Fall-run chinook salmon and steelhead trout spawning survey, September 1998 through January 1999 Mokelumne River, California.

Jose D. Setka

East Bay Municipal Utility District, 500 San Pablo Dam Rd., Orinda, CA., 94563

Abstract: Weekly salmonid (chinook salmon *Oncorhynchus tshawytscha* and steelhead trout *O. mykiss*) spawning surveys were conducted in the lower Mokelumne River from September 1, 1998 through January 31, 1999. The estimated escapement during this period was 7,202 chinook salmon and 11 steelhead. The estimated number of in-river chinook salmon spawners was 4,112 fish. During the survey period 1,116 chinook salmon and 9 steelhead trout redds were observed. One hundred eighty four salmon (16.5%) redds were superimposed. The reach from Camanche Dam to Mackville Road contained 959 salmon redds (86.1%) and the reach from Mackville Road to Elliott Road had 153 redds (13.9%). Distinct differences in the use of spawning habitat between 1997 and 1998 were observed. These differences may be attributed to changes in population density and composition of the salmon runs.

INTRODUCTION

The 627 sq. mile 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 1.2 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 (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 45.8% of the total run per year (1990-1997 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 Scientist 1996). Data generated 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 1998 spawning survey was to enumerate chinook salmon 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 or density. Additional objectives included:

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

The following were 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. An emergence timeline was constructed based on an egg model developed by Vogel (1993) from Piper et al. (1982).

EBMUD has developed a Geographic Information System (GIS) for the LMR. This year's 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 data-set 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

METHODS

SURVEYS

The lower Mokelumne River is divided into 6 reaches between Camanche Dam and the confluence with the Sacramento-San Joaquin Delta. Reaches 5 and 6 cover a 15.8 km (9.8 mile) section of the river from Camanche Dam to Elliott Road. Beginning September 29, 1998 weekly redd surveys were conducted in the LMR from Camanche Dam to Elliott Road (Figure 2). The last survey was conducted January 26, 1999. The reaches were surveyed over a 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. During flows greater than 325 cubic feet per second (cfs) some areas were surveyed from the boat. Redds were marked using fluorescent pink, numbered bricks and locations were recorded using a hand-held Global Positioning System (GPS) unit (Trimble Pro XR) and a laser range finder. Individuals positioned themselves directly behind redds (on the tailspill) to have positions recorded with the laser range finder. Care was taken to avoid impacts to redds during the survey and with placement of bricks.

DATA COLLECTION

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

Levels of superimposition were recorded following the method described in Hartwell 1996 where:

> Level C = egg pocket of one redd superimposed on estimated location of egg pocket of a second redd. The percent of superimposition range (<25%, 25-50%, 51-75%, 76-100%) is estimated
>
> Level D = egg pocket of one redd superimposes egg pocket of two or more redds

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.

Habitat types were based on a geomorphic type habitat mapping scheme designed for the lower American River (Snider et al. 1992). There are four tiers to the mapping scheme: study reach, major channel features, channel feature types and habitat units. Full descriptions of the various components to these tiers are listed in Table 1.

DATA ANALYSIS

Data analysis was performed using ArcView, 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 August 19, 1998 through January 31, 1999 was 7,202 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:

2,887 adult females (54.0% of known sex fish)

2,459 adult males (46.0% of known sex fish)

386 unknown adults

1,470 unknown grilse (20.4% of total escapement)

In addition to chinook salmon, 11 adult steelhead trout (4 female, 7 unknown sex) were observed. California Department of Fish and Game uses the criteria of 40cm fork length to differentiate between steelhead and resident rainbows, with steelhead being greater than 40cm. The 1998 salmon run peaked during the last week in October and the first week in November (Figure 3). The highest single day migration took place on October 25 when 632 salmon passed WD.

Hatchery staff recorded 3,090 (42.9% of run) chinook salmon entering the hatchery during the 1998 spawning season. The sex and age composition of returning salmon was 1,311 adult females (42.4%), 1,194 adult males (38.6%) and 585 grilse (18.9%). By subtracting the hatchery count from the observed escapement at WD, there were an estimated 4,112 in-river spawners during the 1998 season. The 1998 total compares with 3,690 in-river spawners in 1997. Extrapolating the known sex ratio obtained from trapping at WD to the unknown fish at WD and subtracting the hatchery returns resulted in an in-river sex composition of 1,784 adult females (55.3% of adults), 1,443 adult males (44.7% of adults) and 885 grilse (21.5% of total in-river estimate and assumed to be greater than 90% male).

