Lower Mokelumne River Salmonid Redd Survey Report:
October 2018 through January 2019

September 2019

Ed Rible and Alan Webster
East Bay Municipal Utility District, 1 Winemasters Way, Lodi, CA 95240

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

---

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 2 October 2018 through 28 January 2019. Estimated total escapement from video monitoring during the 2018/2019 season was 17,475 Chinook salmon. The estimated number of in-river spawners was 10,294 Chinook salmon. The first salmon redd was detected on 2 October 2018. During the surveys, 2,352 salmon redds were identified. Four hundred and seventy-one (20.0%) Chinook salmon redds were superimposed on other Chinook salmon redds and 1,685 (72%) redds were located within spawning habitat restoration sites. The reach from Camanche Dam to Mackville Road (reach 6) contained 2,161 (91.9%) salmon redds and the reach from Mackville Road to Elliott Road (reach 5) contained 191 (8.1%) salmon redds. The highest number of Chinook salmon redds (760) was detected during survey week 10 (3 December 2017 through 5 December 2017). Thirty-eight *O. mykiss* redds were identified during the surveys. The first *O. mykiss* redd was found on 3 December 2018. Three *O. mykiss* redds were superimposed on Chinook salmon redds. Eighteen (47%) *O. mykiss* redds were located within spawning habitat restoration sites. Reach 6 contained 28 (73.7%) *O. mykiss* redds and reach 5 contained 10 (26.3%) *O. mykiss* redds. The highest number of *O. mykiss* redds (12) was detected on 14 January 2019. A result of large water releases from Camanche Dam prematurely ended the 2018 *O. mykiss* survey on 28 January 2019.

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 and steelhead 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 1.4 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; Bilski and Rible 2015). The Mokelumne River Fish Hatchery (MOKH) 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 (1990-2018 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 2018/2019 salmonid redd surveys (referred to as the 2018 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 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 2 October 2018 and

concluded on 28 January 2019. Both reaches were surveyed once per week during 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; Bilski and Rible 2015). Either Kayaks, or a Drift boat, were used to transport surveyors between spawning areas and were also used to search for redds that were not wadeable.

Trimble Geo XH and Trimble Geo 7X Global Navigation Satellite Systems (GNSS) were used to record the location of salmonid redds (<1 meter real-time accuracy). The GNSS units also allowed the surveyors to display previously recorded data in the field. The ability to see data from previous surveys eliminates the need to physically mark redds and reduces the potential of counting a single redd more than once. Surveyors positioned themselves directly downstream of each redd and recorded the position of the tail-spill. 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.

To assess spatial and temporal variability, water depth and velocity measurements were recorded just above the nose from roughly one in every 10 Chinook salmon redds and one in every two *O. mykiss* redds. 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). Ambient air temperatures were obtained from the EBMUD gauging station at Camanche Dam (rkm 103). In addition, a total of sixteen HOBO TidbiT© waterproof temperature loggers were buried below the gravel surface on 6 September 2018 to record hourly 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.

