below the gravel surface at burial depths of 25 cm and 40 cm on 12 April 2016. The remaining four temperature loggers, buried at rkm 97.3 and 94.7, were not recovered. A comparison of average daily subsurface water temperatures recorded at burial depths of 25 and 40 cm and average daily surface water temperatures at the McIntire (rkm 101) and Elliot Road (rkm 86) gauging stations is presented graphically in Figure 3. A comparison of maximum daily subsurface water temperatures recorded at burial depths of 25 and 40 cm and maximum daily surface water temperatures at the McIntire (rkm 101) and Elliot Road (rkm 86) gauging stations is presented graphically in Figure 4.

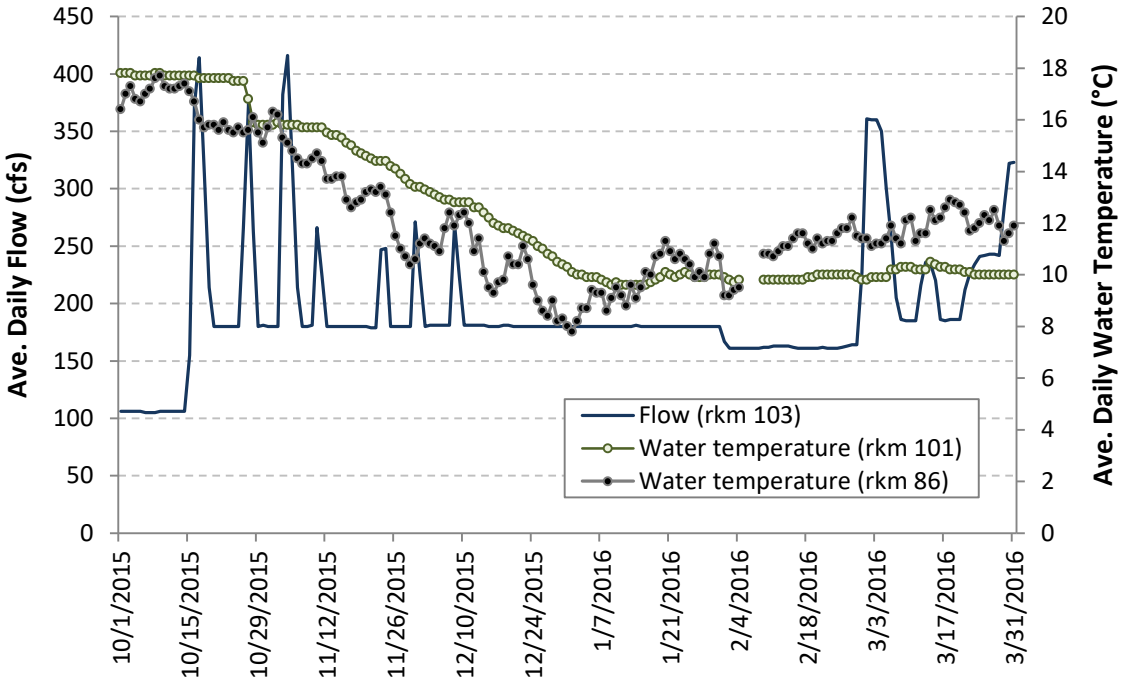

Figure 2. Average daily discharge from Camanche Dam (rkm 103) and average daily surface water temperatures at the McIntire gauging station (rkm 101) and the Elliot Road gauging station (rkm 86) in the lower Mokelumne River during the 2015 salmonid redd surveys.

Average daily hyporheic water temperatures at 25 and 40 cm generally fell within the range of surface water temperatures recorded at the McIntire (rkm 101) and Elliot Rd. (rkm 86) gauging stations throughout the spawning and incubation periods. However, hyporheic water temperatures at both burial depths were occasionally higher than surface water temperatures (rkm 101 and rkm 86) in early November, just before the majority (>95%) of Chinook salmon redds were constructed.

Maximum daily hyporheic water temperatures at 25 and 40 cm were frequently higher than the range of surface water temperatures recorded at the McIntire (rkm 101) and Elliot Rd. (rkm 86) gauging stations during the first half of the incubation period. During the second half of the incubation period, maximum daily hyporheic water temperatures generally fell within the range of surface water temperatures recorded at the McIntire (rkm 101) and Elliot Rd. (rkm 86) gauging stations.

Over the last four spawning and incubation seasons (2012-2015) average daily hyporheic water temperatures typically fell within the range of surface water temperatures recorded at the McIntire and Elliot Rd. gauges, regardless of burial depth (Figure 5). Although there were periods of time when average daily hyporheic water temperatures were marginally higher than surface water temperatures. Each season, over 95% of all salmon redds were constructed when all water temperatures were below 16.4°C, with the exception of 2014, when surface water temperatures at the McIntire gauge were just above 16.4°C for a short time.