During the 1998/99 survey period 1,116 redds were observed. The first redd was observed on September 29, 1998. Redd construction peaked during the third week of November and lasted through January (Figure 4). Due to increased flows (>800cfs), surveys were discontinued at the beginning of February. Reach 6 contained 959 (86.1%) redds, while Reach 5 contained 153 (13.9%) redds. An additional 4 redds were located in the area of WD (S. Plummer (NRS) per. comm.). The season's redd count was less than the 1,325 redds observed in 1997.

Nine steelhead trout redds were observed during the 1998/99 surveys. Steelhead trout were observed on all 9 redds. The first trout redd was observed on 12/16/98. All of the redds were located in Reach 6 within the Mokelumne River Day Use Area (MRDUA) (Figure 2).

ENHANCEMENT GRAVEL USAGE

In 1998 505 (45.2%) redds were constructed in habitat enhancement areas (Figure 5). Habitat enhancement areas are depicted in Figure 6. Two sites were enhanced in 1998; Dock Island in the MRDUA and a site in Reach 5 adjacent to the George Reed gravel quarry. The number of redds constructed in the Dock Island area in 1998 (46) was nearly identical to 1997 (45). At the George Reed site the number decreased from 44 in 1997 to 14 in 1998. As a percentage of total redds, the number constructed in Reach 5 decreased from 16.1%(214 redds) in 1997 to 13.9%(153 redds) in 1998. The number of redds constructed in Reach 5 has decreased over the past 3 seasons. Consequently there has been an increase in the number and percentage of redds constructed in Reach 6.

Figure 7 depicts the percentage of total redds that were constructed in areas enhanced from 1990-1996. The use of areas enhanced since 1996 is presented in Figure 8. Enhancement areas located in Reach 6 have all experienced increases in use post-project. While there has been a trend of decreasing use of habitats in Reach 5, it also appears that the enhancement of habitats in the reach have not resulted in significant increases in use.

SUPERIMPOSITION

During the 1998 season 184 redds (16.5%) were superimposed. Ninety-four percent of redd superimposition (SI) occurred in Reach 6, while the remaining 6% occurred in Reach 5. During the peak of the run, weekly SI levels were 11% to 22% (Figure 9). Site specific superimposition levels varied from 30% at Murphy Creek to 0% at George Reed (Figure 5). The 1998 level of SI is an increase over the 12.5% of 1997 but is comparable to the 17% of 1996 (Figure 10). While there are only 8 data points, there appears to be some relationship between the number of in-river males and the level of SI (r^2=0.64). This relationship is more evident over the past three seasons. The relation between estimated in-river spawners and SI is slightly stronger (r^2=0.70).

ENVIRONMENTAL DATA

Water temperatures below Camanche Dam during the period of October 31, 1998 to January 31, 1999 ranged from 16.5°C to 9.5°C (Figure 11). During the same time period, water temperatures at Mackville Road ranged from 16.4°C to 9.1°C. Of the 1,116 redds, 333 were constructed when water temperatures were greater than 16.0°C, 963 were constructed at temperatures greater than 15.0°C and 153 were constructed at temperatures less than 15.0°C.

Releases from Camanche Dam during the survey period ranged from 335cfs on September 1, 1998 to 627cfs on January 31, 1999 (Figure 12). There were some variations in flow during the survey period to comply with Army Corp of Engineers flood control requirements. Releases were increased to 611cfs on December 10, 1998 and were reduced to 507cfs on January 22, 1999. Approximately 963 redds were constructed at the 325cfs release, while the remaining 153 observed redds were constructed between 500cfs and 600cfs. Prior to reducing flows on January 13-14, 1999 survey data were analyzed to determine what level of flow was needed to avoid impacting or dewatering any redds constructed at 600cfs. It was determined that a reduction to 500cfs would have no measurable impact (de-watering or elimination flow across redd) to any redds. This determination was confirmed by field observations.

REDD PHYSICAL CHARACTERISTICS AND HABITAT PREFERENCES

Habitat preferences

Although the number of in-river spawners increased in 1998 (4,112 fish) compared to 1997 (3,690), the total number of redds constructed and the use of key habitats decreased. The number and percentage of redds constructed in riffle and run habitats remained the same from 1997 to 1998 (Figure 13). However, there were decreases in lateral, transverse, mid-channel and channel spanning bar habitat use by chinook spawners (Figure 14).