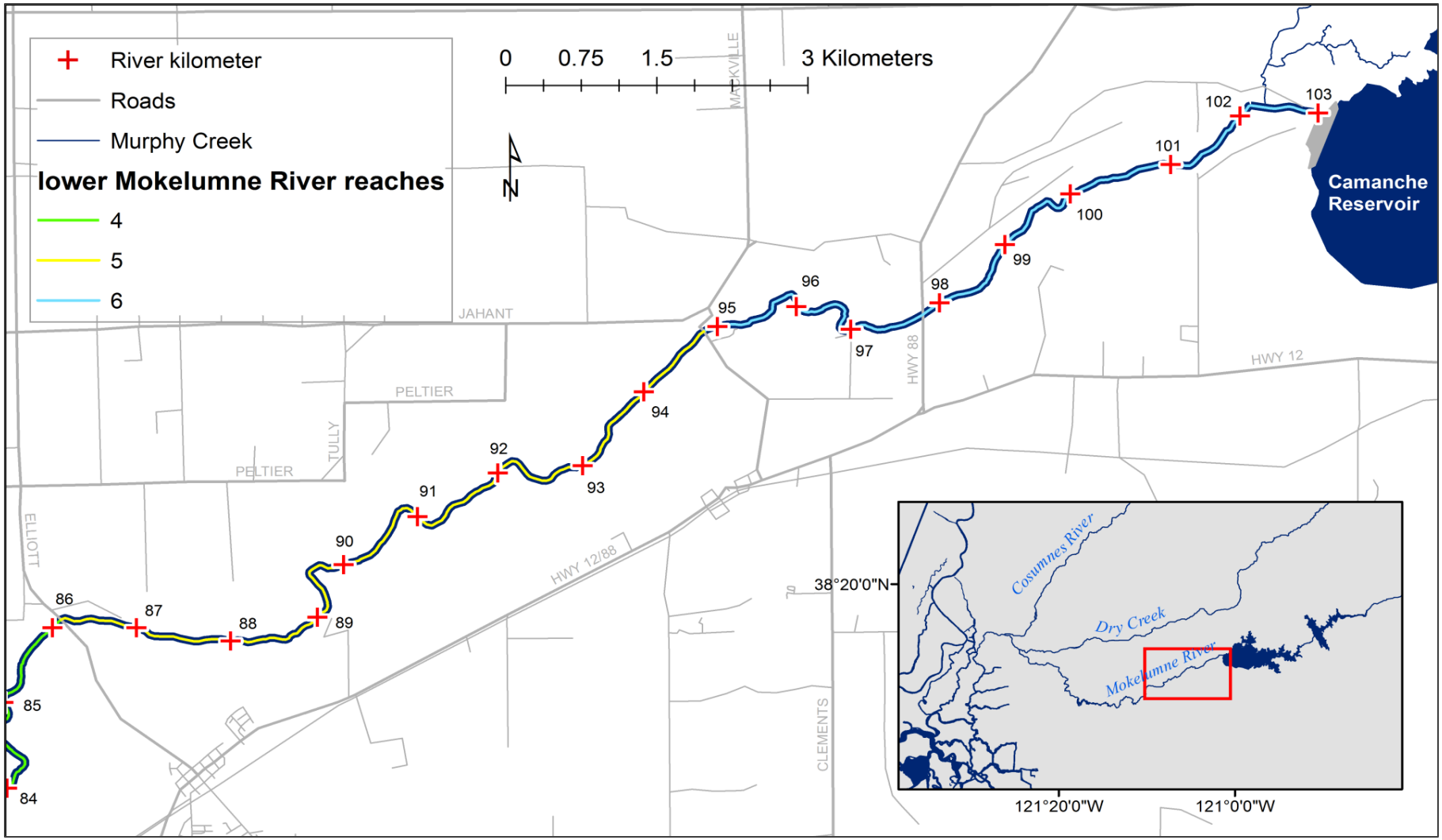

Figure 1. The location of river reaches 5 and 6 on the lower Mokelumne River, where salmonid redd surveys took place during the 2018 season.

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 5.90 software. After field data were collected, the data files were downloaded and processed using GPS Pathfinder Office 5.90 software. Upon download, geographic positions were corrected using the nearest base data providers. The data files were then imported to an ArcMap 10.2.2 (ESRI) database.

Data analyses were performed using ArcMap 10.2.2 (Arc/Info (ESRI) systems), JMP 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 2018, a series of fish attraction flows were released from Camanche Dam throughout September, October, and the beginning of November (Figure 2). Average daily flow from Camanche Dam peaked near 1,550 cubic feet per second (cfs) during the first two pulses and peaked between 1,334 and 975 cfs during the following four pulses.

During the redd survey period (2 October 2018 – 28 January 2019), average daily discharge from Camanche Dam ranged from 335 to 1,551 cfs (Figure 2). Average daily flow during this time period was 507 cfs. Average daily flow when Chinook salmon redds were detected (2 October 2018 through 3 January 2019) ranged from 335 to 1,551 cfs and averaged 513 cfs. The average daily flow when *O. mykiss* redds were detected (3 December 2018 through 28 January 2019) ranged from 335 cfs to 752 cfs and averaged 401 cfs.

Average daily surface water temperatures at the McIntire gauging station (rkm 101, reach 6) ranged from 10.9°C to 15.3°C during the survey period (Figure 2). The average temperature during this time frame was 13.4°C. Average daily water temperatures during the time period Chinook salmon redds were detected (2 October 2018 through 3 January 2019) ranged from 11.6°C to 15.3°C and averaged 14.0°C. The average daily water temperatures during the time period when *O. mykiss* redds were detected (3 December 2018 through 28 January 2019) ranged from 10.9°C to 14.4°C and averaged 12.4°C.

Maximum daily surface water temperatures at the McIntire gauging station (rkm 101, reach 6) ranged from 11.1°C to 15.5°C during the survey period (Figure 4). The average maximum temperature during this time frame was 13.8°C. The maximum daily water temperatures during the time period Chinook salmon redds were detected (2 October 2018 through 3 January 2019) ranged from 12.1°C to 15.5°C and averaged 14.4°C. The maximum daily water temperatures during the time period when *O. mykiss* redds were detected (3 December 2018 through 28 January 2019) ranged from 11.1°C to 14.8°C and averaged 12.7°C.

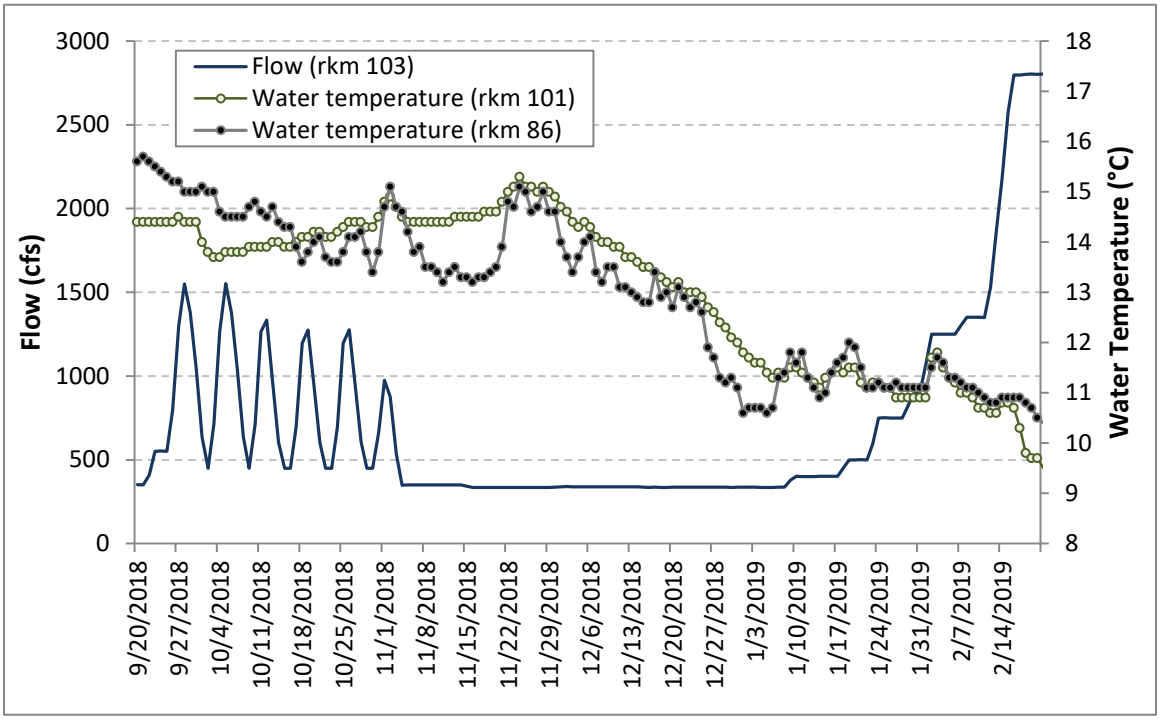

Figure 2. Average daily discharge from Camanche Dam (rkm 103) and average daily surface water temperatures at the McIntire gauging station (rkm 101) and the Victor gauging station (rkm 80) in the lower Mokelumne River during the 2018 salmonid redd surveys.