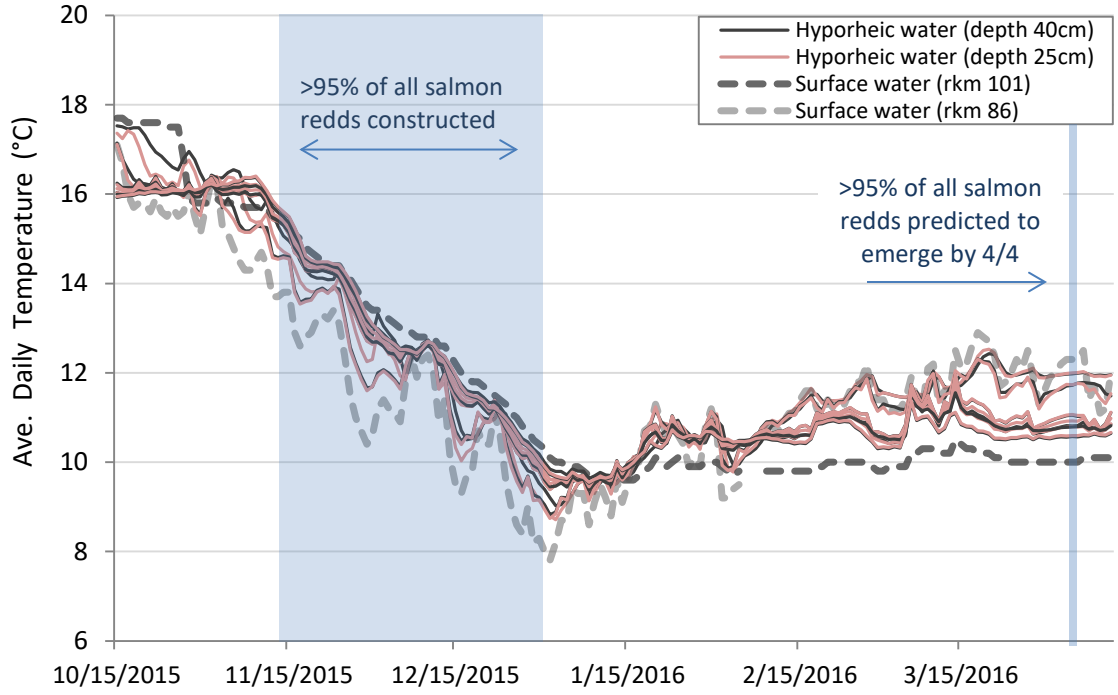

Figure 3. Average daily surface and subsurface (hyporheic) water temperatures recorded on the lower Mokelumne River during the 2015 redd survey season.

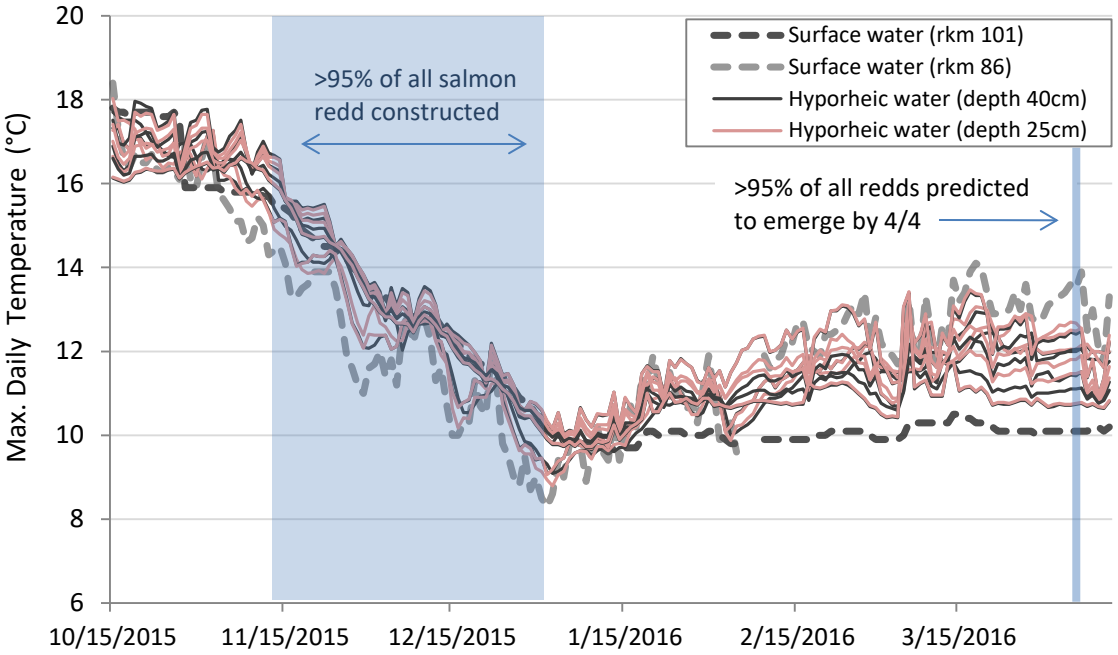

Figure 4. Maximum daily surface and subsurface (hyporheic) water temperatures recorded on the lower Mokelumne River during the 2015 redd survey season.

