LOWER MOKELUMNE RIVER CHINOOK SALMON (*Oncorhynchus tshawytscha*) SPAWNING SURVEY REPORT FOR FALL/WINTER 1997

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INTRODUCTION

The 627 sq. mile Mokelumne River watershed ranges from the Sierran Crest to the Sacramento - San Joaquin Delta. Pardee and Camanche reservoirs are located on the Mokelumne River (Figure 1) and 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) as part of their Upper Mokelumne River Project. The PG&E project includes 19 dams, 7 storage reservoirs, 7 diversion facilities, 3 regulating reservoirs, 2 forebays, and other associated structures (F.E.R.C. 1993). 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 (*O. mykiss*) for spawning and rearing. Adult chinook salmon ascend the river as early as August and may begin spawning in September. The peak of the run usually occurs in November and tapers off through the month of December (Hartwell 1992-1996; Setka 1997, Marine and Vogel 1994, 1996). In addition to the in-river spawning, the Mokelumne River Fish Installation (MRFI), 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 conducting annual spawning surveys in the lower Mokelumne River since 1990 (Hagar 1991, Hartwell 1996, Setka 1997). Concurrently with these surveys, EBMUD enumerates chinook salmon escapement at Woodbridge Dam (WD) (Biosystems 1992, NRS 1996). Data generated from WD monitoring and MRFI returns allow for an estimation of the number of chinook salmon within the LMR at any time.

OBJECTIVES

The primary objective of the 1997 spawning survey was to enumerate chinook salmon redds in the LMR. With the escapement data from WD and MRFI, an estimate was obtained for the total escapement to the river, which is used to associate the number of redds and their characteristics with the population level or density. Additional objectives included:

- Map locations of individual redds.
- Determine spawning preferences for salmon: stream velocity, nose velocity, depth, substrate, and distance from shore.
- Determine average redd size and area.
- 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 usage levels of enhancement gravel areas.

Summaries of the following notes and observations were prepared:

- Visible injuries to salmon, attached fishing gear, adipose clips or tags.
- Behavior and numbers of salmon associated with redds.

A summary of environmental parameters and flow for the spawning period was compiled. 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. The system has been used for the development of a flood-plain model, vegetation map and an aquatic habitat map of the Mokelumne River from Camanche Dam to Elliott Rd. This year's results were compared to past years 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. Some of the results generated by the GIS include:

- Spatial distribution of redds.
- Temporal distribution of redds within specific areas.
- Total area used by spawners.
- Relationship of redd spatial distribution to run size or age composition.
- Habitat associations of salmon spawning.

METHODS

SURVEYS

Beginning October 1,1997, weekly redd surveys were conducted in the LMR from Camanche Dam to Elliott Road (Figure 2). The last full weekly survey was conducted December 31, 1997. A 9.76 mile section of the river, Camanche Dam to Elliott Road, was surveyed over 2 days each week. The river is broken up into three distinct reaches: A (Camanche Dam to Highway 88, 2.95 miles), B (Highway 88 to Mackville Rd., 1.66 miles), and C (Mackville Rd. to Elliott Rd., 5.15 miles) (Figure 2). Surveys consisted of three individuals walking abreast down the river (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 (Fritsch 1995, Hartwell 1993-1995, Keefe et al. 1994, Setka 1997). A boat was used to transport surveyors between spawning areas. Redds were marked using fluorescent orange-colored, numbered bricks and locations were recorded using a Global Positioning System (GPS) hand-held unit (Trimble Pro XR).

DATA COLLECTION

Quantitative data collected, instruments used and description of data are listed in Table 1. In addition to the quantitative data, qualitative notations were made regarding the characteristics and locations of redds. These measurements include: redd type, dominant substrate size, level of development, cover type, structure (LOD, berm, groin), number of fish associated with each redd, and other information that could influence redd construction. Redd type is based on the shape and characteristics used by Burner (1953):

C = Classical oval shape.

L = Longitudinal shape; stretched out, usually made in fast water.

S = Scattered shape with no discernible tail-spill. Usually associated with small substrate and low flows.

P = Redd constructed perpendicular to the flow, usually on berm.

Level of development rankings are based on descriptions given by Burner (1953) in Hartwell (1995). They are as follows:

1 = definite depression but no discernible area of deposition (egg pocket).

2 = some discernible area of deposition.

3 = egg deposition well underway (from observation of female and/or size of redd).

4 = egg deposition nearly finished (from observation of female and/or size of redd).

5 = deposition completed, female may be wandering in the area and digging sporadically without depositing eggs.

Only redds of levels 4 and 5 had their corresponding data recorded. Redds of a 1 to 3 level were noted and data were collected if and when they were sufficiently developed.

Levels of superimposition were recorded as follows (Hartwell 1996):

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.

Dominant substrate sizes were based on size categories ranging from sand to large cobble (Table 2) and were visually estimated (Bovee and Milhous 1978). Physical and environmental parameters were measured and recorded using a variety of instruments. Water temperatures were monitored through the use of hand-held thermometers, Campbell data loggers (Campbell Scientific Inc., USA), and dissolved oxygen/temperature meter (YSI Inc., USA). Along with temperature, the Campbell data loggers (Figure 2) 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 3. The focus of the geomorphic habitat mapping scheme is on the structure of the river channel and bottom. Structure provides the transition areas chinook salmon prefer for spawning (Vronskii 1972, Vronskii and Leman 1991, Healy 1991).

DATA ANALYSIS

Heavy precipitation during the fall resulted in flow increases on the LMR from November 22, 1997, to the completion of the spawning survey, and varying physical conditions (depth, velocities) during construction of individual redds. Therefore, the possibility existed for an individual salmon to choose an area for specific habitat criteria that was later altered due to flow increases. One of the objectives of the survey was to identify spawning habitat preferences. For redds surveyed during or directly after a flow increase, the data may misrepresent the true habitat preferences chosen by the salmon. To ensure accurate habitat preference analysis, only data on redds constructed and surveyed during periods of stable flows were used for statistical analysis of parameters that could be impacted by flow changes (e.g. nose velocities, depths, etc…).

Redd locations were downloaded from the GPS unit into the GIS system on a weekly basis. Data analysis was performed using ARCVIEW and ARCINFO (ESRI) systems. Statistical analysis was done using Lotus 123, (Lotus Development Corp.), Statgraphic (Manguistics Inc.), Excel (Microsoft Corp.) 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 flow of 202cfs) with a 1:4,800 scale.

RESULTS

ESCAPEMENT AND REDD NUMBERS

Total escapement to the Mokelumne River from September 1 through December 31, 1997 was 10,175 chinook salmon (adults and grilse). Counts were based on video monitoring, trapping and salmon rescued from spillbay basins (methodologies detailed in NRS 1994). The composition of the run was as follows: 3,207 adult females (56.8% of known sex adults), 2,437 adult males (43.2% of known sex adults), 3,799 unknown adults, 36 grilse females, 110 grilse males and 574 grilse unknown. In addition to chinook salmon, a total of 23 steelhead were observed. Only two of the steelhead were classified as adults (>40cm fork length). The remaining steelhead were classified as sub-adults, possibly 'half-pounders' (sexually immature steelhead that spend less than a year in the ocean) or migrating resident trout. This year's salmon run peaked the last week of October through the second week of November. The highest daily migration counts occurred on October 25, 1997 when 812 salmon passed WD. The total migration of 10,163 chinook salmon is the highest since EBMUD monitoring programs began in 1990 and the initiation of

Lower Mokelumne River Management Plan (LMRMP) (Biosystems 1992) in 1992 (Figure 3).

MRFI staff recorded 6,485 chinook salmon entering the hatchery during the 1997 spawning season. The sex and age composition was 3,227 (49.7%) adult males, 3,070 (47.3%) adult females, and 188 (2.9%) grilse. By subtracting the hatchery total count from the NRS WD total count, there were an estimated 3,690 in-river spawners for the 1997 season. In comparison, the in-river spawner estimate for 1996 was 3,887 (24% adult male, 23% adult female, 53% grilse). Extrapolating the known sex ratio of salmon recorded at WD to the unknown portion of the WD count resulted in an estimated in-river spawning composition of 848 (21.9%) adult males, 2,316 (59%) adult females and 485 (9.9%) grilse (Table 4).

