UNITED STATES DEPARTMENT OF THE INTERIOR

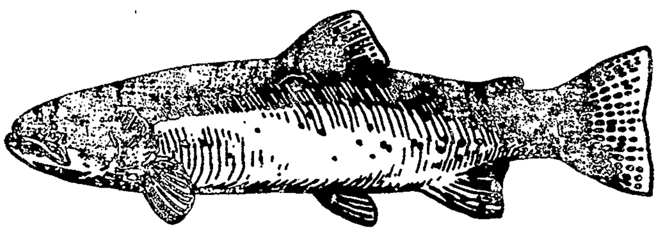
FISH AND WILDLIFE SERVICE

SACRAMENTO RIVER

CHICO LANDING TO RED BLUFF PROJECT

JUVENILE SALMON STUDY

1985



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U.S. FISH AND WILDLIFE SERVICE
Division of Ecological Services
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SACRAMENTO RIVER
CHICO LANDING TO RED BLUFF PROJECT
1985 JUVENILE SALMON STUDY

by

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Prepared for

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INTRODUCTION

This study was conducted for the Sacramento District, Corps of Engineers (Corps) to determine: (1) the effect placement of rock revetment on selected outside bends of the Sacramento River has on juvenile chinook salmon (Oncorhynchus tshawytscha, Walbaum) rearing habitat, and (2) the usefulness of specific slope and substrate modifications, in lieu of standard revetment, as salmon rearing habitat. The original study scope included analysis of all the mitigation slopes constructed by the Corps of Engineers. The two sites, RM 215R and RM 227.5L, were not included in this study because river flows were not high enough to cover these areas.

This is the third field study addressing fishery issues in this river reach funded by the Corps. The initial study was conducted by the California Department of Fish and Game between January and June 1981 and published in August 1983 (Schaffter et al. 1983). This study focused on fish resource values, diet analyses, juvenile distribution and spawning. The second effort, a 1984 study conducted by the U.S. Fish and Wildlife Service, focused on the relationship of juvenile chinook salmon to rock revetment bank protection (Michny and Hampton 1984).

Studies conducted on other river systems associated with channel modifications, stream channelization, and bank stabilization, consistently indicate that these actions are deleterious to the aquatic habitat and fauna (Sandheinrich, personal communication). Bank stabilization causes decreased species richness, diversity, and densities of juvenile and larval fishes when compared to natural banks (Hjort et al. 1984; Li et al. 1984). Stream bank stabilization on the Willamette River, Oregon has transformed the river from a highly braided stream with numerous islands to one that is more linear and incised (Li, personal communication). In the Willamette and Missouri Rivers, these changes caused an increase in water depth, flow velocity, and reduced the hydraulic diversity. Channelization of the Iowa-Nebraska portion of the Missouri River has resulted in an 80 percent decrease in channel area and a 66 percent decrease in water surface area (Hallberg et al. 1979 referenced by Sandheinrich, personal communication). In response to these alterations, recent study efforts have concentrated on analyzing the effects of selected mitigation structures to ameliorate alteration effects (Edwards et al. 1984; Carline and Klosiewski 1985).

In river systems such as the Sacramento, the problems of biotic integrity associated with bank stabilization work are compounded by the presence of anadromous fish. The loss of juvenile salmon rearing areas through the modification of nearshore habitats is a direct result of project construction. It may also affect the recruitment of spawning gravel by lateral bank erosion.

The number of spawning chinook salmon in the Sacramento River has declined significantly since the 1950's. The most extensive record of spawning stock estimates is for fall-run chinook salmon. The average spawning stock estimates for fall-run chinook salmon above Red Bluff for 1950-1959, 1960-1969, 1970-1979 are 190,000, 130,000 and 48,000, respectively (Buer et al. 1984). From 1980 to 1985, the average count dropped to 33,000 fish.

This value is only 17 percent of the spawning population of the 1950's. The decline of the fall-run chinook salmon typifies what is occurring in the system. The winter and spring-run salmon have experienced even greater declines; however, the period of record is shorter.

Some of the more severe events affecting the Sacramento River include the closure of the river above Redding, California by Shasta Dam in 1940, and the completion of Red Bluff Diversion Dam in 1966. Shasta Dam blocked access to the upper Sacramento River and its two major tributaries, the McCloud and Pit Rivers. This eliminated 40 percent of the pre-Shasta Dam spawning areas upstream of the confluence with the Feather River (U.S.D.I. 1940). The Red Bluff Diversion Dam has caused fish passage problems for both adults and juveniles in addition to those resulting from diverting water out of the system.

In addition to these projects, bank stabilization work along the Sacramento River system is thought to be one of the contributing causes for the decline of the Sacramento River salmon and steelhead resource. The potential impacts of bank stabilization on salmon have increased due to the change in salmon distribution in the river system. There has been a large increase of salmon spawning, and subsequently rearing, below the Red Bluff Diversion Dam in the project area. Therefore, this study focused on juvenile salmon abundance at various types of shoreline habitats. They included natural banks, stabilized banks, and stabilized banks modified to recreate rearing habitat. From the abundance indices, comparisons can be made on relative use of the various habitats, emphasizing effects of substrate and slope modifications.

PROJECT DESCRIPTION

The Sacramento River, Chico Landing to Red Bluff Project was authorized by the Flood Control Act of 1958 (Public Law 85-500, 85th Congress, 2nd Session) and the Water Resources Development Act of 1976 (Public Law 94-587, 94th Congress, 2nd Session). Concomitant State legislation was passed in 1959 whereby California adopted the project and accepted the responsibility for the Federal requirements of local cooperation.

The authorized project extends from Chico Landing to Red Bluff, California, river miles (RM) 194 to 243 on the Sacramento River. The authorized plan provides for construction of bank protection and incidental channel improvements. Only such work is to be constructed as is found to be economically justified at the time of construction in light of conditions then prevailing along the river. The authorization also provides that the existing project for flood control on the Sacramento River be extended to Keswick Dam for the purpose of zoning the area below the dam; flood plain zoning was included as a local interest requirement. The recent proposed plan of construction includes bank protection on virtually all the outside bends of the 50 miles of river between Chico Landing and Red Bluff. This proposal will result in the conversion of about 40 percent of the natural river banks to rock revetment.

