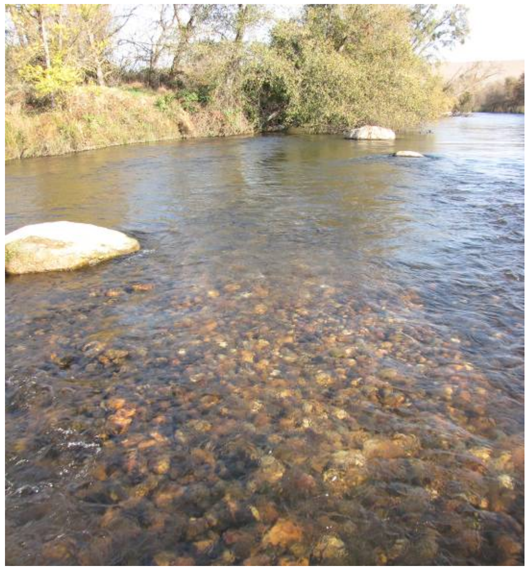
Lower Mokelumne River Salmonid Redd Survey Report: October 2009 through March 2010



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Key words: lower Mokelumne River, salmonid, fall-run chinook salmon, *Oncorhynchus mykiss*, redd survey, spawning, superimposition, gravel enhancement

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Abstract

Weekly fall-run chinook salmon (*Oncorhynchus tshawytscha*) and *Oncorhynchus mykiss* spawning surveys were conducted on the lower Mokelumne River from 14 October 2009 through 25 March 2010. Estimated total escapement during this time period was 2,233 chinook salmon. The estimated number of in-river spawners was 680 chinook salmon. The first salmon redd was detected on 21 October 2009. During the surveys, a total of 248 salmon redds were identified. Thirty-five (14.1%) chinook salmon redds were superimposed and 130 (52.4%) were located within gravel enhancement areas. The reach from Camanche Dam to Mackville Road (reach 6) contained 223 (89.9%) salmon redds and the reach from Mackville Road to Elliott Road (reach 5) contained 24 redds (9.7%). The highest number of chinook salmon redd detections took place on 23 November 2009. The first *Oncorhynchus mykiss* redd was found on 17 December 2009. Sixty-six *O. mykiss* redds were identified, of which one was superimposed and 16 were located within gravel enhancement areas. Reach 6 contained 41 redds (62.1%) and reach 5 contained 25 redds (37.9%). The highest number of *O. mykiss* redds was detected on 26 January 2010 and 4 February 2010.

INTRODUCTION

The Mokelumne River is an east-Delta tributary that drains more than 1,642 square kilometers (600 square miles) of the eastern 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 Reservoir, Pardee Reservoir and Camanche Reservoir. Water releases to the lower Mokelumne River (LMR) are controlled by Camanche Dam. The LMR is defined as the approximate 103 kilometer (km) long portion of the Mokelumne River between Camanche Dam (the farthest downstream major impoundment) and the confluence with the San Joaquin River. 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 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 are owned and operated by the East Bay Municipal Utility District (EBMUD), 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 by fall-run chinook salmon (*Oncorhynchus tshawytscha*) and both resident and anadromous forms of *Oncorhynchus mykiss* (*O. mykiss*) for spawning and rearing. 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 Hatchery (MRFH) was constructed in 1964 to mitigate for spawning habitat lost during construction of Camanche Dam and receives approximately 57% of the total run per year (1990-2008 average). EBMUD has conducted annual spawning surveys on the LMR since 1990 (Hagar 1991; Hartwell 1996; Setka 1997). EBMUD conducts chinook salmon carcass surveys concurrent with the redd surveys. The carcass surveys provide estimates of in-river spawning chinook salmon.

OBJECTIVES

The primary objective of the 2009/2010 salmonid redd surveys (referred to as the 2009 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 enhancement gravel areas.

Due to a low number of carcasses found in the LMR this season, the redd survey was also used to estimate the number of in-river spawning chinook salmon.

METHODS

Surveys

The LMR is divided into 6 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 these two reaches. Specifically, surveys took place within a 13-km reach, from river km 103 (the base of Camanche Dam) downstream to river km 90 (Figure 1). Weekly redd surveys began on 14 October 2009 and were concluded on 25 March 2010. Both reaches were surveyed once per week. However, two survey weeks were missed (surveys weeks 15 and 18) due to poor visibility caused by high turbidity and inclement weather. Surveys consisted of two to three individuals walking abreast downstream (water depths up to 1.2 meters) searching for redds. This method has been used in past Mokelumne River spawning surveys and in other rivers and streams (Keefe et al. 1994; Fritsch 1995; Hartwell 1996; Setka 1997). A canoe or drift boat was used to transport surveyors between spawning areas.

In previous years, redd locations were marked with numbered cattle ear tags and/or colored bricks. However, with high resolution Global Positioning Systems (GPS) technology available, locations were recorded using two Trimble Geo XH GPS units. The Trimble Geo XH GPS 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 one 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 survey.

A subset of depth and velocity measurements was recorded just above the nose of chinook salmon and *O. mykiss* redds. Depth measurements were recorded to the nearest centimeter (cm) using a top-setting velocity 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). Surveyors determined if previously detected redds were superimposed based on the amount of time that had elapsed since a redd was first detected. Water temperature and flow data were obtained from EBMUD's gauging stations at Camanche Dam and McIntire.