There were 1,062 instances where cover was associated with individual redds (Figure 15). Many of these instances involved one redd associated with multiple cover types. The most common cover types used were canopy (27.8%), overhanging vegetation (25.5%) and LOD (20.6%).

Very few natural boulders are present within the channel of the LMR. As part of habitat enhancement projects from 1996 to 1998, boulders were placed in specific locations with spawning gravels. The boulders may provide refugia for salmonids and add stability to the gravel berms. Three boulders were placed at the Van Assen site and 2 were placed at the Mackville Road site in 1997, while 1 boulder was placed at Alder Island in 1996 and two at the Dock Island site in 1998. Redds were adjacent to each of the boulders at these sites in 1998. Four percent (45) of redds constructed in 1998 were associated with boulders compared to 1.2% (16) in 1997.

BEHAVIOR AND TAGS/MARKS

The number of salmon associated with a single redd ranged from 0 to 7. Of the 1,116 redds observed, 420 (37.6% of total redds) were active with at least one fish on the redd. There were 56 (5%) instances of more than 2 salmon on a single redd.

One ad-clipped salmon carcass was observed. The head was removed and bagged along with a label detailing size, sex and location of fish. The specimen was given to hatchery staff for coded wire tag recovery and reading.

EMERGENCE TIMELINE

It was estimated that fry began emerging from redds the week of December 13, 1998 and continued through April 27, 1999 (Figure 16). The peak of fry emergence was estimated to be the week of February 2, 1999. The first fry observed during seining surveys was on December 16, 1998, while the first fry captured in the rotary screwtraps at WD occurred on December 19, 1998 (traps installed December 15th).

DISCUSSION

The escapement of 7,202 salmon and total redd count of 1,116 in 1998 were the third highest in the 1990 to 1998 period (Figure 17). This year's escapement was 205% of the historical 1940-1998 average (Figure 18). Flow increases in late January 1999 did not allow for continued redd surveys and likely resulted in steelhead trout redd numbers being under counted.

Spawning salmon and redds were exposed to water temperatures in excess of 15°C and some to greater than 16°C. Temperature above 15°C are considered stressful and sub-optimal (Brett 1952, Hinze et al. 1956, Alderdice and Velson 1978, Healy 1979, Vogel and Marine 1991). While constant exposure to sub-optimal temperatures in a laboratory setting results in mortality levels of up to 50%, the effects on wild salmon within the river are not clear. Comparisons between the estimated number of outmigrants (measured at WD) and the percentage of the spawning/incubation period (approximately September through March) with average daily water temperatures exceeding 15°C from 1994-1998 indicated no relation (r^2=0.19) between the two in the lower Mokelumne River.

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 1994-1998 is depicted in Figure 19. This year's male to female ratio was 1.3:1, while in 1997 it was 0.5:1. The grilse component varied from 10% in 1997 to 20.4% in 1998. The average salmon size measured at WD decreased from 75cm in 1997 to 70cm in 1998 (Figure 20).

There were variations in the use of habitats by spawning chinook salmon between 1997 and 1998 that may be explained by changes in run composition. The use of key bar habitats decreased from 1997 to 1998, yet the estimated number of in-river spawners increased from 3,690 fish to 4,112 fish in the same period. Two run composition components that may have influenced the decline in habitat use were the number of in-river females and grilse. While the estimated number of in-river spawners increased from 1997, the estimated number of in-river females decreased from 2,316 in 1997 to 1,784 in 1998. Moreover, the percentage of grilse (predominantly male) within the spawning population increased in 1998. These two factors resulted in fewer redds constructed and likely influenced the decreased use of various habitat types. Adult female salmon are responsible for the construction of redds, so decreases in females lead to concurrent decreases in redd numbers. Grilse use already constructed redds by satellite spawning (males) or by superimposing (females) (Crisp and Carling 1989, van de Berghe and Gross 1989, Healy 1991, Wilson 1997). As the grilse component of a population increases it would be expected that the number of redds and the amount of habitat used would decrease. The decrease in habitat use (channel feature type) appeared to be evenly distributed among all habitat types (Figures 13 and 14).