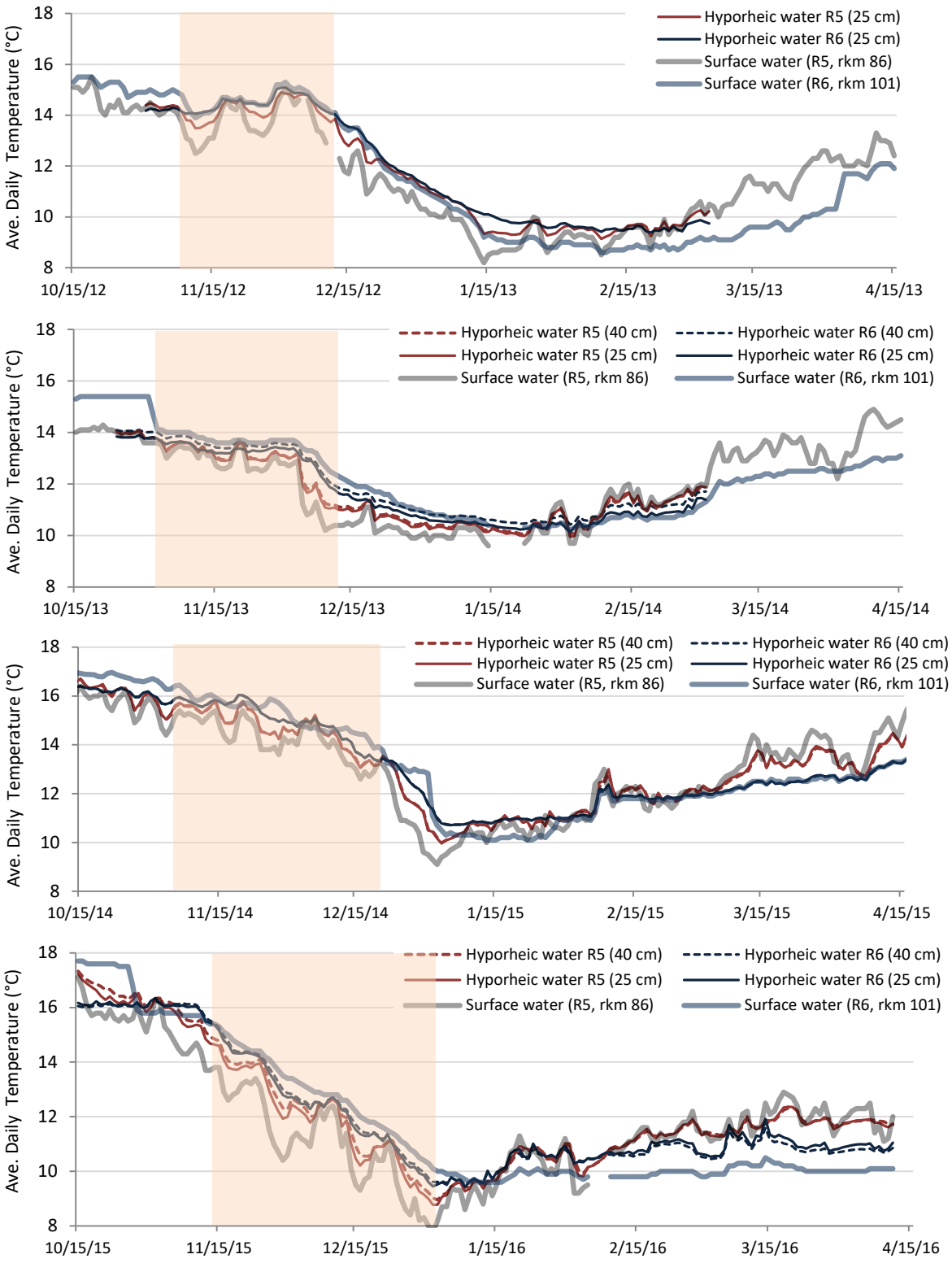

Figure 5. Average daily surface and subsurface (hyporheic) water temperatures recorded on the lower Mokelumne River during the 2012-2015 redd survey seasons (R6=reach 6, R5 =reach 5) The transparent orange area depicts the time frame when >95% of the Chinook salmon redds were constructed.