Data Collection and Analysis

A minimum of ten points were collected for each redd and point data files were stored in the GPS unit using Terrasync software. After field data were collected, information was downloaded and processed using GPS Pathfinder Office 3.10 software. Once downloaded, geographic positions were corrected using the nearest base data provider. The point data files were then imported to an ArcMAP 9.3 (ESRI) data base.

Data analyses were performed using ArcMAP, Arc/Info (ESRI) systems, JMPIN 4.0.4 (Academic), Microsoft (MS) Access 2003 and MS Excel 2003. A P-value ≤ 0.05 was considered statistically significant.

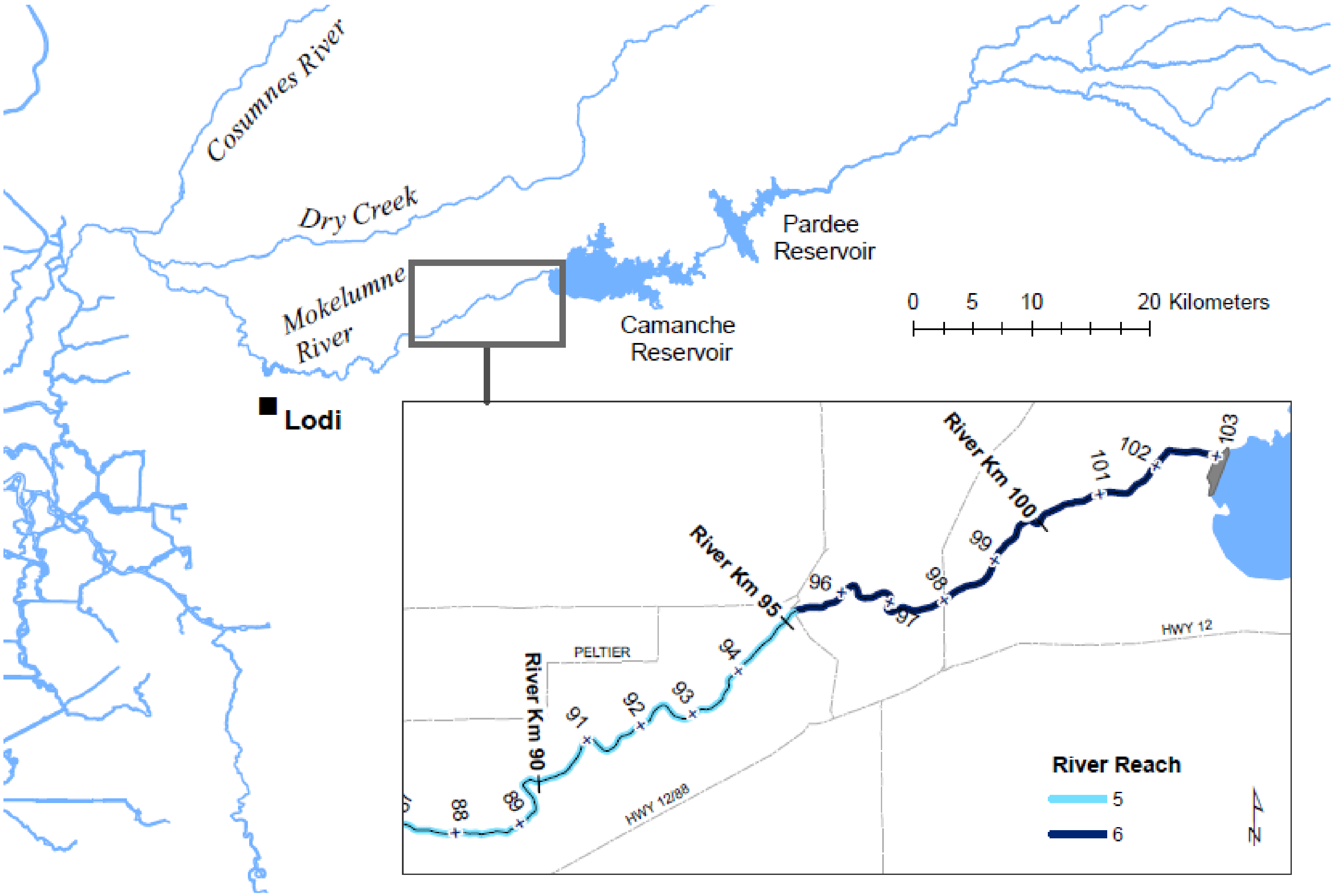

Figure 1. **Mokelumne River watershed (extent) and salmonid redd survey reach (inset) locations.**

RESULTS

Environmental data

In 2009, three pulse flow events took place between 5 October and 9 November 2009. The first large release from Camanche Dam peaked at 2,000 cubic feet per second (cfs) on 8 October 2009. The second pulse peaked at 1,200 cfs on 15 October 2009 and the third pulse peaked at 600 cfs on 10 November 2009.

During the redd survey period (14 October 2009 – 25 March 2010) average daily releases from Camanche Dam ranged from 326 cfs to 1,194 cfs (Figure 2). The average daily flow during this time period was 364 cfs. The average daily flows from 21 October 2009 through 26 January 2010 (time period chinook salmon redds were detected) ranged from 326 cfs to 606 cfs and averaged 338 cfs. The average daily flows from 17 December 2009 through 17 March 2010 (time period *O. mykiss* redds were detected) ranged from 329 cfs to 445 cfs and averaged 335 cfs.