A total of 1,325 redds were found during the 1997 survey period. The first redd was observed on October 6, 1997. Redd construction peaked during the third week of November and lasted through December (Figure 4). Additional spawning activity was observed during fish community surveys in January 1998. However, due to flows, enumeration was difficult. Redd construction per reach by week is depicted in Figure 5. Reach A contained 936 (70.6%) of the redds, reach B contained 172 (13.0%) and reach C contained 214 (16.1%). Three redds were observed in the area surrounding WD and are included in the total count. This year's redd count surpassed the previous high of 929 redds in 1996 (survey ended first week of December 1996 due to high flows).

ENHANCEMENT GRAVEL USAGE

A total of 508 (38.4%) redds were constructed in areas of gravel enhancement, which is an increase over the 283 (30.5% of total redds) of 1996 (Figure 6). Enhancement sites are depicted in Figure 2. Three new sites were enhanced in August 1997: Mackville Road, Van Assen, and Sutter's property (Figure 7). While no spawning activity was ever observed at the Van Assen site in the survey period from 1990 to 1996, a total of 22 redds were constructed there in the 1997. Additional spawning activity was seen in the Van Assen area after December 31, 1997, however it was not possible to quantify numbers of additional redds due to high flows. Anglers reported observing salmonid spawning activity and capturing *O. mykiss* in the enhancement site (J. Merz per. com.). From 1996 to 1997 spawning activity increased slightly in the Sutter enhancement area from 15 to 21 redds, while the Mackville Road enhancement area saw a reduction in the number of redds (17 to 6 redds). There was an overall increase in the use of reach A in 1997 (70.6% of total redds), with correspondingly lower redd counts in the reaches B and C.

SUPERIMPOSITION

One hundred seventy-seven redds (12.5%) were superimposed during the 1997 season. A total of 77% of superimpositions occurred in reach A, 12% in reach B and 11% in reach C. Site specific levels of superimposition varied from none to 17%, the highest level occurring adjacent to the fish barrier below MRFI (Figure 8). This year's overall superimposition level is lower than the previous high of 17% observed in 1996 (Figure 9).

ENVIRONMENTAL DATA

Water temperatures ranged form 14.9°C to 10.3°C at Mackville Road during the 1997 survey (September 1 to December 31) (Figure 10). During the 1996 season, water temperature ranged from 16.1°C to 11.8°C at Mackville Road during the same period. None of the 1,325 redds constructed in 1997 were exposed to the upper level of the sub-optimal temperature range 15°C - 16°C (0 to 50% mortality) (Alderdice and Velson 1978, Brett 1952, Healy 1979, Hinze et al. 1956, Vogel and Marine 1991). Ninety-five percent of 1997 redds were constructed between water temperatures of 14°C to 15°C (Figure 10). The remainder were constructed at ≤14°C.

Camanche Dam releases during the survey period varied from 325 cfs September 1, 1997 to 600cfs December 31, 1997 (Figure 11). A total of 857 redds were constructed at a flow of 325cfs, while the remainder of observed redds were built at 450-600 cfs. In 1996 flows ranged from 325cfs to 3,000cfs during the same period. Water clarity ranged from 63 cm to 210 cm in reach A and 62 cm to 240 cm in reach C. The lowest clarity reading from 1996 was 137 cm.

REDD PHYSICAL CHARACTERISTICS AND HABITAT PREFERENCES

REDD AREAS AND DISTANCES, STREAM AND NOSE VELOCOTIES, DEPTHS

The average redd size in 1997 was 123 ft^2. Average sizes for reaches A, B and C were 122, 116, and 128 ft^2 respectively. There were no significant differences in size between reaches (KW=0.9739, P=0.61). In 1996 the average redd area was 106 ft^2. While there were no significant differences in size between 1996 and 1997 (F=0.78, P=0.3778), there are significant differences when areas are sorted based on flows. When areas are broken down based on three flow groups, 325 cfs, 450 cfs and 600 cfs, there were significant differences between the 325cfs group and the other two (F=3.10, P=0.0484). Redds constructed at 325 cfs were significantly larger than those of the other two flow groups. Average stream velocity per redd was 2.02 ft/s (Figure 12). There were no significant differences in stream velocities between reaches (F=0.91, P=0.4081). Nose velocities averaged 1.12 ft/s and the average depth was 1.56 ft (Figure 13 and 14). There were no significant differences between reaches in nose velocity (F=0.71, P=0.4983) or depths. There were no significant relationship between redd area and nose velocity (F=0.73, P=0.3980) or stream velocity (F=0.51, P=0.4788).

Distances between redds were analyzed non-temporally and temporally. Non-temporal distance analysis involved using nearest neighbor distances between redds to generate average minimum distances. Temporal distance analysis involved determining nearest neighbor distances of each redd within the first three weeks after construction to generate average minimum distances. Temporal analysis attempts to account for nest defense behavior of salmonids and residency times (Quinn and Foote 1994, Stearley 1992, van den Berghe and Gross 1986, 1989, Wilson 1997). Comparing non-temporal distances between redds in 1996 and 1997, there were significant differences (F=4.54, P=0.0332). Spacing of redds was significantly closer in 1997 (5.1 m, SD=0.2m) compared to 1996 (5.7 m, SD=0.2m) (Figure 15).

Summary statistics for redd physical parameters are contained in Table 5.

Habitat preferences

Changes in the use of specific habitat types were observed as the estimated in-river spawning population decreased from 3,887 to 3,530 during the 1996-97 period. The number and percentage of redds constructed in riffle and run habitats increased from 1996 to 1997 (Figure 16). Additionally, there were increases in lateral, transverse, mid-channel and channel spanning bar habitat use by chinook spawners (Figure 17). The percent of total available area (based on average 100 ft^2 redd size) used in habitat units and channel feature types in 1997 are depicted in Figure 18 and 19.

Use of cover types varied between the beginning and end of the run (X^2=43.31, P<0.0001). Turbulence and canopy were used more than expected in the beginning of the run, while LOD and overhanging vegetation were used more in the second half of the run. Overall, there were more redds associated with cover in the second half of the run than in the first half (X^2=10.05, P=0.0015). Canopy, LOD and overhanging vegetation were the most used cover types (Figure 20). There were no significant differences in nose (F=0.22, P=0.64) or stream (F=0.05, P=0.83) velocities when compared to presence or absence of LOD. However, there was a significant difference in depth when compared to presence or absence of LOD (F=4.33, P=0.0433). Redds associated with LOD were significantly deeper than those without.

As part of habitat enhancement projects in 1996 and 1997, boulders were placed with spawning gravels. 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. Redds were associated with each of the boulders at these sites in 1997.

BEHAVIOR AND TAGS OBSERVED

Numbers of fish seen on a redd at one time ranged from zero to seven fish. There were 16 instances of more than two fish seen on a single redd. As a comparison, in 1996 there were 38 instances of more than two fish on a redd. NRS tagged approximately 500 of the salmon passing WD with Peterson disc tags. A total of 14 disc-tagged fish were seen in the river during the survey period. Tag data was collected and reported to NRS staff.

EMERGENCE TIMELINE

Fry emergence was estimated using the egg model and river temperature data. It was estimated that fry began emerging the week of December 7, 1997 and continued through March 4, 1998. The first chinook fry was collected December 6, 1997 during seining as part of the fish community survey (J. Merz pers. com.). Peak emergence was estimated to occur during the week of January 30, 1998 (Figure 21).

