Fall-run chinook salmon and steelhead trout spawning survey, September 2002 through March 2003 Mokelumne River, California

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Abstract: Weekly fall-run chinook salmon Oncorhynchus tshawytscha and steelhead trout O. mykiss spawning surveys were conducted in the lower Mokelumne River from October 1, 2002 through March 10, 2003. The estimated escapement during this period was 10,755 chinook salmon and 56 steelhead. The estimated number of in-river chinook salmon spawners was 2,834 fish. During the survey period 848 chinook salmon and 50 steelhead trout redds were observed. Seventy-two (8.5%) salmon redds were superimposed. The upstream reach from Camanche Dam to Mackville Road contained 683 salmon redds (80.5%) and the reach from Mackville Road to Elliott Road had 165 redds (19.5%). Additional redds were located above the fishway at Woodbridge Dam. A total of 413 redds (48.7%) were constructed in enhancement areas. Increased aquatic macrophyte biomass resulted in reduced spawning habitat suitability in the upper two spawning sites.

INTRODUCTION
The lower Mokelumne River (LMR) is used by fall-run chinook salmon Oncorhynchus tshawytscha and steelhead trout O. mykiss for spawning and rearing. Adult chinook salmon ascend the river as early as late August and may begin spawning in late September. The peak of the run usually occurs in November and tapers off through the month of December (Marine and Vogel 1994, Hartwell 1996, Setka 1997). The Mokelumne River Fish Hatchery (hatchery), constructed in 1964 to mitigate for spawning habitat lost with the construction of Camanche Dam, receives approximately 53% of the total run per year (1990-2002 average). EBMUD has conducted annual spawning surveys in the lower Mokelumne River (LMR) since 1990 (Hagar 1991, Hartwell 1996, Setka 1997). Concurrent with these surveys, EBMUD enumerates chinook salmon escapement at Woodbridge Dam (Biosystems 1992, Natural Resource Scientists Inc. 1996). Data collected from WD monitoring and hatchery returns allow for an estimation of the number of chinook salmon within the LMR at any time during the spawning season.

OBJECTIVES
The primary objective of the 2002 spawning survey was to enumerate chinook salmon and steelhead redds in the LMR. With the escapement data from WD and the hatchery, an estimate was obtained for the total escapement to the river. The escapement estimate was used to associate the number of redds and their characteristics with population structure and/or density. Additional objectives include:

- Mapping locations of individual redds
• Determining specific preferences of spawning chinook with cover (overhanging vegetation, canopy, undercut banks, water depth and turbulence, etc.), habitat type, and large organic debris (LOD)
• Enumerating redds impacted by superimposition
• Determining use of enhancement gravel areas

The following were also noted:
• Visible injuries to salmon, attached fishing gear, adipose clips or tags
• Behavior and numbers of salmon associated with redds

Environmental parameters and flow during the spawning period were summarized. The emergence timeline was constructed using an egg model based on daily temperature units (Piper et al. 1982).

EBMUD has developed a Geographic Information System (GIS) for the LMR. The 2002 results were compared to past year’s in order to further develop spawning preference criteria, analyze differences between the years due to densities, and summarize the dataset collected to date. The GIS was used to spatially display and analyze much of the current data. The results generated by the GIS included:
• Spatial distribution of redds
• Total area used by spawners
• Relationship of redd spatial distribution to run size or age composition
• Habitat associations for spawning salmon

**SITE**

The 1,700km² Mokelumne River watershed ranges from the Sierran Crest to the Sacramento - San Joaquin Delta. Pardee and Camanche reservoirs, located on the Mokelumne River (Figure 1), are owned and operated by East Bay Municipal Utility District (EBMUD), which provides water for 1.3 million customers in Alameda and Contra Costa Counties. Additionally, there are reservoirs and power generation facilities located upstream of Pardee Reservoir owned and operated by Pacific Gas & Electric Company (PG&E). Downstream of Camanche Dam, Woodbridge Irrigation District (WID) operates Woodbridge Dam (WD) and an associated system of irrigation canals near Lodi, CA.

