1996 LOWER MOKELUMNE RIVER CHINOOK SALMON *Oncorhynchus tshawytscha* SPAWNING SURVEY REPORT

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EXECUTIVE SUMMARY

- Natural Resource Scientist biologists recorded 7,775 chinook salmon passing Woodbridge Irrigation Dam (WID) from 9/3/96 to 12/10/96. This year's escapement was the highest number recorded since 1990 and was 142.5% of the 1940 to 1996 average (3,305). Flood control releases caused the suspension of escapement monitoring on 12/10/96. The recorded run was comprised of 4,468 adults (54% male, 46% female based on known sex ratios) and 3,307 grilse (80% male, 20% female based on known sex ratios). The run peaked near the beginning of November. On 10/30/96 a total of 1423 salmon were recorded passing Woodbridge Dam, the highest one day total since monitoring began in 1990.
- Redd surveys were conducted weekly from 10/11/96 to 12/3/96, when they were canceled due to flood flow releases. A total of 929 redds were counted during the survey period. Peak redd construction occurred during the third week of November. Percentages of redd construction per reach were: 61.5% A (Camanche Dam to Highway 88), 18.1% B (Highway 88 to Mackville Road), and 20.5% C (Mackville Road to Elliott Road). Based on 1992 through 1995 averages, it is estimated that 27.6% (s.d. ± 8.1%) of the total redd construction was missed due to the cessation of surveying because of flood flows. Therefore, it is estimated that the actual number of redds constructed in 1996 was between 1155 and 1445.
- A total of 283 (30.5%) of the total redds were constructed in enhancement gravel areas. Usage of these gravels has increased steadily since their initial addition in 1990.
- A total of 158 (17%) redds were superimposed at the >25% level (C&D type). This is up from 14% of last year. Because of the shortened survey period, it should be assumed that the superimposition figure for this year is an underestimate. Superimpositions have historically been more numerous during the second half of the run.
- Water temperatures at Mackville Road ranged from 16.1° to 11.8°C during the survey period. This compares to the 1995 range of 16.1° to 14.9°C at the same location. Dissolved oxygen levels ranged from 7.4 to 9.9 mg/l.
- Significant differences occurred in stream velocities between redds associated with large organic debris (LOD) and/or berms and those not associated with LOD and/or berms. Stream velocities were lower surrounding berm and LOD associated redds, which may be indicative of parameters , such as permeability, being improved within the substrate around these structures. Additionally, redd area was significantly smaller as stream velocities increased. This difference may be due to the higher velocity water carrying away tailspill materials, or the higher bioenergetic costs of holding position within higher velocities results in less energy for construction and a smaller redd.
- Significant differences in dominant substrate selected occurred between the stream reaches. Substrate size was smaller in the lower reaches. The decreased size is related to the lack of availability of larger substrate in reach C. The decreased substrate size was accompanied by a trend of increased velocity, though it was not significant. This would be expected due to the lower permeability of smaller substrates and the need for greater velocities to provide intergravel flows.
- A majority of redds (93%) were constructed in glide or riffle habitat. Sixty four percent of redds were constructed on berms (transition zones), which are generally made up of optimal sized gravels with high permeability. One hundred ten redds (11.8% of total) were associated with LOD.
- Redd characteristics and flows from 1991-1996 were examined to determine if significant differences in various redd characteristics occurred between flows. The only significant

difference occurred with nose velocities. Velocities increased with flows. This may be indicative that other parameters, such as substrate or depth, play a more important role in site selection than velocity. If velocity was a key parameter then no significant differences between flows would be apparent.

- GIS analysis indicated that out of 536,760 square meters of river area available (Camanche to Elliott Road), 174,424 square meters or 32% were used for spawning (using 100 ft^2 as the average redd area). The percent available habitat used per reach was as follows: A 27%, B 39%, C 34%. The river area available is a total area and does not indicate spawning habitat available. Habitat mapping in 1997 will further refine the available habitat estimate. Sixty percent of the 1996 redds were associated with riparian woodlands, which provide shading and cover.

INTRODUCTION

The Mokelumne River is an eastside tributary to the Delta and as such it is part of the Sacramento-San Joaquin drainage that encompasses the Sierra Nevada range, Coastal range, Cascade range and the Central Valley of California. The Mokelumne River watershed is composed of 585 sq. miles and 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 operated by Pacific Gas & Electric (PGE) as part of their Mokelumne River Project. The PGE project includes 19 dams, 7 storage reservoirs, 7 diversion facilities, 3 regulating reservoirs, 2 forebays, and other associated structures (F.E.I.S. 1993).