Average daily water temperatures at the McIntire gauging station (Rkm 101, reach 6) ranged from 10.8 °C to 16.2 °C during the survey period (Figure 2). The average temperature during this time frame was 13.1 °C. The average daily water temperatures from 21 October 2009 through 26 January 2010 (time period salmon redds were detected) ranged from 11.5 °C to 16.2 °C and averaged 14.1 °C . The average daily water temperatures during the time period *O. mykiss* redds were detected (17 December 2009 through 17 March 2010) ranged from 10.8 °C to 13.5 °C and averaged 11.7 °C.

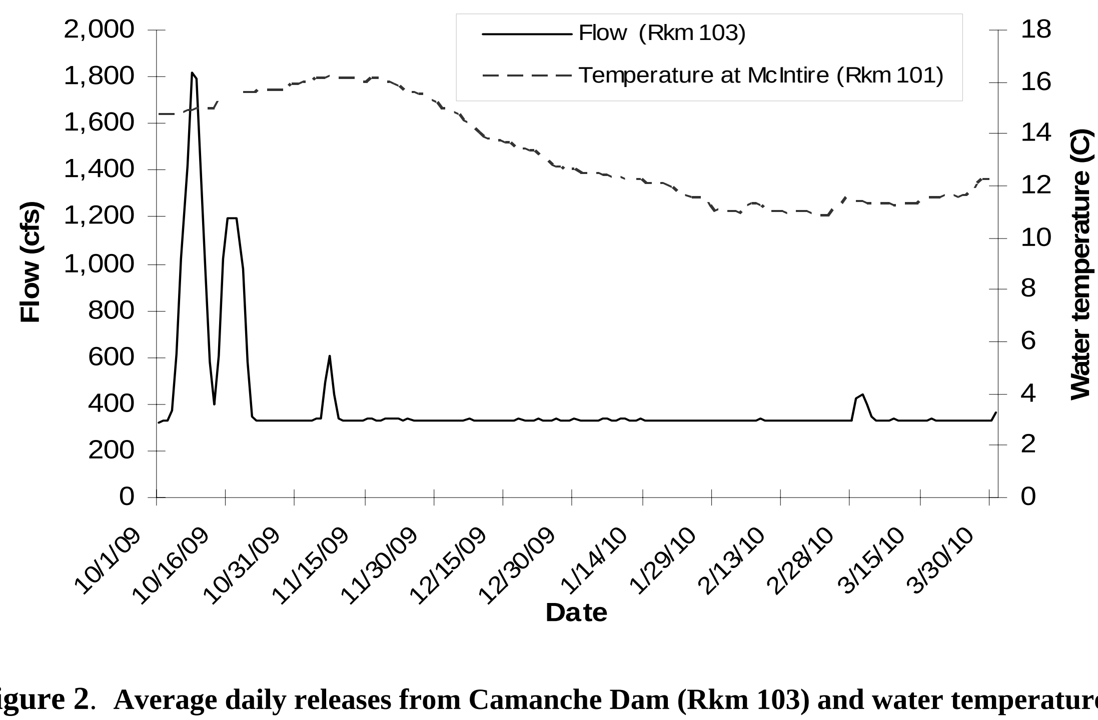

Figure 2. Average daily releases from Camanche Dam (Rkm 103) and water temperatures at the McIntire Station (Rkm 101) in the lower Mokelumne River during the 2009 redd surveys.

Chinook Salmon

Redd totals and Escapement

During the annual redd survey period, 248 chinook salmon redds were detected. The first and last redd detections occurred on 21 October 2009 and 26 January 2010, respectively. The highest number of redds (59) was detected on 23 November 2009 (Figure 3). Reach 6 contained 223 redds (89.9%) and reach 5 contained 24 redds (9.7%). An additional redd was found in reach 2, just below WIDD, during a rotary screw trap check. The 2009 annual redd count was 67% below the long term average (1990-2008) of 755, 60% below the pre-Joint Settlement Agreement (JSA) average (1990-1997) of 625 and 71% below the post-JSA average (1998-2008) of 850 (Figure 4).

A mark-recapture carcass survey was conducted from October 2009 to January 2010 to estimate fall-run chinook salmon escapement in the LMR. The in-river escapement estimate was 697 (95% CI: 86-1,308) based on 59 carcass recoveries. Despite closely matching escapement estimates generated from the carcass and redd surveys (697 and 680, respectively), the large confidence interval precluded use of the carcass survey estimate this season. The in-river escapement estimate was therefore based on the estimated number of spawners per redd. A total of 248 chinook salmon redds were found during the 2009 season. Consequently, the fall-run chinook salmon in-river escapement estimate for 2009 was 680 using the historic average of 2.74 salmon per redd. MRFH's count of hatchery spawners was 1,553. The total escapement estimate on the LMR was 2,233. The hatchery spawning population consisted of 47% adults and 53% grilse. The adult component consisted of 46% male and 54% female. The grilse component consisted of 93% male and 7% female.