Nine temperature loggers were recovered from below the gravel surface at burial depths of 25 cm and 40 cm on 11 and 13 September 2019. 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 (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 (rkm 86) gauging stations is presented graphically in Figure 4.

Average daily hyporheic water temperatures at burial depths of 25 and 40 cm fell outside the range of surface water temperatures recorded between the McIntire (rkm 101) and Elliot (rkm 86) gauging stations on 19 occasions during the period when Chinook salmon redds were constructed. Temperatures deviated from the McIntire and Elliot gauging stations by an average of 0.02°C during the spawning period.

Maximum daily hyporheic water temperatures at burial depths of 25 and 40 cm fell outside the range of surface water temperatures recorded between the McIntire (rkm 101) and Elliot (rkm 86) gauging stations on 16 occasions during the period when Chinook salmon redds were constructed. Temperatures deviated from the McIntire and Elliot gauging stations by 0.02°C during the spawning period.

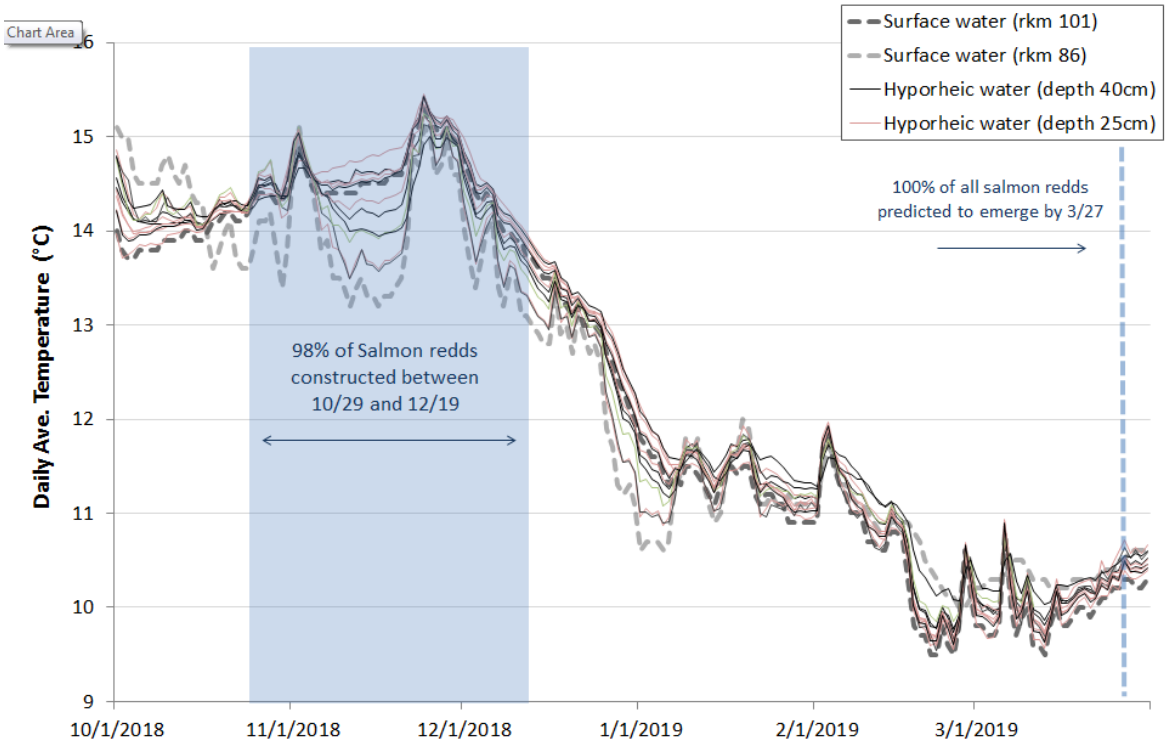

Figure 3. Average daily surface and subsurface (hyporheic) water temperatures recorded on the lower Mokelumne River during the 2018 redd survey season.