Chinook salmon (*Oncorhynchus tshawytscha*) are the most abundant anadromous salmonid found in Central Valley tributaries. The Central Valley rivers discharge into the Pacific Ocean via San Francisco Bay and are the approximate southern border for the chinook's range. This has resulted in a unique seasonal race grouping of the population (Healy 1993, Moyle 1976, Reynolds et al 1993). There are four distinct runs of chinook in the Sacramento-San Joaquin River systems: fall, late fall, winter (federally threatened) and spring (state listed). This seasonal structure of runs results in the year-round presence of chinook salmon, in some life stage form, within the Sacramento-San Joaquin system.

The Mokelumne River is used by fall-run chinook salmon and steelhead (*O. mykiss*) for in-migration, spawning, rearing, and out-migration. Adult chinook salmon may begin ascending 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 1993, 94, 95, 96; NRS 1994, 95). In addition to the in-river spawning, the Mokelumne River Fish Installation (MRFI) was constructed in 1964 to mitigate for spawning habitat lost with the construction of Camanche Dam. The MRFI receives approximately 43.3% of the total run per year (1990-1996 average). EBMUD biologists have been conducting annual spawning surveys in the lower Mokelumne River since 1990 (Hagar 1991, Hartwell 1996). Concurrently with the annual spawning surveys, EBMUD has contracted with private environmental consulting firms to enumerate chinook salmon escapement as the fish pass Woodbridge Irrigation Dam (WID) in Lodi, California (Biosystems 1992, NRS 1994). Data generated from WID monitoring and MRFI returns allow for an estimation of the number of chinook salmon within the system at any given time.

OBJECTIVES

The primary objective of the 1996 spawning survey was to enumerate the number of chinook salmon redds in the lower Mokelumne River. With the escapement data from WID and MRFI, an estimate can be obtained for the total escapement to the river, which can be 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 for specific parameters: stream velocity, nose velocity, depth, substrate, and distance from shore.
- Measure redd widths and lengths for determination of average redd areas.
- Determine specific preferences for association of redds with: cover (overhanging vegetation, canopy, undercut banks, water depth and turbulence, etc.), structure (berm, groin, etc.), habitat type (riffle, run or glide), and large organic debris (LOD).
- Note number and type of superimposition.
- Identify usage levels of enhancement gravel areas.

Summaries of the following notes and observations were prepared;

- Visible injuries, attached fishing gear or tags.
- Behavior and numbers of salmon associated with redds.
- Impacts to stream and riparian habitats.

A summary of environmental measures and flow for the spawning period (Sept. - Dec.) was compiled. These parameters were statistically compared to the construction of redds and migration of chinook. An emergence timeline was constructed based on an egg model developed by NRS (1993) based on Piper (1982).

Geographical Information Systems (GIS) are a relatively new tool in the field of fisheries research and management. Specifically, GIS is an expanded database program that stores sets of data in a series of records and links them to geographically referenced objects (Isaak et al. 1997). This allows for spatial analysis of data. Land managers, foresters, city planners and other like officials have used GIS for mapping, change detecting, calculating harvest rates, and other tasks. EBMUD Fisheries & Wildlife Division is currently developing a GIS for the lower Mokelumne River. The system has already been used for the development of a flood-plain model and a vegetation 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 being developed will be used to graphically and statistically analyze much of the current data. Some of the results to be generated by the GIS include:

- Spatial distribution of redds.
- Temporal distribution of redds within specific areas.
- Association of redds and riparian vegetation.
- Total area used by spawners.

METHODS

SURVEYS

Beginning 10/11/96, weekly redd surveys were conducted in the lower Mokelumne River from Camanche Dam to Elliott Road (Figure 2). Increased flows due to heavy precipitation forced an end to the surveys in early December. The last full survey was conducted 12/3/96. A 9.76 mile section of the river, Camanche Dam to Elliott Road, was surveyed over 2-3 days each week using canoes as the transportation vehicle. The river is broken up into three distinct reaches A (Camanche Dam-Highway 88, 2.95 miles), B (Highway 88-Mackville Rd., 1.66 miles), and C (Mackville Rd.-Elliott Rd., 5.15 miles), which are indicated in Figure 2. Survey method 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 93,94,95, Keefe et al. 1994). Redds were marked using fluorescent yellow colored bricks and mapped on line drawing maps traced from orthorectified aerial photos taken on 2/28/94 (202 cfs).

