

REDWOOD CREEK ESTUARY MONITORING AND MANAGEMENT
1990 Progress Report
Redwood National Park
by David Anderson

During the summer and fall of 1990, fishery personnel of the Fish and Wildlife Branch of Research and Resource Management continued the study initiated in 1980 on Redwood Creek estuary planning and monitoring. The study is designed to provide information on salmonid utilization of the estuary, monitor the effects of management activities, and develop and implement management and restoration strategies. To accomplish this, the objectives are:

- I. To estimate the numbers of juvenile salmonids utilizing the estuary throughout the summer-fall season.
- II. To determine the mean growth of the juvenile salmonids utilizing the estuary.
- III. To monitor the water quality of the estuary during the summer and fall.
- IV. To determine the importance of the estuary to salmonid survival.
- V. To manage the water level of the estuary to maintain fish habitat without flooding adjacent private landowners.
- VI. To develop estuarine restoration alternatives.

PROJECT BACKGROUND

The National Park Service undertook active management of the remnant Redwood Creek estuary in 1982. Management activities are designed to maintain what little fish rearing habitat remains, and to prevent flooding of private property resulting from natural embayment formation.

During late spring and early summer months, as water discharge in Redwood Creek decreases, a sand berm often builds at the mouth of the creek, forming an embayment east of the beach. This embayment provides rearing habitat for optimal growth and marine acclimation of anadromous juvenile salmonids, particularly chinook salmon. The configuration of the Redwood Creek estuary was significantly altered by channelization and construction of flood control levees in 1968. However, when the embayment forms, and water levels exceed 6.0 ft above mean sea level, adjacent privately-owned land is flooded. Controlled breaching of the berm by Redwood National Park lowers the water level, while maintaining estuarine habitat for rearing salmonids. This management effort is described in more detail in Hofstra (1983).

In 1987, a gated culvert was built in the south levee to improve water quality, circulation, and summer rearing habitat for juvenile salmonids in the south slough. The culvert project was part of a California Department of Transportation (CalTrans) mitigation package to offset fishery losses resulting from construction of the Highway 101 Bypass. The culvert, designed by the U.S. Army Corps of Engineers, and funded by CalTrans, is operated by Redwood National Park.

The National Park Service has funded several studies to determine baseline biological and physical information and estuary functions (Gregory 1982, Ricks 1985, Larson 1987, McKeon 1985, and Salamunovich 1987). Redwood National Park (RNP) has reported annually (1984 - 1988) on estuarine management and research activities at the mouth of Redwood Creek (RNP 1984, 1985, 1986, 1987, 1988).

STUDY AREA

Redwood Creek drains a narrow 720-km² 108-km long watershed. The mouth of Redwood Creek is located west of the town of Orick, California at the Pacific Ocean. The estuary consists of the areas between and west of the flood control levees (called the embayment), the north slough, and the south slough (Figure 1). The rip-rapped levees altered the extent, duration, and quality of estuarine conditions. Flow characteristics and direction changed and sedimentation increased, causing a loss of estuary volume. The north slough was separated from the main embayment, and the last bend of the river, now called the south slough, was isolated. The necks (outlets) of both sloughs are prone to sedimentation due to the configuration of the levees. The creek has been impacted by upstream land use activities, road construction, natural events such as floods, and in the estuary and lower river, loss of adjacent wetlands to agriculture. For more detailed descriptions of the study area, refer to Hofstra (1983), Larson (1987), Ricks (1987), and Salamunovich (1987).

Both salmonid and non-salmonid fish species are found in the estuary (Table 1). Juvenile salmonids use the estuary as rearing habitat before smolting and migrating to the ocean. Adult and half pounder forms of steelhead trout are occasionally caught in the estuary, but in low numbers. If the mouth of the