The bank protection project has been divided into five reaches between points having a relatively stable river channel. This study focused on Reach 1 of the project between the Red Bluff Diversion Dam and Tehama Bridge (RM 231-241) (Figure 1).

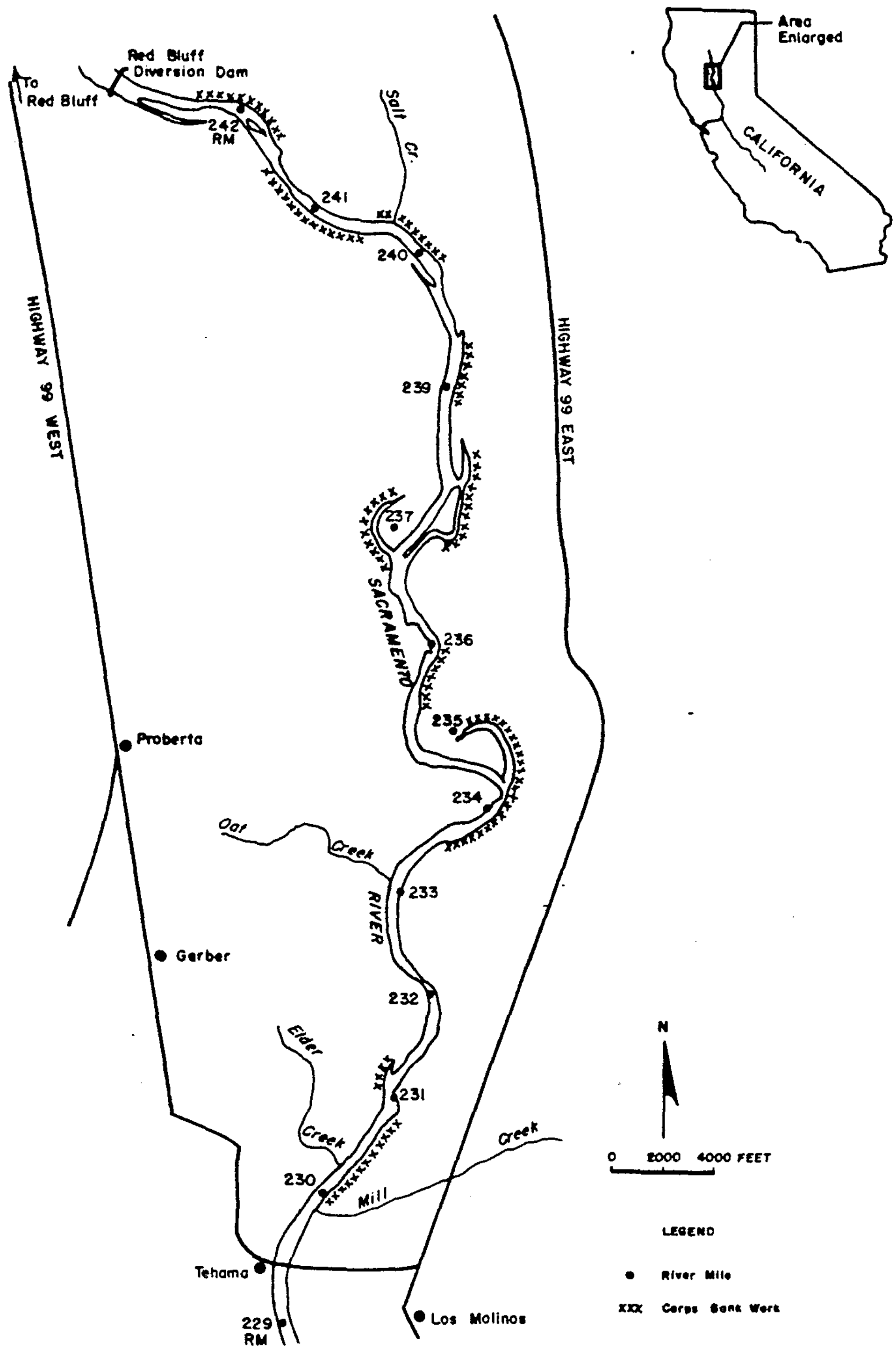

Figure 1. Study area on the Sacramento River below Red Bluff, California

Bank protection work has been an ongoing activity of the Corps within the project area. As a result of the recognition of problems associated with the degradation of salmonid rearing habitat, a modification was incorporated into standard construction design. It consisted of a rearing bench, with a 1V:5H slope covered with river-run gravel, incorporated into the standard 1V:3H design (Figure 2). The 20-foot wide rearing bench is designed to be submerged during the late winter-spring period when a large number of rearing salmon are expected in the river. The design of the rearing bench is intended to simulate shallow gravel bars which are known rearing areas for juvenile salmon.