DATA COLLECTION

Quantitative data collected, instruments used and description of data are listed in Table 1. Complete data was taken for every tenth redd and a minimum depth taken for every redd. 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 (1951) 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.

Generally, only redds of levels 3-5 had their corresponding data recorded. Redds of a 1-2 level were noted and data was collected the following week when they were more fully developed.

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

Level A = tail-spill of one redd superimposed on tail-spill of second redd.

Level B = tail-spill of one redd superimposed on estimated location of egg pocket of a second redd.

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 superimposed 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 water temperatures, air temperatures, gauge heights (flows computed from heights).

Habitat types were broken down into the following categories developed by Bisson et al. (1981): glide, riffle, riffle-glide complex (RGC), side channel glide (SCG), and side channel riffle (SCR). Habitat type for each redd location was noted.

DATA ANALYSIS

Heavy precipitation during the fall resulted in numerous flow increases on the lower Mokelumne River from 11/20/97 on. These changes resulted in varying physical conditions (depth, velocities) during construction of individual redds. Therefore, there is the possibility of an individual salmon choosing an area for specific habitat criteria that was later altered due to flow increases. One of the objectives of the survey is 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 insure accurate habitat preference analysis, only data of redds constructed and surveyed during periods of stable flows were used for statistical analysis of parameters that could be impacted by flow changes.

Redd mapping data were transferred manually into a GIS database along with associated habitat preference data. Approximate locations (± 30ft) of each redd were marked on river maps as they were discovered. The GIS was used for graphical and numerical analysis of redd proximity, associations with cover, and temporal distributions.

Statistical analysis was done using Lotus 123, (Lotus Development Corp.), Statgraphic (Manguistics Inc.), Statistix (Analytical Software), Excel (Microsoft Corp.) and EBMUD lower Mokelumne River GIS. The lower river GIS is based on two data-sets: a regional USGS map set with a 1:24,000 scale and a local map set based on orthorectified photos (taken 2/28/94, 202cfs) with a 1:4,800 scale.

RESULTS

ESCAPEMENT AND REDD NUMBERS

Natural Resource Scientist Inc. biologists recorded a total of 7775 returning chinook salmon (adults & grilse) at WID (NRS provisional data). The counts are based on video monitoring, physical trapping and salmon rescued from spillbay basins from 9/3/96 through 12/10/96 (methodologies detailed in NRS 1994). Monitoring was discontinued on 12/10/94 due to high flows. The WID boards were removed and Lake Lodi emptied on November 4-5, 1996. Of those adults whose sex were determinable, 54% were male and 46% female. The grilse population was primarily male (80%). In addition to chinook salmon, 93 steelhead were counted. Only 11 of the steelhead were adults, while the remainder were classified as sub-adults, possibly "half-pounders" (sexually immature steelhead that spend less than a year in the ocean). The salmon run peaked during the last part of October/early November (Figure 3). On 10/30/96, 1,423 fish were counted passing WID. This figure is the highest single day count in the 1990-1996 period. The total of 7,775 salmon is the highest run on record since EBMUD monitoring programs (1990) and Lower Mokelumne River Management Plan (LMRMP) (Biosystems 1992) were initiated (Figure 4).

The timing of the 1996 run is similar to those of the past three years (Figure 5). MRFI staff recorded a total of 3,883 chinook entering the hatchery. The sex and age composition was: 948 (24%) adult male, 880 (23%) adult female, 2,055 (53%) grilse. By subtracting the hatchery total count from the WID total count, we estimate an in-river spawning population of 3,887 fish during the survey period. Extrapolating the sex ratio of fish recorded at WID (24% adult male: 23% adult female) to the in-river population resulted in an estimated 1,463 adult males, 1,174 adult females, and 1,250 grilse river spawners. At this time, due to monitoring methodologies, there is no data indicating differences in sex compositions between early and late portions of spawning runs (NRS 1996). However, flood flows prevented counting a portion of the spawning run; therefore, these estimates should not be used as an absolute number for the total number of fish in the river.

A total of 929 redds were found during the survey period. Redd construction began the first part of October, peaked the third week of November and had fallen off to 131 new redds during the first week of December (Figure 6). The first redd was observed on 10/11/96 and recorded on 10/15/96. A significant portion of the spawning period was missed due to flood flows. Based on 1992-1995 averages, 27.6% (std. dev. 8.1%) of redd construction occurs after the first week in December. Although data is available for 1991, it was the fifth year of a drought and the timing of the run was more than likely atypical. Therefore, 1991 data was not used for the average. Using the calculated percentage, it is estimated that a total of 1,284 (1,155-1,445) redds were constructed during the 1996 spawning run. The timing of redd construction was similar to 1994 and 1995 spawning runs (Figure 6). During the spawning runs of 1991 through 1993 the peak of spawning activity occurred in the early part of December.