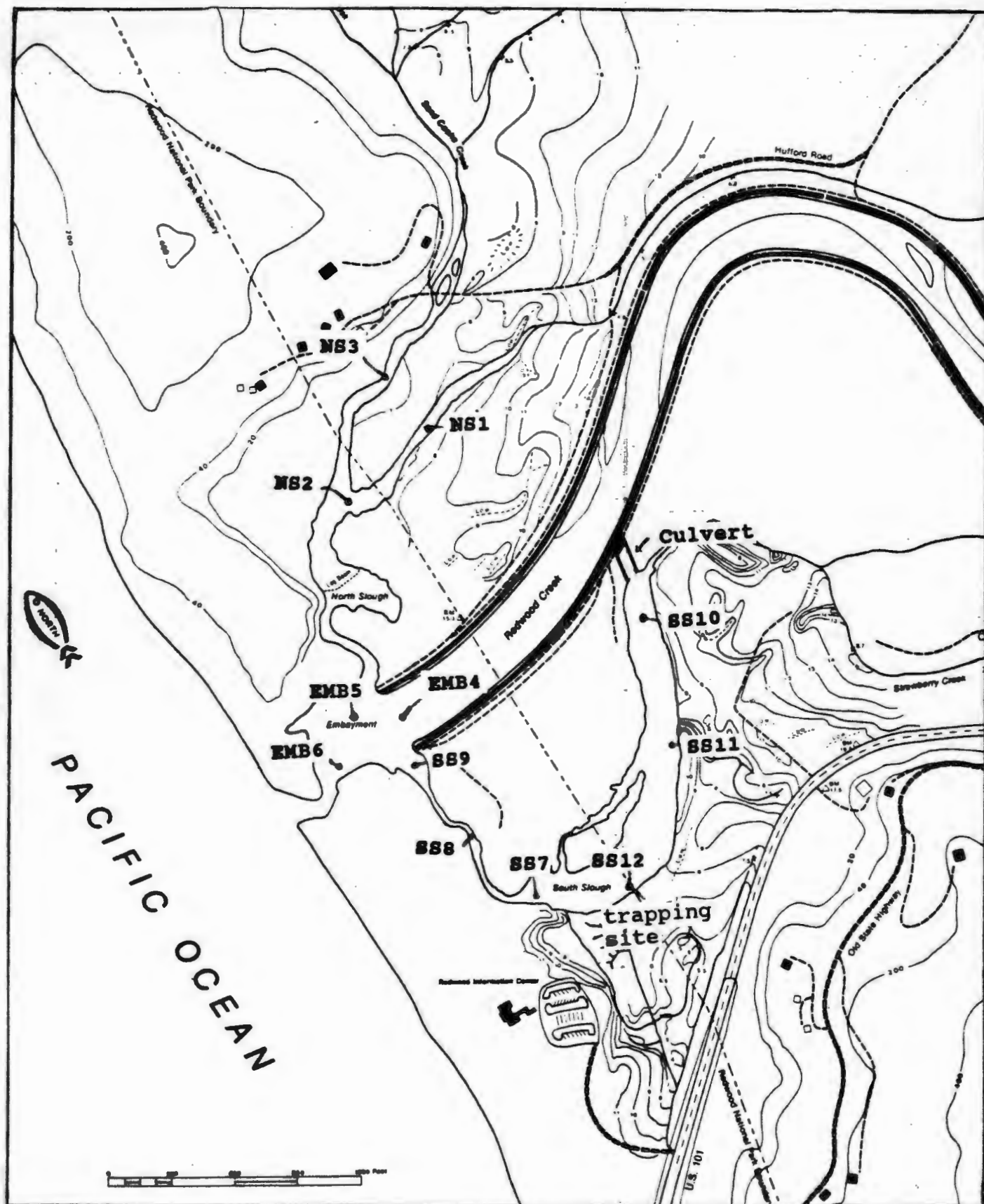


Figure 1. Redwood Creek estuary, Humboldt County California, including water quality sample stations and south slough trapping site. NS = North Slough, SS = South Slough, and EMB = Embayment.

Table 1. List of salmonid and non-salmonid species seined in the embayment of the Redwood Creek estuary, 6/05/90 through 9/28/90, Humboldt County, California. The mouth of Redwood Creek was open to the ocean during this period.

COMMON NAME	SPECIES
<u>Salmonids</u>	
Chinook Salmon *	<u>Oncorhynchus tshawytscha</u>
Coho Salmon *	<u>Oncorhynchus kisutch</u>
Steelhead Trout *	<u>Oncorhynchus mykiss</u>
Coastal Cutthroat Trout *	<u>Oncorhynchus clarki</u>
<u>Non-salmonids</u>	
Prickly Sculpin *	<u>Leptocottus armatus</u>
Staghorn Sculpin *	<u>Cottus asper</u>
Three Spine Stickleback *	<u>Gasterosteus aculeatus</u>
Starry Flounder	<u>Platichthys stellatus</u>
Surf Smelt	<u>Hypomeus pretiosus</u>
Night Smelt	<u>Spirinchus starksi</u>
Shiner Surfperch *	<u>Cymatogaster aggregata</u>
Saddleback Gunnel *	<u>Pholis ornata</u>
Bullfrog	<u>Rana catesbeiana</u>
Dungeness Crab	<u>Cancer magister</u>
Bay Shrimp	<u>Crangon franciscorum</u>
Mysid Shrimp	<u>Neomysis mercedis</u>
Ctenophores	

* Also trapped in South Slough (7/26/90)

creek is open to the Pacific Ocean, a large number of marine species will also use the estuary. Shiner surf perch (which give birth in the estuary), starry flounder, and thousands of surf smelt are commonly seined in the estuary.

I. POPULATION ESTIMATION

A. EMBAYMENT

Methods

To estimate the population of juvenile chinook salmon (Oncorhynchus tshawytscha) and steelhead trout (O. mykiss), the Peterson mark-recapture method was used. Fish were captured using a 150-foot long beach seine, 1/4 inch mesh size. The net was deployed in a semi-circular pattern from the shore using a boat equipped with an outboard motor. The net was pulled in at both ends, and the captured fish bagged in the center of the net. The fish were transferred in buckets to floating live carts. Captured fish were anesthetized with MS222 (tricaine methanesulfonate) and marked with Alcian Blue dye using a Panjet needleless injector. Fish were marked on the upper caudal fin, lower caudal fin, middle of the caudal fin, and the anal fin. The mark employed depended upon its previous usage. The fish were allowed to recover from the MS222 in buckets and then released into the estuary. Fish were marked over two consecutive days. A day was allowed to pass to insure the marked fish intermixed with unmarked fish. The following day fish were again seined. The captured fish were anesthetized and examined for marks. All salmonids were marked, including coho salmon (O. kisutch) and coastal cutthroat trout (O. clarki); the latter two species were in lower numbers, and the likelihood of recapturing these marked fish was low.

The formula used to estimate the population (Youngs and Robson 1978) was:

$$N^{\wedge} = m \times c / r$$

where: $N^{\wedge}$ = number of fish in population
 m = number of marked fish in population
 c = number of fish in a sample
 r = number of marked fish in c

Variance of $N^{\wedge}$ was calculated as:

$$V(N^{\wedge}) = (N^{\wedge})^2 (N^{\wedge} - m) (N^{\wedge} - c) / m \times c (N^{\wedge} - 1)$$

We were unable to meet one of the assumptions of the Peterson mark-recapture method: the population is closed to recruitment and immigration. Fish may migrate into the estuary from upstream or out of the estuary to the ocean when the mouth of Redwood Creek is open. To lessen this bias, the estimate took place over a short period, and fish marked and then recaptured in later population estimates were not used in subsequent calculations.

Twenty-four days were spent monitoring the fish and water quality in the Redwood Creek estuary during the summer of 1990. This covered the period between June 5 and September 28, 1990. A total of seven growth estimates and five population estimates were conducted, water quality was measured four times, and the South Slough trapped once. The south slough culvert gates remained closed all summer.

Results

Seven population estimates were attempted in summer-fall 1990. The first population estimate attempted on June 5 was unsuccessful because of combined river and tidal currents and ocean waves propagating into the embayment. Another attempt during the week of August 20 was unsuccessful. Only three unmarked salmonids (2 steelhead and 1 chinook salmon) were caught in 12 seine hauls on August 23, a recapture day, making an estimate impossible. Population estimates for coastal cutthroat trout and coho salmon were not possible because of their low numbers; recaptures of marked fish for these species was rare.