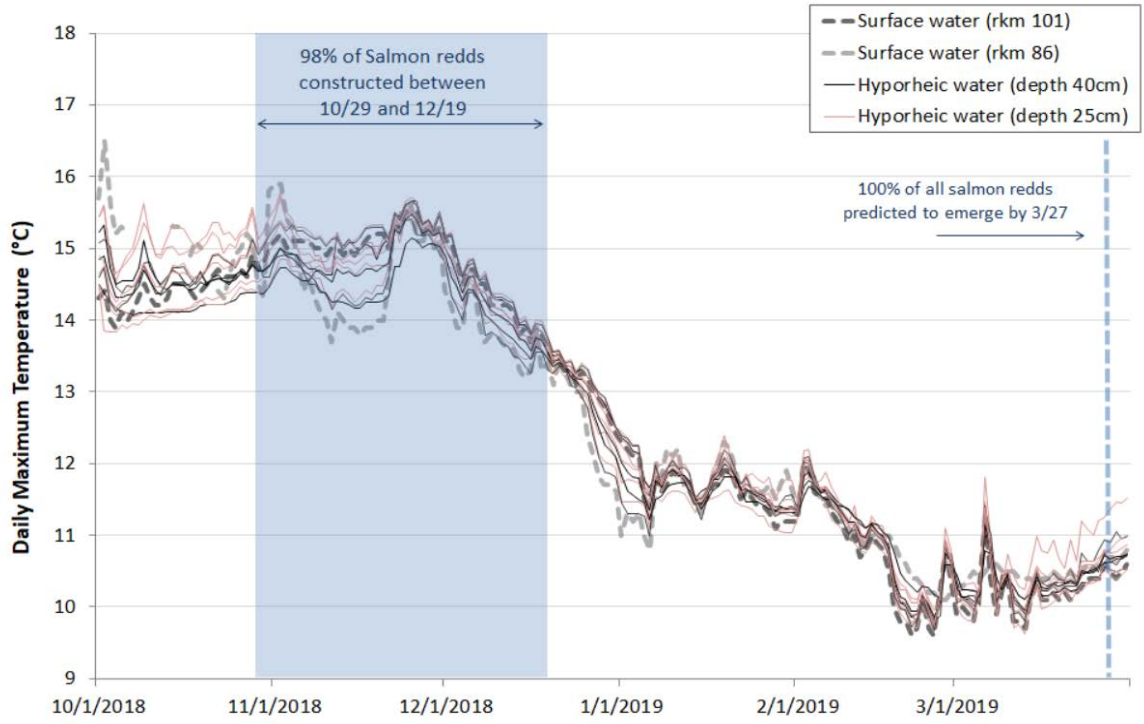

Figure 4. Maximum daily surface and subsurface (hyporheic) water temperatures recorded on the lower Mokelumne River during the 2018 redd survey season.

Chinook Salmon

Redd totals and escapement

During the 18 week redd survey period, 2,352 Chinook salmon redds were detected. The first and last redd detections occurred on 2 October 2018 and 3 January 2019, respectively. The highest number of redds (760) were detected during survey week 10 on 3, 4, and 5 December 2018 (Figure 5). Reach 6 contained 2,161 redds (91.9%) and reach 5 contained 191 redds (8.1%).

The 2018 annual redd count was 192% above the long term average (1990-2017) of 804, 276% above the pre-Joint Settlement Agreement (JSA) average (1990-1997) of 625, and 169% above the post-JSA average (1998-2017) of 876 (Figure 6).

To estimate fall-run Chinook salmon escapement in the LMR during the 2018 season, video monitoring was conducted at WIDD between 1 August 2018 and 13 June 2019. An estimated 17,475 Chinook salmon passed through the fish ladders at WIDD (Del Real and Hunter 2018). Approximately 65% (11,387) of the Chinook salmon that returned to the LMR were classified as adults, while the remaining 35% (6,088) were classified as grilse. Sexual composition of the run was 49% (8,595) male, 51% (8,862) female, and less than 1% (18) could not be determined. The total count that entered the MOKH this season was 7,181.

The LMR in-river escapement estimate of 10,294 fall-run Chinook salmon was calculated by subtracting the MOKH salmon count from the video monitoring count at WIDD. A LMR in-river escapement estimate of 5,310 female Chinook salmon was calculated by subtracting the MOKH female count of 3,552 from the video monitoring count of 8,862 females.

Spawning habitat restoration site use

During the 2018 redd survey, 1,500 (63.8%) Chinook salmon redds were found within the restored upper 1.3 rkm reach, just below Camanche Dam (SHIRA reach – Spawning Habitat Integrated Rehabilitation). Overall, 1,685 (71.6%) Chinook salmon redds were constructed within SHR sites. One thousand, six hundred and eight redds (91.4%) in SHR sites were constructed in reach six. Seventy-seven salmon redds (4.6%) were constructed in SHR sites in reach 5.

Superimposition

Four hundred and seventy-one Chinook salmon redds (20.0%) were superimposed on other Chinook salmon redds during the 2018 redd survey season. Most of the superimposition took place in reach 6 (456 redds), while just 15 redds were superimposed in reach 5.

The 2018 superimposition rate was higher than the long-term average of 10.4% (1991-2017), the pre-JSA average of 9.0% (1991-1997) and the post-JSA average of 10.9% (1998-2017). There was a significant positive linear relationship between the annual redd

count and the annual superimposition rate (Linear regression: $F = 39.85$; df = 1, 26; $P < 0.001$). The annual redd count explained 61% of the variation in the annual superimposition rate.

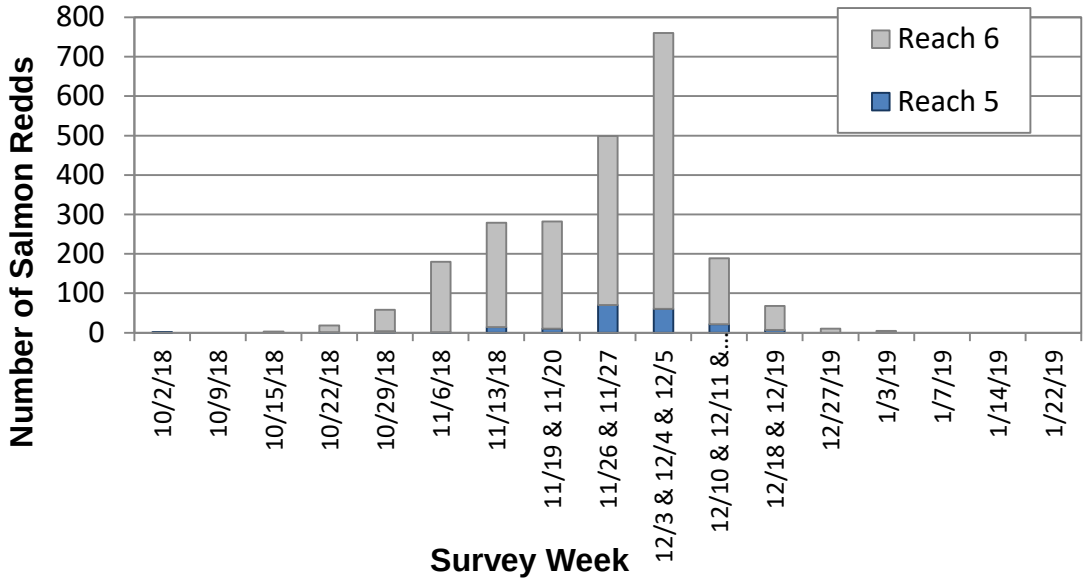

Figure 5. Weekly Chinook salmon redd totals by reach on the lower Mokelumne River during the 2018 survey.