Redd construction per reach is depicted in Figure 7. Percentages of redd distribution for each reach over the past 6 years are listed in Table 3. Reach A has shown a definite increase in percent use with the increased run sizes of the past two years, while reach C has shown a decrease.

ENHANCEMENT GRAVEL USAGE

A total of 283 (30.5%) redds were constructed in enhancement gravel. The use of these gravels, along with escapement, has increased steadily since 1991 (Figure 8). However, the total percentage of spawners using enhancement gravel has also increased: 1991=11.8%, 1992=19.2%, 1993=16.2%, 1994=16.9%, 1995=22.5%, 1996=30.5%. (Table 4) Gravel enhancement projects were conducted in 1990, 1992, 1993, 1994, and 1996.

SUPERIMPOSITION

Of 929 redds counted, 158 (17%) were superimposed. Superimposition was defined as redds whose egg pockets were superimposed >25% (C&D type). Percent superimposition for the past six years are listed in Table 5. The suspension of survey activities due to high flows presumably affected the number and percent of superimposition noted. Historical superimposition data on enhancement gravel areas (Table 6), suggests that a portion of the redd construction had yet to occur after the first week of December. In 1994 and 1995, enhancement gravels had higher percentages of superimposition than in the shortened 1996 survey, while the escapement levels for 1994 and 1995 were lower than 1996.

ENVIRONMENTAL DATA AND RELATION TO SPAWNING ACTIVITY

Water temperatures ranged from 16.1°C - 11.8°C at Mackville Rd. during the 1996 survey (Figure 9). This compares to the 1995 range of 16.1° -14.9°C during the same period (Hartwell 1996). Redds constructed in or exposed to the higher range of suboptimal temperatures (15°-16°C) were limited in number. A total of 131 redds (14%) were constructed during water temperatures of <14°C, which compares to 38 redds (4%) in 1996. Dissolved oxygen levels ranged from 7.4 to 9.9 mg/l , which are within optimal levels (Piper et al. 1982, Reiser 1979).

Water clarity ranged from 4.6-5.0ft (5.0ft = river bottom) in the Mokelumne River Day-Use Area (MRDUA) and from 4.5-7.3ft near Mackville Rd. Overall, secchi readings varied by approximately 3 feet over the survey period. Most of the variation can be attributed to precipitation events and flow increases that likely mobilized material from banks and surrounding land.

Flows during the latter part of the 1996 surveys varied significantly from past years (Figure 10). While there are concerns of substrate mobility and impacts to existing redds, preliminary results from outmigrant monitoring have not indicated any impacts to date.

REDD PHYSICAL CHARACTERISTICS HABITAT PREFERENCES

Area, Velocities, Depths

The average area for redds constructed (level 4-5) was 106ft^2 (N=79). Averages for reaches A-C were 108, 100, and 104 ft^2 respectively. There were no significant differences in redd areas between reaches (F= .261, P= .7710) or between beginning and end of survey (F=1.525, P=.22).

Average stream velocities are listed in Table 7. There were no significant differences in mean velocities between the reaches (F= .123, P= .884) or between the beginning and end of run (KW= .1013, p=.7503). Stream velocities did differ significantly when associated with LOD (F= 4.29, p=.0417) and berms (KW=5.254, p=.0219). Redds associated with LOD and berms had lower velocities. These differences may be indicative of the value of in-stream structures. As water approaches LOD it is slowed temporarily, which allows suspended sediment to fall out. This leaves 'clean' water that is accelerated around the LOD and cleanses surrounding gravel of fine sediment, thereby increasing permeability (Hunter 1991). The salmon may choose these areas of lower velocity because of the cover the LOD provides or the increased permeability of the substrate. Additionally, there was a significant relationship between area and velocity (F=6.40, p=.0135). Increasing velocities were correlated with decreasing redd areas. The correlation may be a factor of the flow carrying away tail-spill material making the redd area appear smaller. Moreover, the increased energy needed for a fish to maintain position in high flow areas may lead to smaller redds or multiple small redds by a single female (Neilson & Banford 1983). Nose and minimum depths did not differ significantly between the beginning and end of run ($F=1.525$, $p=.221$) and are listed in Table 8.

Ranges for area, stream velocity (.6), nose velocity, and nose depth are depicted in Figures 11-13.