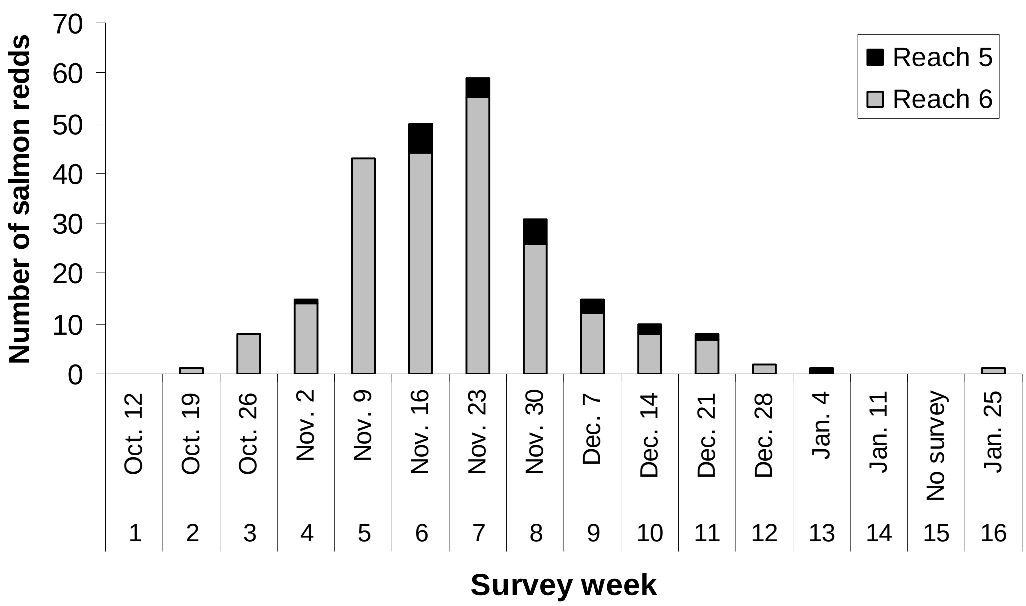

Figure 3. Chinook salmon weekly redd totals by reach on the lower Mokelumne River during the 2009 redd surveys.

Gravel enhancement area usage

Since 2001, the Spawning Habitat Integrated Rehabilitation Approach (SHIRA) has been implemented to restore geomorphic processes and salmonid spawning habitat within the upper 1-km reach of the LMR, just below Camanche Dam. An additional 4,776 cubic yards (yd^3) of gravel were placed in the SHIRA enhancement reach this season. This brings the total volume of Phase II gravel added to the reach to 14,016 yd^3, approximately 3,000 yd^3 short of the Phase II goal. During the 2009 redd survey, nine chinook salmon redds were found within the 2009 project site and 55 redds were found within the entire SHIRA reach. This represents 22% of the total number of redds found during the survey season.

In 2009, 130 chinook salmon redds, or 52.4% of the total number of redds detected (248), were constructed in gravel enhancement areas. Eighty-nine percent of redds (115) constructed in enhancement areas were located in reach 6 and 11% (7) were located in reach 5.

There was a statistically significant relationship between the annual percentage of total redds found in gravel enhancement areas and the cumulative amount of gravel added to the LMR (Figure 5, Logistic regression: $F = 98.9699$; df = 1, 18; $P < 0.0001$). The total amount of gravel added to the LMR explained 85% of the variation in the annual percentage of redds found in gravel enhancement areas.

Superimposition

Thirty-five redds (14.1%) were superimposed during the 2009 redd survey season, all of which were found in reach 6. The superimposition rate was higher than the long-term

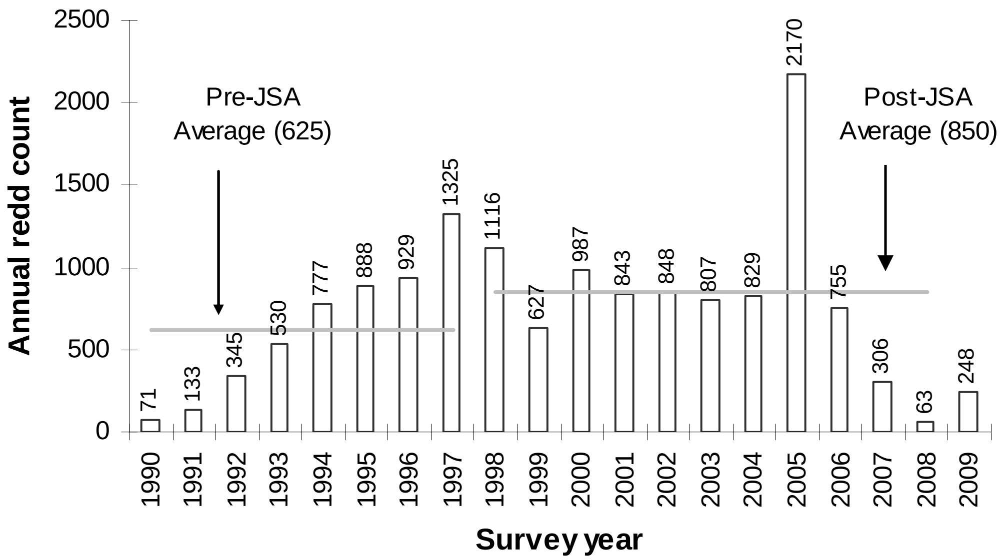

Figure 4. Chinook salmon redd totals on the lower Mokelumne River during pre-JSA flows (1990 – 1997) and post-JSA flows (1998 – 2008).

average of 10.4% (1991-2008), the pre-JSA average of 9.0% (1991-1997) and the post-JSA average of 11.3% (1998-2008). There was a significant relationship between the annual redd count and the annual SI rate (Figure 6, Linear regression: $F = 20.7061$; df = 1, 19; $P = 0.0003$). Annual redd counts explained 55% of the variation in annual SI rates.