The estimates of salmonids utilizing the Redwood Creek estuary during summer-fall 1990 are presented in Table 2. On June 19, juvenile numbers were estimated at 6,390 chinook salmon and 10,050 steelhead trout. Chinook salmon numbers declined to 100 on September 10. Steelhead declined to 3,180 by September 10, but this was an increase of 1,000 fish over the previous August 6 estimate of 2,170 fish. The population trend of both of these species declined during the summer, bottoming out in early August (Figures 2 and 3). In the fall, steelhead numbers increased again, but the salmon numbers remained low. Confidence intervals (95%) of the estimates were generally good, especially for steelhead trout. The exception was for chinook salmon on July 17, which ranged from 209 to 12,770.

Discussion

Populations of both species of concern, chinook salmon and steelhead trout, declined throughout the summer and may have peaked even before the first population estimate could be made on June 19. The causes of the low numbers of salmonid fish in the estuary throughout the summer are unknown, but the following conditions probably contributed to their paucity: 1) reduced estuarine habitat and the Redwood Creek mouth remaining open throughout the summer, 2) poor estuarine water quality, and 3) poor fish production.

The Redwood Creek estuary mouth did not close until mid-September (see Section V - water level management). As a result, the amount of estuarine rearing habitat available to fish in the summer was subject to tidal influence, and was much less than if a natural embayment had formed. Areas in the estuary, at times were less than two feet deep, and only a few 'deep' (≈ 6 ft) water channels existed. These were found close to the berm and in the center of the embayment. The lack of fish cover in the form of water depth made most areas of the estuary unsuitable.

The open creek mouth probably affected the quality of estuarine habitat, particularly food production. The production of algae and benthic organisms is influenced by substrate stability. When the mouth is open, the sandy substrate moves and prevents algae from colonizing the substrate. Also, less water is impounded when the sand berm and sill across the mouth is low. This creates less habitat for fish food invertebrates important to salmonids such as Corophium, a tube dwelling amphipod, and dipterans, which colonize the algal masses.

Additionally, when the creek mouth is open, the fish may elect to leave the estuary when in a smolted condition. On June 27, we investigated a visitor

Table 2. Population estimates and 95% confidence intervals for juvenile salmonids utilizing the Redwood Creek estuary during the summer of 1990, Humboldt County, California.

	Population Estimate	95% Confidence Interval	
<u>Chinook Salmon</u>			
6/19/90	6,390	4,180	8,590
7/17/90	5,410	209 ^a	12,770
8/06/90	64	15 ^a	175
8/20/90	1 ^a		
9/10/90	100	38 ^a	180
<u>Steelhead Trout</u>			
6/19/90	10,050	7,410	12,700
7/17/90	7,120	6,150	8,090
8/06/90	2,170	1,000	3,350
8/20/90	159 ^a		
9/10/90	3,180	2,960	3,400
<u>Coho Salmon</u>			
6/19/90	4 ^a		
7/17/90	33 ^a		
8/06/90	7 ^a		
8/20/90	2 ^a		
9/10/90	28	10 ^a	56
<u>Coastal Cutthroat Trout</u>			
6/19/90	7 ^a		
7/17/90	20 ^a		
8/06/90	1 ^a		
8/20/90	0		
9/10/90	3 ^a		