DISCUSSION

The escapement of 10,175 salmon and total redd count of 1,325 in 1997 were the highest in the 1990 to 1997 period (Figure 3). This year's escapement was 295% of the historical 1940-1997 average (Figure 22). A total of 6,485 chinook entered the MRFI, leaving an estimated 3,690 in-river spawners. A significant correlation was observed between number of redds and total escapement (R^2=0.94) during the 1990-1997 period (Miyamoto and Hartwell 1998). Additionally, during the 1990-1997 period hatchery returns and spawning escapement were significantly correlated (R^2=0.97). Using the following regression equations based on 1990-1996 data;

$$\text{Escapement} = (210.349+1.722) \times \text{hatchery return}$$

$$\text{Escapement} = (-279.99+6.045) \times \text{redds observed}$$

estimated escapement in 1997 based on redd observations was 7,731and 11,377 based on hatchery returns. The prediction based on hatchery returns appears to be more accurate. NRS and WID staff indicated that numerous salmon passed WD during the board pulling activity in November, therefore the actual escapement number is greater than 10,163 and closer to the prediction based on hatchery returns.

Composition of a run can play a role in 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 involves the ratio of males to females, total population, temporal density and the grilse component. Figure 23 denotes the male to female ratio from 1994-1997. Note that the 1997 ratio was 0.5, while in 1996 it was 1.6. In 1997 the grilse component was less than 10%, while in 1996 it was greater than 40%. As would be expected, the average size of fish was significantly smaller in 1996 when compared to 1997 (Figure 24).

As noted in the result section, redds were significantly closer in 1997 when compared to 1996. Also, there were notable differences in the usage patterns of riffle and run habitats. Riffle and run habitats were used more in 1997 when compared to 1996 (Figure 15). Likewise, there were differences in channel feature type usage (Figure 16). The larger average size of fish in 1997 could have resulted in larger redds being built, yet there were no significant differences in redd sizes between 1996 and 1997. One explanation for the difference in habitat usage involves spawning behavior of grilse. Many grilse satellite spawn (wait in the surrounding redd area for an opportunity to sneak in and deposit milt while the male is occupied) into already constructed redds (Healy 1991, Wilson 1997). While in-river spawner estimates were nearly equal for 1996 and 1997, the minimal grilse component and resulting decrease in satellite spawning of the 1997 run may explain the increased usage of habitat units and feature types. Additionally, the substrate requirements of grilse are different than adults in terms of size (smaller for grilse) and velocities (less oxygen needed and metabolic wastes produced). These differences are due to the limitations that grilse have in moving larger substrate and their smaller egg size (Foote 1989, Flemming and Gross 1990, Beacham and Murray 1993). Not only are grilse able to use areas that are less than optimal (in terms of adult habitat needs), but these areas also allow for increased success in egg deposition due to decreased losses from stream velocities (eggs being swept away by current) (Vronskii and Leman 1991). Defense of prime habitat and females by adult males may further act to force grilse to spawn in less than optimal areas (Flemming and Gross 1994, Groot and Morgolis 1991, Healy and Prince 1995). The combination of behavioral aspects (spawning strategies, territorial competition) and habitat needs of grilse may explain the different habitat usage patterns between 1996 and 1997.

Superimposition (SI) levels decreased from 17% in 1996 to 12.5% in 1997 (Figure 9). The Alder Island area usually has a high redd density and superimposition level. Although the number of redds nearly doubled from 120 in 1996 to 220 in 1997, the percent and number of superimposition dropped to 12.0% (26) from 16.7% (20). Distribution of redds along the Alder Island sites are depicted in Figure 25 for 1996 and 1997. The sex ratio and grilse composition of the 1997 run may explain the reduction in superimposition, although the in-river population was essentially the same in 1996. There was approximately double the number of females to males in 1997 (male to female ratio of 0.5) when compared to 1996 (Table 4). The lower male to female ratio may have minimized territorial competition between males due to the abundance of females. While females defend their redd site, males defend larger territories and can displace other salmon (Wilson 1997, Healy 1991). Additionally, the small grilse component of the 1997 run may have reduced incidents of superimposition compared to 1996. Although impacts of 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 reduced SI, related to the lack of grilse, is the average size of the fish. Larger fish can more readily use areas of larger substrate and greater velocities. In the Alder Island area, there was more usage of the center portion of the channel in 1997 than 1996.

The addition of enhancement gravels over time may also play a role in the reduction of superimposition through the expansion of optimal spawning habitat. There were 22 redds constructed at the Van Assen site that was enhanced prior to the run in 1997. Although it is difficult to say exactly where these fish would have spawned had that location not been suitable, spawning density at some other site more than likely would have increased and possibly lead to more superimposition. 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 (Vronskii and Leman 1991, Healy 1991, Merz 1996).

Spawning chinook salmon show preferences for structure and cover in the form of large organic debris (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 (Beechie and Sibley 1997, Bisson 1987). 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 1997 and 1994 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 those benefits listed above, velocities would be increased in areas surrounding LOD as would permeability. There was also 100% use of habitat surrounding boulders placed within the river. It is clear that structure is an integral part of salmonid spawning habitat in the LMR and should continued to be part of any enhancement project.

Comparisons of 1996 and 1997 runs suggest that run composition may play an important role in how available spawning habitat is used. When developing indices for carrying capacities of river systems, compositions of runs should be incorporated. It should also be realized that absolute capacity numbers are almost impossible to calculate in advance due to unknowns regarding run composition. Additionally, survey results from this year indicate the positive nature of enhancing habitat within areas of higher spawning densities. Fifty percent of spawning activity from 1994 to 1997 occurred in the approximately 1.6 mile section below Camanche Dam. Therefore, to reduce competition for spawning habitat, a majority of the spawning habitat enhancement project effort should be focused on the two-mile section below Camanche Dam.

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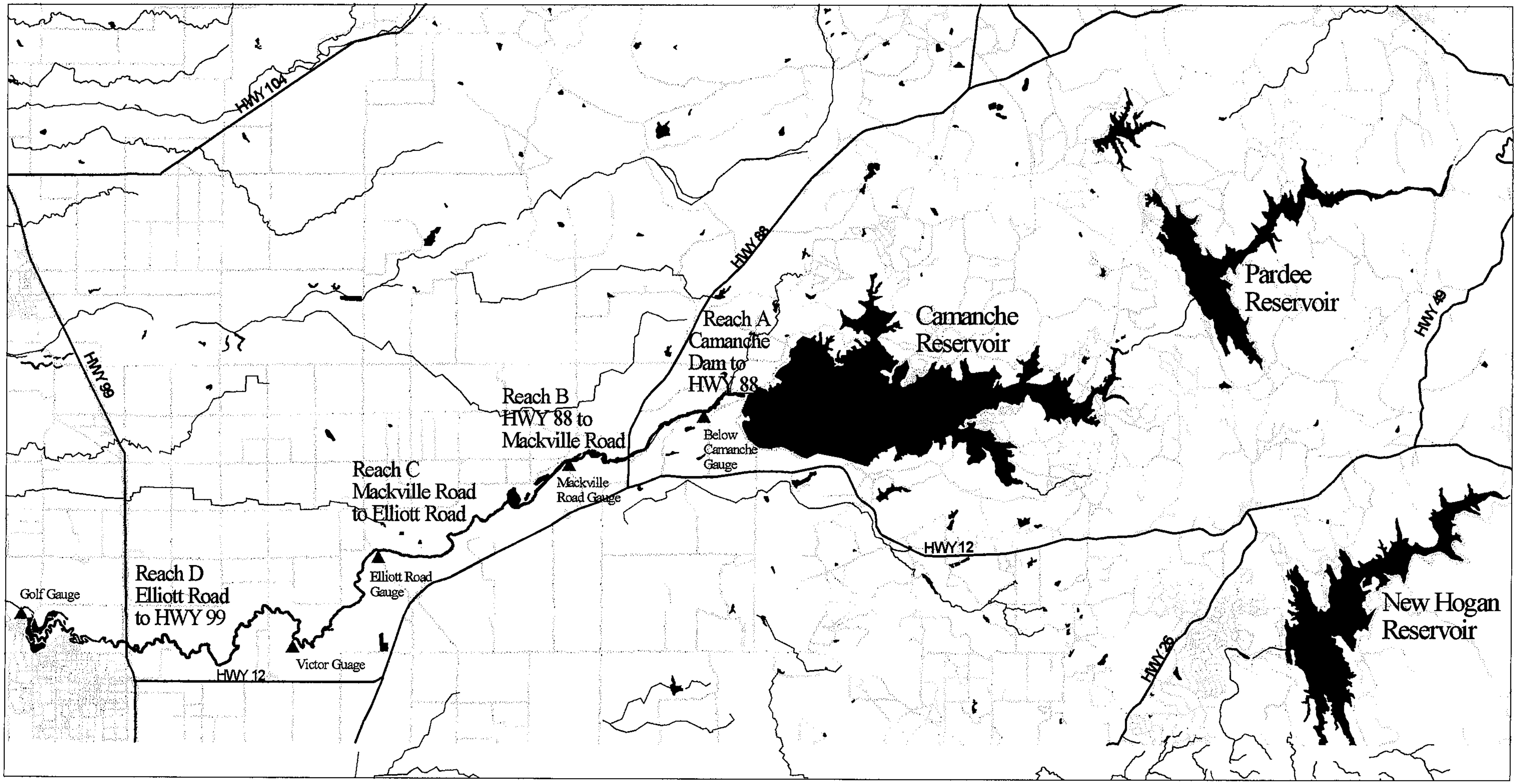
Figure 1. Spawning Reaches and Gauging Stations - Lower Mokelumne River