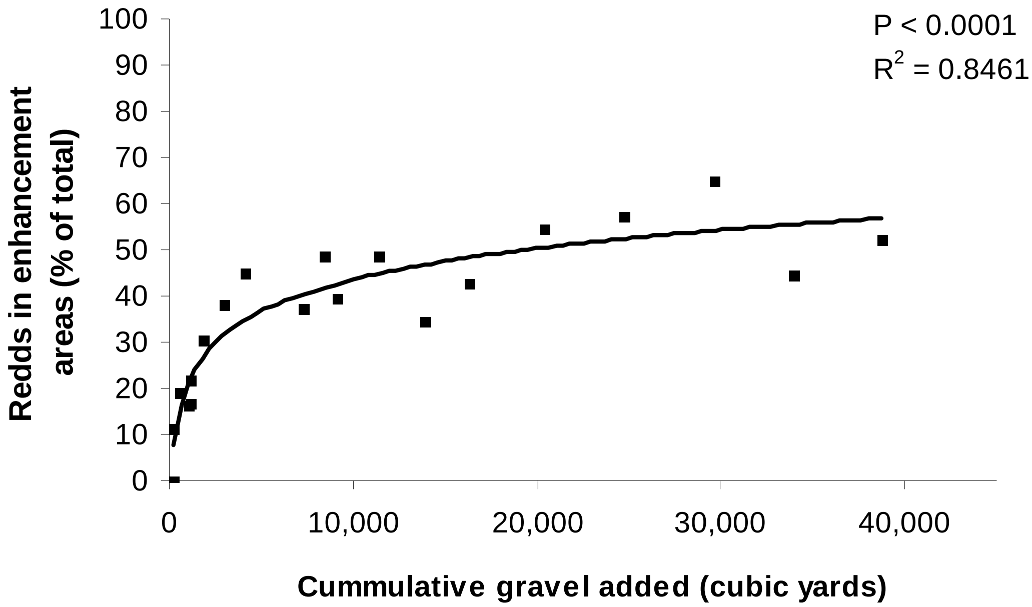

Figure 5. Logistic relationship between the percentage of chinook salmon redds constructed in gravel enhancement areas and the cumulative total amount of spawning gravel added to the lower Mokelumne River from 1990-2009.

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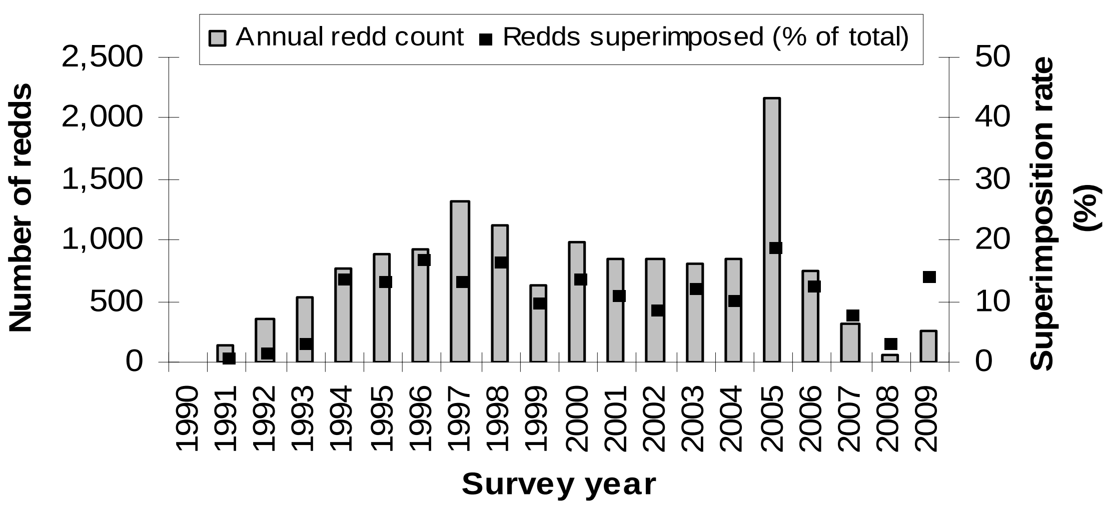

Figure 6. Chinook salmon superimposition rates compared with redd counts by survey year on the lower Mokelumne River from 1991 through 2009.

O. mykiss

Redd totals

Sixty-six *O. mykiss* redds were detected during the survey. The first and last detections occurred on 17 December 2009 and 17 March 2010, respectively. The largest count of *O. mykiss* redds (17) was detected on 26 January 2010 and 4 February 2010 (Figure 7). Reach 6 contained 41 redds (62.1%) and reach 5 contained 25 redds (37.9%). The 2009 annual redd count was 155.6% above the long-term (2000-2008) average of 42 (Figure 8). The *O. mykiss* redd count was the highest on record (1994-2008), although *O. mykiss* redd surveys were not conducted throughout the entire spawning season until 2000.

Gravel Enhancement Area Usage

During the 2009 redd survey season, sixteen *O. mykiss* redds, or 24.2% of the total number of redds detected (66), were constructed in gravel enhancement areas. Sixty-nine percent of redds (11) constructed in enhancement areas were located in reach 6 and 31% (5) were located in reach 5.

Superimposition

One redd (1.5%) was superimposed during the 2009 season, which occurred in reach 6.