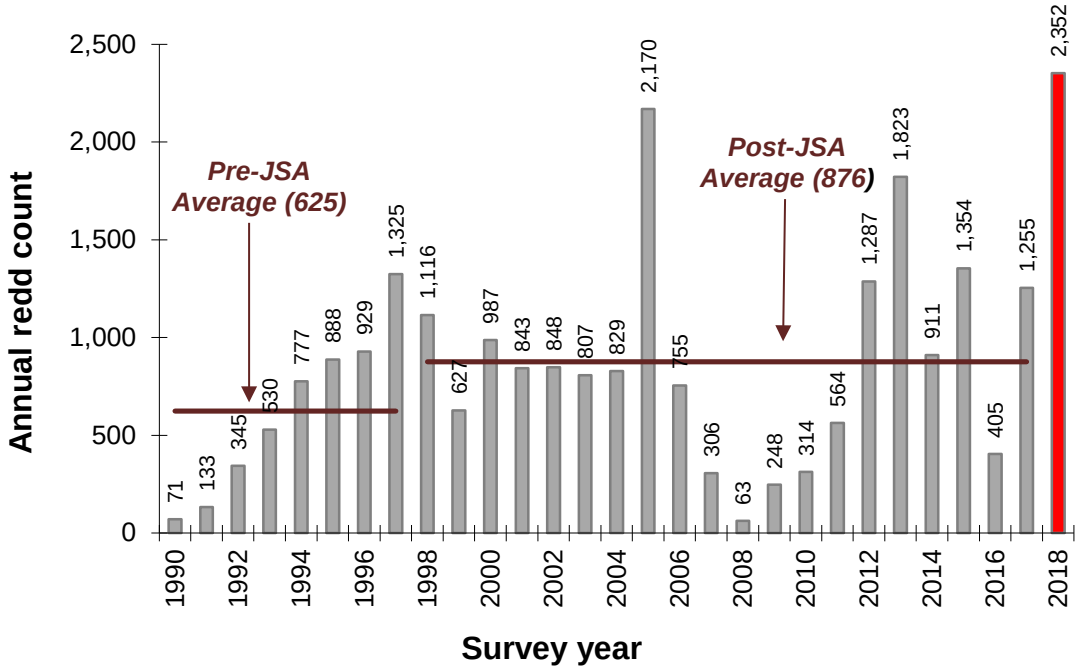

Figure 6. Chinook salmon redd totals on the lower Mokelumne River during pre-JSA flows (1990 – 1997), post-JSA flows (1998 – 2017), and for the 2018 survey season.

Habitat use – water depth and velocity

One hundred and ninety-one water depth and velocity measurements were taken just above the nose of Chinook salmon redds from 2 October 2018 to 3 January 2019. Daily discharge from Camanche Dam ranged from 335 to 450 cfs on the dates the measurements were recorded. Chinook salmon redd water depths ranged from 8 to 112 cm and averaged 47 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 0.03 to 1.21 m/s and averaged 0.55 m/s (SD = 0.23). The central 50% of measured redd velocities were between 0.38 and 0.71 m/s.

Flow range had a statistically significant effect on redd water depth (two-way ANOVA: $F_{3, 986}$= 2.66, P = 0.0472) and redd water velocity (two-way ANOVA: $F_{3, 994}$ = 2.83, P = 0.0375) (Figure 7). Survey year also had a statistically significant effect on redd water depth (two-way ANOVA: $F_{7, 986}$ = 4.12, P = 0.0002) and redd water velocity (two-way ANOVA: $F_{7, 994}$ = 3.32, P = 0.0017).