^a Actual number caught

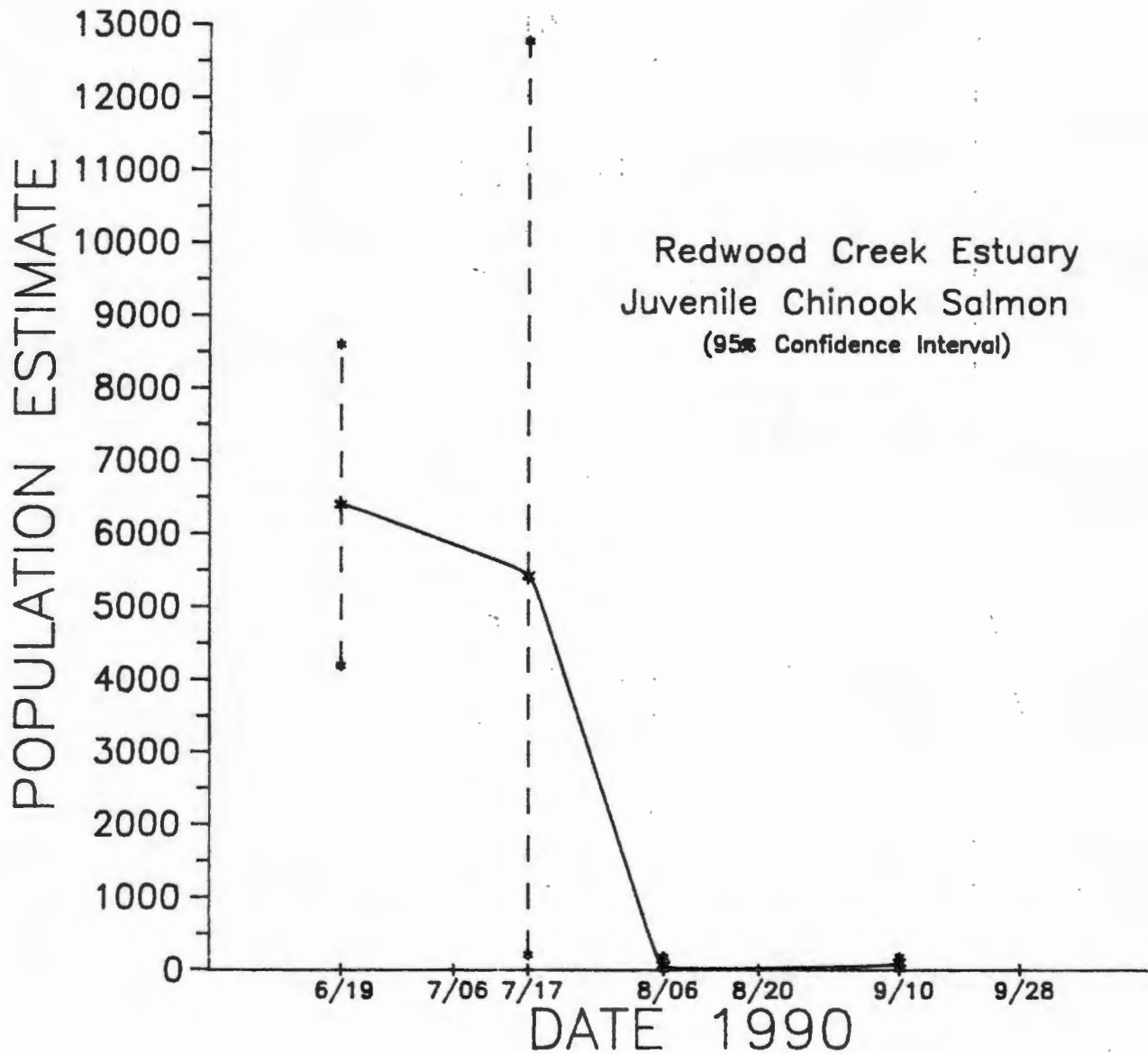


Figure 2. Population estimates and 95% confidence intervals of juvenile chinook salmon utilizing the Redwood Creek estuary, Humboldt County, California, during the summer and fall of 1990.

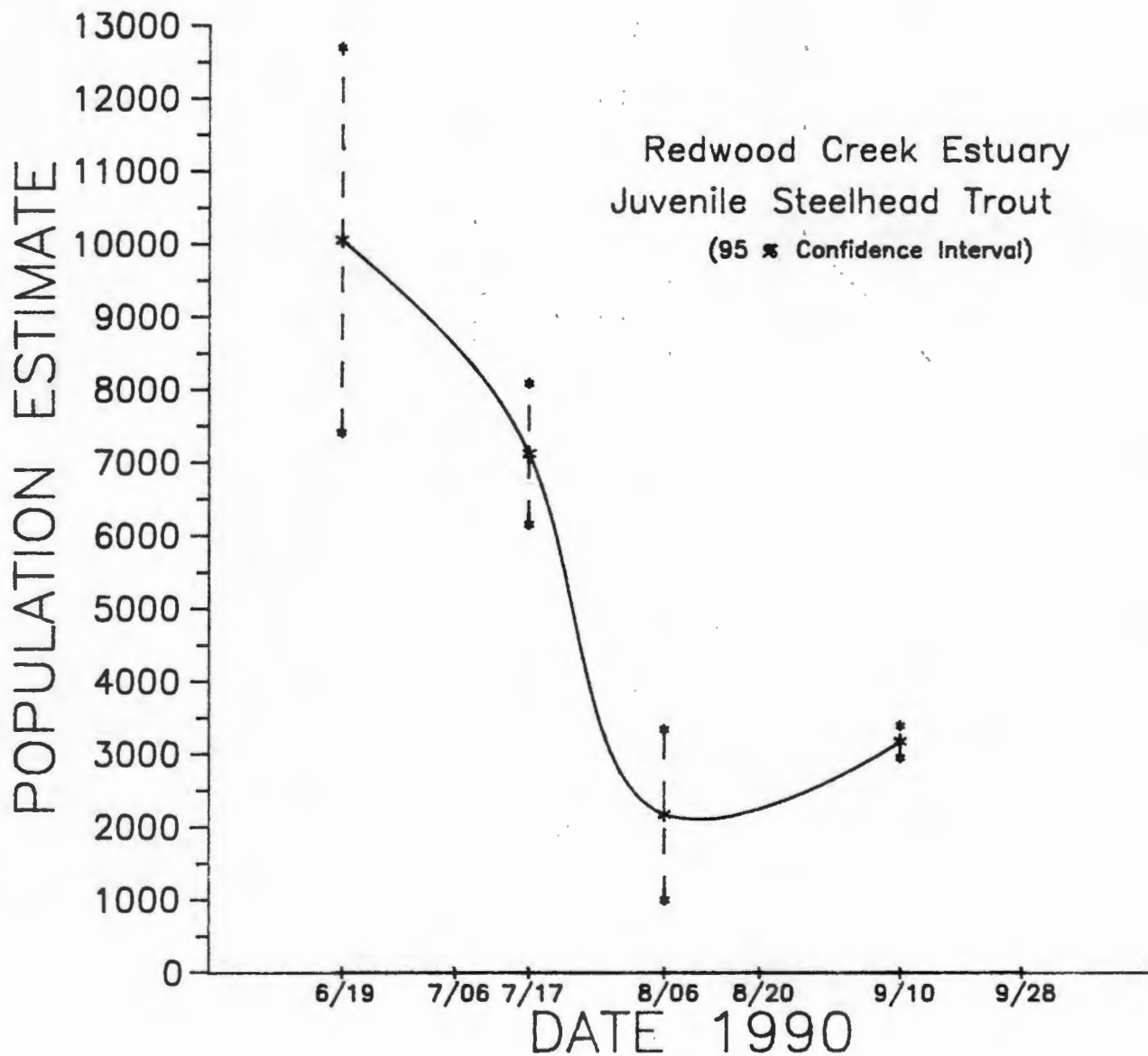


Figure 3. Population estimates and 95% confidence intervals of juvenile steelhead trout utilizing the Redwood Creek estuary, Humboldt County, California, during the summer and fall of 1990.

complaint about sport fishermen fishing on juvenile salmonids with throw nets in the surf at the mouth of Redwood Creek at flood tide. We observed juvenile salmonids jumping out of the incoming waves and swells. The fishermen were releasing salmonids caught in their nets, but keeping the smelt. The juveniles were outside the embayment proper, apparently in sea water. A problem arises if fish leave prematurely before smolting and become entrained involuntarily through the mouth into the ocean. Ocean survival and growth may be affected as the fish are not physiologically prepared for salt water. Also, based on scale analysis of returning chinook salmon adults, Reimers (1973) concluded the survival of those fish that left earlier in summer was less than those that grew larger and remained in the estuary till fall.

Poor water quality in the estuary in the form of high water temperatures was another factor that may have affected the fish. Temperatures measured in the estuary embayment ranged from 16.0 to 23.0°C (see section III - Water Quality). The highest embayment temperatures were measured at the end of July, prior to the low population estimates. The preferred temperature ranges reported by Reiser and Bjornn (1979) for rearing chinook salmon and steelhead trout are 7.3 - 14.6°C and 7.8 - 14.6°C, respectively. The higher water temperatures in the estuary may have 'thermally pushed' fish out of the estuary.