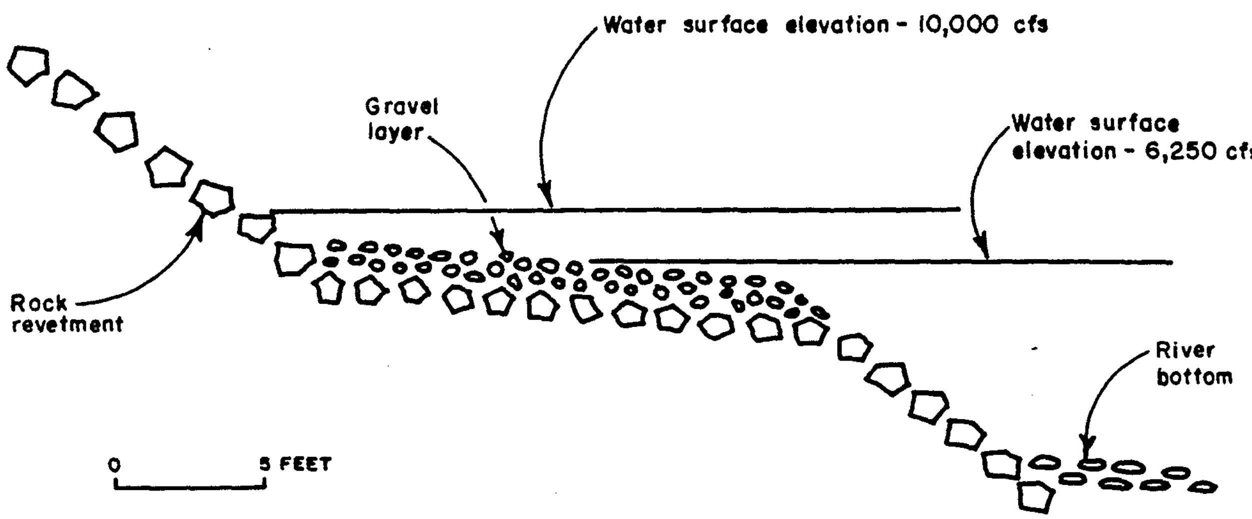

Figure 2. Diagram of fish rearing slope constructed at River Mile 241R, Sacramento River, with water levels at two flows.

STUDY AREA

The study area consists of the river reach between the Red Bluff Diversion Dam and Tehama Bridge (RM 229.5-243) in Tehama County. The predominant land use along this section of the river is agriculture, consisting primarily of walnut and almond orchards. Because of intensive agriculture, riparian vegetation has been significantly reduced from its historical extent, and is limited to areas along the river where conditions are not suitable for agriculture or where conversion has not yet taken place.

This 14-mile stretch of the river is alluvial and is classified into two geomorphic types (Buer et al. 1984). The river from the Red Bluff Diversion Dam downstream 4.5 miles is straight and stable with gravel bars having a narrow meander belt width of 1,200 feet. The remaining portion of the study reach is sinuous and anabranching as evidenced by frequent cut banks and deposition bars. The meander belt varies in width from 1,400 to 5,400 feet.

Throughout the study reach, a pool-riffle sequence is present. Riffles occur either in crossover areas between meander bends or in anabranching areas, with pools located in the meander bends. The riverbed is sand, gravel and cobbles. Bank erosion is a natural phenomenon along the river. The dynamic process of erosion and deposition of the eroded material creates everchanging stream habitats, including gravel bars and backwater areas.

The major intent of this study was to determine the effectiveness of the rearing benches as a mitigative measure for impacts of bank stabilization work on salmon rearing habitat. Three rearing benches occur in the upper reach of the study area. Fish rearing benches have been constructed at two other sites (RM 227L and 215R), but their elevation is such that they are usually dry during normal spring flows. Additional sites were selected in order to compare the rearing values of the benches to standard riprap and natural banks.

The location and description of the habitat for each sample site is listed in Table 1. The natural eroding bank sites are subdivided into two separate habitat types: eroding riparian bank corresponds to sites having dense riparian vegetation with downed trees in the water, and the denuded eroding bank which lack both dense riparian vegetation and significant numbers of trees within the water. The rearing benches are designed to be partially submerged at a flow of 6,000 cubic feet/second (ft^3/s), and completely submerged at 14,000 $ft.^3/sec$. The standard revetted slope has a one vertical to three horizontal (1:3) slope that is covered with quarry stone. Corps specifications require that the majority of stone armoring be in the 30 to 170 pound range (USCE 1985).

Standard construction methods include complete removal of all debris and vegetation when the bank is contoured to the proper slope. This affects the area from the top of the embankment, including a construction right-of-way, down to the toe of the reconstructed bank. A toe trench 5 feet below the existing river bed is excavated at the bottom of the reconstructed bank. Quarry stone is then used to fill the toe trench and cover the bank up to a predetermined flow level, usually the top of the bank.

Table 1. Location and description of habitat type at the 15 sample sites.

Site No.	Location	Habitat Type
1	241.6 L	Natural eroding bank (Riparian)
2	240.7 L	Gravel Bar
3	241.2 R	Riprap
4	241 R	Rearing Bench
5	238 L	Sand Bar
6	238.2 L	Riprap
7	238 L	Rearing bench
8	237.8 L	Rearing banch
9	237.6 L	Riprap
10	237.6 L	Natural Eroding Bank (Riparian)
11*	236.6 R	Natural Eroding Bank (Riparian)
12*	235.3 R	Natural Eroding Bank (Riparian)
13*	233 R	Natural Eroding Bank (Riparian)
14*	232.7 R	Natural Eroding Bank (Denuded)
15*	230 R	Natural Eroding Bank (Denuded)

* Proposed future bank protection site

METHODS

The study enumerated juvenile salmon at the selected study sites. Electroshocking equipment was utilized as the primary method of data collection. A completely outfitted 16-foot electrofishing boat was used to collect the fish. Two 8-foot long aluminum booms with four telescoping probes attached to the bow of the flat-bottomed boat served as anodes. The boat hull was the cathode.

The electrofishing boat was fished with the anode positioned near the bank. When the anode was in position, the electrical field was turned on. Electrical settings for all of the sites was 3 amperes of direct current at 60 pulses-per-second with a pulse width of 60 percent. The boat was then positioned at the downstream end of each sampling site and fished upstream. Each sampling effort was a 500-foot long pass with the boat near the shore parallel to the bank. Fifteen sample sites were selected and marked prior to initiation of the study. Each sample site was a contiguous 500-foot long transect, except for sample sites 3 and 4 at RM 241. Due to the lineal extent of the riprap and rearing slopes, sites 3 and 4 were subdivided into fifteen and twenty-three 100-foot long segments, respectively.

