Lower Mokelumne River Salmonid Redd Survey Report:
October 2017 through March 2018

September 2018

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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 2 October 2017 through 19 March 2018. Estimated total escapement from video monitoring during the 2017/2018 season was 19,963 Chinook salmon. The estimated number of in-river spawners was 5,644 Chinook salmon. The first salmon redd was detected on 23 October 2017. During the surveys, 1,255 salmon redds were identified. One hundred and forty-four (11.5%) Chinook salmon redds were superimposed on other Chinook salmon redds and 944 (75%) redds were located within spawning habitat restoration sites. The reach from Camanche Dam to Mackville Road (reach 6) contained 1,118 (89%) salmon redds and the reach from Mackville Road to Elliott Road (reach 5) contained 137 (11%) salmon redds. The highest number of Chinook salmon redds (342) was detected during survey week 10 (5 December 2017 and 6 December 2017). One hundred and nineteen *O. mykiss* redds were identified during the surveys. The first *O. mykiss* redd was found on 18 December 2017. Twenty-four *O. mykiss* redds were superimposed on Chinook salmon redds. Fifty-two (44%) *O. mykiss* redds were located within spawning habitat restoration sites. Reach 6 contained 74 (62.2%) *O. mykiss* redds and reach 5 contained 45 (37.8%) *O. mykiss* redds. The highest number of *O. mykiss* redds (27) was detected on 30 January 2018.

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) to Camanche Dam (rkm 103, the first major impoundment and limit to anadromy). 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 reservoir, Camanche reservoir, 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 following the construction of Camanche Dam and receives approximately 64% of the total run per year (1990-2017 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 2017/2018 salmonid redd surveys (referred to as the 2017 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 occurs 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 2017 and ended on 23 March 2018. Both reaches were surveyed once per week during

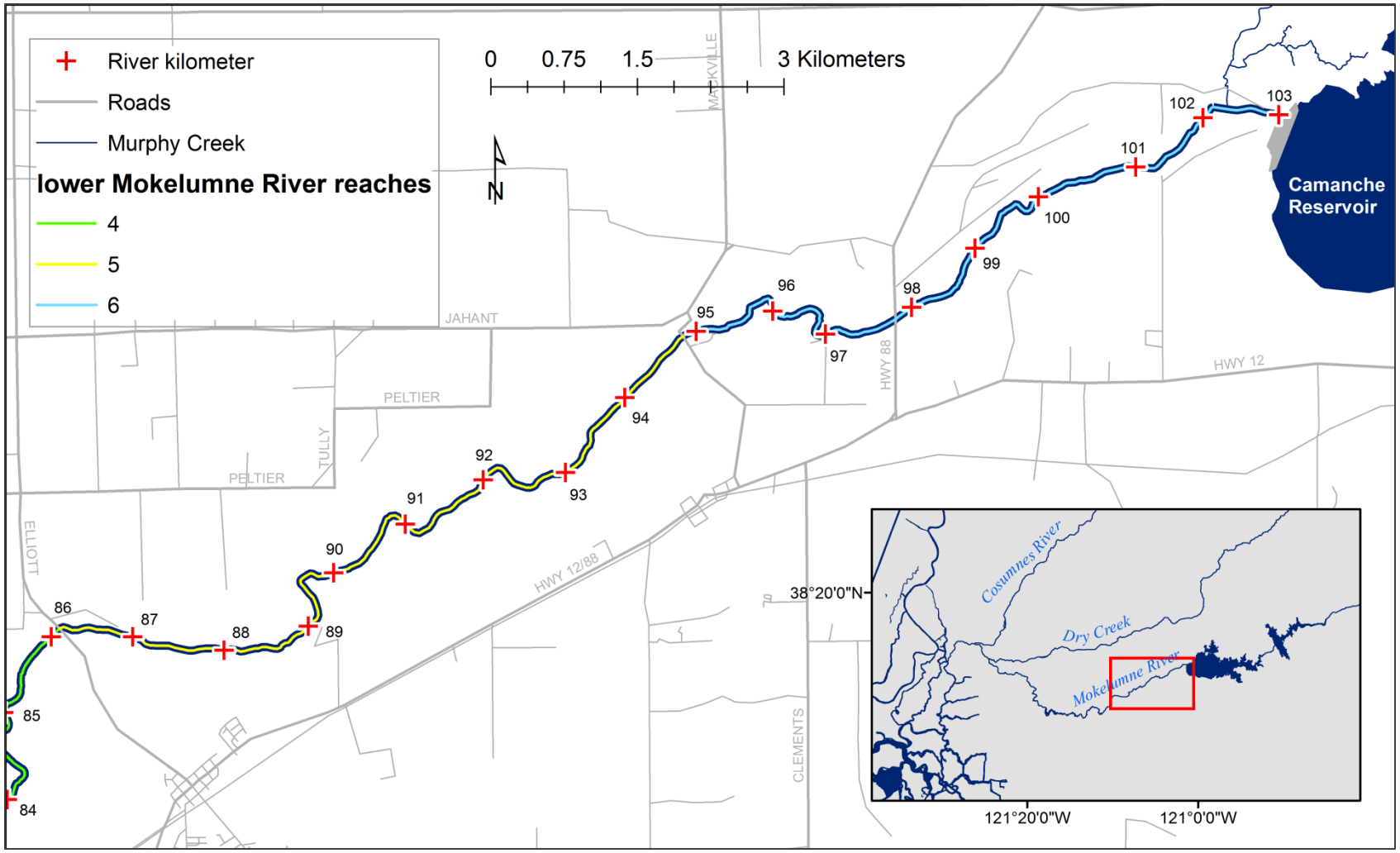

Figure 1. The location of river reaches 5 and 6 on the lower Mokelumne River, where salmonid redd surveys took place during the 2017 season.