Substrate and Associations with Structure, LOD, Cover

Dominant substrate selected for redd construction ranged from small gravel to small cobble. (Table 9) There were significant differences in substrate sizes between the reaches ($X^2=12.76$, $p=.1780$). Reach A redds were composed of the largest size substrates, while reach C redds were made up of smaller size substrate. This difference is most likely a result of the lack of large and medium gravel below reach B. A general trend of faster stream velocities with smaller substrates occurs (entire spawning reach), but is not significant ($F=1.310$, $p=.2773$). The reduced permeability of smaller substrate may be offset by increased velocities, thereby increasing the functionality and preference for this substrate. There was also a trend towards smaller redd areas with increased substrate size. Not only do larger substrates have increased permeability, they provide increased interstitial spaces for eggs which may result in smaller redds. Larger substrates demand more energy during construction which may also influence the redd area.

Summary statistics for redd characteristics, including distance to bank, are listed in Table 10.

Habitat Preference

A majority of redds were constructed in glides or riffles (Table 11). Increased flows lead to areas that under normal conditions (325cfs) would be classified as riffles instead being noted as glides.

In-stream structures (berms and groins) were greatly used during redd construction in 1996 (Table 12). These structures are made up of optimal substrates and provide the necessary depths and velocities favored by chinook salmon. The association of redds and berms since 1991 are noted in Table 13.

LOD is an in-stream structure which provides many benefits including cover, improved velocities and cleaning of substrate. One hundred ten redds (11.8% of total) were associated with LOD. The percent usage of LOD increased in the lower reaches (Figure 14). There has been a decline in LOD usage since 1994. This may be due to increased flood flows and the resulting movement of LOD. It may take time for the LOD to be deposited in areas that have functional spawning substrate or vice versa.

The percent and numbers of redds associated with cover is shown in Figure 15. Many of the redds were associated with multiple types of cover. The total number of redds per reach that were associated with in-stream structures or cover were: 221 reach A, 54 reach B, 85 reach C, for a total of 38.7% of all redds surveyed.

There were no significant differences with cover or structure selection between the reaches, or between the beginning and end of the run ($X^2 = 1.6792$, $p= .1950$).

OBSERVATIONS

Tags, Marks or Injuries Observed

Carcasses encountered during the redd survey were examined for presence of marks or tags. One adipose fin clipped chinook was found. The head was given to MRFI staff for inclusion into the Mokelumne River coded wire tag returns. A preliminary disc tagging program was initiated this year to identify spawning behavior and timing in the Mokelumne (Merz 1997). Eight tagged fish were observed during the survey. Sex, size, location and color of tag for each fish observation was recorded and forwarded to the Lodi F&W office.

Behaviors and other notes

There were 38 instances where more than two (one each male and female) salmon were seen depositing eggs or fertilizing the same redd. One redd had seven fish associated with it. This year's run was comprised of 43% (3,305) grilse and one would expect many of these fish to 'steal into' redds with adult pairs. In a few instances adult females were seen spawning with jack-size males with no adult male seen. However, only 10 occurrences of more than 2 fish on a redd were recorded in 1995, when 14% (783 fish) of the total escapement was comprised of grilse.

River and Riparian Areas

Many instances of riparian disturbances were observed during this year's surveys. There were two notable disturbances occurring on private lands; one involved burning brush piles along the bases of cottonwoods; and the second involving topping and removal of riparian trees. These two areas have since shown accelerated bank erosion and sloughing.

Ongoing cattle grazing appears to have significantly impacted the bank structure and vegetative cover in a few areas of private ownership. Some areas impacted by cattle are in or near spawning grounds.

EMERGENCE TIMELINE

Fry emergence was estimated using the egg model and temperature data. It was estimated that fry began emerging the week of 12/9/96 and continued through 2/22/97, peaking the week of 2/01/97 (Figure 16). There would likely be an additional month of emergence from those redds that were not surveyed due to high flows. The first juvenile chinook from the 1996 brood were captured 12/23/96 (J. Merz per. comm.). One of the fry was 36mm and seamed, which would suggest that it had emerged from the gravel at least a week prior.

COMPARISONS BETWEEN YEARS AND FLOWS

In order to compare redd characteristics between flows from 1991-1996, the following groupings were constructed:

Flow Group #	Group Flow Range (in cfs)
1	160-248
2	269-328
3	359-457
4	482-498
5	565-602
6	808

Groupings were based on historical flows during past surveys and similarities (depths, wetted widths) between flows. Comparisons were made among flow groups and between the beginning, middle, and end of spawning runs. The runs were broken up into beginning, middle, and end by dividing the number of weeks surveyed by three, except in 1996 where it is estimated the last 25% of the spawning activity was missed due to high flows. Therefore, the 1996 figure was broken into beginning and middle of run only. The only significant difference among flow groups was nose velocity (KW=17.5956, p=.0015), which increased as flow increased. This may be an indication that other parameters, such as substrate or depth, play more of a role in selecting a site than velocity. Although there were increases in velocities, salmon remained in specific areas based on other parameters.