These sites were systematically sampled to obtain a more representative sample of the entire site. The systematic sample involved random selection of one element from the first K elements and then selection of every "K"th element thereafter (Schaeffer et al. 1979). In order to sample 500 lineal feet, site 3 is a one in three systematic sample and site 4 is a one in four systematic sample. The 100-foot long sampling units were assumed to be independent of each other. With this, the number of salmon observed in each of the five sampled units could be summed thereby yielding a value equivalent to a 500-foot sampling unit. This assumption is reasonable because the minimum distance between units is 200 feet. Electrofishing one unit would not affect the fish in the unit 200 feet upstream. Any fish displacement would probably be downstream away from the next sampling unit.

It was originally planned to compare the relative importance of gravel bars on the inside of river bends with the 1:5 fish rearing benches. Seining was planned for these areas because the electrofishing boat was ineffective in the shallow gently sloping inside bends. However, salmon abundance indices for electrofishing and seining are considered to be so different that they could not be compared. Sampling by seining was eliminated primarily due to the lack of water on the fish rearing benches.

Snorkeling was utilized at some of the study sites on two occasions. Numbers and distribution of juvenile salmonids were observed; however, use data was collected by electroshocking.

RESULTS

Thirteen sites were sampled by electrofishing for two periods of time: February 28 through March 20, 1985 during the peak abundance of the fall-run juvenile chinook salmon, and June 6 through July 17, 1985 when juvenile salmon numbers are considerably lower. The results of the two sampling periods were kept separate.

The results of the February through March electroshocking are presented in Table 2. The results of the June-July sampling are presented in Table 3. Salmon abundance dropped significantly in the June to July period reflecting the post-emigration period for fall-run salmon.

Table 2. Number of juvenile chinook salmon per 500-foot lineal sampling section observed by electrofishing, Sacramento River, February and March 1985.

		Sampling Dates							
Sampling Station	Habitat Type	2/28	3/01	3/06	3/07	3/13	3/14	3/19	3/20
1	Natural bank(R)	264	298	----	----	210	357	138	134
3	Riprap	23	52	16	8	19	-0-	-0-	3
4	Rearing bench	112	30	102	95	74	23	11	12
6	Riprap	56	10	---	---	-0-	-0-	-0-	-0-
7	Rearing bench	48	14	---	---	38	12	-0-	8
8	Rearing bench	1	39	---	---	392	11	15	36
9	Riprap	11	20	---	---	25	1	-0-	3
10	Natural bank(R)	156	164	---	---	250	221	23	24
11	Natural bank(R)	407	---	---	---	---	---	145	222
12	Natural bank(R)	---	---	---	189	---	---	82	15
13	Natural bank(R)	---	---	---	102	183	190	111	89
14	Natural bank(D)	---	---	---	69	315	193	132	62
15	Natural bank(D)	37	---	---	---	12	11	38	20

--- not sampled that date
(R) = Riparian
(D) = Denuded

Table 3. Number of juvenile chinook salmon per 500-foot lineal sampling section observed by electrofishing, Sacramento River, June and July 1985.

Sampling Station	Habitat Type	6/10	6/11	6/18	6/19	7/16	7/17
1	Natural bank(R)	32	37	42	49	20	5
3	Riprap	-0-	-0-	3	-0-	-0-	-0-
4	Rearing bench	-0-	-0-	3	6	1	-0-
6	Riprap	-0-	-0-	-0-	-0-	-0-	-0-
7	Rearing bench	-0-	1	-0-	-0-	-0-	-0-
8	Rearing bench	4	2	-0-	-0-	-0-	-0-
9	Riprap	6	1	3	-0-	1	2
10	Natural bank(R)	45	9	3	4	1	8
11	Natural bank(R)	2	22	6	6	7	9
12	Natural bank(R)	0	12	1	-0-	-0-	-0-
13	Natural bank(R)	10	20	27	6	7	6
14	Natural bank(D)	3	2	-0-	0	2	7
15	Natural bank(D)	6	16	6	9	1	4

	N. Bank R	17.8	20	15.8	3.2	7.0	5.6	106.9
	N. Bank D	4.5	9	3.0	4.5	1.5	6.5	43.8
(R) = Riparian	RIPRAP	2.0	0.3	2.0	0	0.3	0.7	7.4
(D) = Denuded	Rearing Bench	1.3	1	1	2	0.3	0	36.0

Summary statistics on salmon abundance for the February-March sampling period are presented in Table 4 and Figure 3. Salmon abundance was greatest in the naturally eroding banks. In the February-March period, the riparian and denuded eroding banks had 13 and 7 times more salmon than the revetted sites. Abundance at the two unmodified habitat types were 4 and 2 times greater than the rearing bench habitat type. Results were similar for the June-July period, but numbers were considerably reduced. Salmon abundance at the fish rearing benches was 4 times greater than on riprap during February-March. Due to reduced numbers of fish, there was no noticable difference in abundance between fish rearing benches and riprap during June-July.

16.6
0.93

0.07

0.33

C-049866

Table 4. Summary statistics for juvenile chinook salmon of four habitat types in the Sacramento River, River Miles 231 to 242.

Habitat Type	Total number of samples	Mean number of fish per sample	Range	Standard Error	Coefficient of Variation
Riprap	14	12.9	0-52	14.5	112.4
Rearing bench	22	48.8	0-392	82.5	169
Natural Eroding Bank (Denuded)	10	88.9	11-315	101	113
Natural Eroding Bank (Riparian)	23	173	15-407	100	57.8