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; 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 in areas that were not wadeable.

Trimble Geo XH 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 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.

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 Victor (rkm 80). 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 2 October 2017 to record hourly subsurface water temperatures. Two temperature loggers were buried at depths of 25 cm and 40 cm within seven 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.

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. Upon download, 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), 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 2017, a series of fish attraction flows were released from Camanche Dam throughout October, November, and the beginning of December (Figure 2). Average daily flow from Camanche Dam peaked near 1,300 cubic feet per second (cfs) during the first five pulses and peaked near 1,400 cfs during the sixth pulse.

During the redd survey period (2 October 2017 – 19 March 2018), average daily discharge from Camanche Dam ranged from 329 to 1,386 cfs (Figure 2). The average daily flow during this time period was 504 cfs. The average daily flow when Chinook salmon redds were detected (23 October 2017 through 23 January 2018) ranged from 332 to 1,386 cfs and averaged 496 cfs. The average daily flow when *O. mykiss* redds were detected (18 December 2017 through 13 March 2018) ranged from 330 cfs to 402 cfs and averaged 350 cfs.

Average daily surface water temperatures at the McIntire gauging station (rkm 101, reach 6) ranged from 10.4°C to 16.4°C during the survey period (Figure 2). The average temperature during this time frame was 13.3°C. The average daily water temperatures during the time period Chinook salmon redds were detected (23 October 2017 through 23 January 2018) ranged from 10.7°C to 16.4°C and averaged 14.0°C. The average daily water temperatures during the time period when *O. mykiss* redds were detected (18 December 2017 through 13 March 2018) ranged from 10.4°C to 13.1°C and averaged 11.3°C.

Maximum daily surface water temperatures at the McIntire gauging station (rkm 101, reach 6) ranged from 11.5°C to 17.0°C during the survey period (Figure 3). The average maximum temperature during this time frame was 13.9°C. The maximum daily water temperatures during the time period Chinook salmon redds were detected (23 October 2017 through 23 January 2018) ranged from 11.6°C to 17.0°C and averaged 14.4°C. The maximum daily water temperatures during the time period when *O. mykiss* redds were detected (18 December 2017 through 13 March 2018) ranged from 11.5°C to 13.6°C and averaged 12.1°C.

Daily ambient air temperatures at the Camanche Dam gauging station (rkm 103, reach 6) ranged from -2.8°C to 32.2°C during the survey period (Figure 3). The average maximum temperature during this time frame was 18.5°C. The maximum daily air temperatures during the time period Chinook salmon redds were detected (23 October 2017 through 23 January 2018) ranged from 11.1°C to 32.2°C and averaged 17.8°C. The maximum daily air temperatures during the time period when *O. mykiss* redds were detected (18 December 2017 through 13 March 2018) ranged from 10.6°C to 24.4°C and averaged 15.9°C.

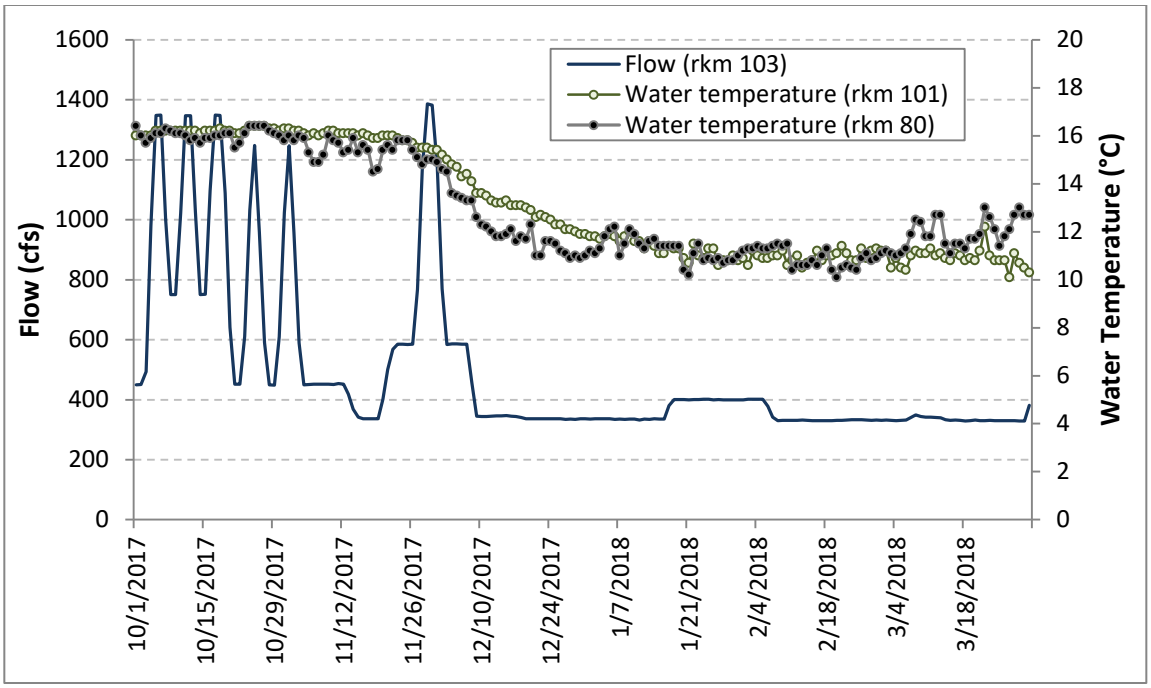

Figure 2. Average daily discharge from Camanche Dam (rkm 103) and average daily surface water temperatures at the McIntire gauging station (rkm 101) and the Victor gauging station (rkm 80) in the lower Mokelumne River during the 2017 salmonid redd surveys.