Comparisons between beginning, middle and end of runs for each year produced some interesting results. Studies have shown that early arriving spawners may provide a selective advantage to their progeny by selecting the higher quality spawning habitats (Nielson and Branford 1983). While there was no significant differences in berm selection between beginning, middle and end of runs (X^2 = .39, p=.8210), significant differences did occur in overhanging vegetation (X^2 = 8.42, p=.0149), stream velocity (p=.0141), and substrate (F=5.8, p=.0163) selection. Early arriving fish construct redds that are associated with more overhanging vegetation, faster stream velocities and larger substrates than later arriving fish.

GIS RESULTS

Figure 17a-b shows the redd locations for 1996. Although not evident in the numbers of redds per reach, reach C has the most square meters of redd area. (Table 14) This calculation of square meters of redds is based on an average redd size of approximately 100 ft^2.

Table 14. Square meters used for spawning 1996.

REACH	SQUARE METERS USED	TOTAL SQUARE METERS AVAILABLE	TOTAL PERCENT USED
A	50,531	187,886	27
B	41,481	106,798	39
C	82,412	242,076	34
TOTAL SPAWNING REACH	174,424	536,760	32

Reaches B and C have a greater percentage of their total area used for spawning. While the GIS database does not differentiate habitat characteristics or types at this time, the total habitat used for spawning 174,424 square meters could be considered a rough estimate of available spawning habitat. This estimate may be particularly significant based on the size of the 1996 salmon run.

Two areas , Alder Island (reach A) (Figure 18a-d) and C.C. Wood (reach C) (Figure 19a-d), were used to graphically depict the temporal distribution of redds. The Alder Island reach has been used extensively by salmon and it has been enhanced over the last seven years. It is classified as a riffle which decreases in depth downstream. Figure 18a-d shows that the first spawners choose areas of transitions and groins for constructing their redds. This is consistent with previously cited literature. As the weeks progress other areas are used, however the areas of transitions are saturated by spawners. The C.C. Wood section is comprised of a series of three berms with some smaller mounds of gravel within the area. The temporal distribution in this area is more even than at Alder Island. The berms provide more transition type habitat and relieve spawning pressures on any given point within the area.

Using aerial photos bank vegetation was mapped using the following categories:

Annual Grassland = Annual grasses and weeds

Riparian grassland = Wetland plants

Riparian scrub = Blackberry *Rubus spp.*

Riparian woodland A = 1-2 tree species.

Riparian woodland B = 3 or more tree species.

Willow = Patches of willow *Salix spp.*

Upland = Vegetation outside of riparian area.

Associations of redds with specific vegetation types were based on the nearest bank to an individual redd. The results were:

Table 15. Redd associations with vegetation.

VEGETATION TYPE	LEFT BANK	RIGHT BANK	ALL (% of Total)
Annual Grassland	131	91	222 (24%)
Riparian Grassland	49	34	83 (9%)
Riparian Woodland A	227	198	425 (46%)
Riparian Woodland B	63	63	126 (14%)
Willow	0	5	5 (.5%)

A majority of the redds (60%) were associated with riparian woodlands. Obviously, appropriate spawning substrate and conditions must exist near specific vegetation types in order for an association to occur. At this time data does not exist to make a comparison between adequate spawning habitats and vegetation types.

DISCUSSION

The escapement of 7,775 chinook salmon and total redd count of 929 were the highest in the 1990 - 1996 period (Figure 4). This year's escapement was 142.5% of the average from 1940-1996. (Figure 20) Due to the flood flows of early December, surveys were discontinued as of 12/5/96 and based on 1992-1995 redd counts it was estimated that between 1155-1445 redds were actually constructed. From 1990-1996 there is a good correlation between number of redds counted and in-river females (adjusted R^2=.82). There is a better correlation between hatchery escapement and total escapement (adjusted R^2=.98) with the removal of 1996 from data set. However, when using the regression equation to predict 1996 escapement the analysis is not accurate and predicts an escapement of 6,122, when the actual number was at least 7,775. At this time, no accurate predictors are available to replace survey and monitoring programs.