Chinook Salmon

Redd totals and escapement

During the 22 week redd survey period, 1,359 Chinook salmon redds were detected. The first and last redd detections occurred on 21 October 2015 and 9 February 2016, respectively. The highest number of redds (332) was detected during survey week 7 on 1 and 2 December 2015 and survey week 8 on 8 and 11 December 2015 (Figure 6). Reach 6 contained 1120 redds (82%) and reach 5 contained 239 redds (18%).

The 2015 annual redd count was 174% of the long term average (1990-2014) of 780, 217% of the pre-Joint Settlement Agreement (JSA) average (1990-1997) of 625, and 159% of the post-JSA average (1998-2014) of 853 (Figure 7).

To estimate fall-run Chinook salmon escapement in the LMR during the 2015 season, video monitoring was conducted at WIDD between 1 August 2015 to 31 May 2016. An estimated 12,879 Chinook salmon were counted passing the fish ladders at WIDD. The total count of Chinook salmon that entered the MRFI this season was 8,298.

The LMR in-river escapement estimate of 4,581 fall-run Chinook salmon was calculated by subtracting the MRFI salmon count from the video monitoring count at WIDD. Approximately 64% (8,236) of the Chinook salmon that returned to the LMR were classified as adults, while the remaining 36% (4,641) were classified as grilse. Less than 1% (2) could not be determined. Sexual composition of the run was 57% (7,383) male, 43% (5,494) female, and less than 1% (2) could not be determined.

Spawning habitat restoration site use

During the 2015 redd survey, 688 (50.6%) Chinook salmon redds were found within the restored upper 1.3 rkm reach, just below Camanche Dam (SHIRA reach). Overall, 824 (60.6%) Chinook salmon redds were constructed within SHR sites. In reach six, 754 redds (91.5%) were constructed in SHR sites. Seventy salmon redds (8.5%) were constructed in SHR sites in reach 5.

Superimposition

One hundred ninety-four Chinook salmon redds (14.3%) were superimposed on other Chinook salmon redds during the 2015 redd survey season. Most of the superimposition took place in reach 6 (174 redds), while just twenty redds were superimposed in reach 5.

The 2015 superimposition rate was higher than the long-term average of 10.4% (1991-2014), the pre-JSA average of 9.0% (1991-1997) and the post-JSA average of 11.0% (1998-2014). There was a significant positive linear relationship between the annual redd count and the annual superimposition rate (Linear regression: $F = 28.31$; df = 1, 23; $P < 0.001$). The annual redd count explained 55% of the variation in the annual superimposition rate.

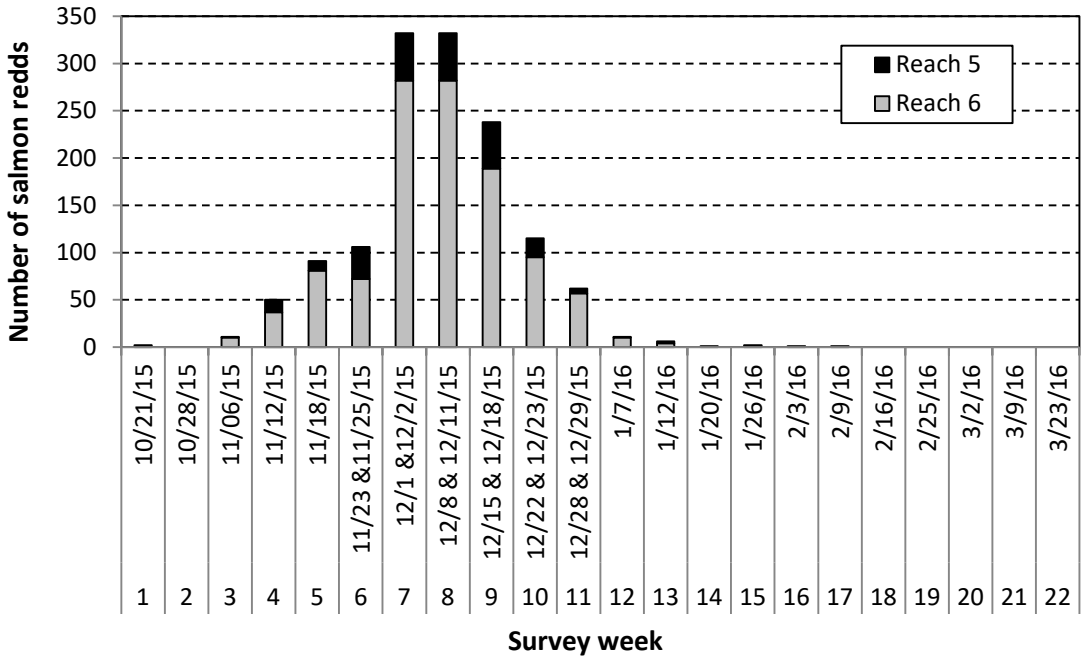

Figure 6. Weekly Chinook salmon redd totals by reach on the lower Mokelumne River during the 2015 surveys.