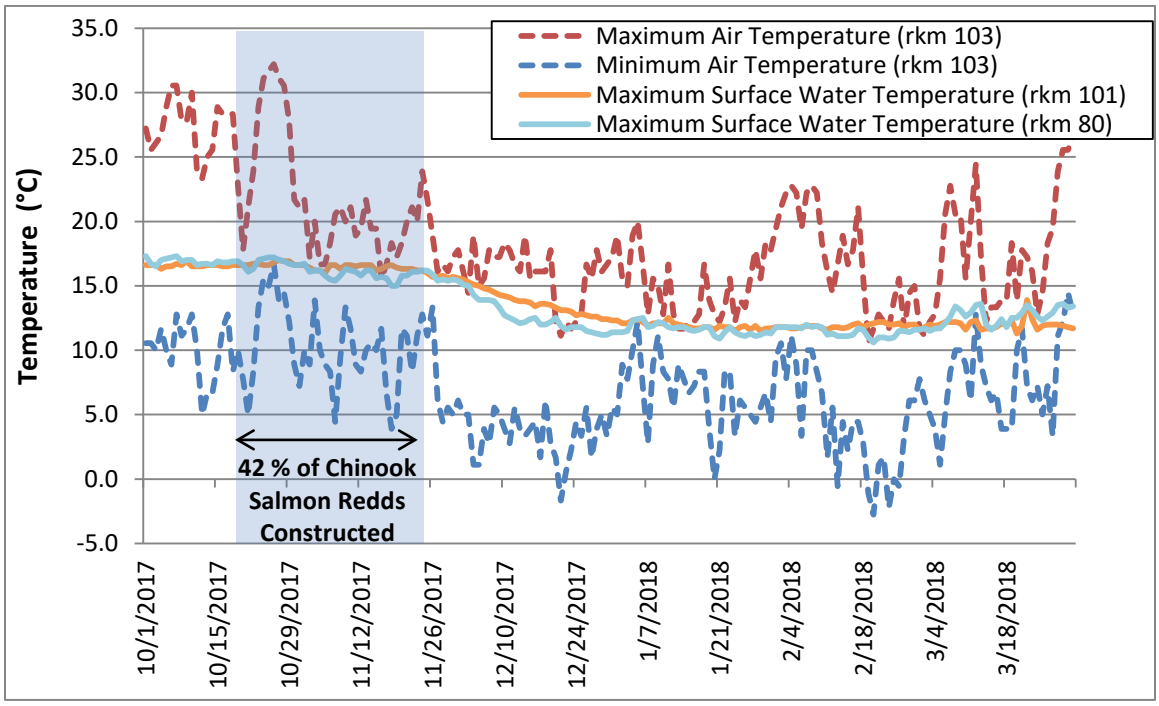

Figure 3. Maximum daily air temperatures at Camanche Dam (rkm 103) and maximum daily surface water temperatures at the McIntire gauging station (rkm 101) and the Victor gauging station (rkm 80) in the lower Mokelumne River during the 2017 salmonid redd surveys.

Sixteen temperature loggers were buried during the incubation period at depths of 25 cm and 40 cm below the gravel surface, and were recovered on 11 July and 5 September 2018. 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 Victor (rkm 80) gauging stations is presented graphically in Figure 4. 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 Victor (rkm 80) gauging stations is presented graphically in Figure 5.

Average daily hyporheic water temperatures at 25 and 40 cm marginally exceeded the range of surface water temperatures recorded between the McIntire (rkm 101) and Victor (rkm 80) gauging stations. Temperatures at both burial depths had a mean difference of 0.3°C warmer than the McIntire gauge throughout the spawning period.

Maximum daily hyporheic water temperatures at 25 and 40 cm exceeded the range of surface water temperatures recorded at the McIntire (rkm 101) and Victor (rkm 80) gauging stations by an average of 0.3°C throughout the spawning period and incubation periods, and had a mean difference of 0.1°C warmer than the McIntire gauge throughout the spawning period.