Sources: 1/4800 Photogrammetry and 1/24000 USGS Quadrangles

East Bay Municipal Utility District (EBMUD)
500 San Pablo Dam Road, Orinda, CA 94563-1604

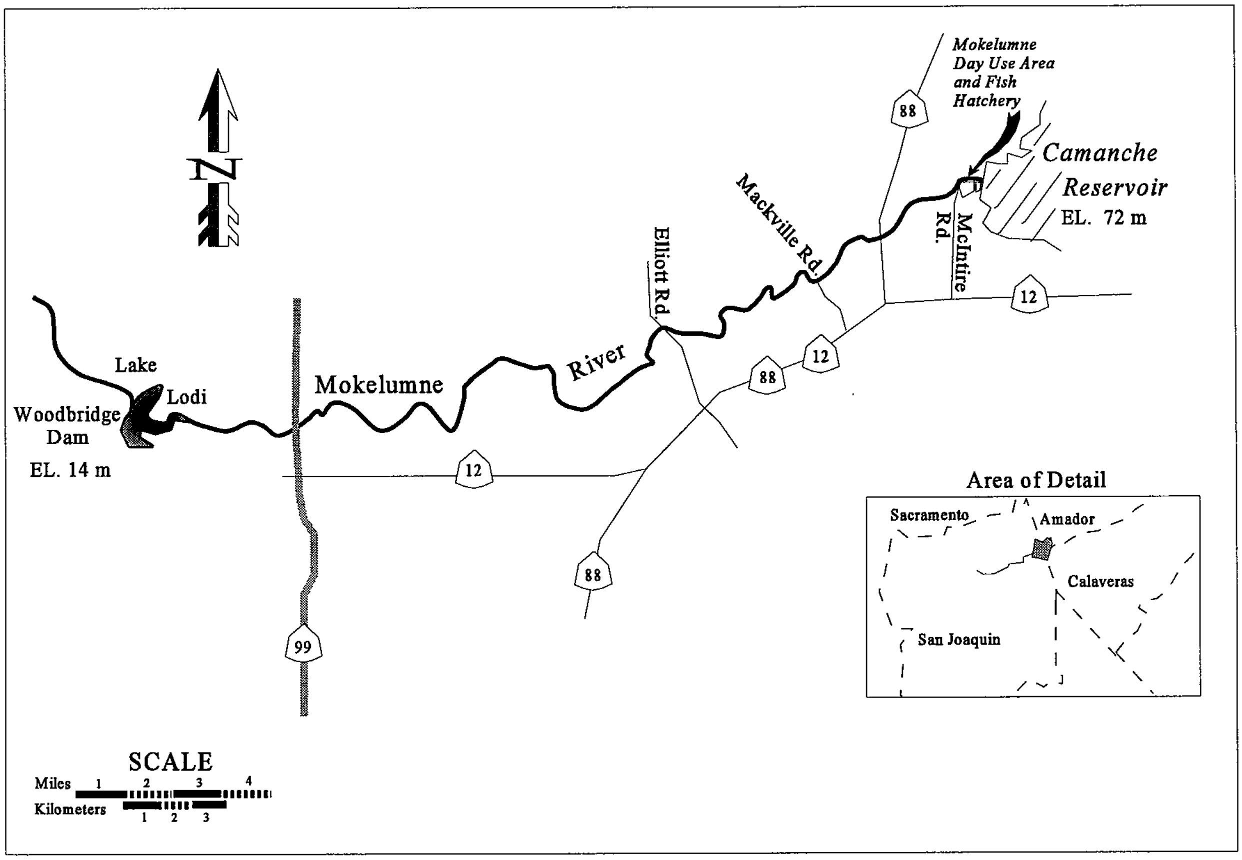


Figure 2. The lower Mokelumne River between Camanche Dam and Woodbridge Dam. San Joaquin County, California.

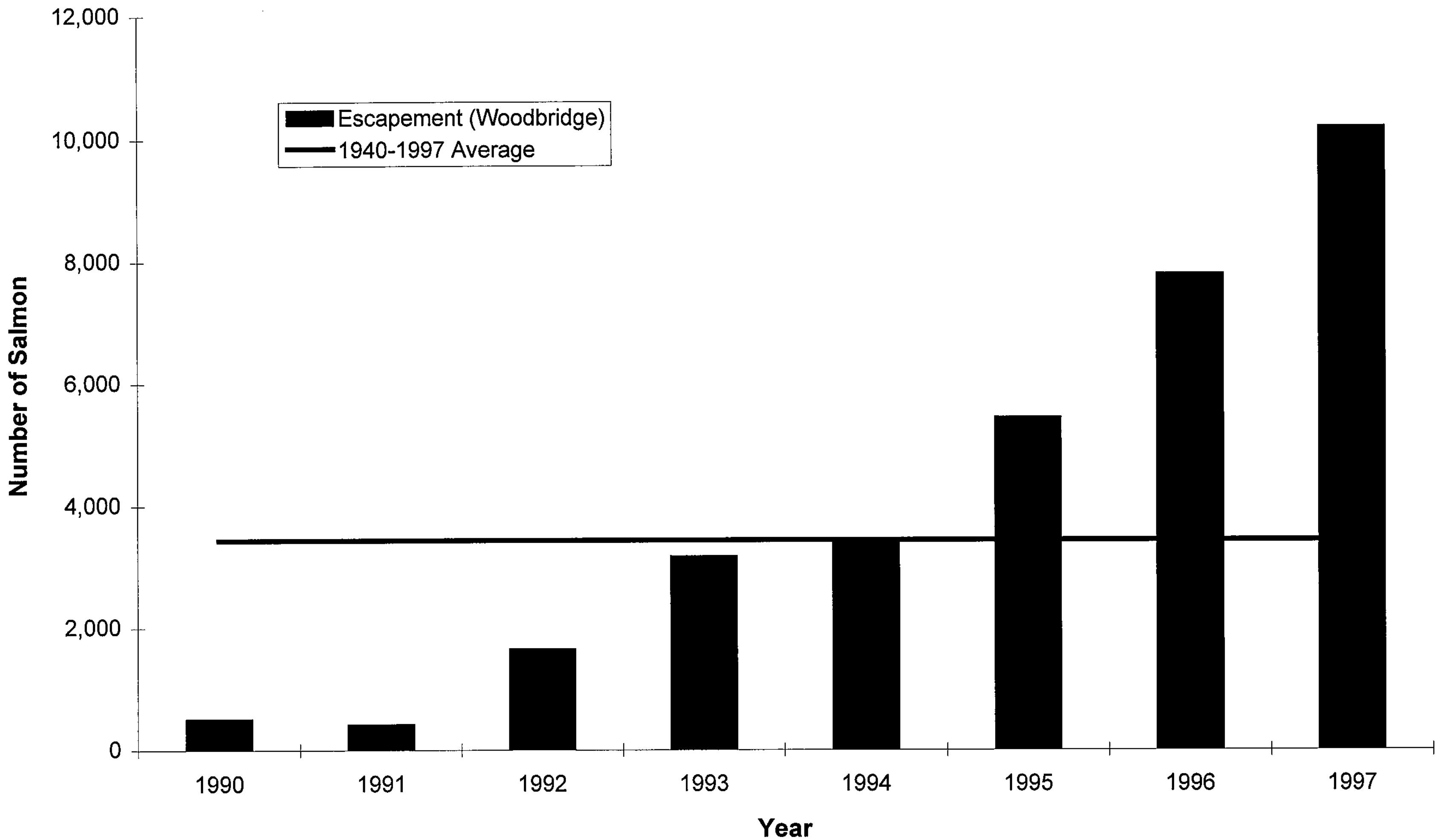


Figure 3. Lower Mokelumne River fall-run chinook salmon escapement pass Woodbridge Dam from 1990 through1997.