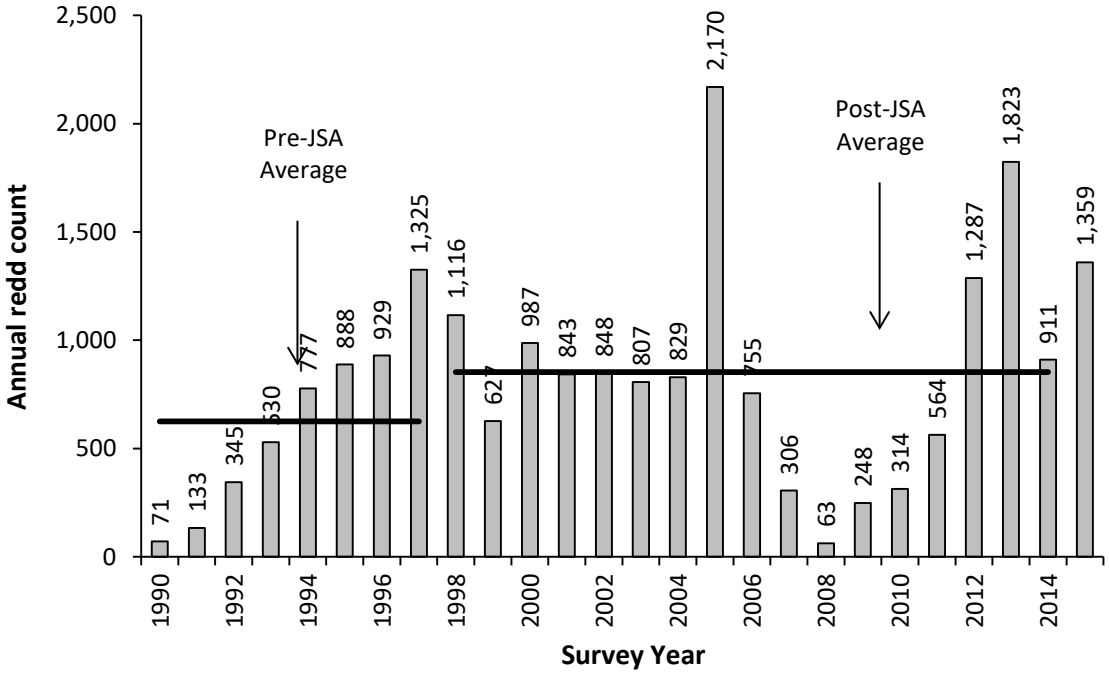

Figure 7. Chinook salmon redd totals on the lower Mokelumne River during pre-JSA flows (1990 – 1997), post-JSA flows (1998 – 2014), and for the 2015 survey season.