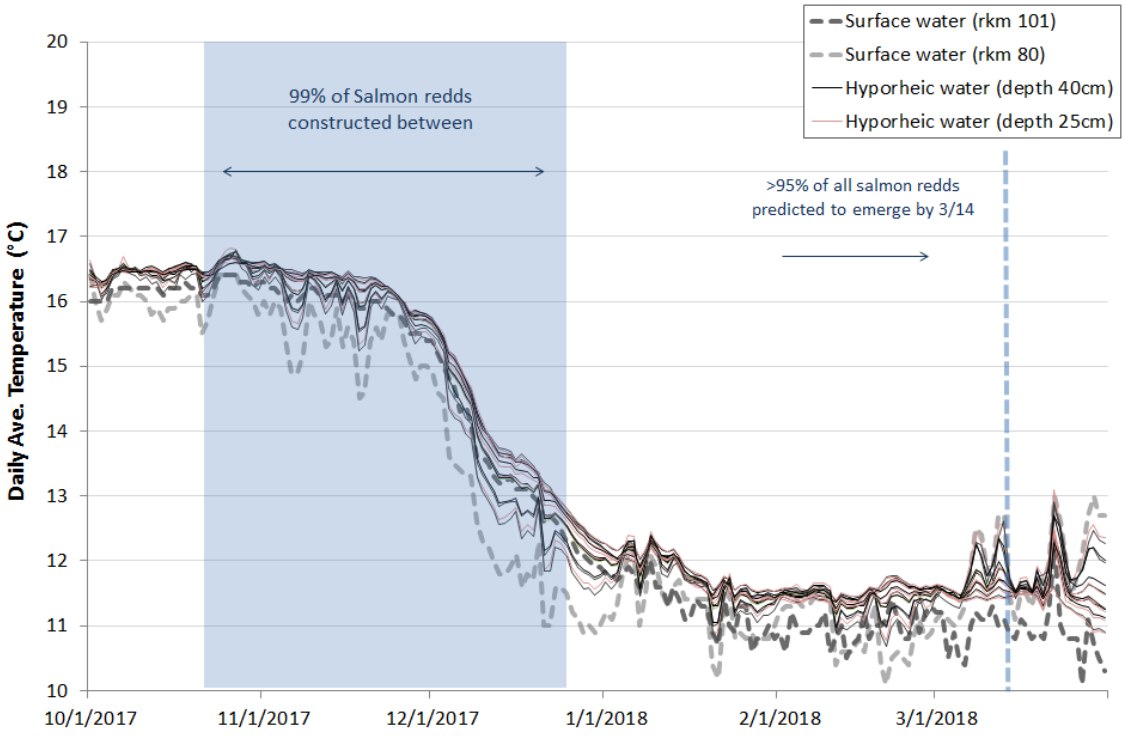

Figure 4. Average daily surface and subsurface (hyporheic) water temperatures recorded on the lower Mokelumne River during the 2017 redd survey season.

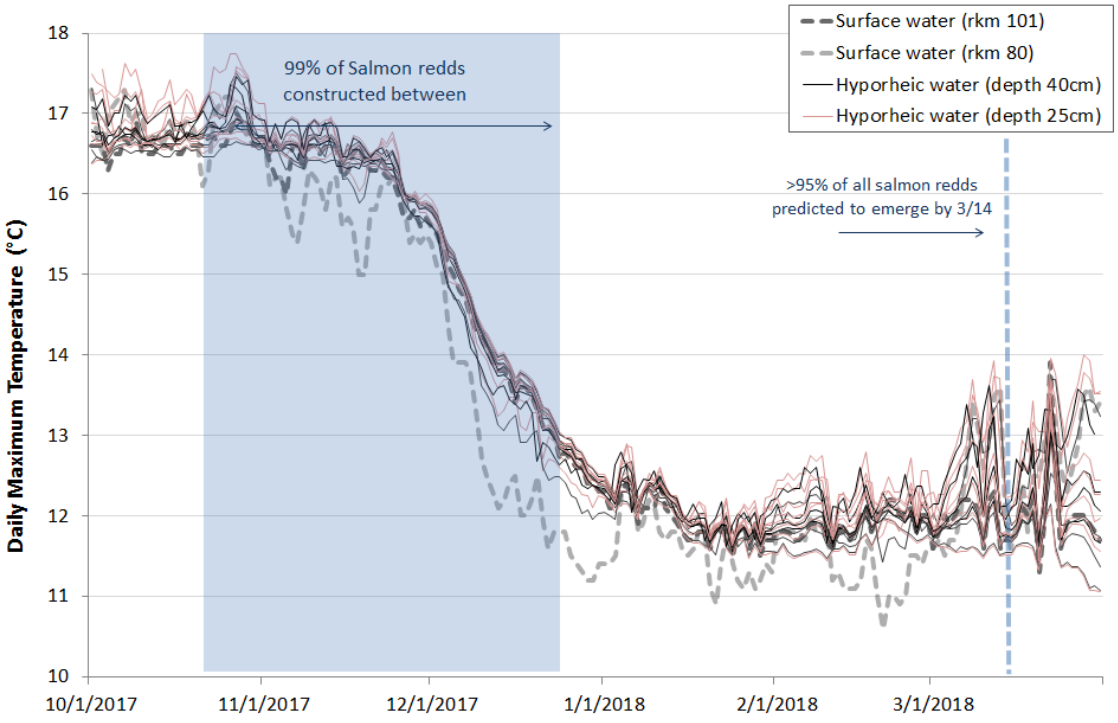

Figure 5. Maximum daily surface and subsurface (hyporheic) water temperatures recorded on the lower Mokelumne River during the 2017 redd survey season.

Chinook Salmon

Redd totals and escapement

During the 25 week redd survey period, 1,255 Chinook salmon redds were detected. The first and last redd detections occurred on 23 October 2017 and 23 January 2018, respectively. The highest number of redds (342) were detected during survey week 10 on 5 and 6 December 2017 (Figure 6). Reach 6 contained 1,118 redds (89%) and reach 5 contained 137 redds (11%).

The 2017 annual redd count was 59% above the long term average (1990-2016) of 787, 101% above the pre-Joint Settlement Agreement (JSA) average (1990-1997) of 625, and 47% above the post-JSA average (1998-2016) of 856 (Figure 7).