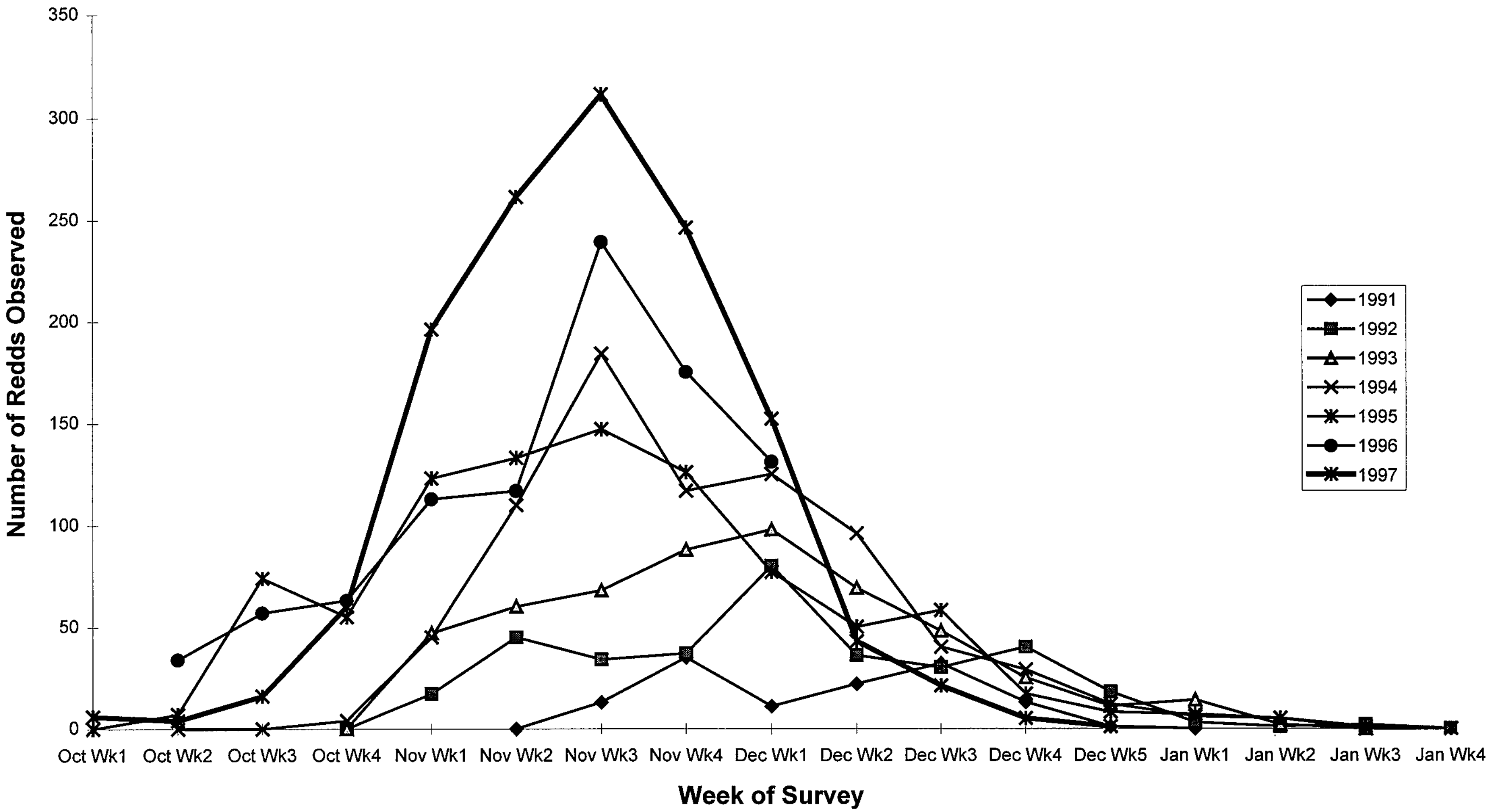


Figure 4. Chinook salmon redds built per week 1991-1997, lower Mokelumne River.

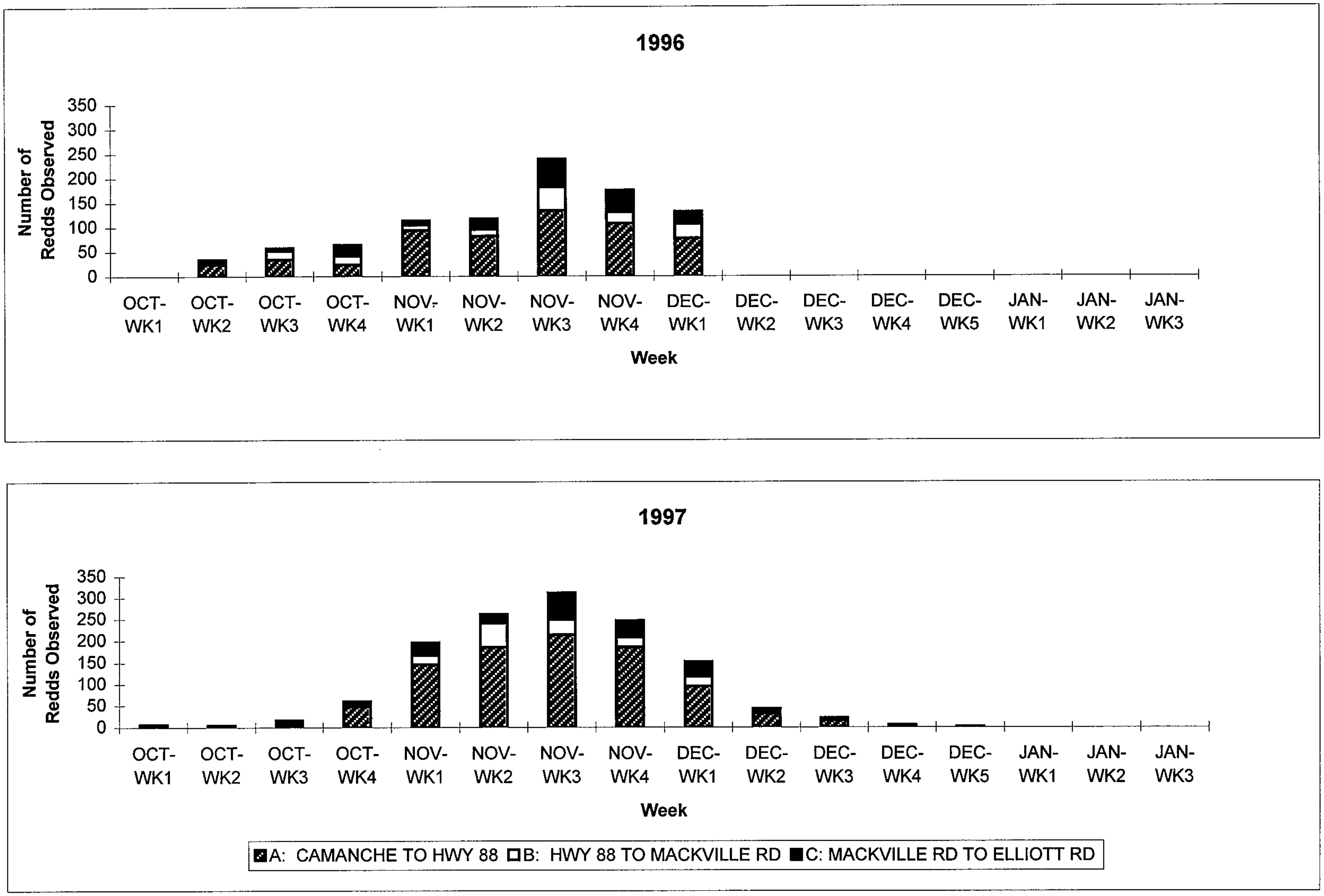


Figure 5. Fall-run chinook salmon redd construction observed by reach 1996 and 1997, lower Mokelumne River.