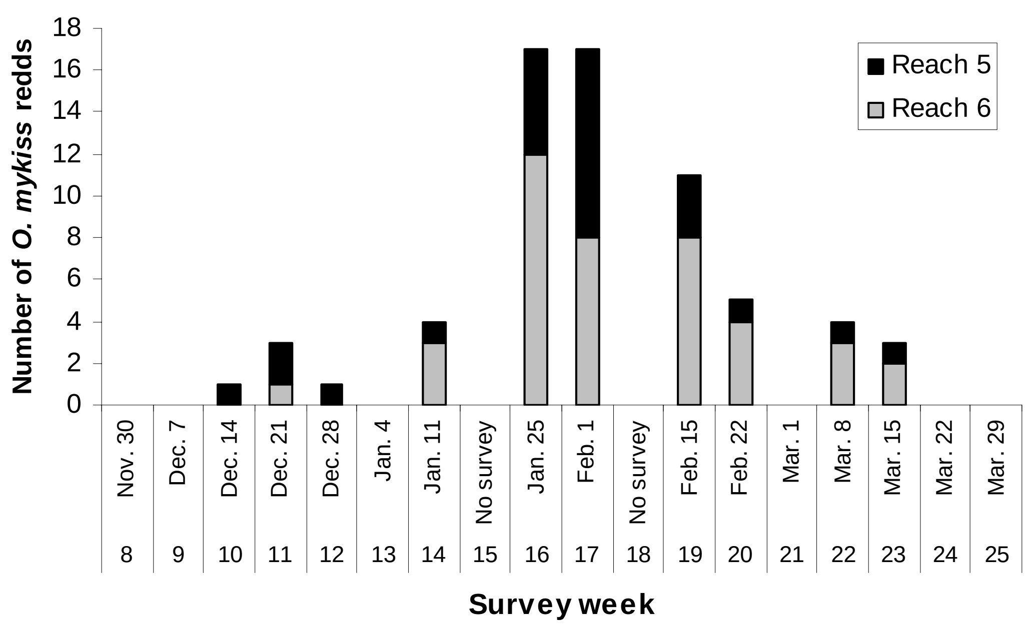

Figure 7. *O. mykiss* weekly redd totals by reach on the lower Mokelumne River during the 2009 survey season.

Habitat Use

Depth and Velocity

A total of 148 depth measurements and 147 velocity measurements were taken just above the nose of chinook salmon redds during the 2009 survey period. Depths ranged from 18 to 112 cm and averaged 51 cm. The central 50% of the depth measurements (within Q1 and Q3) occurred between 36 and 58 cm. Velocity measurements ranged from 0.14 m/s to 1.26 m/s and averaged 0.59 m/s. The central 50% of the velocity measurements occurred between 0.39 and 0.80 m/s.

A total of 31 depth and velocity measurements were taken just above the nose of *O. mykiss* redds during the 2009 season. Depths ranged from 20 to 104 cm and averaged 49 cm. The central 50% of the depth measurements (within Q1 and Q3) occurred between 32 and 66 cm. Velocity measurements ranged from 0.24 m/s to 1.07 m/s and averaged 0.59 m/s. The central 50% of the velocity measurements occurred between 0.42 and 0.71 m/s.

There was no significant difference between depth measurements taken at chinook salmon and *O. mykiss* redds (t-test: $t = 0.59$; df = 177; $P = 0.6117$). Furthermore, velocity measurements taken at *O. mykiss* redds were not significantly different than velocity measurements taken at chinook salmon redds (t-test: $t = 0.12$; df = 176; $P = 0.9038$).

Distance to Shore

Mean distance to the shoreline was compared between chinook salmon and *O. mykiss* redds during the 2007, 2008, and 2009 spawning seasons (Table 1).

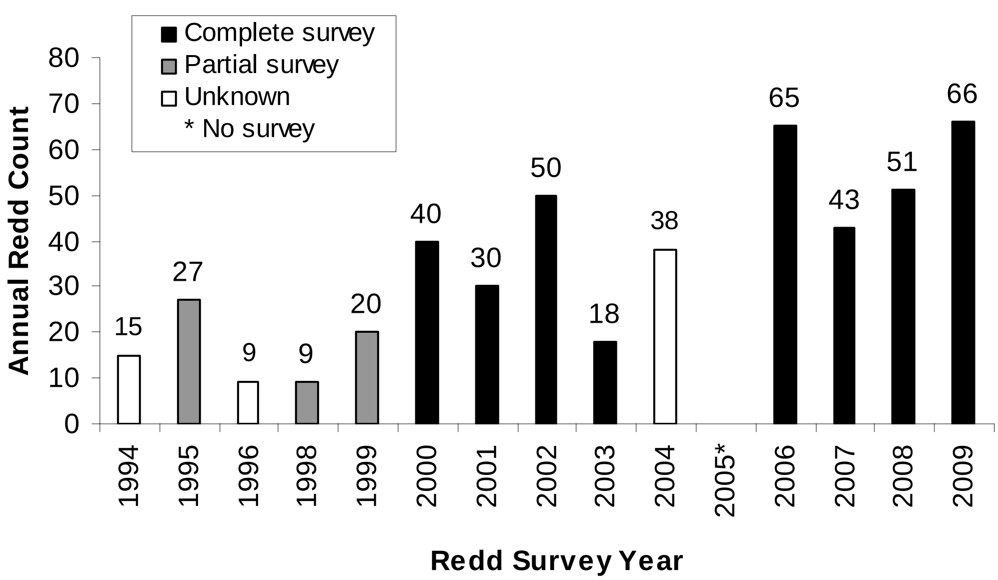

Figure 8. *O. mykiss* redd totals on the lower Mokelumne River from 1994 through 2009.