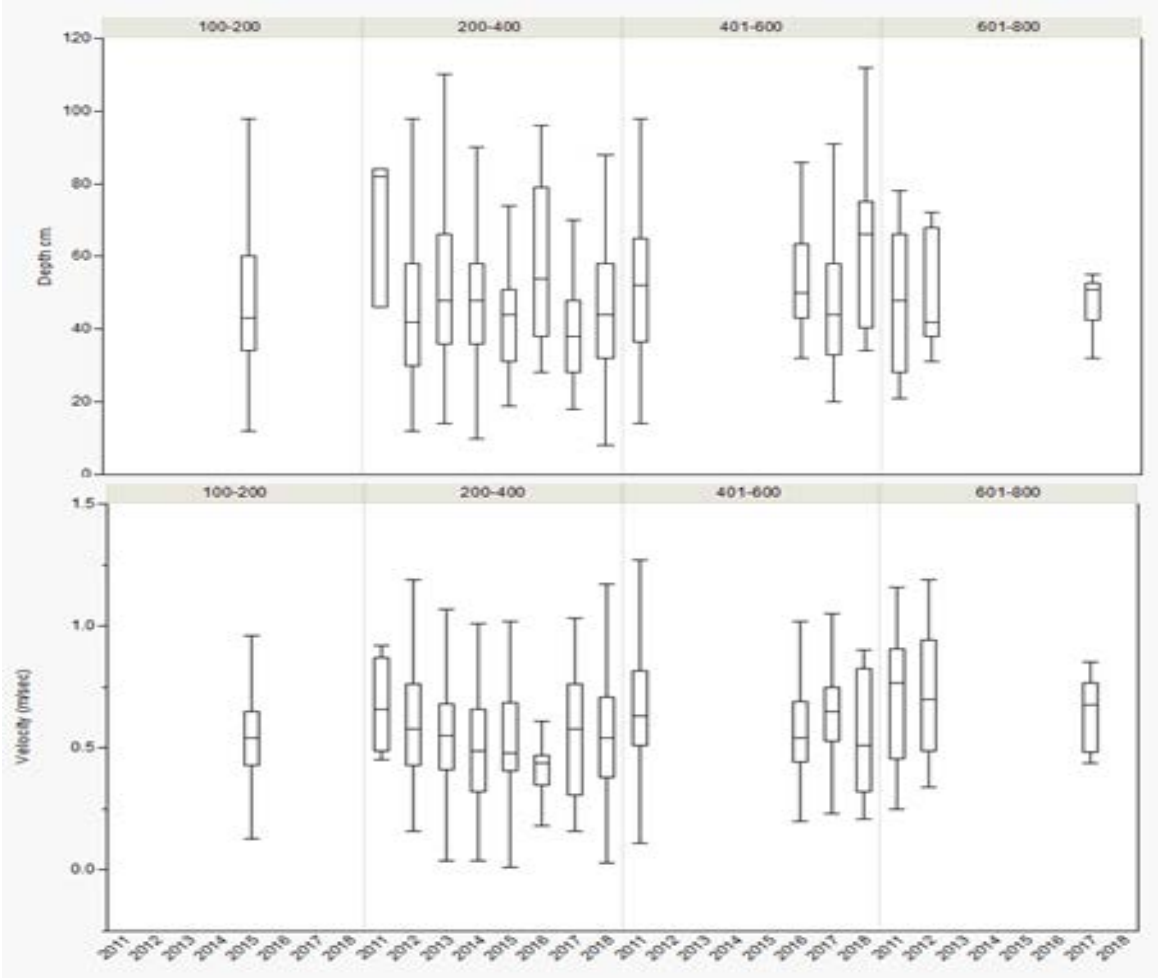

Figure 7. Boxplots of water depths and velocities measured just above the nose of Chinook salmon redds by survey year (2011-2018) and by flow range (100-200 cfs, 201-400 cfs, 401-600 cfs, 601-800 cfs) on the lower Mokelumne River.

Oncorhynchus mykiss

Redd totals

Thirty-eight *O. mykiss* redds were detected during the 2018 salmonid redd survey. The first and last detections occurred on 3 December 2018 and 28 January 2019, respectively. The largest number of *O. mykiss* redds (12) were detected on 14 January 2019 (Figure 8). Reach 6 contained 28 redds (73.7%) and reach 5 contained 10 redds (26.3%). The 2018 annual redd count was 28% below the long-term (2000-2017) average of 53 (Figure 9).

Spawning habitat restoration site use

During the 2018 redd survey, thirteen (34%) *O. mykiss* redds were found within the SHIRA reach. Overall, 18 *O. mykiss* redds, or 47% of the total number of redds detected (38), were constructed in SHR sites. Eighty-nine percent (16) of redds constructed in SHR sites were located in reach 6 and 11% (2) were located in reach 5.

Superimposition

Three *O. mykiss* redds were superimposed on Chinook salmon redds during the 2018 season. There were no observations of *O. mykiss* redds superimposed on other *O. mykiss* redds this season.

Habitat use – water depth and velocity

Twenty-four water depth and velocity measurements were taken just above the nose of *O. mykiss* redds between 3 January 2019 and 28 January 2019. Discharge from Camanche Dam ranged from 337 to 749 cfs on the dates the measurements were taken. Water depths ranged from 26 to 90 cm and averaged 50 cm (SD = 17). The central 50% of measured *O. mykiss* redd depths (between Q1 and Q3) were between 38 and 58 cm. Water velocity measurements ranged from 0.25 m/s to 1.66 m/s and averaged 0.60 m/s (SD = 0.32). The central 50% of measured *O. mykiss* redd velocities were between 0.38 and 0.70 m/s.