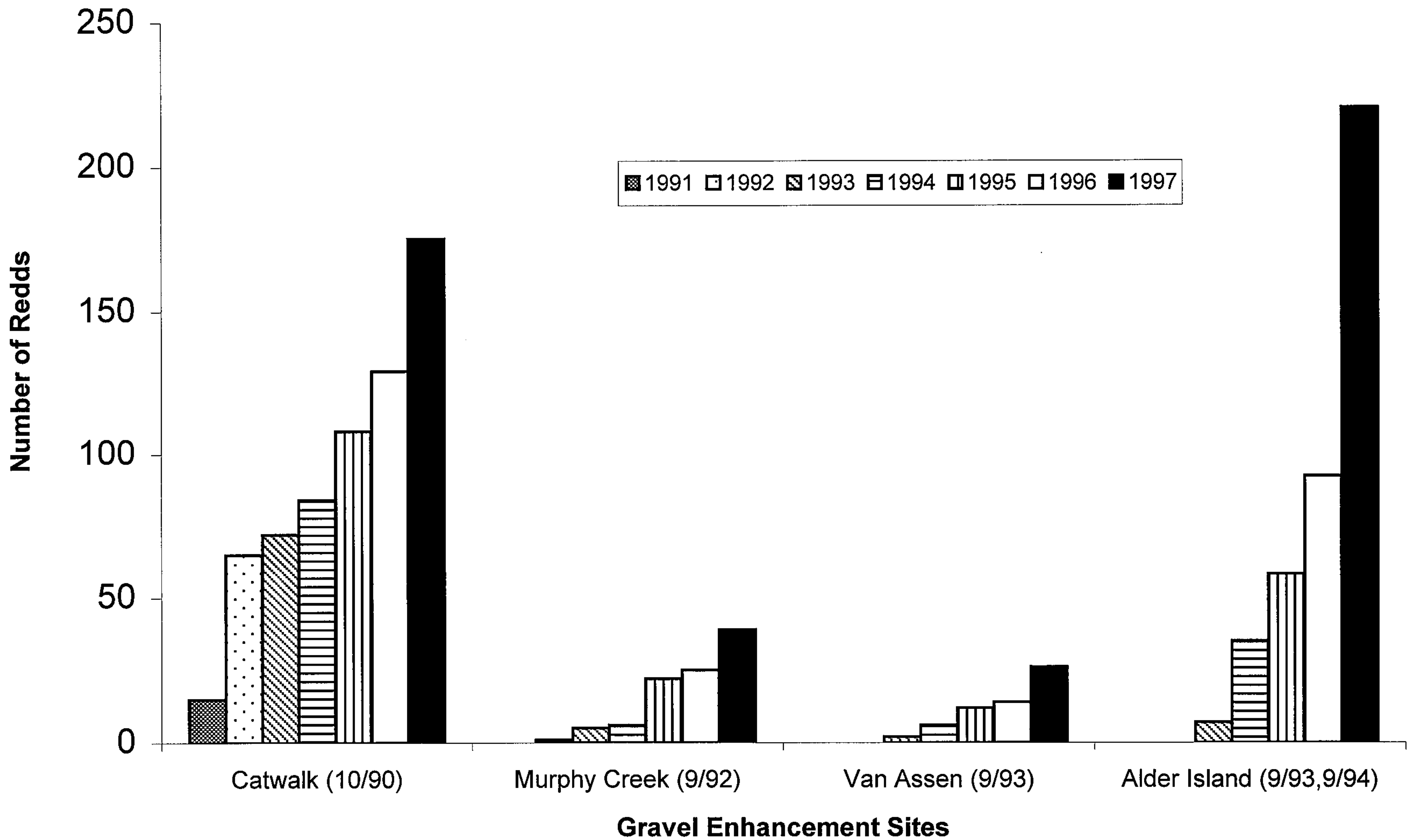


Figure 6. Number of redds built in gravel enhancement sites 1991-1997, lower Mokelumne River. (Dates within parenthesis are dates of enhancements)

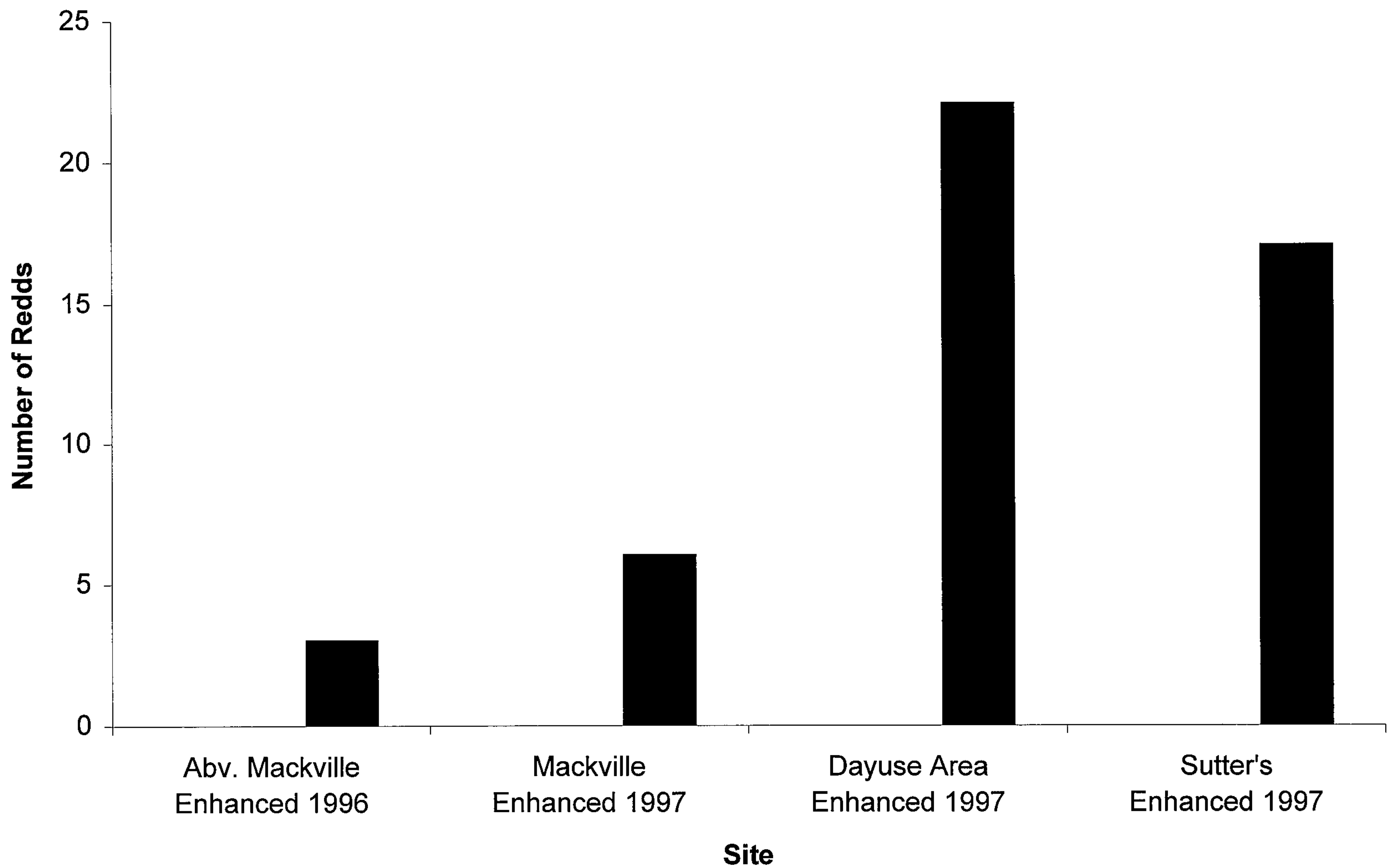


Figure 7. Number of fall-run chinook salmon redds built in recent enhancement sites in 1997, lower Mokelumne River.