To estimate fall-run Chinook salmon escapement in the LMR during the 2017 season, video monitoring was conducted at WIDD between 1 August 2017 and 31 May 2018. An estimated 19,963 Chinook salmon passed through the fish ladders at WIDD (Del Real and Hunter 2018). Approximately 46% (9,276) of the Chinook salmon that returned to the LMR were classified as adults, while the remaining 54% (10,684) were classified as grilse, less than 1% (3) could not be determined. Sexual composition of the run was 63% (12,584) male, 37% (7,376) female, and less than 1% (3) could not be determined. The total count that entered the MOKH this season was 14,319.

The LMR in-river escapement estimate of 5,644 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 2,756 female Chinook salmon was calculated by subtracting the MOKH female count of 4,620 from the video monitoring count of 7,376 females.

Spawning habitat restoration site use

During the 2017 redd survey, 802 (63.9%) Chinook salmon redds were found within the restored upper 1.3 rkm reach, just below Camanche Dam (SHIRA reach – Spawning Habitat Integrated Rehabilitation). Overall, 944 (75.2%) Chinook salmon redds were constructed within SHR sites. In reach six, 863 redds (91.4%) were constructed in SHR sites. Eighty-one salmon redds (8.6%) were constructed in SHR sites in reach 5.

Superimposition

One hundred forty-four Chinook salmon redds (11.5%) were superimposed on other Chinook salmon redds during the 2017 redd survey season. Most of the superimposition took place in reach 6 (137 redds), while just seven redds were superimposed in reach 5.

The 2017 superimposition rate was higher than the long-term average of 10.4% (1991-2016), the pre-JSA average of 9.0% (1991-1997) and the post-JSA average of 10.9% (1998-2016). There was a significant positive linear relationship between the annual redd count and the annual superimposition rate (Linear regression: $F = 30.78$; df = 1, 25; $P <$

0.001). The annual redd count explained 55% of the variation in the annual superimposition rate.

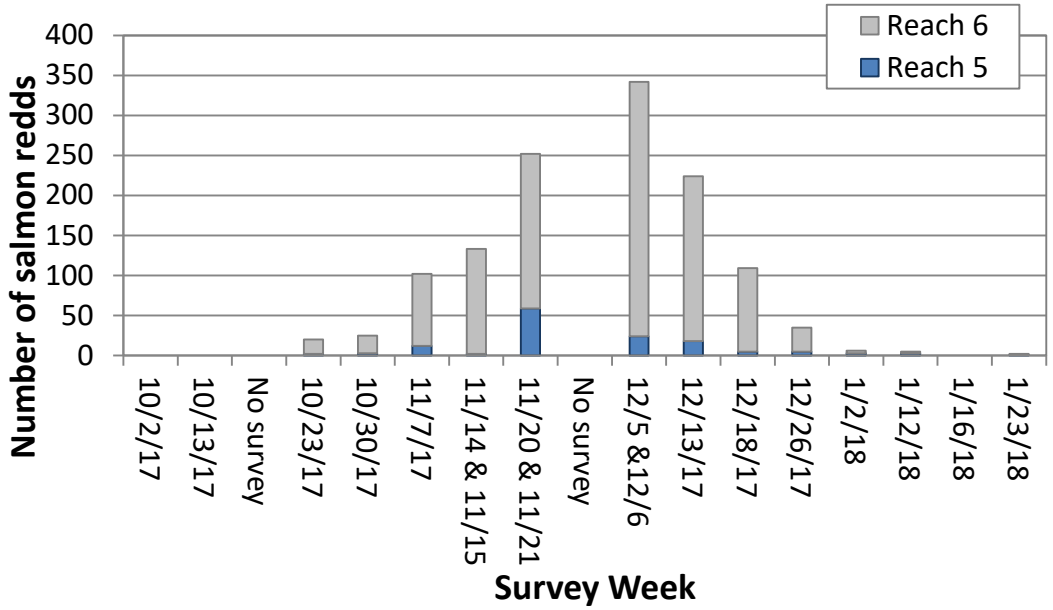

Figure 6. Weekly Chinook salmon redd totals by reach on the lower Mokelumne River during the 2017 surveys.