Flood flows can impact salmonid eggs, benthic fish and invertebrates. Large-scale movement of bed material and mechanical grinding of substrate can kill benthic organisms and salmonid eggs (Erman et al. 1988). This can be especially relevant in rivers or streams constrained by snow banks or levees. While the Mokelumne River downstream of Elliott Road is constrained by levees, most of the spawning areas are wider and have set-back or no levees. Preliminary out-migration estimates would indicate that no significant deleterious effects occurred because of sustained flood control releases of 5,000cfs.

Water temperature is one of the most important environmental parameters during chinook spawning . Fish in the reproductive life stage are highly vulnerable to temperatures outside of optimum ranges (Gerking 1980). A review of existing literature on temperature effects on spawning salmonids indicates that the chronic (long-term effects) range is 17° - 20°C, while the sublethal range is 14° - 17°C (Marine 1992). Spawning adults can experience reduced gamete production and higher bioenergetic cost when exposed to above optimal temperatures. Embryonic and alevin development is also highly dependent on water temperatures. Embryo and alevin exposure to higher than optimal temperatures can result in premature emergence, reduced growth, and reduced survival (Beachham and Murray 1990, Heming 1982, Homolka and Downey 1995). Long term exposure to temperatures of $\geq$16°C have been shown to cause 50% embryonic mortality (Alderdice and Velsen 1978, Brett 1952, Healy 1979, Hinze et al. 1956, Vogel and Marine 1991).

Water temperatures started out in the less than optimal range and were well into the optimal range at the end of our surveys. Temperature play a role in the timing of spawning. Chinook generally do not start spawning until water temperatures near 16°C, thereby reducing exposure of eggs to lethal temperatures

(Healy 1991). Natural fluctuations of temperatures can be expected once they have dropped below 16°C (upper limit for 50% mortality), resulting in exposure of eggs-alevin to higher temperatures for short periods of time. These types of transitory exposures are not thought to cause significant egg mortality as does long-term exposure. Reduced egg viability or mortality may arise when, due to weather and/or upstream reservoir operations, the reduction of temperature to the 16°C mark is delayed. This may shorten the time window that the salmon have to spawn, resulting in a saturation of the best spawning habitat and increased superimposition. Temporal distribution of redds near Alder Island (Figure 18a-d) depicts a fairly even distribution of redds near areas of transition in the first weeks and the movement of redd locations into the less optimal areas as the spawning season progressed.

A key habitat attribute needed by spawning chinook salmon is appropriately sized gravel. Gravel is the medium used by salmonids to build redds (nests) and is used by rearing juveniles for cover. Gravel size is an important attribute of spawning habitat due to the many functions it serves. The interstices or spaces between individual stones are where the eggs come to rest after being buried by the female salmon during the spawning process. The spaces allow water to flow through and provide oxygen to the eggs and alevins, and remove metabolic wastes that accumulate in the substrate (Stuart 1953, Wicket 1954). Salmon alevin use the interstices to move about the redd area, to seek cover from currents, and to relocate during periods of dewatering (Dill 1969). The two main factors affecting spawning gravel quality are lack of gravel recruitment and excessive sedimentation. The construction of dams has halted the natural recruitment of gravel from up-river erosional processes (Kondolf et al. 1996, Ligon et al. 1995). Spawning gravel existing below dams can be impacted by sediment-laden runoff from a variety of sources including: agricultural fields, range lands, feed lots, and other areas of unstable land (Meehan 1991). Siltation problems in spawning gravel are compounded by a lack of natural gravel recruitment.

The importance of enhancement gravel is illustrated by the increasing use of these areas over the past five years. Not only do these enhancement sites provide for increased in-river spawning, they may reduce the dependence on the MRFI for overall production. Due to confinement, the hatchery is more susceptible to water quality problems and catastrophic disease outbreaks. Therefore, river production should be maximized with the addition of gravel and structures where appropriate. Both state and federal agencies encourage projects that enhance wild production and associated habitat.

Spawning chinook salmon show preferences for structure and cover in the form of large organic debris (LOD), berms and groins, 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 and berms, 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 berms provide cover, they are used extensively by spawning chinook salmon due to their high permeability (Leman 1988).