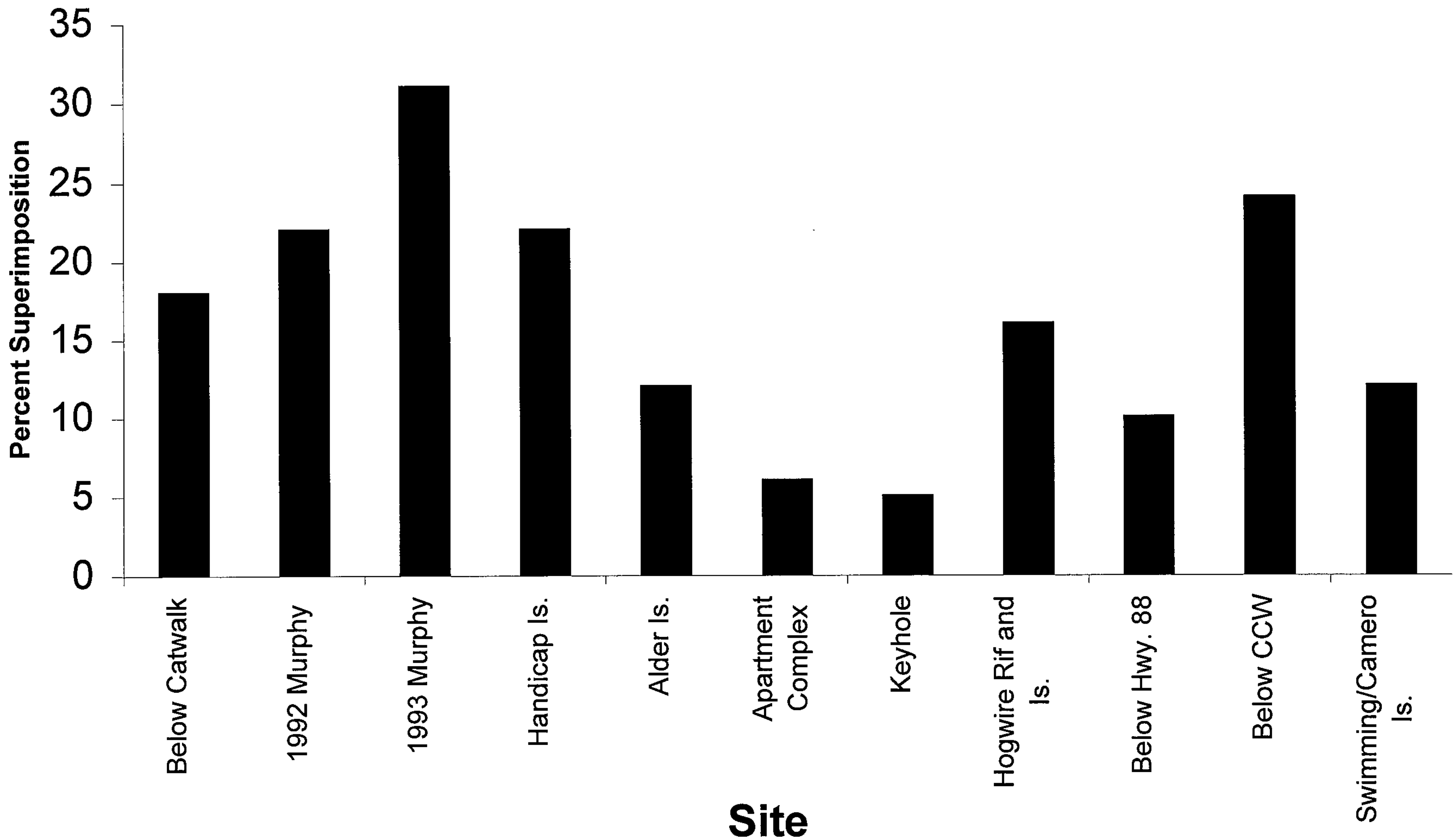


Figure 8. Percentage of redd superimpositions in selected high density spawning areas, Sept1 - Dec 31, 1997, lower Mokelumne River.

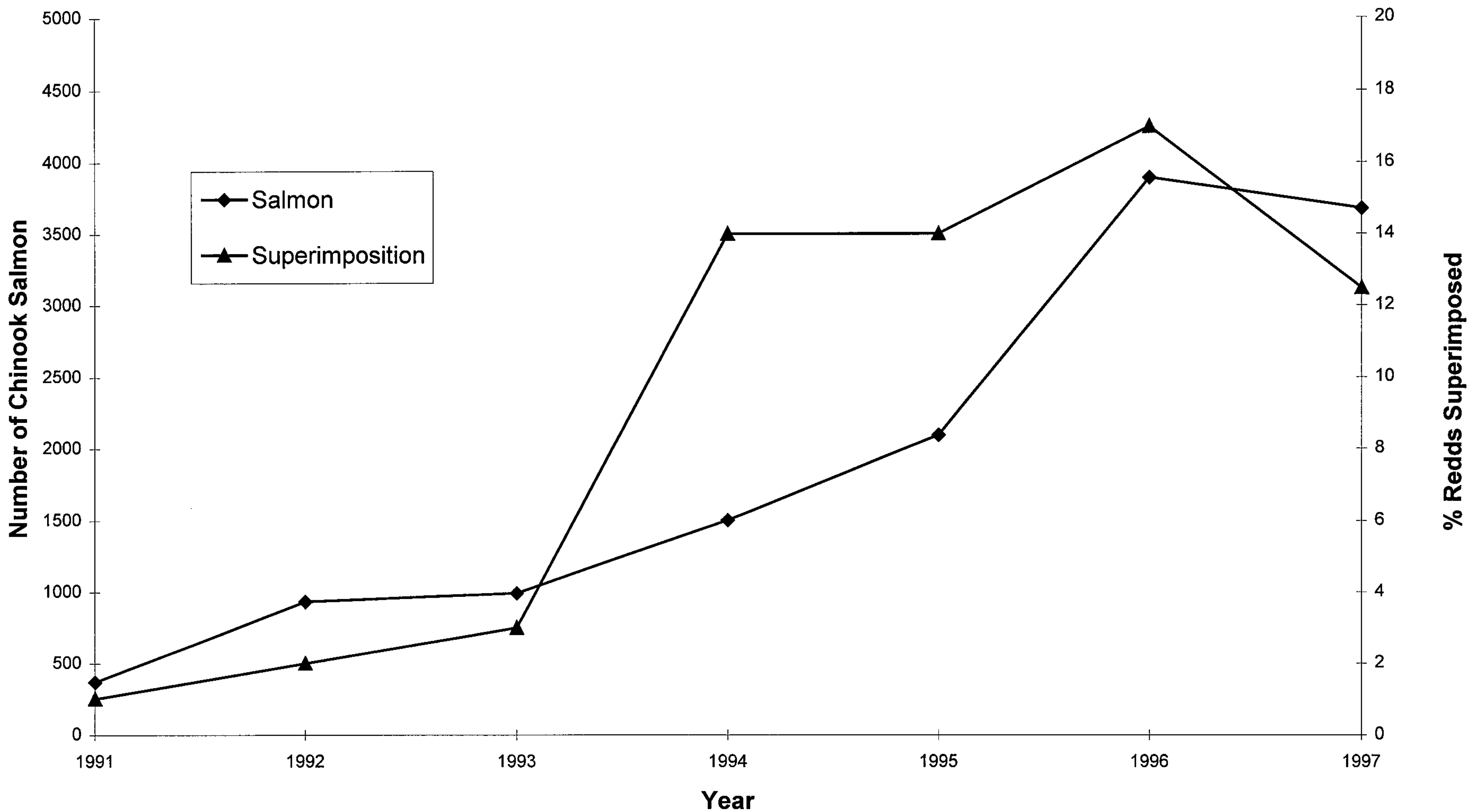


Figure 9. Number of estimated in-river spawners vs. percent superimposition 1991-1997, lower Mokelumne River.