Poor fish production during the winter of 1989-90 may have also contributed to the low numbers of fish. In October 1989, a large storm caused extensive erosion from the Highway 101 Bypass project. At the time, erosion control structures were not in place as CalTrans had elected to continue grading work. A large amount of fine sediment was transported into the numerous tributaries flowing into Prairie Creek, where much remained in storage over the 1989-90 winter (Redwood National Park 1991). This sediment infiltrated spawning gravel and any subsequent redds constructed by fish. During the winters of 1989-90 and 1990-91 Redwood National Park has been studying this impact on hatching and emergence survival of salmonid eggs in Prairie Creek. Preliminary results indicate survival has been affected (see 1991 winter bypass monitoring progress report).

A new moon on July 21, 1990, a natural factor, may have influenced an early migration to the ocean. Fish are known to migrate on a new moon. Hormonal levels affecting smoltification vary with the lunar cycle.

Other factors that could have influenced salmonid numbers were management activities such as: 1) artificial breaching of the sand berm, 2) fire suppression activities at the estuary, and 3) the hatchbox fish supplementation program on Prairie Creek.

Management activities such as artificially breaching the berm to lower water levels can potentially affect the fish residing in the estuary. A rapid decline in the water level and its accompanying flow out the mouth will entrain fish in the outgoing current. Breaching during the summer of 1990, did not take place until late September when the mouth closed. The majority of the fish, particularly chinook salmon had already migrated to the ocean. Thus, its effect was probably minimal.

On August 2, 1990, a large fire burned all of the southern slope of the northern hill adjacent to the estuary. Helicopter water drops were made on the hill with north slough water. The helicopter may have 'spooked' the fish in the embayment.

To augment the expected reduction in natural fish production, the Pacific Coast Federation of Fishermen's Associations (PCFFA) Trinidad Fishermen's Salmon Enhancement Prairie Creek Project released 33,900 chinook salmon on May 16 and 21, 1990, at 120/lb., ranging from 48 to 89 mm (mode 70 mm). None were coded wire tagged and adipose clipped due to California Fish and Game budget constraints. These fish were not readily identifiable in the estuary. In a few cases, we observed chinook with partially eroded blackened dorsal fins. If they were present, it could not be determined by our population estimates.

The PCFFA also released 24,800 juvenile steelhead in Prairie Creek on July 18, ranging from 38 to 78 mm (mode 48 mm). They were not fin clipped. Further analysis of length-frequency data will be needed to establish whether these fish were in the estuary during the summer.

PCFFA released 35,645 coded wire tagged and adipose fin clipped coho salmon; 1,640 untagged fish escaped, giving a total of 37,285 coho. Most coho salmon caught in the embayment were adipose fin clipped. Thus, it appears that most, if not all, coho seined in the estuary were from PCFFA project releases. The five tagged release dates were from June 25 to July 12. Though only one coho population estimate was possible, coho numbers in the estuary peaked on July 17, just after the last release. The 33 coho seined in the estuary that day (30 tagged, 1 untagged), ranged from 89 to 155 mm in fork length. Based upon PCFFA coho length frequencies at release, these fish were at or above the 83 percentile level of the released fish. The mean fork length of released fish was 79 mm (n=100) (PCFFA 1990). The larger fish must have migrated to the estuary. Normally, juvenile coho salmon are not found in the embayment during the summer and fall. Coho salmon smolts migrate to the ocean in the spring after remaining in their natal stream for one year.

Coastal cutthroat trout were more numerous in early summer and peaked on July 17. These fish most likely represented downstream migrating smolts. In their review of coastal cutthroat, Pauley et al. (1989) reported that downstream movement in Washington and Oregon takes place March to June, peaking in mid-May. Smolting was variable and somewhat size dependent, but the fish usually ranged from 200 - 250 mm fork length. Those in coastal streams averaged age IV and 210 mm, which falls within our size range. Cutthroat trout captured in the Redwood Creek estuary averaged between 182 and 251 mm (range 135 to 389 mm).

When compared with previous years, the 1990 estimated chinook and steelhead populations were generally lower (Figures 4 and 5). A further report encompassing past years data is forthcoming.

B. SOUTH SLOUGH

Methods

Due to dense aquatic vegetation in the south slough, seining is not effective. Thus, trapping was utilized. We can not estimate populations by trapping in