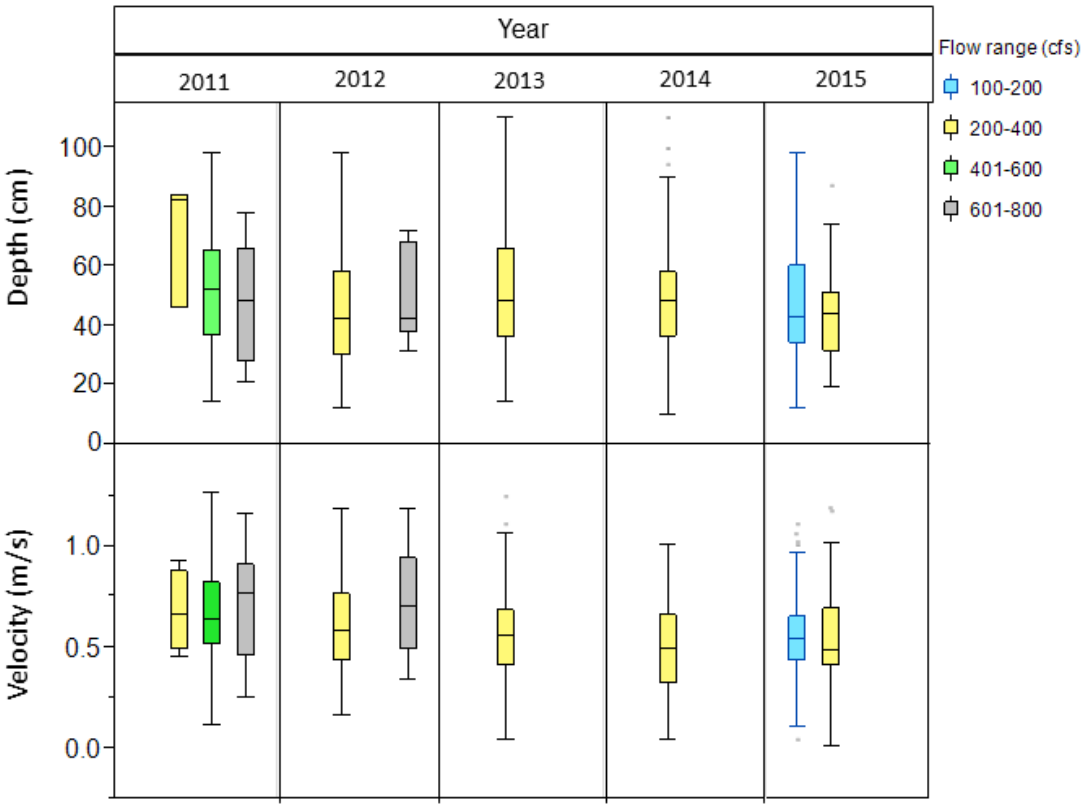

Figure 8. Boxplots of water depths and velocities measured just above the nose of Chinook salmon redds by survey year (2011-2015) and by flow range (100-200 cfs, 201-400 cfs, 401-600 cfs, 601-800 cfs) on the lower Mokelumne River.

Habitat use – water depth and velocity

One hundred and eighty-seven water depth and velocity measurements were taken just above the nose of Chinook salmon redds from 6 November 2015 to 3 February 2016. Daily discharge from Camanche Dam ranged from 161 to 269 cfs on the dates the measurements were recorded. Chinook salmon redd water depths ranged from 12 to 98 cm and averaged 46 cm (SD = 18). The central 50% of measured redd depths (between Q1 and Q3) were between 33 and 58 cm. Water velocity measurements ranged from 0.01 to 1.19 m/s and averaged 0.54 m/s (SD = 0.21). The central 50% of measured redd velocities were between 0.43 and 0.67 m/s.

Flow range did not have a statistically significant effect on redd water velocity (two-way ANOVA: $F_{3, 663} = 1.20$, $P = 0.3078$) or redd water depth (two-way ANOVA: $F_{3, 655} = 1.04$, $P = 0.3745$) (Figure 8). However survey year did have a statistically significant effect on redd water depth (two-way ANOVA: $F_{4, 655} = 2.93$, $P = 0.0204$), and redd water velocity (two-way ANOVA: $F_{4, 663} = 4.13$, $P = 0.0026$).

Oncorhynchus mykiss

Redd totals

Sixty-one *O. mykiss* redds were detected during the 2015 salmonid redd survey. The first and last detections occurred on 1 December 2015 and 23 March 2016, respectively. The largest number of *O. mykiss* redds (10) was detected on 9 March 2016 (Figure 9). Reach 6 contained 37 redds (60.7%) and reach 5 contained 24 redds (39.3%). The 2015 annual redd count was 23.2% above the long-term (2000-2014) average of 51 (Figure 10).

Spawning habitat restoration site use

During the 2015 redd survey, seven (11%) *O. mykiss* redds were found within the SHIRA reach. Overall, 15 *O. mykiss* redds, or 25% of the total number of redds detected (61), were constructed in SHR sites. Sixty percent (9) of redds constructed in SHR sites were located in reach 6 and 40% (6) were located in reach 5.

Superimposition

Seventeen *O. mykiss* redds were superimposed on Chinook salmon redds during the 2015 season. There were no observations of *O. mykiss* redds superimposed on other *O. mykiss* redds this season.

Habitat use – water depth and velocity

Thirty water depth and twenty-nine water velocity measurements were taken just above the nose of *O. mykiss* redds between 12 January and 23 March 2016. Discharge from Camanche Dam ranged from 161 to 360 cfs on the dates the measurements were taken. Water depths ranged from 20 to 90 cm and averaged 42 cm (SD = 16). The central 50% of measured *O. mykiss* redd depths (between Q1 and Q3) were between 29 and 50 cm. Water velocity measurements ranged from 0.27 m/s to 1.19 m/s and averaged 0.59 m/s (SD = 0.22). The central 50% of measured *O. mykiss* redd velocities were between 0.40 and 0.73 m/s.