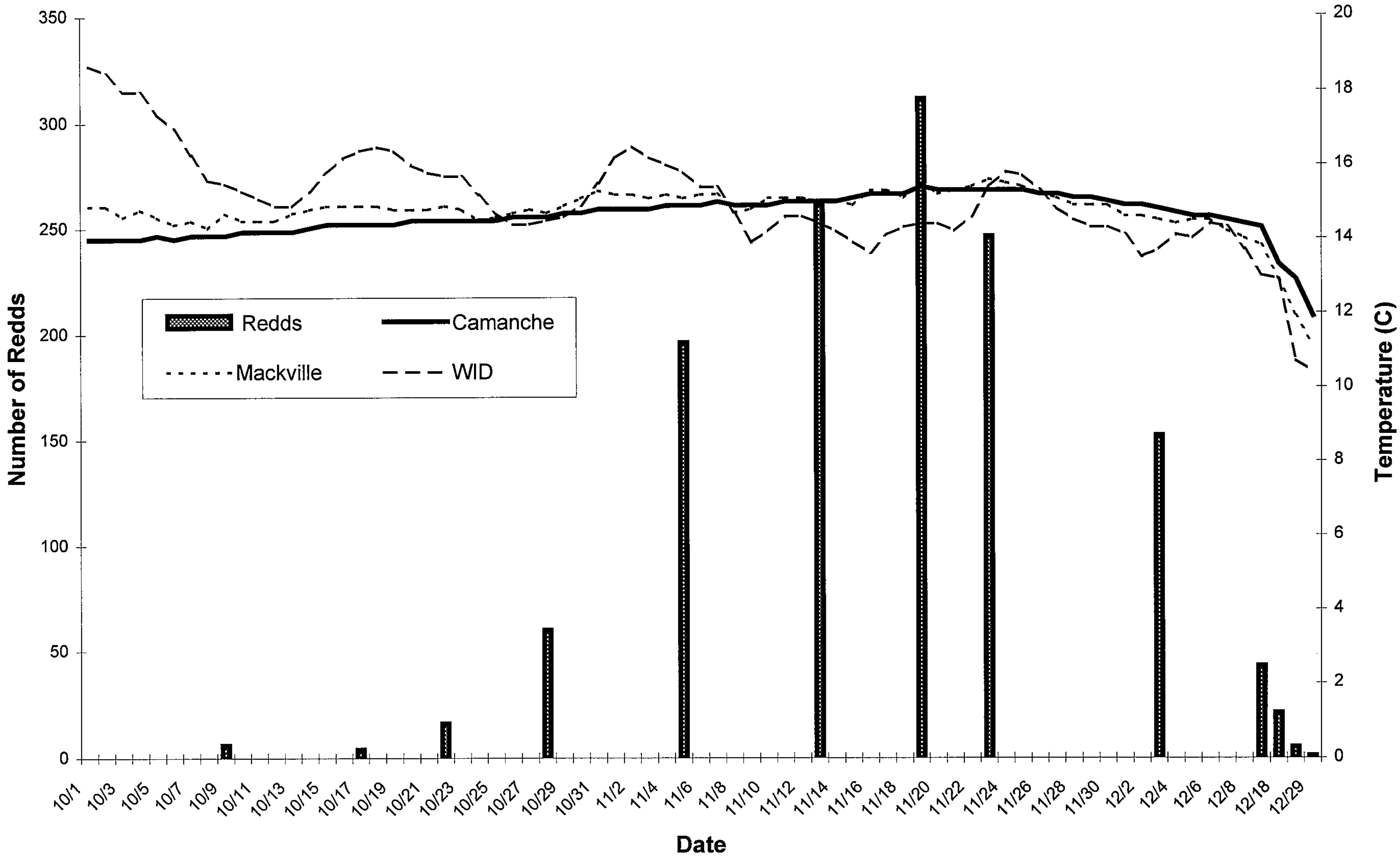


Figure 10. Constructed redds per week vs water temperature(Camanche, Mackville, and WID) 1997, lower Mokelumne River.

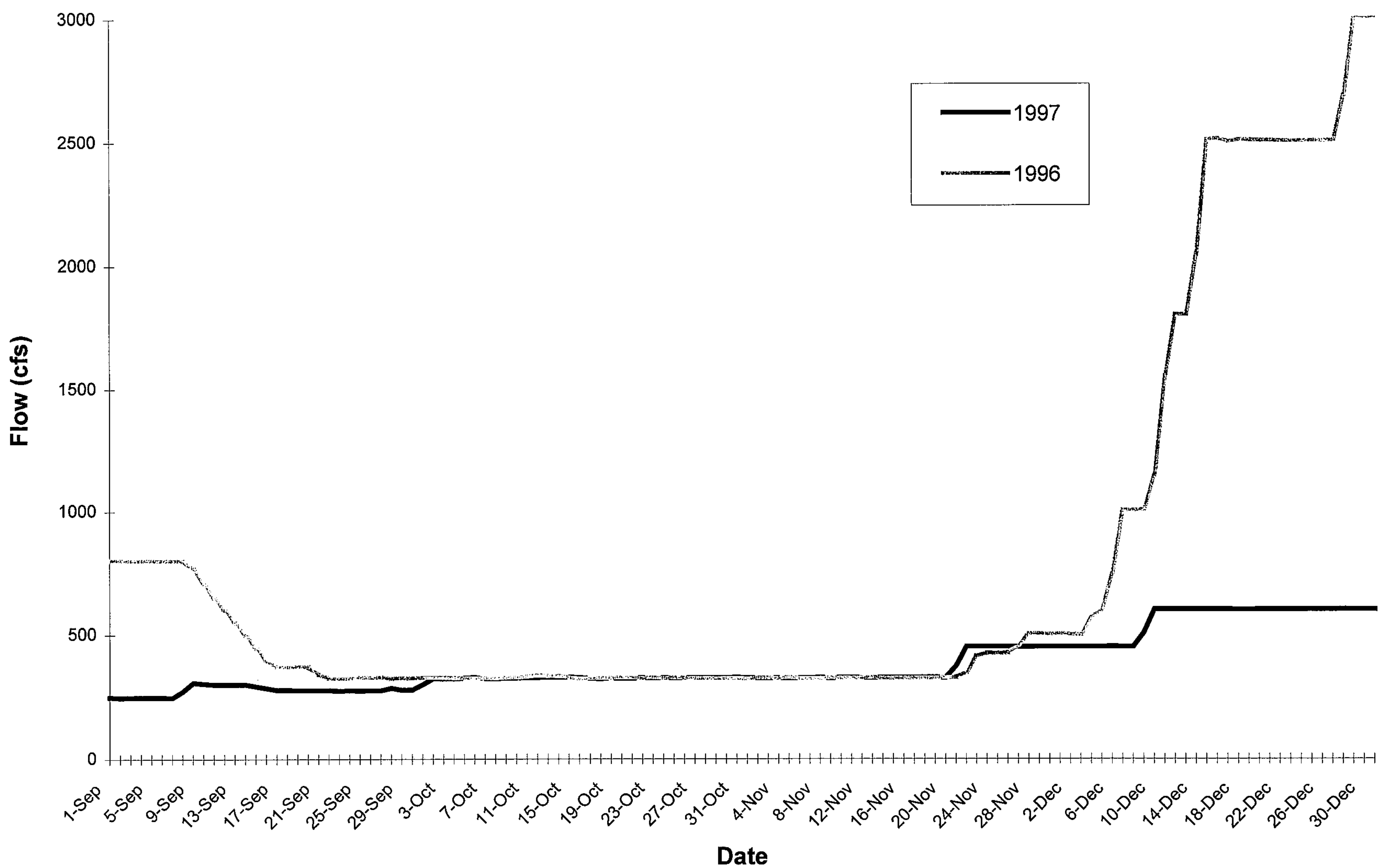


Figure 11. Camanche Dam releases from September 1 through December 31, 1996 and 1997, lower Mokelumne River.