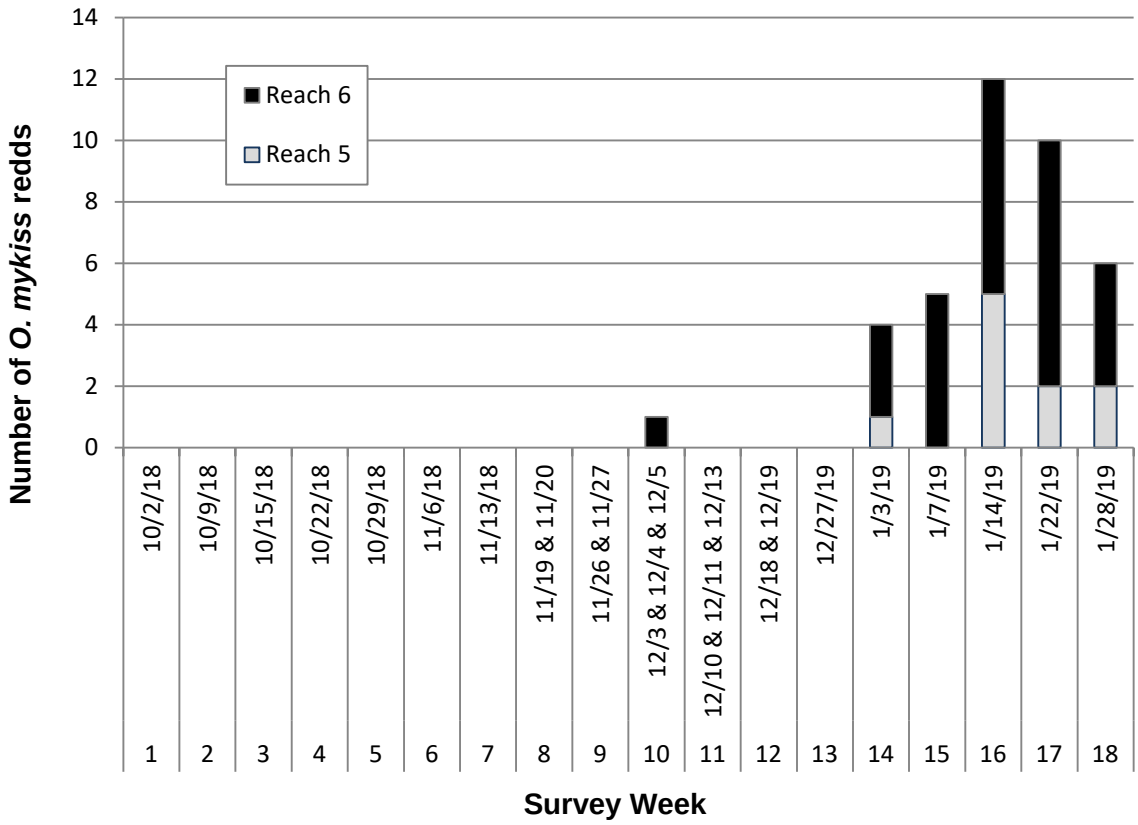

Figure 8. Weekly *O. mykiss* redd totals by reach on the lower Mokelumne River during the 2018 survey season.

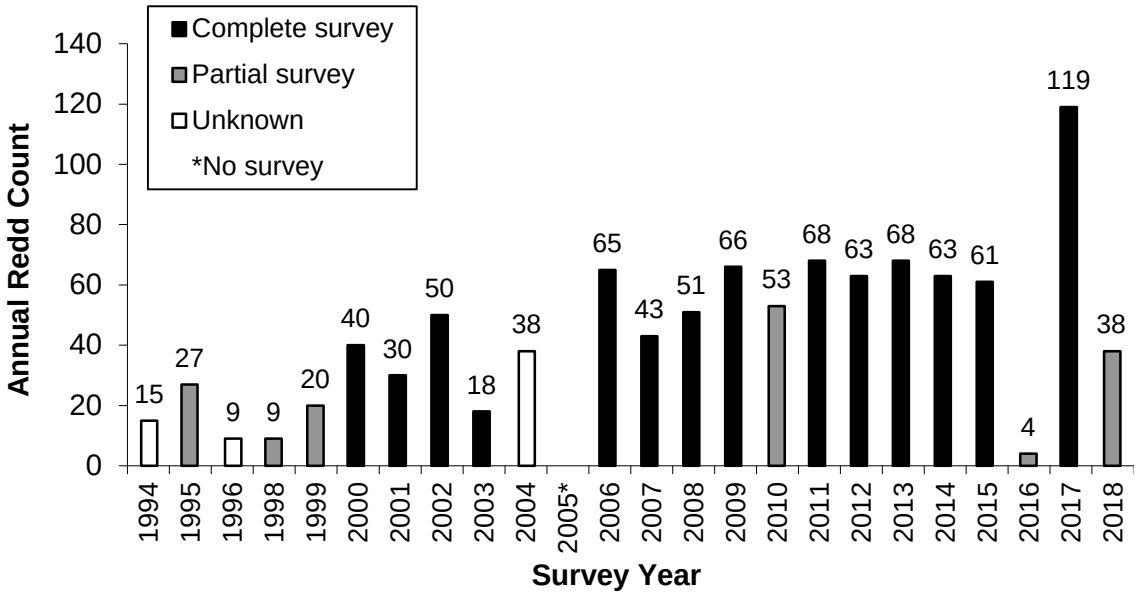

Figure 9. Annual *O. mykiss* redd totals on the lower Mokelumne River from 1994-2018.

DISCUSSION

Operating under a normal and above water year, average daily surface and maximum water temperatures for BY18 never exceeded the Camanche hypolimnion threshold of 16.4°C during periods when Chinook salmon redds were constructed or throughout the incubation period. Nor did average or maximum daily subsurface water temperatures exceed the Camanche hypolimnion threshold of 16.4°C when redds were constructed. 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; Geist et al. 2006). Only fifteen (<1%) redds were constructed when average surface water temperatures fell below 13°C, but the average temperatures were 13.4°C, which is very good for the LMR during the Chinook salmon spawning period.

Over the previous seven spawning and incubation seasons (2012-2018), average daily hyporheic water temperatures typically fell within the range of surface water temperatures recorded at the McIntire Rd. and Elliot Rd. gauges, regardless of burial depth. Throughout periods from October, 2018 to February, 2019, maximum and average daily hyporheic water temperatures were marginally higher than surface water temperatures with an average difference of <0.1°C. These data indicate that the range of average daily surface water temperatures provided by the McIntire and Elliot Rd. gauges provide a good general estimate of subsurface water temperatures for incubating Chinook salmon embryos.

The 2018 LMR Chinook salmon escapement estimate of 17,475 was 242% above the historical (1940-2017) average of 5,116, 408% above the pre-JSA (1940-1997) average of 3,439, and 83% above the post-JSA (1998-2017) average of 9,558. Preliminary 2018 escapement data from GrandTab[1] indicate that 172,099 fall-run Chinook salmon returned to the California Central Valley this season. This included 148,515 salmon that returned to the Sacramento River system and 23,584 salmon that returned to the San Joaquin River system. This season, the LMR accounted for 10% of the total return to the California Central Valley and 74% 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 2018 Chinook salmon redd count was the highest on record since 1990. In addition, it was 168% higher than the post-JSA average of 876. Roughly 65% of the returning population were adults and 7,181 (41%) of returning Chinook salmon were trapped at the MOKH this season; below the range of the previous 4 seasons; 2017 (72%), 2016 (78%), 2015 (64%) and 2014 (73%). The other 59% of the population (10,294 salmon) remained in the LMR. The in-river population Peak spawning on the LMR occurred between the last week of November and the first week of December. Of the 10,294 Chinook salmon spawning in the Mokelumne River, 4,966 were classified as males (48%) and 5,310 were classified as females (52%).