The lower Mokelumne River is divided into 6 reaches between Camanche Dam and the confluence with the Sacramento-San Joaquin Delta. The reach designations are based on gradient, substrate and tidal influence. Reaches 5 and 6 cover a 15.8 km section of the river from Camanche Dam to Elliott Road. With the exception of some sporadic gravelled areas near bridge abutments and WD, reach 5 and 6 contain all the available salmonid spawning habitat within the LMR.
METHODS

SURVEYS
Beginning October 1, 2002 weekly redd surveys were conducted in the LMR from Camanche Dam to Elliott Road (Figure 1). From January until the end of surveys the interval was extended to 2-weeks due to decreased numbers of spawners. The last survey was conducted March 10, 2003. The reaches were surveyed over a 1 to 2 day period each week. Surveys consisted of three individuals walking abreast down the river (water depths to 4 feet) and searching for signs of redd construction. 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 boat was used to transport surveyors between spawning areas. Redds were marked using 6-8 inch bolts with bright pink, individually numbered cattle tags attached to the head end. Locations were recorded using a hand-held Global Positioning System (GPS) unit (Trimble Pro XR) and a laser range finder (Laser Atlanta). While one person stood at the downstream end of each redd, an offset position was “shot” using the range finder and a real-time corrected position is recorded. Mapped redds were marked at the downstream portion of the tailspill by inserting the bolt-tags into the substrate. Care was taken to avoid impacts to redds during the survey of spawning beds and with placement of tags.

DATA COLLECTION
Location data for each redd were stored in the GPS unit and later downloaded to an ArcMAP 8.2 (ESRI) database. In addition to redd locations, notations were made regarding the associated characteristics. Additional measurements included cover type, numbers of fish associated with each redd, and other information, such as recruitment of LOD into specific areas, that could influence redd construction.

Water temperatures were measured using hand-held thermometers, Campbell data loggers (Campbell Scientific Inc., USA), and a dissolved oxygen/temperature meter (YSI Inc., USA). The Campbell data loggers also measured gauge heights from which river flows are computed.

DATA ANALYSIS
Data analysis was performed using ArcMAP, Arc/Info (ESRI) systems and EBMUD LMR GIS. The lower river GIS is based on two data sets: regional USGS maps with a 1:24,000 scale and local maps based on orthorectified photos (taken February 28, 1994, at a release of 202cfs from Camanche Dam) with a 1:4,800 scale.

RESULTS
ESCAPEMENT AND REDD NUMBERS
The total observed escapement to the Mokelumne River from September 2002 through January 2003 was 10,755 chinook salmon (adults and grilse). Counts were based on video monitoring, trapping and salmon rescued from spillbay basins (methodologies detailed in Marine and Vogel 1994). The composition of the run was as follows:

4,271 adult females (40% of total escapement)
4,240 adult males (40% of total escapement)
521 female grilse (5% of total escapement)
1,681 male grilse (15% of total escapement)
42 unknown (.4% of total escapement)

In addition to chinook salmon, 56 adult steelhead trout were observed. The California Department of Fish and Game uses a length criterion to differentiate between steelhead and resident rainbow trout, with steelhead being greater than 40cm fork length. The 2002 salmon run peaked during the first week in November (Figure 2). The highest single-day migration took place on November 7th when 662 salmon passed WD.

Hatchery staff recorded 7,919 (73.6% of run) chinook salmon entering the hatchery during the 2002 spawning season. The sex and age composition of salmon returning to the hatchery was 2,514 adult females (31.7%), 3,286 adult males (41.5%), and 2,119 grilse (26.8%). Of the grilse entering the hatchery, 554 were female (26%) and 1,564 were male (74%). By subtracting the hatchery count from the observed escapement at WD, there were an estimated 2,834 in-river spawners during the 2002 season. The in-river sex composition for the 2003 season was approximately 1,757 adult females (62% of in-river fish), 954 adult males (34% of in-river fish) 117 male grilse (4% of in-river fish), and no female grilse (Figure 3).

During the 2002/2003 survey period 848 redds were observed. The first redd was observed on October 8, 2002. Redd construction peaked between the first and second week of November and lasted through January (Figure 4). Reach 6 contained 683 (81%) redds, while Reach 5 contained 165 (19%) redds. The season’s redd count was similar to the 843 redds observed in 2001.

Fifty steelhead trout redds were observed during the 2002/2003 surveys. The first trout redd was observed on January 3, 2003. Forty-nine of the redds were located in Reach 6 and one of the redds was within Reach 5.

**ENHANCEMENT GRAVEL USAGE**

Since 1992 the District has conducted gravel enhancement projects in the lower Mokelumne River in cooperation with federal and state agencies (Figure 5). In 2002, 413 (48.7%) redds were constructed in habitat enhancement areas (Figures 6 and 7).