most stable popn

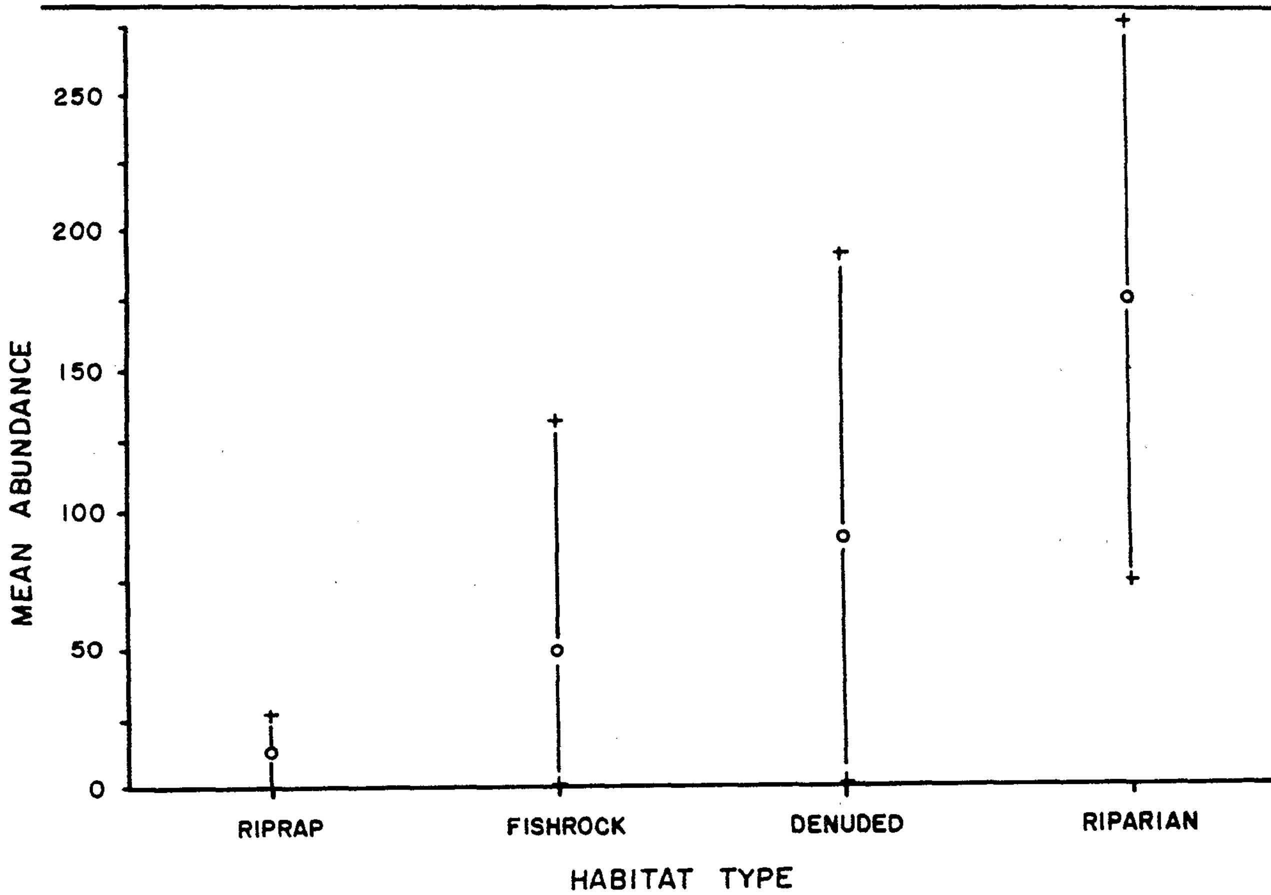

Figure 3. Mean salmon abundance (+ and -1 standard error) by habitat type for juvenile salmon collected in the Sacramento River (fishrock = rearing bench).

Salmon abundance was high and more stable through time at the eroding riparian bank habitat. Abundance at the revetted sites was always relatively low. Numbers of fish found in the rearing bench habitat, although higher, varied more than the revetted habitat.

Clumped distribution and schooling behavior of juvenile salmon was encountered during this study. This, along with the transient nature of the fish, contributed to the high variability in salmon abundance indices. The greatest concentrations of salmon occurred behind object cover such as root wads, fallen trees, and logs when they were present. The clumped distribution was more evident for modified habitats than for natural banks. This is because object cover is scarce in the modified habitats and more common and evenly distributed in the eroding riparian banks, resulting in a lower variability in the mean abundance in the natural habitat.

The variability of the samples, as depicted by the coefficient of variation, shows a gradation by habitat type. Abundance was less variable for natural riparian banks than denuded eroding banks. Abundance for rearing benches varied the most. The magnitude of this variability was due to data obtained on March 13, 1985 at site 8 when 392 salmon were collected. This had a significant effect on the mean and standard error.

Potential rearing habitat of the rearing bench at RM 241 increased with flows above 6,000 ft^3/sec (Table 5). At this flow, water began covering the bench; it fully covered the bench at about 9,000 cfs. Depth preference of juvenile salmon is in the range of 1 to 3 feet; therefore, the maximum rearing habitat potential should occur at a flow of about 12,000 ft^3/sec.

Table 5. Average depth and velocity measurements at three flows on rearing benches, RM 241R Sacramento River.

	Location on rearing bench					
	Landward Edge		Mid Section		Waterward edge	
Flow (ft^3/sec)	Depth (feet)	Velocity (ft/sec)	Depth (Feet)	Velocity (ft/sec)	Depth (Feet)	Velocity (ft/sec)
6,250	0	-	0	-	.6	.3
6,900	0	-	.5	.5	1.2	1.0
10,000	.6	.4	1.7	1.4	2.1	1.8

Flow measurements taken on rock revetment and natural gravel bottoms differed in velocity distribution (Figure 4). The flows over gravel bars are quite laminar in nature and increases rapidly above the stream bottom. High velocities, over 1-foot per second, are usually reached within a few tenths of a foot above the gravel substrate. In contrast, flows over riprap are quite turbulent, and velocity is reduced for 1 to 2 feet above the quarry rock substrate.