Table 1. Distance of chinook salmon and *O. mykiss* redds to the LMR shoreline during the 2007, 2008, and 2009 spawning survey seasons.

Year	Species	Number	Mean distance (meters)	Std Error	Lower 95% CI	Upper 95% CI
2007	chinook salmon	306	9.24	0.29	8.67	9.81
2007	*O. mykiss*	43	7.07	0.77	5.55	8.60
2008	chinook salmon	63	10.39	0.64	9.11	11.67
2008	*O. mykiss*	51	7.26	0.72	5.84	8.68
2009	chinook salmon	248	8.97	0.37	8.24	9.70
2009	*O. mykiss*	66	6.00	0.72	4.58	7.42

During all three seasons, there was a statistically significant difference in mean distance to the shore between chinook salmon and *O. mykiss* redds ([2007] t-test: $t = 2.618$; df = 347; $P = 0.0092$, [2008] t-test: $t = 3.250$; df = 112; $P = 0.0015$, [2009] t-test: $t = 3.657$; df = 312; $P = 0.0003$).

DISCUSSION

Chinook Salmon

The 2009-2010 LMR chinook salmon escapement estimate of 2,233 was 46.5% lower than the historical 1940-2008 average of 4,171 (Figure 9), 35% lower than the pre-JSA (1940-1997) average of 3,434 and 71.1% lower than the post-JSA (1998-2008) average of 7,720. For the third consecutive season, chinook salmon escapement was very low throughout the Central Valley. Pacific Fishery Management Council is investigating the factors responsible for the low returns. An initial report indicates that unfavorable environmental conditions, particularly ocean conditions, are the likely causes (Lindley et al. 2009). Other factors that may have affected the 2009 Mokelumne River chinook salmon run include straying and water supply operations in the Delta. Preliminary coded-wire-tag return data suggest that a large number of adult Mokelumne origin salmon strayed into the lower American River this season (Table 2).

The number of redds detected during the 2009 surveys (248) was lower than the post-JSA average of 850, but an improvement from the count (63) in 2008 (Del Real and Rible 2009). Peak spawning on the LMR typically occurs during the third week of November, which was consistent with the spawning pattern observed this season. Water temperatures ranged from 11 to16 °C during the time chinook salmon redds were detected. While water temperatures fell outside of the range necessary for maximum embryo survival (5 to13 °C), a 50% survival rate (from fertilization to hatching) has been

Table 2. Origin of coded-wire-tagged chinook salmon recovered within the lower American River and at Nimbus Fish Hatchery (2009/2010)*.

Hatchery of origin	Run	Recovery Locations			Totals	% of Total
		Lower American River	Nimbus Fish Hatchery	Nimbus Fish Hatchery Weir		
Coleman (Sacramento River)	Fall	3	10	4	17	
	Late-fall	77	110		187	**15%**
Feather River	Fall	43	101	196	340	
	Spring	1		59	60	**30%**
Mokelumne River	Fall	22	358	27	407	**30%**
Nimbus (American River)	Fall	21	241	10	272	**20%**
Tag not recovered	–	17	22	27	66	**5%**
Totals		184	842	323	1349	**100%**

* Data are preliminary and subject to change.

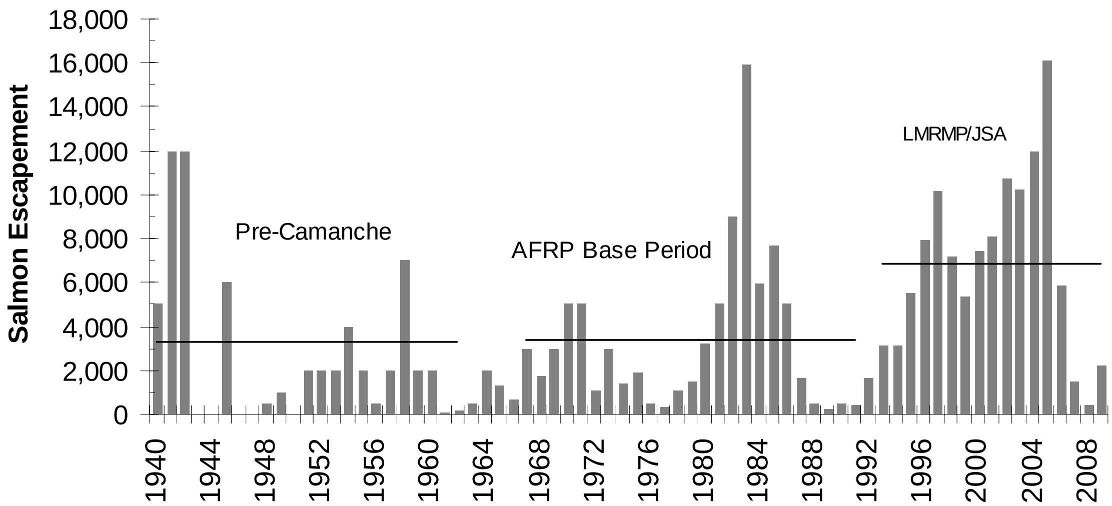

Figure 9. Estimated chinook salmon escapement on the lower Mokelumne River from 1940 through 2009.

recorded for chinook salmon embryos incubated at 16 °C (Moyle 2002; McCullough 1999). In addition, the 2009 water temperatures fell within the range recorded during previous spawning seasons on the LMR (Setka 2004). The three flood-flow events, peaking at 2,000, 1,200, and 600 cfs, occurred several weeks prior to the peak of spawning and no dewatered redds were detected during the surveys. In addition, the largest pulse removed a significant proportion of invasive aquatic macrophytes from several gravel enhancement sites (Bilski et al. 2009).