**SUPERIMPOSITION**

During the 2002 season 72 redds (8.49%) were superimposed. Ninety-six percent of redd superimposition (SI) occurred in Reach 6, while the remaining 4% occurred in Reach 5. During the peak of the run, weekly SI levels were 2% to 8.2% (Figure 8). Site-specific superimposition levels varied from 25% at Alder Island to 0% at Van Assen (Figure 9).

**ENVIRONMENTAL DATA**

Water temperatures below Camanche Dam during the period of October 8, 2002 to January 3, 2003 ranged from 16°C to 10.4°C (Figure 10). During the same time period, water temperatures at Mackville Road ranged from 15.9°C to 9.9°C, and temperatures at Woodbridge Dam ranged from 17.3°C to 9.1°C. All redds were constructed in water temperatures under 16°C. Releases from Camanche Dam during the survey period
ranged from 324cfs on October 8, 2002 to 254cfs on February 17, 2003 (Figure 11). All of the observed redds were constructed at a flow of 270 cfs.

**REDD PHYSICAL CHARACTERISTICS AND HABITAT PREFERENCES**

There were 858 instances where cover was associated with individual redds (Figure 12). Many of these instances involved one redd associated with multiple cover types. The most common cover types used were turbulence (35.0%), canopy (23.5%), overhanging vegetation (19.4%) and LOD (12.7%). Overall there were 546 redds that utilized at least one type of cover. Very few natural boulders are present within the channel of the LMR. As part of habitat enhancement projects from 1996 to 2002, boulders were placed in specific locations with spawning gravels. The boulders may provide refugia for salmonids and add stability to the gravel berms. Less than one percent (8) of redds constructed in 2002 were associated with boulders, of these redds five were associated with boulders placed in the river for enhancement purposes.

**BEHAVIOR AND TAGS/MARKS**

The number of salmon associated with a single redd ranged from 0 to 6. Of the 848 redds observed, 296 (34.9% of total redds) were active with at least one fish. There were 23 (2.71%) instances of more than 2 salmon on a single redd.

**EMERGENCE TIMELINE**

Using the egg model, it was predicted that chinook fry began emerging from redds the week of December 7, 2002 and continued through March 26, 2003 (Figure 13). The peak of fry emergence was estimated to be the week of January 24, 2003. The first fry captured in the rotary screwtraps at WD occurred on December 17, 2002 (traps installed December 16th).

**DISCUSSION**

The 2002-2003 escapement of 10,755 chinook salmon was 282% of the historical 1940-2001 average (Figure 14). Although the number of in-river spawners in 2002 (2,834) was slightly higher than the 2001 total (2,305), the 2002 estimated escapement number, redd count and hatchery returns were very similar to 2001 (Table 1). Due to monitoring problems encountered during the 2001/2002 season, data were not available for comparing the sex and life-stage ratios to those of the 2002/2003 season. The grilse component of the total 2002 escapement was approximately 20% of the run, of which a majority entered the hatchery. While the estimated escapement of steelhead trout was 56, a total of 50 trout redds were observed. Since *O. mykiss* are much less tolerant of people nearing their redds, trout tend to escape to sheltered areas as surveyors approach. This factor makes it difficult to ascertain whether resident trout or steelhead are responsible for a given redd, therefore the steelhead redd counts likely include those of resident *O. mykiss*. Pacific lamprey *Lampetra tridentata* use substrate that is similar in size to that used by salmonid, yet the shape of lamprey redds is distinctly circular and unlikely to be mistaken for a salmonid redd.

Surveys were conducted until no new redds were found in the 15.8km stretch below Camanche Dam. Some past surveys have been cut short, as early as the first week of December, due to increased releases from Camanche Dam. Once flows reach approximately 800cfs it becomes difficult to conduct thorough surveys. The 2002
spawning survey encompassed the entire known spawning period for anadromous salmonids in the LMR.