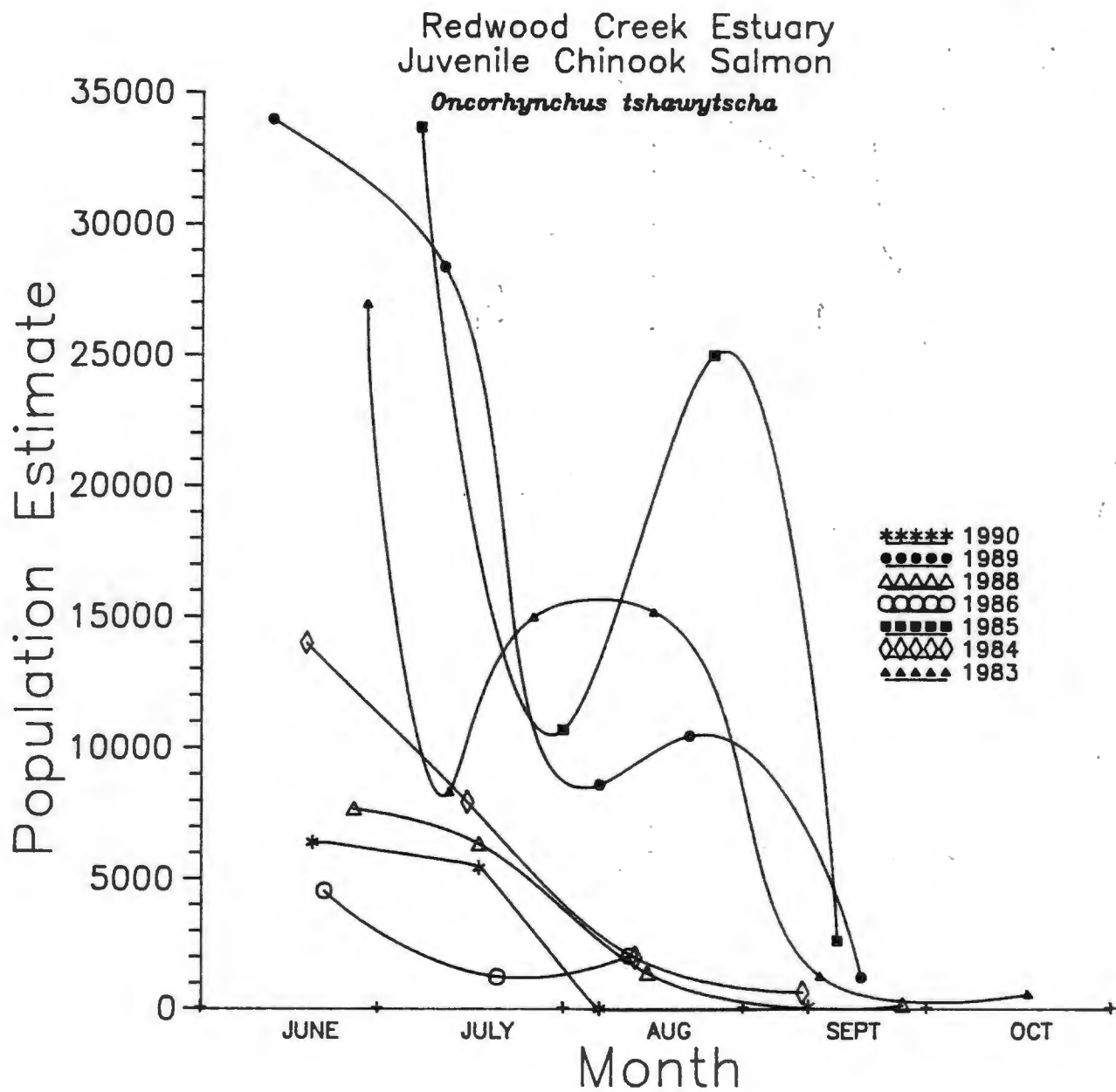


Figure 4. Population estimates of juvenile chinook salmon utilizing the Redwood Creek estuary, Humboldt County, California, during the summer and fall of the 1980 decade.

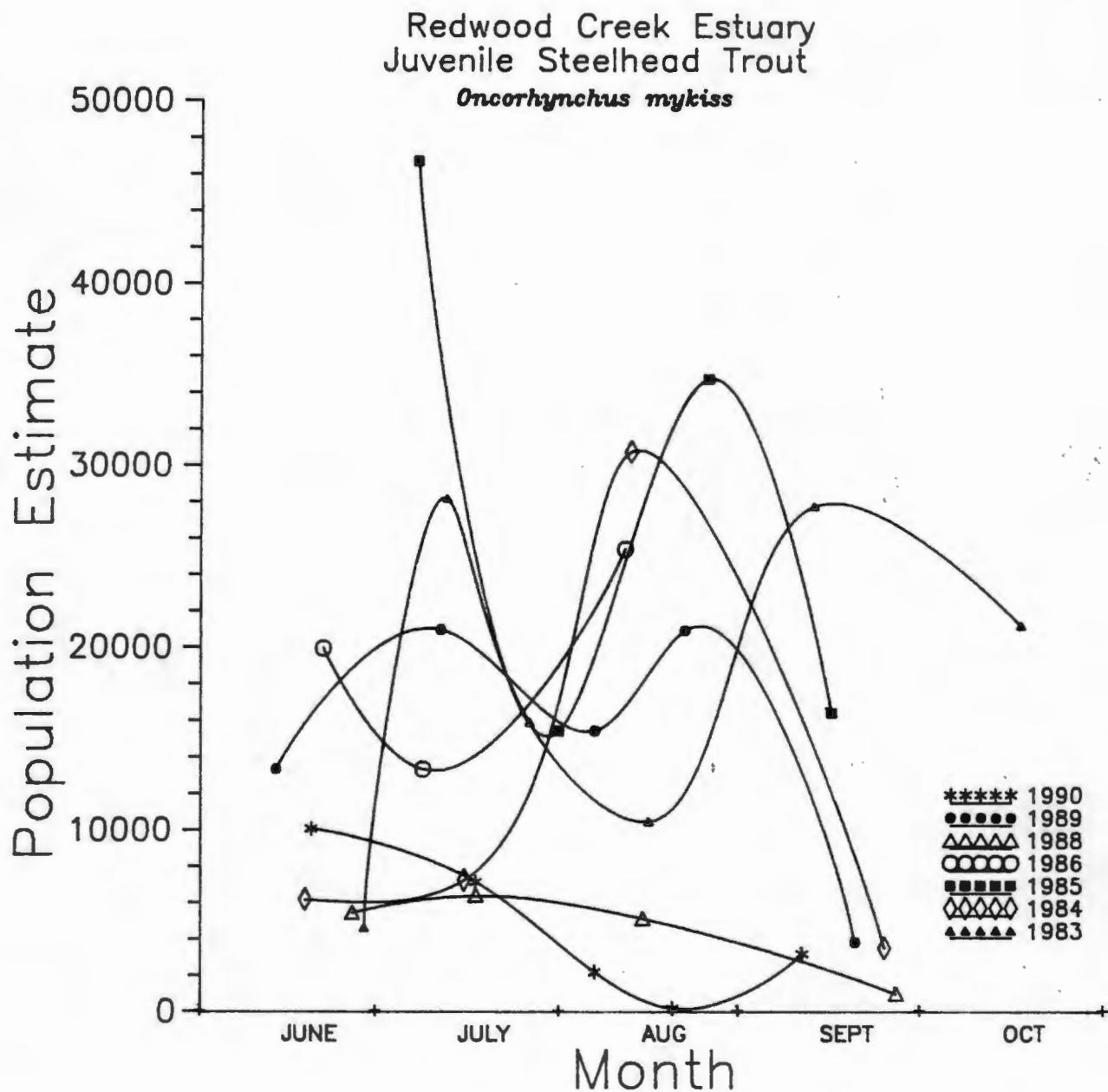


Figure 5. Population estimates of juvenile steelhead trout utilizing the Redwood Creek estuary, Humboldt County, California, during the summer and fall of the 1980 decade.