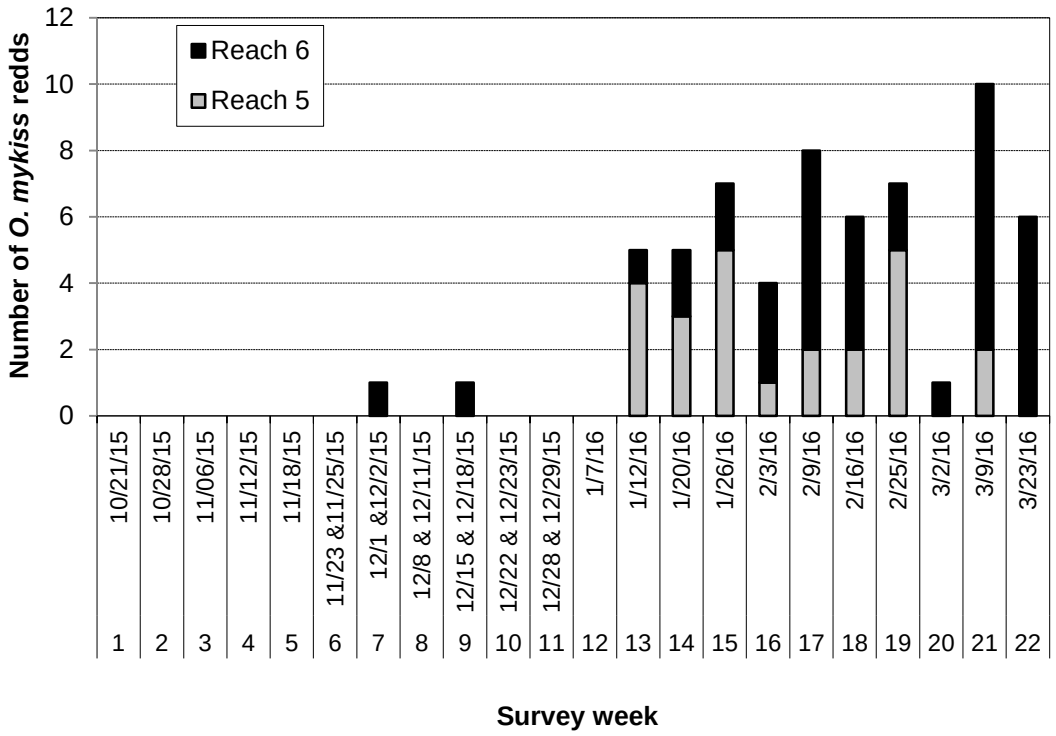

Figure 9. Weekly *O. mykiss* redd totals by reach on the lower Mokelumne River during the 2015 survey season.

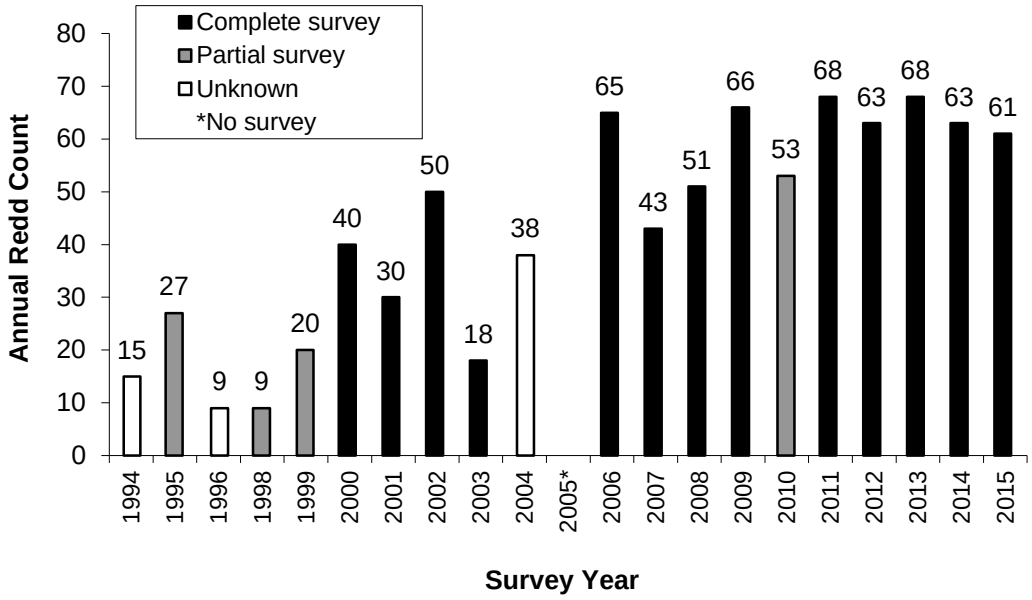

Figure 10. Annual *O. mykiss* redd totals on the lower Mokelumne River from 1994-2015.