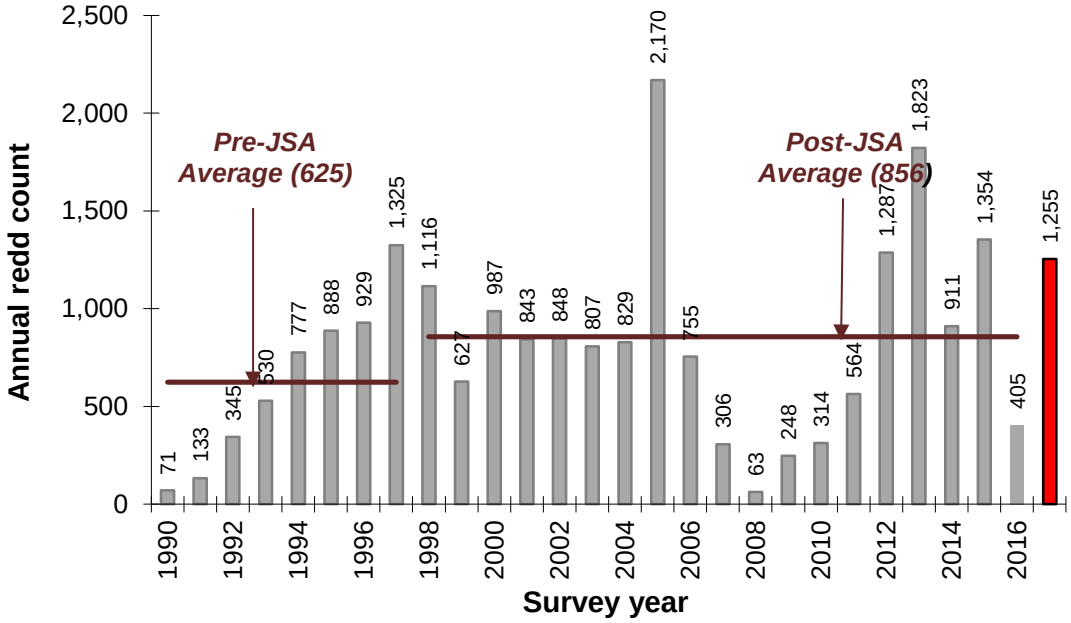

Figure 7. Chinook salmon redd totals on the lower Mokelumne River during pre-JSA flows (1990 – 1997), post-JSA flows (1998 – 2017), and for the 2017 survey season.

Habitat use – water depth and velocity

One hundred and twelve water depth and velocity measurements were taken just above the nose of Chinook salmon redds from 23 October 2017 to 12 January 2018. Daily discharge from Camanche Dam ranged from 335 to 611 cfs on the dates the measurements were recorded. Chinook salmon redd water depths ranged from 18 to 91 cm and averaged 43 cm (SD = 16). The central 50% of measured redd depths (between Q1 and Q3) were between 31 and 54 cm. Water velocity measurements ranged from 0.16 to 1.13 m/s and averaged 0.62 m/s (SD = 0.22). The central 50% of measured redd velocities were between 0.46 and 0.75 m/s.

Flow range did not have a statistically significant effect on redd water depth (two-way ANOVA: $F_{3, 796}$= 1.54, P = 0.2030) but did have a statistically significant effect on redd water velocity (two-way ANOVA: $F_{3, 804}$ = 3.26, P = 0.0212) (Figure 8). Survey year also had a statistically significant effect on redd water depth (two-way ANOVA: $F_{4, 796}$ = 4.49, P = 0.0002), and redd water velocity (two-way ANOVA: $F_{4, 804}$ = 3.94, P = 0.0007).

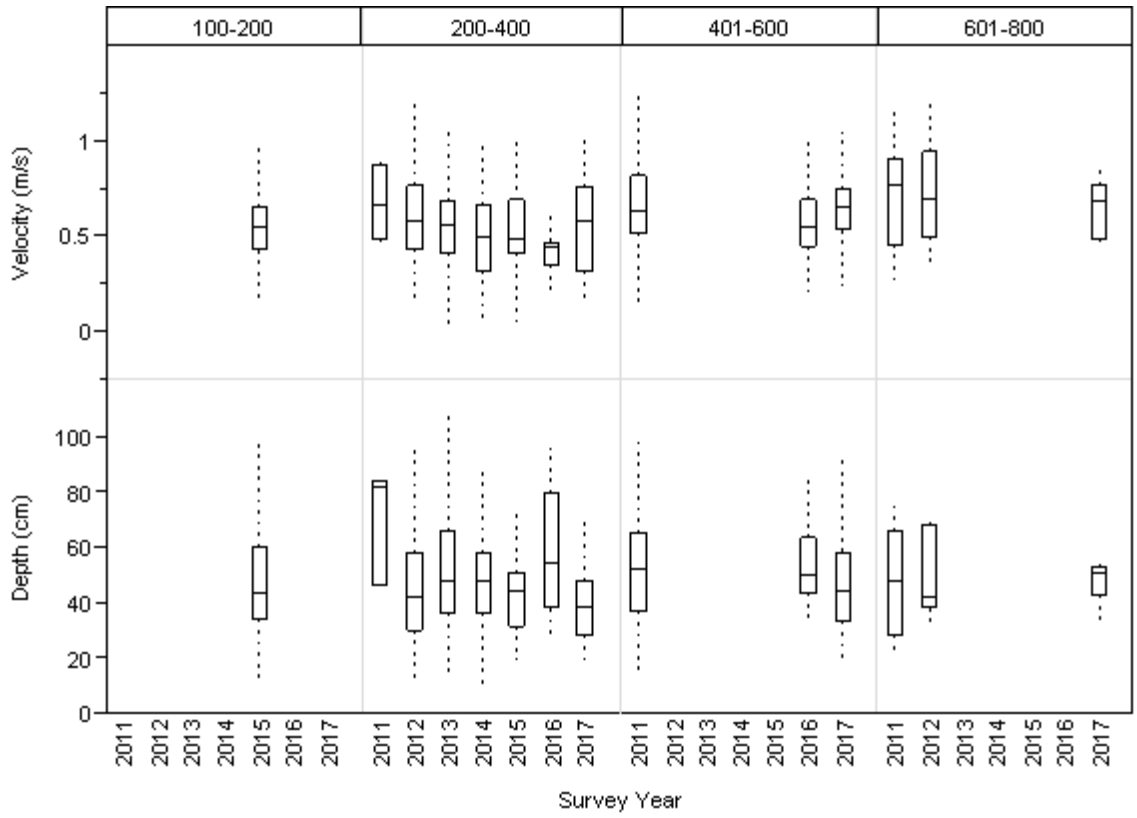

Figure 8. Boxplots of water depths and velocities measured just above the nose of Chinook salmon redds by survey year (2011-2017) and by flow range (100-200 cfs, 201-400 cfs, 401-600 cfs, 601-800 cfs) on the lower Mokelumne River.