the south slough, however trapping does demonstrate utilization of the slough by salmonids. Two fyke nets were placed in the south slough at the RNP boundary line in the remnant creek channel in about five feet of water (Figure 1). One net was oriented facing upstream (toward the culvert) and the other facing downstream (toward the slough neck). The fyke nets have six 3-foot hoops, with two 15-foot long wing nets set to at a 90° angle. The mesh size is 1/4 inch, and the opening in each net funnel trap is 2.5 by 2.5 inches. The mouth of Redwood Creek remained open, subjecting the slough to the tide. The gates in the south levee culvert were closed. Both nets were in place at 1130 h on 7/25 and retrieved 24.75 hours (upstream facing) and 26.50 hours (downstream facing) later. The gage height was 2.86 ft (@ 1115 h 7/25) and 2.75 ft (@ 1145 h 7/26).

Results

A combined total of 3,327 fish were caught, 2,738 from the upstream facing net, and 589 from the downstream facing net (Table 3). For salmonids, a total of 13 chinook, 36 steelhead, and 1 cutthroat were caught. Of the 36 steelhead, three had bottom and one had top caudal Panjet marks. The blue dye marks were used in previous mark-recapture population estimates in the embayment. The bottom caudal mark had been applied on 7/17 and 18, six days earlier to 1,474 steelhead. The top caudal mark had been applied on 6/19 and 20, 34 days earlier to 609 steelhead. These results demonstrate that some fish utilize both the estuary and south slough during the summer.

Table 3. Numbers and percentages of fish trapped in the South Slough, Redwood Creek estuary on 7/25-26/90.

SPECIES	NUMBER	PERCENTAGE
Three spined Stickleback	2,676	80.4
Prickly Sculpin	286	8.6
Shiner Surfperch	278	8.4
Staghorn Sculpin	36	1.1
Steelhead Trout	36	1.1
Chinook Salmon	13	0.3
Cutthroat Trout	1	0.03
Saddleback Gunnel	<u>1</u>	<u>0.03</u>
TOTAL NO.	3,327	100.00

II. JUVENILE GROWTH

A. EMBAYMENT

Methods

Fish fork lengths were sampled every other week during the summer. The same methods used to capture and handle fish in the marking operation were employed during the growth study. Two hundred fork lengths each of chinook salmon and steelhead trout were measured to the nearest 1.0 mm. Thirty fish of each of these species were weighed on an Ohaus dial-o-gram scale, and fish scales were collected. Fork lengths of other species, coho salmon, coastal cutthroat trout, and the occasional half-pounder and adult steelhead trout were measured.

Results

Seven growth estimates were conducted during the summer-fall of 1990, June 19 to September 25 (Tables 4 and 5, Figures 6 and 7). Mean fork length of chinook salmon increased 21.8 mm, from 79.9 to 101.7 mm. For steelhead trout, mean fork length increased 40.1 mm, from 120.4 to 160.5 mm, even though several age classes were represented. Due to the low numbers of coastal cutthroat sampled, the growth trend was unclear. Coho salmon mean fork length increased from 69.0 to 136.0 mm. All were assumed to be young-of-the-year from the PCFFS hatchbox project.

Discussion

Fish continued to grow throughout the summer-fall season. Small sample sizes for chinook salmon during the season probably accounted for the erratic growth rate changes over the season (Figure 6). Despite this, size increased over the study period. Generally, the growth rate for steelhead was constant throughout the season (Figure 7). It appears the numbers of chinook and steelhead did not affect their growth rates (Figures 6 and 7), unlike the results of Reimers (1973) in the Sixes River estuary, Oregon. He found chinook growth slowed during the peak estuary population, and then accelerated when the population declined in fall. In the Redwood Creek estuary, scale analysis revealed no significant difference in riverine and estuarine circuli spacing; chinook salmon appeared to remain in the estuary for a period of extended, but not accelerated growth (McKeon 1985). The advantage derived from residing in the estuary for the entire summer appears to be an opportunity for an extended period of optimal growth before entering the ocean. Those chinook salmon that reared in the estuary till fall before ocean entry had a greater chance of returning as spawners (Reimers 1973).

For comparison purposes, 1983 through 1990 chinook mean fork lengths are presented in Figure 8. Further analysis is needed, but it appears 1990 fish entered the ocean at a smaller size than some previous years.

Table 4. Mean fork lengths (mm) and weights (g), standard deviation (Std. Dev.), and range of salmonids utilizing the Redwood Creek estuary, Humboldt County, California, summer 1990.

SUMMER 1990 REDWOOD CREEK ESTUARY

JUVENILE CHINOOK SALMON (Oncorhynchus tshawytscha)

Date	FORK LENGTH (mm)			WEIGHT (g)		
	No.	Mean	Std. Dev.	Range Min. - Max.	No.	Mean
6/19/90	202	79.9	9.5	47 - 110	30	7.1
7/06/90	18	90.8	16.3	61 - 128	18	9.2
7/17/90	206	84.5	6.6	70 - 119	30	8.7
7/26/90 ^a	13	90.5	12.1	71 - 110	-	-
8/06/90	15	88.1	5.7	77 - 98	15	7.7
8/23/90	1	86.0	-	-- --	-	-
9/10/90	37	101.7	8.8	89 - 130	30	11.1
9/25/90	1	100.0	-	-- --	-	-

JUVENILE STEELHEAD TROUT (O. mykiss)

Date	FORK LENGTH (mm)			WEIGHT (g)		
	No.	Mean	Std. Dev.	Range Min. - Max.	No.	Mean
6/19/90	159	120.4	15.2	64 - 106	30	22.5
7/06/90	355	130.7	11.9	94 - 163	30	26.7
7/17/90	205	134.6	13.6	103 - 182	30	28.3
7/26/90 ^a	36	124.6	20.2	58 - 162	-	-
8/06/90	205	133.0	12.8	87 - 169	30	26.0
8/20/90	159	145.5	14.4	100 - 185	30	34.1
9/10/90	231	152.5	16.0	109 - 191	30	39.5
9/28/90	52	160.5	20.2	119 - 218	30	47.5

^a Trapped in South Slough fyke nets, all others were seined in the embayment.