DISCUSSION

Despite operating under a critically dry water year due to four consecutive years of drought, average and maximum daily surface and subsurface water temperatures for BY15 were lower than the Camanche hypolimnion threshold of 16.4°C when >95% of all Chinook salmon redds were constructed and throughout the incubation period. Although the threshold falls outside of the range necessary for maximum embryo survival (5 to 13°C) (McCullough 1999), a 50% survival rate (from fertilization to hatching) has been recorded for Chinook salmon embryos incubated at 16°C (Moyle 2002; McCullough 1999). Over the last four spawning and incubation seasons (2012-2015), average daily hyporheic water temperatures typically fell within the range of surface water temperatures recorded at the McIntire and Elliot Rd. gauges, regardless of burial depth. These data indicate that the range of average daily surface water temperatures provided by the McIntire and Elliot gauges may provide a good general estimate of subsurface water temperatures for incubating Chinook salmon embryos. It is recommended to continue collecting and comparing subsurface and surface water temperatures over a variety of water years in an attempt to detect other possible trends. These data may be used to assess management strategies for cold water releases from Pardee Reservoir and Camanche Dam during the early stages of the Chinook salmon embryo incubation period.

The 2015 LMR Chinook salmon escapement estimate of 12,879 was 272% of the historical (1940-2014) average of 4,739, 374% of the pre-JSA (1940-1997) average of 3,439, and 147% of the post-JSA (1998-2014) average of 8,791. Preliminary 2015 escapement data from GrandTab[1] indicate that 152,663 fall-run Chinook salmon returned to the California Central Valley this season. This included 130,878 salmon that returned to the Sacramento River system and 21,785 salmon that returned to the San Joaquin River system. This season, the LMR accounted for 59% of the total return to the San Joaquin River system, which includes the Cosumnes River, the LMR, the Stanislaus River, the Tuolumne River, and the Merced River.

The 2015 Chinook salmon redd total was higher than all but one of the annual redd counts over the last decade. In addition, it was higher than the post-JSA average of 853. Roughly 64% of the returning population was adult salmon. Similar to 2014, a large proportion (64%) of returning Chinook salmon was trapped at the hatchery this season, when compared to 2013 (42%) and 2012 (55%). The other 36% of the population (4,581 salmon) remained in the LMR. Peak spawning on the LMR typically occurs between the middle and the end of November; however, warmer water temperatures may have delayed the peak of spawning to early and mid-December this season.

One of the primary objectives of EBMUD's ongoing habitat rehabilitation projects is to supplement depleted coarse sediment with suitable-sized spawning gravel in the LMR. These projects are intended to improve and expand spawning habitat for adult Chinook salmon and steelhead in the LMR. As of 1990, EBMUD has completed 23 annual spawning habitat rehabilitation projects in reaches 5 and 6 of the LMR in cooperation

[1] California Department of Fish and Game - Fisheries Branch Anadromous Assessment, http://grandtab.calfish.org/GTFall4.aspx, accessed on 9/15/2016.

with federal and state agencies, local partnerships, and public organizations. These projects continue to provide high-quality spawning habitat as demonstrated by the large percentage of salmon redds constructed within the SHIRA reach (50.6% this season) and within all SHR sites (60.6% this season).

The 2015 Chinook salmon redd superimposition rate of 14.3% was higher than the long term average (1991-2014) of 10.4%. Spawning density (using annual redd counts) explained 55% of the variation in the annual salmon redd superimposition rate. During the 2015 spawning season, the Chinook salmon redd count was much higher than the long-term average, likely resulting in a higher than average superimposition rate.

Most of the Chinook salmon redd water depths and velocities recorded this season fell within the expected ranges for the species (Moyle 2002). Flow range did not have a statistically significant effect on Chinook salmon redd water velocity or water depth from 2011-2015. However, survey year did have a significant effect on redd water velocity and redd water depth. These results suggest that the selection for several physical spawning habitat parameters (water depth and velocity) is relatively consistent despite variable flows ranging from 100-800 cfs. However, there may be variation among brood stocks and other potential sources of annual environmental variation.

Sixty-one *O. mykiss* redds were observed during the 2015 season, which was consistent with or slightly above *O. mykiss* redd counts over the last decade. However, the hatchery return of adult *O. mykiss* (total length ≥ 16 in.) during 2015 was 64, which was the 2nd lowest total over the last ten years. Several factors may have contributed to the discrepancy between the annual redd count and the hatchery return this season, including redd survey frequency and the mixed life history characteristics of *O. mykiss* in the California Central Valley. Redd survey frequency is dependent on a number of factors, including weather conditions, flows, and the number of staff available to conduct the surveys. This season, low flows, optimal weather, and adequate staffing allowed for weekly redd surveys to be conducted through the end of March without any weekly surveys missed. Also, given the mixed life history of *O. mykiss* in Central Valley streams, the difference between resident rainbow trout redds and winter-run steelhead redds could not be distinguished during the spawning surveys, and it is possible that many of the *O. mykiss* redds detected were constructed by resident fish (Zimmerman et al. 2009), some of which may be <16 inches in total length.

ACKNOWLEDGEMENTS

We would like to thank Nicole Aha, Jason Shillam, Matt Saldate, and Ed Rible for assistance with the surveys. Thanks to all EBMUD Lodi Fisheries and Wildlife staff for their contributions.

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