Superimposition levels increased from 12.5% in 1997 to 16.5% in 1998 (Figure 9). Although the number of redds decreased from 220 in 1997 to 164 in 1998 within the Alder Island area, the percent of superimposition increased from 12.0 (26) to 13.4% (22). Distribution of redds along the Alder Island sites are depicted in Figure 21 for 1997 and 1998. The sex ratio and grilse composition of the 1998 run may explain the increase in superimposition. The increase in males can lead to increased competition for space. Females defend their immediate redd site while males defend larger territories and can displace other salmon (Healy 1991, Wilson 1997). Additionally, the increased grilse component of the 1998 run may have increased incidents of superimposition compared to 1997. The percentage of redds observed with more than 2 fish on them increased from 1% in 1997 to 5% in 1998. Although impacts of female grilse superimposition are minimal in terms of reduced egg survival, their opportunistic spawning strategy may increase SI levels (Crisp and Carling 1989, van de Berghe and Gross 1989). An additional component to the increased SI, related to the grilse population levels, is the average size of the fish. Larger fish can more readily use areas of larger substrate and greater velocities than smaller fish. In the Alder Island area, there was more usage of the center portion of the channel in 1997 (larger fish) than in 1998 (Figure 21). The center portion of the channel has higher velocities, depths and larger substrate. Overall there has been an upward trend in SI since 1991 resulting from the upward trend in salmon escapements. From 1995 to 1998 the variations in the SI level appear to coincide with the number of in-river males (Figure 10).

The addition of enhancement gravels may also reduce superimposition through the expansion of spawning habitat. Enhancement areas, especially in Reach 6, have experienced consistent increases in the percentage of total redds built within the sites (Figures 7 and 8). National Marine Fisheries Service recently proposed that fall-run chinook salmon be listed under the Endangered Species Act (63 FR 11482, March 9, 1998). One of the concerns expressed in the listing proposal is a possible over-reliance on hatchery production. Spawning habitat enhancement is a relatively low cost way of reducing reliance on hatchery production, while increasing the quality and survival of natural production. Enhancement gravel projects provide high-quality spawning habitat with transition zones resulting in higher substrate permeability desirable for spawning chinook salmon (Healy 1991, Vronskii and Leman 1991, Merz 1996). These same areas provide rearing habitat for juvenile fish and substrate for invertebrate production.

In 1998, as with past years, spawning salmon in the Mokelumne River showed preferences for structure and cover in the form of LOD, various bars, boulders, overhanging vegetation, undercut banks, and water depth, presumably to provide cover from predators, sunlight, and flows. Additionally, LOD and boulders provide structural enhancement in gravel bars, assist in preserving the bars and berms, and allow for pool formation that provides thermal refugia for fish (Bisson et al.1987, Beechie and Sibley 1997). Structure is particularly important in streams below dams where natural gravel and LOD recruitment have been eliminated or reduced (Maser and Sedell 1994). Not only do gravel bars provide cover, they are used extensively by spawning chinook salmon due to their high permeability (Leman 1988). In 1994 and 1997 redds associated with LOD were deeper than those without (Merz 1996). LOD may provide distinct advantages in areas that would otherwise be too deep for chinook spawners. In addition to the benefits listed above, velocities would be increased in areas surrounding LOD as would substrate permeability. There was also 100% use of habitat adjacent to boulders placed within the river. It is clear that structure is an integral part of salmonid spawning habitat in the LMR and should continue to be part of any enhancement project.

Comparisons of 1997 and 1998 runs suggest that run composition may play an important role in the use of available spawning habitat. When developing indices for carrying capacities of river systems, variation due to run composition should be incorporated. Carrying capacity should be a range that is dependent on the density and composition of a run. It should also be realized that absolute capacity numbers are almost impossible to calculate in advance due to unknowns regarding run composition.

Survey results from this year indicate the positive nature of enhancing habitat within areas of high spawning densities. Fifty percent of spawning activity from 1994 to 1998 occurred in the approximately 1.6 mile section below Camanche Dam. The heavy use of this section is likely the result of the behavioral aspects of the salmon in which individuals try to go as far up a river system as they can. Enhancement areas in Reach 6 have shown consistent increases in their use while those in Reach 5 have had more variable usage. Therefore, to reduce competition for spawning habitat, a majority of the spawning habitat enhancement effort should be focused on the two-mile section below Camanche Dam.

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