Oncorhynchus mykiss

Redd totals

One hundred and nineteen *O. mykiss* redds were detected during the 2017 salmonid redd survey. The first and last detections occurred on 18 December 2017 and 13 March 2018, respectively. The largest number of *O. mykiss* redds (27) were detected on 30 January 2018 (Figure 9). Reach 6 contained 74 redds (62.2%) and reach 5 contained 45 redds (37.8%). The 2017 annual redd count was 125.5% above the long-term (2000-2016) average of 53 (Figure 10).

Spawning habitat restoration site use

During the 2017 redd survey, thirty-five (29%) *O. mykiss* redds were found within the SHIRA reach. Overall, 52 *O. mykiss* redds, or 44% of the total number of redds detected (119), were constructed in SHR sites. Seventy-three percent (38) of redds constructed in SHR sites were located in reach 6 and 27% (14) were located in reach 5.

Superimposition

Twenty-four *O. mykiss* redds were superimposed on Chinook salmon redds during the 2017 season. There were no observations of *O. mykiss* redds superimposed on other *O. mykiss* redds this season.

Habitat use – water depth and velocity

Seventy-five water depth and velocity measurements were taken just above the nose of *O. mykiss* redds between 18 December 2017 and 13 March 2018. Discharge from Camanche Dam ranged from 330 to 401 cfs on the dates the measurements were taken. Water depths ranged from 21 to 96 cm and averaged 49 cm (SD = 17). The central 50% of measured *O. mykiss* redd depths (between Q1 and Q3) were between 36 and 62 cm. Water velocity measurements ranged from 0.11 m/s to 1.03 m/s and averaged 0.59 m/s (SD = 0.19). The central 50% of measured *O. mykiss* redd velocities were between 0.44 and 0.73 m/s.

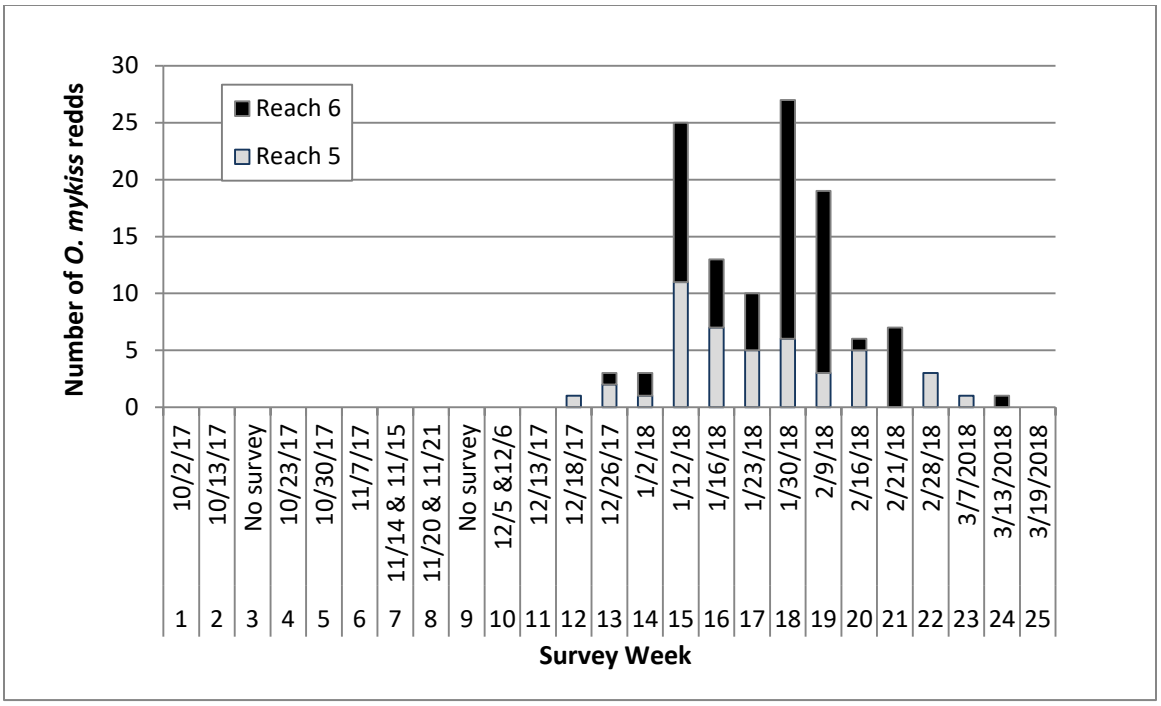

Figure 9. Weekly *O. mykiss* redd totals by reach on the lower Mokelumne River during the 2017 survey season.