The number of adult in-river spawners has been increasing steadily over the last three survey seasons (Figure 3), concurrent with the increased escapements. The number of in-river spawners increased by 490 fish in 2002 compared to the number of in-river spawners in 2001. The number of in-river grilse was 2.4% of the total in-river population. This grilse component is much lower than the approximately 34% in 1999 and the 20% of in-river spawners in 2000. Generally, grilse use already constructed redds either through satellite spawning (males) or superimposing (females) (Crisp and Carling 1989, van de Berghe and Gross 1989, Healy 1991, Wilson 1997). The low grilse component for the 2002 in-river spawners may indicate that the number of redds observed was closer to being an accurate representation of the number of in-river spawning pairs than other years. A larger 2002 in-river population, combined with a decrease in suitable spawning habitat due to increased coverage of aquatic macrophytes, should result in an increased level of superimposition within the remaining habitat. However, the superimposition level for the 2002 season (8.5%) was lower than the 2001 SI level (10.9%). This SI decrease may be partially accounted for by the lower grilse component of the in-river spawners. The addition of enhancement gravels may have also reduced superimposition through the expansion of spawning habitat. Finally, modifications made to the fish ladder entry after the 1999 season, apparently, have resulted in three consecutive years of >70% of the total escapement entering the hatchery. The increased hatchery escapement has likely had an effect on the catwalk area SI levels.

An additional factor affecting the distribution and numbers of redds observed was the composition of the in-river spawning population. Run composition can play a significant role in the habitat use patterns and density of spawning salmonids (van de Berghe and Gross 1989, Vronskii and Leman 1991, Wilson 1997). The composition of a run is expressed as the ratio of males to females; total population; temporal density; and the grilse component. The male to female ratio from 1994-2002 is depicted in (Figure 15). This year’s male to female ratio was 0.6:1, which translates into nearly twice as many female salmon as male. The disproportionate number of male and female fish likely impacted the spawning activity in the river by reducing the amount of individual pairs, ultimately reducing the number of redds expected with a female population of nearly 1,800 fish.

The overall percent use of enhancement areas increased in 2002 (48.7%) compared to 2001 (39.6%). Only one new enhancement area was constructed between the 2001 and 2002 survey seasons. This newest enhancement area, Keyhole Slough, recruited 30 (3.4%) of the total redds constructed. Pre-enhancement, the same area also received 30 (3.6%) of the redds. This similarity suggests that the freshness of the enhanced gravel is not a deterrent to redd recruitment. Although the number of redds remained the same as pre-enhancement levels, the quality of enhancement gravels regarding water temperatures, gravel permeability and hyporeic flow is much higher than un-enhanced areas. Presumably, the improved environmental conditions within the substrate lead to increased egg and alevin survival.

Until 1999, enhancement areas, especially in Reach 6, had experienced consistent increases in the percentage of total redds built within the sites (Figures 14 and 15). From
1999 to 2002 the percentage of total redds built within spawning sites has varied both within sites and between sites. Alder Island, Above Mackville Road, Dock Island, and Sutters are enhancement areas that have all sustained a steady to increasing percentage of the total redds constructed over the last three years. Areas such as the Catwalk, Above Murphy Creek, Murphy Creek, and Van Assen have all recently experienced a general reduction in the number of redds they support. While containing less than 8% of the total redds this year, the area directly below Camanche Dam has previously contained over 20% of the total redds constructed within a season. The traditionally heavy use of this section is generally attributed to the behavioral aspects of the salmon in which individuals try to go as far up a river system as they can. In order to reduce competition for spawning habitat a large portion of the spawning habitat enhancement effort has been focused on this two-mile section below Camanche Dam. If the enhanced sites are to function at their optimal capacity, the general decline in the use of these enhancement areas needs to be investigated to determine the cause of the new variation. The reduction in redd numbers may be attributed to a number of possible causes including but not limited to natural variations in salmon spawning habitat preferences, the increasing incidence of aquatic macrophytes growing in traditional spawning habitat, and the age of the enhancement projects in the area. Catwalk, Murphy Creek and Van Assen were enhanced twelve, ten, and nine years ago respectively, and are the oldest monitored enhancement sites on the river. A number of flood flow years combined with no new substrate recruitment may be having detrimental effects in terms salmonid spawning habitat. In August 2003 the area below the barrier fence will undergo gravel enhancement.