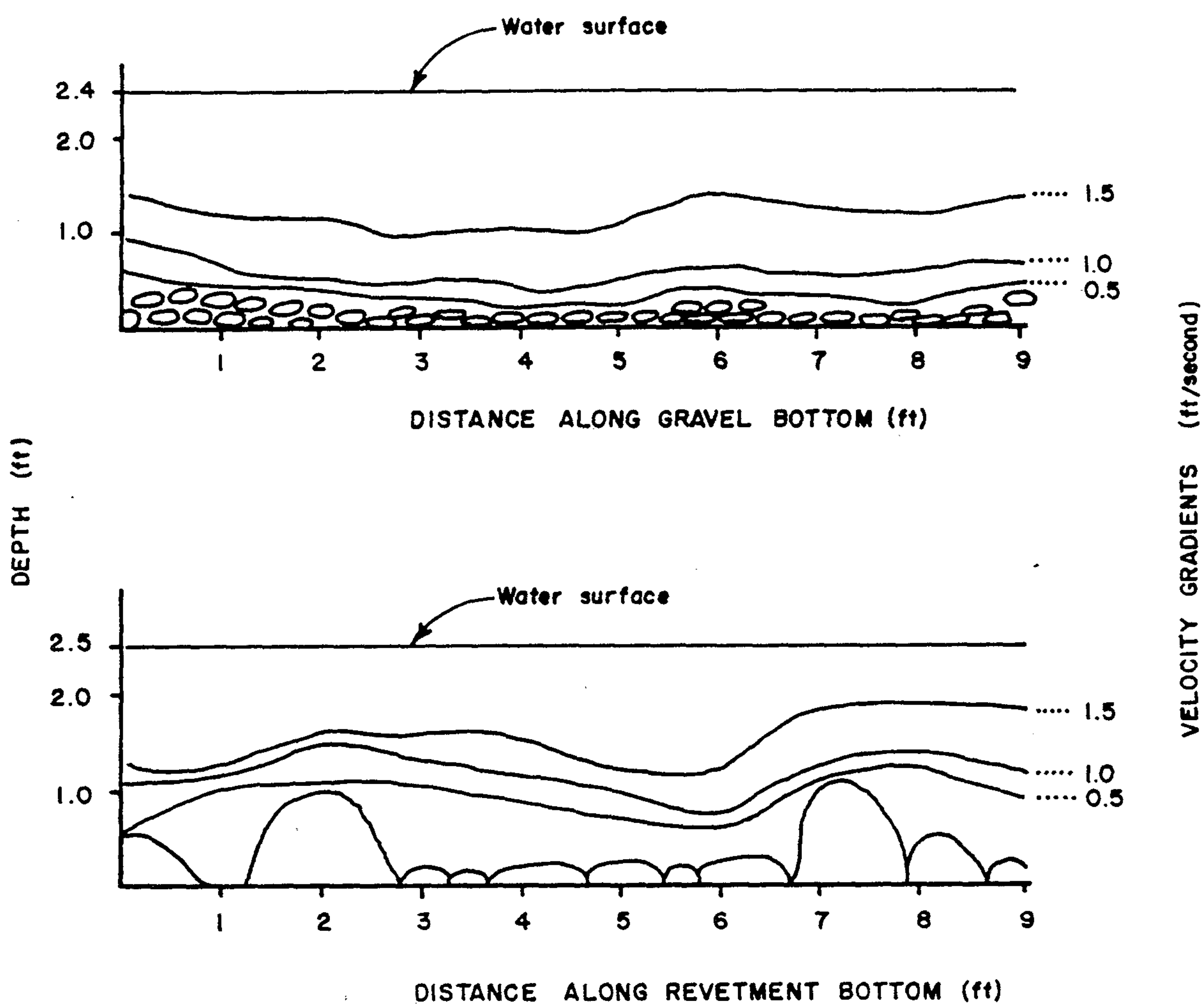

Figure 4. Typical relationship of velocity gradients to substrate at rock revetment and natural gravel bottoms with similar depths and velocities at River Mile 241, Sacramento River.

Selected sites were snorkeled on April 17, 1985 and May 2 and 3, 1985. Water conditions were more conducive on the earlier date for underwater observation. For the first sampling, underwater visibility was about 4 feet and the flow at Vina Bridge was 7,400 ft^3/sec. For the latter dates, underwater visibility was about 2 feet and the flow at Vina Bridge was 8,250 and 8,000 ft^3/sec, respectively.

The results of snorkeling were similar to those of electroshocking. Many more salmon were observed at the natural eroding bank sites than at the modified sites (Table 5). For modified habitats, there also appeared to be a tendency for greater concentrations of fish to occur at the older revetted sites. Also, schools of larger fish, greater than 60mm fork length, were observed at the older revetted sites. The interstitial spaces at these sites are partially or totally filled in with silt which could explain the number of large fish. Also, fish at the revetted sites are typically found in schools, about one-half to one-third of depth above the bottom, next to a velocity vector or shear zone. Salmon at the fish rearing benches were typically smaller (40-45mm fork length range), and located near the waterward edge of the 1V:5H slope. At that location, water depth and velocity are greater. Again, fish concentrated around submerged object cover where available.

For the eroding bank, fishes of all sizes were common. Salmon were evenly distributed over the sand and gravel substrate in depths less than 3 feet. Dense schools of fish, typically numbering greater than 50 individuals, were found near submerged objects. Water velocity was high throughout the area. Near object cover, salmon were found higher in the water column than those in open areas. They were near the stream bottom in the open areas.

DISCUSSION

The primary intent of the study was to evaluate the effectiveness of certain measures implemented to mitigate juvenile salmon rearing habitat impacted by bank stabilization activities. A mitigation measure incorporated into standard construction techniques included a sloping bench designed to simulate gravel bars. The study measured the degree of use by juvenile salmon of mitigation areas and a number of other habitat types. The other habitat types sampled included standard riprap, eroding banks with riparian vegetation, and eroding banks devoid of vegetation. Of the sampled habitat types, most fish were found along eroding banks, particularly those with riparian vegetation, rearing benches were next in number of fish, and the standard riprapped slopes had the fewest fish.

While juvenile salmon were found in greater numbers in rearing benches than standard riprapped banks, the level of use was significantly lower than naturally eroding banks. However, flow levels were such that during the period of peak salmon abundance, a thorough evaluation of the effectiveness of the benches could not be accomplished. In turn, during the summer sampling period when flows were adequate, the number of fish present in the river was insufficient to obtain meaningful results.