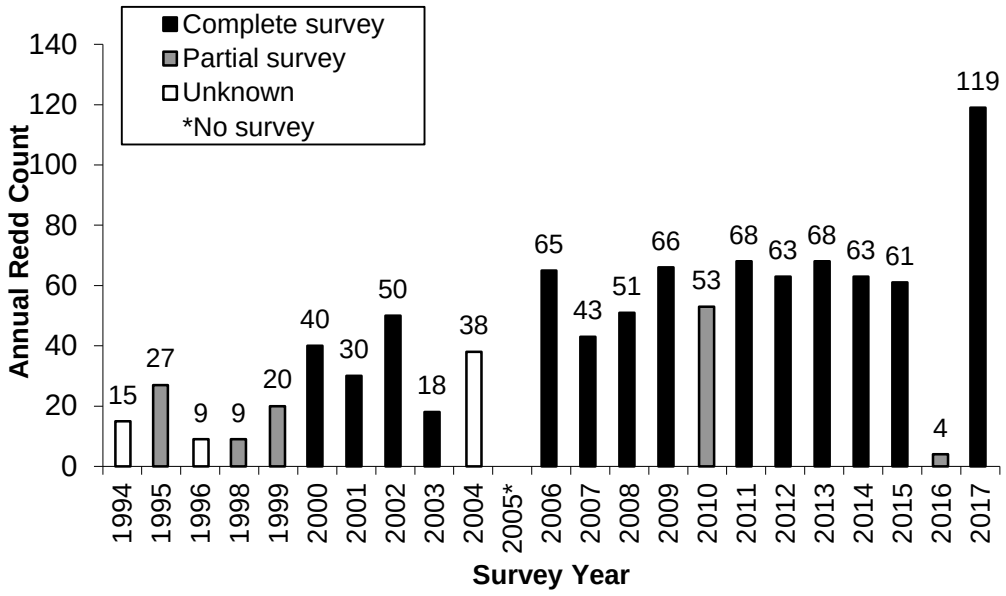

Figure 10. Annual *O. mykiss* redd totals on the lower Mokelumne River from 1994-2017.

DISCUSSION

Operating under a normal and above water year, average daily surface water temperatures for BY17 never exceeded the Camanche hypolimnion threshold of 16.4°C during periods when Chinook salmon redds were constructed or throughout the incubation period. Average and maximum daily subsurface, and maximum surface water temperatures did exceed the Camanche hypolimnion threshold of 16.4°C when the first 532 (42%) 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 48 (4%) redds were constructed when average surface water temperatures fell below 13°C.

Over the previous five spawning and incubation seasons (2012-2016), average daily hyporheic water temperatures typically fell within the range of surface water temperatures recorded at the McIntire Rd. and Victor Rd. gauges, regardless of burial depth. Throughout most of October and November, 2017, ambient air temperatures were unseasonably warm, not allowing the cooling of surface water as it moved downstream through the spawning reaches. Maximum and average daily hyporheic water temperatures were marginally higher than surface water temperatures from October, 2017 to February, 2018, with a mean difference of 0.1°C. These data indicate that the range of average daily surface water temperatures provided by the McIntire and Victor Rd. gauges provide a general estimate of subsurface water temperatures for incubating Chinook salmon embryos. These data may be used to assess future management strategies for cold water releases from Pardee Reservoir and Camanche Dam during the early stages of the Chinook salmon embryo incubation period.

The 2017 LMR Chinook salmon escapement estimate of 19,963 was 306% above the historical (1940-2016) average of 4,909, 480% above the pre-JSA (1940-1997) average of 3,439, and 122% above the post-JSA (1998-2016) average of 9,010. Preliminary 2017 escapement data from GrandTab[1] indicate that 101,222 fall-run Chinook salmon returned to the California Central Valley this season. This included 68,691 salmon that returned to the Sacramento River system and 32,531 salmon that returned to the San Joaquin River system. This season, the LMR accounted for 20% of the total return to the California Central Valley and 60% 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 2017 Chinook salmon redd count was the sixth highest on record since 1990. In addition, it was 47% higher than the post-JSA average of 856. Roughly 46% of the returning population were adults and a large proportion (72%) of returning Chinook salmon were trapped at the MOKH this season; within the range of the previous 3 seasons; 2016 (78%), 2015 (64%) and 2014 (73%). The other 28% of the population (5,644 salmon) remained in the LMR. The in-river population peak spawning on the

[1] California Department of Fish and Game - Fisheries Branch Anadromous Assessment, http://grandtab.calfish.org/GTFall4.aspx, accessed on 5/7/2018.

LMR occurred between the end of November and early December this season. Of the 5,644 Chinook salmon spawning in the Mokelumne River, 2,885 were classified as males (51%) and 2,756 were classified as females (49%).

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 23 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 (63.9% this season) and within all SHR sites (75.2% this season).

The 2017 Chinook salmon redd superimposition rate of 11.5% was higher than the long term average (1991-2016) of 10.4%. Spawning density (using annual redd counts) explained 55% of the variation in the annual salmon redd superimposition rate. During the 2017 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 have a statistically significant effect on Chinook salmon redd water velocity but not water depth from 2011-2017. Survey year had a significant effect on redd water velocity and redd water depth. These results suggest that the selection for water depth as a physical spawning habitat parameter is relatively consistent despite variable flows ranging from 100 to 800 cfs. However, Chinook salmon redd water velocities increased as flow ranges increased, suggesting that available spawning habitat with slower velocities is reduced during higher flows. Subsequently, Chinook salmon created redds where velocities were within the upper extent of suitable expected ranges. There may also be variation among brood stocks and other potential sources of annual environmental variation.

One hundred and nineteen *O. mykiss* redds were observed during the 2017 season and was the largest *O. mykiss* redd count on record. The MOKH had 531 adult *O. mykiss* (total length $\geq$ 16 in.) return, which was the 2nd largest total since Camanche Reservoir was built in 1963. Redd survey frequency is dependent on a number of factors, including weather conditions, flows, and the number of staff available to conduct surveys. This season, normal and above base flows, optimal weather, and adequate staffing allowed for weekly redd surveys to be conducted through the end of March with only one weekly survey 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

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