The overall goal of EBMUD's spawning habitat improvement project is to supplement depleted coarse sediment with suitable-sized gravel in the LMR spawning habitat reaches to provide high quality spawning habitat for chinook salmon and steelhead (Wheaton et al. 2004). As of 1990, EBMUD has completed 18 annual gravel enhancement projects in reaches 5 and 6 on the LMR in cooperation with federal and state agencies, local partnerships, and public organizations. The spawning habitat improvement project continues to provide high-quality spawning habitat as demonstrated by the large percentage of redds constructed within the enhancement areas (52% this season). This represents a population-scale impact by assisting to sustain and possibly expand the existing population of naturally spawning salmon in the LMR.

The logistic relationship between the cumulative amount of gravel added to the LMR and the percentage of redds found within gravel enhancement sites reflects more recent efforts to maintain existing enhancement sites rather than create new ones. In addition, the SHIRA enhancement project (2001-2010) takes geomorphic processes into consideration, requiring a large volume of gravel to re-initiate active bedload transport out of the reach over time.

The 2009 superimposition (SI) rate was approximately 4% higher than the long term average (1991-2008) of 10.4%. All superimposed redds were located in reach 6. A number of factors may be used to explain annual SI rates. Spawning density (using annual redd counts) appears to have a large affect on the annual SI rate, explaining 55% of the variation in the data. In addition, spawning behavior (influenced by the sex ratio and grilse composition) may impact how spawning habitat is used on the LMR (Setka 1997). During the 2009 spawning season, the relatively low density of spawners (reflected by the redd count) may not have influenced the SI rate. However, spawning behavior may have been altered by the large grilse component and a low male to female ratio this year, leading to increased SI levels.

O. mykiss

Sixty-six *O. mykiss* redds were observed during the 2009 season, which is the highest on record from 1994-2008. Redd surveys conclude when flows increase, typically in late fall or early winter, due to decreased visibility and safety concerns. Subsequently, past redd surveys have ended in December and January. From 2000 through 2009 (excluding 2004 and 2005) flows have allowed surveys to continue into March. Almost all of these years account for the largest annual *O. mykiss* redd counts.

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 (Zimmerman et al. 2009). This is a problem within many streams in the Central Valley that contain both resident and anadromous *O. mykiss* (Giovannetti and Brown 2007). While researchers in Oregon have been able to identify differences between the physical habitat of redds built by resident and anadromous forms of *O. mykiss*, this may not be possible in the Central Valley (Zimmerman and Reeves 2000). Temporal segregation of spawning between resident and anadromous *O. mykiss* has not been established on the lower Mokelumne River. Additionally, very few *O. mykiss* are observed constructing redds during the surveys.

Habitat Use

Chinook salmon and *O. mykiss* redd depths and velocities on the LMR fell within the expected ranges for both species (Moyle 2002). No significant differences were found between chinook salmon and *O. mykiss* redd depths and velocities, however redd distance to the shore was significantly different between *O. mykiss* and chinook salmon. *O. mykiss* redds were closer to the shoreline, which has been observed in other Central Valley streams (Giovannetti and Brown 2007). These results suggest that channel position, redd size, substrate size, and run timing, may work well for distinguishing redds between species when fish are not present (Gallagher and Gallagher 2005). When enough data become available from confirmed *O. mykiss* and chinook salmon redds, a model can be used to help differentiate unknown salmonid redds.

To design and evaluate the success of the habitat enhancement projects, habitat suitability indices have been commonly developed and used (McHugh and Budy 2004). Depth and velocity measurements taken at 98 chinook salmon redds in 1991 were combined to create a global habitat suitability index (GHSI) on the LMR (Pasternack et al. 2004). The index utilized data from velocity and depth curves to calculate the overall habitat quality assuming optimal substrate values. The central 50% of velocity measurements recorded at chinook salmon redds in 2009 (0.39-0.80 m/s) fell outside of preferred ("optimal") conditions (0.82 m/s) according to velocity data from chinook salmon redds in 1991. This supports the idea that data collected during the 2009 season should be combined with previous data sets to refine existing habitat suitability indices. Furthermore, preferred spawning conditions (calculated from depth and velocity curves) may be best represented by data sets collected over many years under variable conditions.

MANAGEMENT IMPLICATIONS

The success of the adaptive management strategy for the Mokelumne River fisheries program in 2009 was due to several important actions. The series of flood-flow releases from Camanche Dam effectively cleansed spawning gravels of submerged vegetation and provided an attraction flow for adult spawners, as an estimated 2,233 chinook salmon returned to the LMR (despite record low returns for chinook salmon escapement in the Central Valley). In addition, approximately 366,435 chinook salmon eggs were collected from MRFH origin fish at the Nimbus Fish Hatchery this season. Such efforts help reduce the mixing of different stocks and may also decrease adult straying rates in the future. The effectiveness of both actions supports their use in the future when water supply conditions and staffing are adequate.

However, the closure of the Delta Cross Channel during critical salmonid migration periods also has the potential to significantly reduce the straying rates of Mokelumne River salmonids and may prove to be a very useful management tool. Such actions should also be considered when cooperation from regulatory agencies and environmental conditions permit.

ACKNOWLEDGEMENTS

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