Table 5. Results of snorkel survey, Sacramento River, 1985.

Date	Habitat Type	Habitat Type	Salmon*	Predominant Size Class (mm FL)	Notes
April 17					
	242L	riprap	90	60	9 schools of fish
	241.5L	natural eroding (riparian) bank			
	241R	riprap	19	50-60	2 schools
	241R	rearing bench	45	40-45	
	229.7R	groins	120	60	
	229R	riprap	45	50-60	
May 2					
	215R	riprap	0	---	
	216R	riprap	2		next to sub-merged snag
	216.3R	gravel bar	11		all fish next to submerged structure.
May 3					
	241R	rearing bench	30	---	28 behind one snag
	241R	riprap	8	---	5 near snag
	241L	gravel bar	25	---	evenly spread over bottom
	241.8L	natural eroding (riparian)	500+	---	most of the fish next to or behind woody debris in the water.

* No standard frame of reference, sites viewed varied from 500 to 1000 feet and main effort was to observe orders of magnitude of fish, and distribution within habitat types.

In contrast to both natural eroding banks and standard riprapped slopes, the habitat values associated with the mitigation slopes are extremely flow dependent. Natural and riprapped banks exhibit similar habitat characteristics over a wide range of flows. The mitigation slopes, however, are completely dewatered until flow reaches a certain minimum level (about 6,000 ft^3/sec in the study area), and are not completely covered until flows reach about 10,000 ft^3/sec. Maximum habitat value of the slopes probably occur between flows of 10,000 ft^3/sec and some higher flow in the range of 12,000 to 14,000 ft^3/sec. At this point depths and velocities exceed those preferred by juvenile salmon.

The results obtained in this study are similar to those obtained by two previous investigations. In a 1981 study, juvenile salmon were found to be four times more abundant at natural eroding banks than at revetted banks (Schaffter et al. 1983). A similar study in 1984 found the average number of salmon observed at riparian banks in the same river reach was ten times the number observed at revetted banks (Michny and Hampton 1984). According to both reports, the difference in salmon abundance can be explained by the habitat preference of the fish and the different habitats at the sites.

The physical factors, important for salmon rearing and modified by bank construction activities are water velocity, cover, depth and substrate. These factors are used in today's models that describe or simulate the quantity and quality of salmon habitat (Ruggles 1966; Bovee 1982; and Nickelson and Reisenbichler 1977).

Water velocity is important because it transports the invertebrate drift produced in the riffles and from terrestrial sources (Chapman and Bjornn 1969; and Waters 1969). Salmon are opportunistic feeders and rely on water velocity to bring food to them. Higher water velocities, up to a point, are required, as the fish get larger, to carry larger food items and more of them to the rearing area (Chapman and Bjornn 1969). Actual measurements of water velocity at riprapped and natural sites are highly variable depending on angle of current, curvature of bank, and inwater structures. In addition to the wide range of velocities in near-shore areas of natural and reconstructed banks, the quantity and composition of invertebrate drift was found to be similar at both habitat types. (Schaffter et al. 1983). Thus velocity, in and of itself, does not appear to be a determining factor in habitat preference of juvenile salmon (natural and revetted banks).

Depth influences the distribution and size of salmon found in a particular area (Bjornn 1971). Salmon, less than or equal to 50mm fork length, are found in a narrow range of shallow depths, while larger salmon occupy deeper water (Chapman and Bjornn 1969; Burger et al. 1983; and Hoffman and Deibel 1984). Areas with a gently sloping profile have an abundance of fish of all sizes. Larger fish, in the 60mm size range, were more common at the 1:3 revetted bank sites, while 40mm fish were most common at the 1:5 rearing benches. In general, the naturally eroding banks had steeper banks than the revetted sites, with the exception of the fish rearing benches which are relatively flat. Bank slope does not appear to be a significant factor for fish abundance. Natural banks can be near vertical and still have high numbers of fish. This is probably related to (1) the slopes at the natural banks were somewhat irregular and the total amount of potential habitat at appropriate depths was probably comparable with revetted banks, and (2) other factors such as substrate and cover, which affect the suitability of potential habitat, were dissimilar in the two habitat types and probably act to influence fish distribution in areas with similar depth and velocity characteristics.

Substrate characteristics varied widely at the various study sites. The revetted sites were all similar and consisted of angular quarry rock. The rearing benches were also all similar and consisted of gravel approximately 1 to 4 inches in size. The natural banks had substrate ranging from fine sand and silt to cobble. The actual composition of bottom materials does not appear to be as important as other components of the habitat. Within the natural banks, where cover was present, juvenile salmon of various sizes were collected and observed over a variety of substrates. The lack of salmon at bank construction sites is thought to be due to the disruption of laminar flows necessary for effective feeding strategy, rather than the actual physical composition of the bottom. The substrate of the rearing benches is similar to the available natural substrate and would not be expected to exert any negative influence upon fish distribution. The size of the fish collected appeared to be related to substrate size of revetted banks. Larger fish (60mm) were more common in the riprap areas, while smaller fish (40mm) were more frequently found in the fish rearing benches.

Cover, important for survival, provides rest areas from where the fish can move to obtain food. The quantity and quality of cover greatly determines salmonid distribution and production (Boussu 1954; Chapman and Bjornn 1969; and Burger et al. 1983). Submerged trees and bushes, or similar inwater structure provide the greatest amount and most valuable type of cover in this section of the river. Cover is provided in the form of velocity breaks and areas of refuge. Natural gravel bars provide cover for smaller individuals (less than 50 mm) holding near the substrate. Moreover, inwater structures extend this cover through the water column by providing more rearing habitat per unit area. The most dense concentrations of salmon were found in the eroding riparian banks where cover is common. For the revetted banks, where cover in the water column is limited, the majority of the salmon were located in areas where logs or other debris were lodged. Cover frequency in the water column is also low in the rearing benches. In this habitat type, the majority of fish were also found adjacent to debris; however, fish were also infrequently found distributed throughout the gravel covered slopes. While water column cover was not present in any degree on the rearing benches, the habitat was otherwise similar to natural gravel bars which are known rearing areas. The major difference is width of the slope. Based on snorkeling observations in the Trinity River, juvenile chinook salmon tend to distribute themselves at regular intervals over gravel bars (Hampton, pers. comm). Based on the proposed laminar flow theory, the rearing benches should support an abundance of fish comparable to gravel bars.