In addition to in-stream habitat improvements, riparian zone treatments should be considered to improve the overall ecological health of the system. There are over 135 species of birds that are dependent on riparian areas, including 14 state or federally listed species (Reynolds et al. 1993). It is known that healthy riparian systems reduce the impacts of higher flood flows and improve the environmental conditions within rivers and streams (Hunter 1991, Kauffman et al. 1997). As mentioned previously, the two areas of severe riparian alteration on private lands that were noted during the spawning surveys suffered significant loss of bank material due in part to the alterations. Riparian zones provide input of LOD which is used extensively by salmonids (Meehan 1991). Within the Mokelumne River, this and past reports (Hartwell 1995, Merz 1996) have shown that there are significant differences between substrate, depths, and velocities of redds associated with and without LOD. Individually, these differences provide less than optimal habitat characteristics. However, the combination of benefits, including energetic and physical cover, results in functionally improved spawning habitat. It is clear that LOD can improve what would otherwise be mediocre spawning habitat.

With the apparent benefit of enhancement gravel and the significant use of LOD and riparian cover, manipulation of these two factors could increase the available spawning habitat. Increasing in-river spawning habitat would take the pressure off areas of high superimposition and assist in meeting escapement goals.

Superimposition can have effects on redd viability and ultimately production (McNeil 1964). Studies on the Grande Ronde River, Oregon, averaged 2.4 total fish per redd, while the McKenzie River averaged 8.5 females per redd (Keefe et al. 1994, Ligon et al. 1995). Ideally, the ratio of redds to adult females should be 1:1. Due to the limitations of observation methods at WID, it is not possible to get a complete count of females passing the dam. However, using the data that are collected it is estimated there were a total of 1,408 females in the river for a 1:1.6 female to redd ratio. So, while the level of superimposition has risen over the 1991-1996 period (Figure 21), the estimated ratio of females to redd does not depart significantly from the optimal 1:1.

With such a fairly good ratio, why is there a high percentage of superimposition? Since some females entering the hatchery show damage consistent with digging, the numbers of females participating in redd construction may be underestimated. This behavior could be important since much of the superimposition occurs in gravels near the hatchery entrance. While the percentage of grilse has varied over the years, the actual numbers have substantially increased along with the run size from 1990 to 1996. The increased number of grilse could increase the superimposition levels due to their life history strategy of opportunistic spawning. However, there is evidence that egg burial depth is related to fish size (Crisp and Carling 1989). If this is the case, the impact from grilse superimposition may be much less than from adult salmon. Another factor involves the behavioral aspects of salmonids. Chinook are naturally social animals which travel in schools throughout their lives. The combination of social nature and compressed spawning period due to temperatures may result in a 'mad dash' to spawn, which results in areas of high spawning densities and superimposition. High spawning densities can result in reduced productivity due to delayed spawning from territorial competition, digging up of deposited eggs (superimposition), and delaying spawning past the optimal ripeness of female salmon and their eggs (Chebanov 1991). Since temperatures are primarily a result of natural warming or cooling cycles and cannot be regulated, one way to partially mitigate the problem is through the addition and improvement of spawning habitat.

Another possibility regarding the levels of superimposition involves carrying capacity. Spawning habitat available in the lower Mokelumne River, though not quantified, is thought to be a limiting factor in chinook spawning. Comparison of flow groupings indicate that although redd nose velocities increased in the higher flow groups, salmon still selected particular areas for spawning. Therefore, other factors may be limiting spawning to particular areas. Prior to the construction of Camanche Dam most of the salmon spawning occurred between Clements and the canyon three miles below Pardee Dam (CDFG 1991). It should be expected that there would be a reduced amount of spawning habitat available in the reach below Camanche Dam when compared to the historical area, and that previously unused areas will be used by spawning salmon. So, the superimposition levels may be tied to a carrying capacity being reached. In 1997 the spawning reach will be mapped to further delineate and enumerate the amount of spawning habitat available. The mapping effort will include traditional habitat mapping method and studies on gravel permeability, which has been shown to be a limiting factor on the American River (Vyverberg et al. 1996).

With 43% of the total run comprised of grilse and approximately 33% of the in-river spawners grilse in 1996, it is clear that they play a significant role. Numbers and percentages of adults and grilse for 1990-1996 are shown in Table 16. Why grilse numbers vary over the years is not fully understood, however there may be a relationship between oceanic environmental conditions during the first and second years, and grilse returns (Gudjonsson et al. 1995). Generally, female adult salmon choose larger males for spawning activity, however this does not provide any short-term fitness benefits to the resulting progeny (Foote 1989). Progeny fitness is the result of egg size (provided by female) and environmental conditions. There is a relationship between female and egg size: larger fish produce larger eggs (Flemming and Gross 1990). However, even within populations, egg size is highly variable so the female to egg size relationship can be misleading (Beacham and Murray 1993). Fecundity and egg size is reduced in grilse, which can