[1] California Department of Fish and Game - Fisheries Branch Anadromous Assessment, http://grandtab.calfish.org/GTFall4.aspx, accessed on 7/31/2019.

One of the primary objectives of EBMUD's ongoing habitat rehabilitation projects are 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 24 annual spawning habitat rehabilitation projects in reaches 5 and 6 of the LMR in cooperation with federal agencies, 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 (63.8% this season) and within all SHR sites (71.6% this season).

The 2018 Chinook salmon redd superimposition rate of 20.0% was higher than the long term average (1991-2017) of 10.4%. Spawning density (using annual redd counts) explained 61% of the variation in the annual salmon redd superimposition rate. During the 2018 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 Chinook salmon redd water depths and velocities recorded this season fell within the expected ranges for the species (Moyle 2002). Flow range did have a statistically significant effect on Chinook salmon redd water velocity and redd water depth from 2011-2018. Survey year had a significant effect on redd water velocity and redd water depth. These results suggest that the selection for water depths and velocities as a physical spawning habitat parameter fluctuate within the expected range relative to variable flows ranging from 100 to 800 cfs. There may also be variation among brood stocks and other potential sources of annual environmental variation.

Thirty-eight *O. mykiss* redds were observed during an incomplete 2018 season that was stopped early from large Camanche releases. The MOKH had 253 adult *O. mykiss* (total length ≥ 16 in.) return, which was the 3nd largest total since Camanche Reservoir was built in 1963. This season, high flows, and challenging weather, only allowed for weekly redd surveys to be conducted through the end of January. Peak spawning of *LMR O. mykiss* typically occur from late January through the end of February. 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 some 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 Ryan Ham, Carlie Jackson, Charles Hunter, Jason Shillam, Matt Saldate, James Jones, Terry Cummings, Michelle Workman, Casey Del Real, and Robyn Bilski for their assistance and hard work on the 2018 surveys. Thanks to all EBMUD Fisheries and Wildlife staff for their contributions.

LITERATURE CITED

Bilski, R. and E. Rible, 2015. Lower Mokelumne River Salmonid Redd Survey Report: October 2014 through February 2015. EBMUD Fisheries and Wildlife Division, Lodi, CA.

Del Real, C. and C. Hunter. 2018. LOWER MOKELUMNE RIVER UPSTREAM FISH MIGRATION MONITORING Conducted at Woodbridge Irrigation District Dam. EBMUD Fisheries and Wildlife Division, Lodi, CA. pp 3.

Fritsch, M. 1995. Habitat quality and anadromous fish production on the Warm Springs Reservation, Final Report, Project No. 94-56. Bonneville Power Administration. Portland, OR.

Gallagher, S. P., P. K. J. Hahn, and D. H. Johnson. 2007. Redd counts. Pages 197–234 *in* D. H. Johnson, B. M. Shier, J. S. O'Neal, J. A. Knutzen, X. Augerot, T. A. O'Neil, and T. N. Pearsons, editors. Salmonid field protocols handbook: techniques for assessing status and trends in salmon and trout populations. American Fisheries Society, Bethesda, Maryland.

R. Geist, David & Scott Abernethy, C & D. Hand, Kristine & Cullinan, Valerie & A. Chandler, James & Groves, Phillip. (2006). Survival, Development, and Growth of Fall Chinook Salmon Embryos, Alevins, and Fry Exposed to Variable Thermal and Dissolved Oxygen Regimes. Transactions of the American Fisheries Society. 135. 1462-1477. DOI: 10.1577/T05-294.1.

Hagar, J. 1991. Upstream migration and spawning of fall run Chinook salmon in the Mokelumne River, 1990. East Bay Municipal Utility District, Orinda, CA. pp. 21.

Hartwell, R. 1996. Upstream migration and spawning of fall run Chinook salmon in the Mokelumne River, 1995. East Bay Municipal Utility District, Orinda, CA. pp. 28.

Jones and Stokes Associates, Inc. 1999. Administrative draft environmental impact report/environmental impact statement for the lower Mokelumne River Restoration Program. (JSA 98-059) June 1. Prepared for Woodbridge Irrigation District, Woodbridge, CA.

Keefe, M., R. Carmichael, B. Jonasson, R. Messmer and T. Whitesel. 1994. Investigations into the life history of spring Chinook salmon in the Grande Ronde River basin. Annual Report Project No. 92-026-01. Bonneville Power Administration. Portland, OR. pp. 37.

Marine, K. and D. Vogel. 1994. The Mokelumne River Chinook salmon and steelhead monitoring program 1992-1993. Monitoring of the upstream spawning migration of Chinook salmon and steelhead during October through December 1993. Vogel Environmental Services. Red Bluff, CA. pp. 33.

McCullough, D.A. 1999. A review and synthesis of effects of alterations to the water temperature regime on freshwater life stages of salmonids, with special reference to Chinook salmon. Report No. EPA 910-R-99-010. Environmental Protection Agency, Region 10, Seattle, WA.

Moyle, P.B. 2002. Inland fishes of California, revised and expanded. University of California Press, Berkeley, CA, USA.

Setka, J. 1997. 1996 Lower Mokelumne River Chinook salmon (*Oncorhynchus tshawytscha*) spawning survey report. EBMUD Fisheries and Wildlife Division, Orinda, CA. pp. 55.

Setka, J. and J. Bishop. 2003. Fall-run Chinook salmon and steelhead trout spawning survey, September 2002 through March 2003 Mokelumne River, California. pp. 26.

Vogel, D. 1993. Model for predicting Chinook fry emergence from gravel. Natural Resource Scientists, Inc., Red Bluff, California.

Zimmerman, C.E., G. W. Edwards, and K. Perry. 2009. Maternal Origin and Migratory History of *Oncorhynchus mykiss* captured in rivers of the Central Valley, California. Transactions of the American Fisheries Society. 138:280–291.