As alluded to previously, the upper two spawning sites had significant amounts of aquatic macrophyte biomass. The effects of the vegetation on spawning sites included velocity dissipation, matting over substrate and sedimentation associated with drops in velocity. While there was an observable increased trend in aquatic macrophytes throughout the approximately 10-mile spawning reach, the main apparent impact to spawning habitat was observed in the “catwalk” and “1999 enhancement” spawning sites. Within the catwalk site the number of redds dropped from 160 (16.3 % of total redds) in 2000 to 81 (9.6% of total redds) in 2001, and 57 (6.7% of total redds) in 2002. The 1999 enhancement site dropped from 30 (3% of total redds) in 2000 to less than one percent of total redds for both the 2001 and 2002 season (Figures 6 and 7). The influence of the macrophyte beds is apparent when comparing site selection of spawning chinook from 1999-2002. Since the vegetation began to take hold in 2000, the percentage of total redds in the catwalk area has dropped from approximately 16% to 8%. For the 2002 season the difference amounts to 59 redds. Additionally, since the vegetation has encroached in the upper spawning area the percentage of the run entering the hatchery has increased to over 70% (Figure 16). The catwalk site will undergo a rehabilitation project in Summer 2003 and will likely be free of aquatic vegetation. Depending on the Chinook salmon escapement numbers, the addition of new gravel will allow for analysis of the true impacts of aquatic vegetation on spawning site selection.
ACKNOWLEDGEMENTS

Thanks to the crew of Jose Setka, Bert Mulchaey, and Jacqueline Bishop who braved the sunny conditions week in and week out to collect the data for this report. Moreover, Bert and Jose were an integral part of the editing and preparation of this report. Thanks to EBMUD Fisheries and Wildlife staff who reviewed the document. Further thanks to all who drove our trucks from Camanche to Mackville for us. Also, thanks to Michelle Workman, Leigh Chan, Steve Boyd, and Christian Clausen.

LITERATURE CITED


Figure 1. Spawning Reaches - Lower Mokelumne River, CA.

- Spawning Reach 5
- Spawning Reach 6
- Sites/Points of Interest

Map showing major roads, Mokelumne River, and Camanche Reservoir. Key points include Lodi, Woodbridge Dam, and Pacific Ocean.
Figure 2. Daily fall-run salmon escapement recorded at Woodbridge Dam during 2002 spawning season and flows in the lower Mokelumne River, CA.
Figure 3. The estimated number of chinook salmon in-river spawners from 1994-2002 in the Mokelumne River, CA.

Sex ratios were not available for the 2001 spawning season.
Figure 4. Weekly fall-run chinook salmon redd construction observed by reach in 2000, 2001 and 2002 in the lower Mokelumne River, CA.
Figure 6. Spawning Gravel Enhancement Areas - Lower Mokelumne River, CA.
Figure 6. Percentage of total redds built in pre-1995 gravel enhancement areas within the lower Mokelumne River from 1991-2002.
Figure 7. Percentage of total redds built in post-1995 gravel enhancement areas within the lower Mokelumne River from 1994-2002.
Figure 8. Weekly number and percentage of redds superimposed during the 2002 chinook salmon spawning run, Mokelumne River, CA.
Figure 7. Usage and superimposition of enhancement areas in the Mokelumne River by fall run chinook salmon during the 2002 spawning season.

Figure 9. Usage and superimposition of enhancement areas in the Mokelumne River by chinook salmon during the 2002 spawning run (See Figure 5 for site locations).
Figure 10. Water temperatures and weekly redd counts during 2002/2003 Chinook salmon spawning run, Mokelumne River, CA.
Figure 11. Daily flow from 9/14/2002 through 3/1/2003 in the lower Mokelumne River, CA.
Redds may be associated with more than one cover type.

Figure 12. Percentage of total redds associated with each cover type within the lower Mokelumne River, 2002.

Cover Type

Can = Canopy
Ov = Overhanging Vegetation
Av = Aquatic Vegetation
Ub = Undercut Bank
Rw = Root Wad
Bo = Boulder
Tur = Turbulence
Lt = Lateral Bank
Lb = Lateral Bridge
Ov = Overhanging Vegetation
Can = Canopy

Percentage of Total Redds
Figure 13. Predicted date of emergence for chinook salmon fry in the lower Mokelumne River, CA during the 2002-2003 season.
Figure 14. Chinook salmon escapement estimates to the Mokelumne River, CA 1940-2002.
Figure 15. Estimated male to female ratio of river spawners with in the lower Mokelumne River, CA 1994-2002.

Ratio estimates for 2001 are not available.
Figure 16. Percent of total chinook salmon escapement entering Mokelumne River Hatchery 1990-2002.
Table 1. Estimated Lower Mokelumne River fall-run chinook salmon escapement: 1990-1997.

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<th>Year</th>
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