Water velocity and cover probably have the most influence on salmon distribution based on studies on other salmonids (Lewis 1969). In the Willamette River, Oregon, water velocity was the principle factor influencing fish distribution (Hjort et al. 1984). Ideal conditions are created where these two factors combine to provide a place of refuge and a velocity break, next to a rapid water velocity vector (Lister and Genoe 1970; and Burger et al. 1983). The findings in the present study support the importance of cover and water velocity. Salmon abundance was highest in the areas having the most diverse habitat characteristics. This was the natural banks which contained a variety of depths, velocities and cover. The revetted bank sites, including the rearing benches which provide monotypic habitat, had the lowest numbers of fish. In atypical cases where debris had lodged at these habitat types and diversified the habitat, larger numbers of salmon were found.

All of the preceding factors discussed affect juvenile salmon habitat selection and are modified by bank protection work. We believe, however, that one of the more significant influences on juvenile salmon distribution is actually not any one of these factors but how they interact to affect flow distribution, and how this flow distribution relates to salmon feeding ecology.

Cover in tandem with water velocity is very important for salmon rearing habitat. In both the natural and revetted banks, salmon concentrated near object cover. Stabilizing the banks with riprap reduces the source of cover material and the incidence of it becoming lodged. Preventing erosion eliminates the direct input of large trees, root wads, etc. Also, exposed roots and downed trees can act as debris collectors. Smooth curved revetted banks do not have these collecting structures, thus the incidence of having this type of cover habitat is greatly diminished. Therefore, bank stabilization can have long-term effects and impact a larger area than the stabilized sites.

Based on our observations, juvenile salmon prefer shear areas or velocity breaks, where they can be close to cover and feed on drift organisms that are provided by nearby higher velocity laminar flows. In gravel substrates, or natural banks with inwater roots or limbs, the fish can stay close to the bottom or behind a root or limb, in a low velocity zone, and move only a short distance to feed. In riprapped areas, juvenile fish face several problems: (1) they must rise a longer distance through the water column to reach efficient feeding flows; (2) the turbulent nature of the flows reduces feeding efficiency; (3) extra energy is expended to obtain food items; and (4) the fish are subject to predation for longer periods as they move up and down through the water column to feed. These factors may be acting to cause the apparent negative selection of riprapped areas by juvenile salmon.

CONCLUSIONS AND RECOMMENDATIONS

The construction of standard bank protection projects modifies outside bend habitat in a manner deleterious to juvenile salmon, and as a result, rearing capacity is reduced. The findings of this study, and of the two previous efforts, show that naturally vegetated and eroding banks provide the most valuable outside bend rearing habitat. This is thought to be related to the high diversity of inwater habitat provided at these locations. The study indicated an average reduction of 90 percent in fish numbers from natural banks to riprapped sites during the peak rearing period.

Attempts to mitigate project impacts by substrate slope modification have yet to prove successful. Fish numbers at the rearing benches were four times greater than at riprapped sites; however, they were still only about 30 percent of natural banks. It should be noted, however, that flows during the peak peak rearing period were not optimal for juvenile salmon usage of the fish rearing benches. During this period, flows were generally in the range of 6,500 ft^3/sec. These slopes are completely submerged at about 9,500 ft^3/sec. and, therefore, should be evaluated at flows at, or in excess of, this magnitude.

Based upon the findings of this and previous studies, rearing habitat for juvenile salmon will be reduced if bank protection work proceeds in the conventional manner. The reduction in rearing habitat value can be related to a decrease in the returning adult population. This could seriously hamper the rebuilding of chinook salmon stocks in the upper Sacramento River. Loss of rearing habitat affects all juvenile chinook salmon but is most critical to salmon smaller than 50mm (fork length). This is due primarily to their narrow tolerance for water depth and velocity. Salmon that rear to smolt size in the upper Sacramento River comprise the largest percentage of returning adults (Kjelson, personal communication).

Stabilizing the banks has both site specific and downstream effects. On-site impacts appear to be the most severe. There is a loss of instream habitat diversity, particularly submerged trees and root wads preferred by the salmon for cover. Imposed stabilization affects the particular site and others downstream. It eliminates erosion which is part of the process where cover objects such as trees and root wads are introduced into the system. Therefore, the impacts are spread over a larger area because these objects do not enter the system and cannot be transported to downstream locations.

Modification of standard construction techniques can probably reduce salmon rearing habitat losses associated with bank protection work. Results obtained in 1985, even with less than optimal flow conditions, show that salmon use was higher on the rearing benches than standard riprapped sites. However, it was still considerably lower than at natural banks. While the creation of gravel bars is preferable to riprapped slopes, the incorporation of other modifications into bank protection work to provide velocity breaks and cover should be examined. These modifications could include such features as small groins perpendicular to the bank, and cabling of trees or similar structures adjacent to the bank. The testing and incorporation of these features should be a continuing aspect of any future bank protection work. Our recommendations on future efforts in this regard are as follows:

1. The evaluation of the 1V:5H fish rearing benches be continued in the late winter and early spring of 1986, if appropriate flows are available.

2. Irrespective of flows, a limited amount of inwater study be scheduled during the peak rearing period. This work would aid in defining specific habitat selection parameters of juvenile salmonids for use in developing mitigative measures.

3. Concepts for incorporation of features to reduce rearing habitat losses continue to be solicited from the responsible resource agencies and considered for implementation and testing.

4. An average rearing habitat value be established for bank protection sites and the mitigation features be designed to replace this average value.

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