Table 5. Mean fork lengths (mm), standard deviations (Std. Dev.), and range of salmonids utilizing the Redwood Creek estuary, Humboldt County, California, summer 1990.

COASTAL CUTTHROAT TROUT (Oncorhynchus clarki)

Date	FORK LENGTH (mm)		Std. Dev.	Range	
	No.	Mean		Min. -	Max.
6/19/90	7	182.7	42.2	135	242
7/06/90	14	251.4	82.2	147	389
7/17/90	20	245.8	57.8	167	353
7/26/90 ^a	1	176.0	--	--	--
8/09/90	1	264.0	--	--	--
9/13/90	3	240.0	23.4	226	267

JUVENILE COHO SALMON (Oncorhynchus kisutch)

Date	FORK LENGTH (mm)		Std. Dev.	Range	
	No.	Mean		Min. -	Max.
6/20/90	4	69.0	20.1	56	99
7/06/90	6	105.3	3.9	98	110
7/17/90	31	101.8	6.3	89	115
8/07/90	7	108.7	6.1	99	117
8/21/90	2	125.5	13.4	116	135
9/11/90	10	136.0	9.2	124	152

STEELHEAD TROUT HALF POUNDER (O. mykiss)

Date	FORK LENGTH (mm)		Std. Dev.	Range	
	No.	Mean		Min. -	Max.
9/13/90	9	300.3	19.9	--	--
9/28/90	1	282.0	--	--	--

ADULT STEELHEAD TROUT (O. mykiss)

Date	FORK LENGTH (mm)		Std. Dev.	Range	
	No.	Mean		Min. -	Max.
8/07/90	1	624.0	--	--	--
9/13/90	1	630.0	--	--	--

^a Trapped in South Slough fyke nets, all others were seined in the embayment.

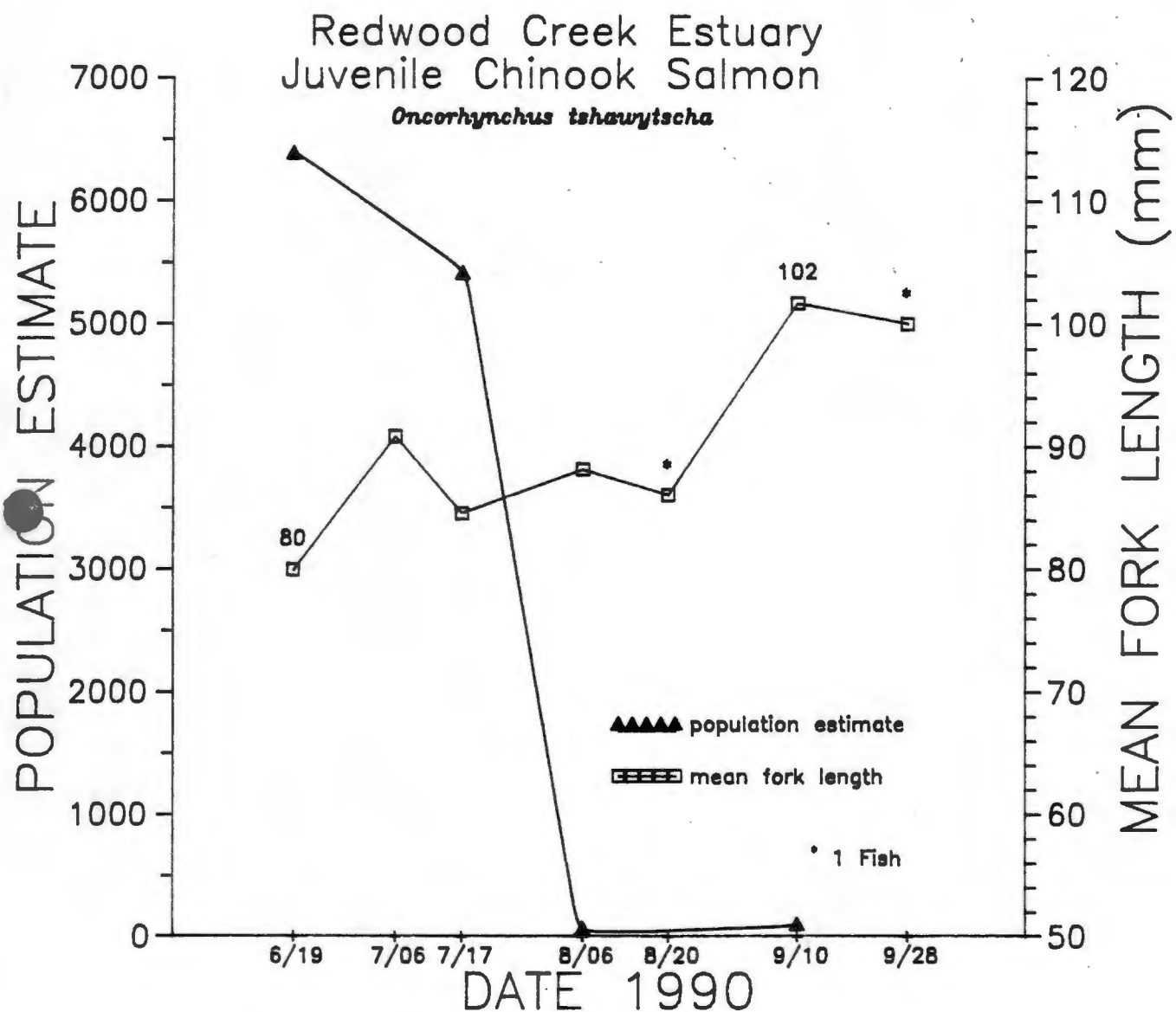


Figure 6. Mean fork lengths (mm) and population estimates for juvenile chinook salmon utilizing the Redwood Creek estuary, Humboldt County, California, during the summer and fall of 1990.

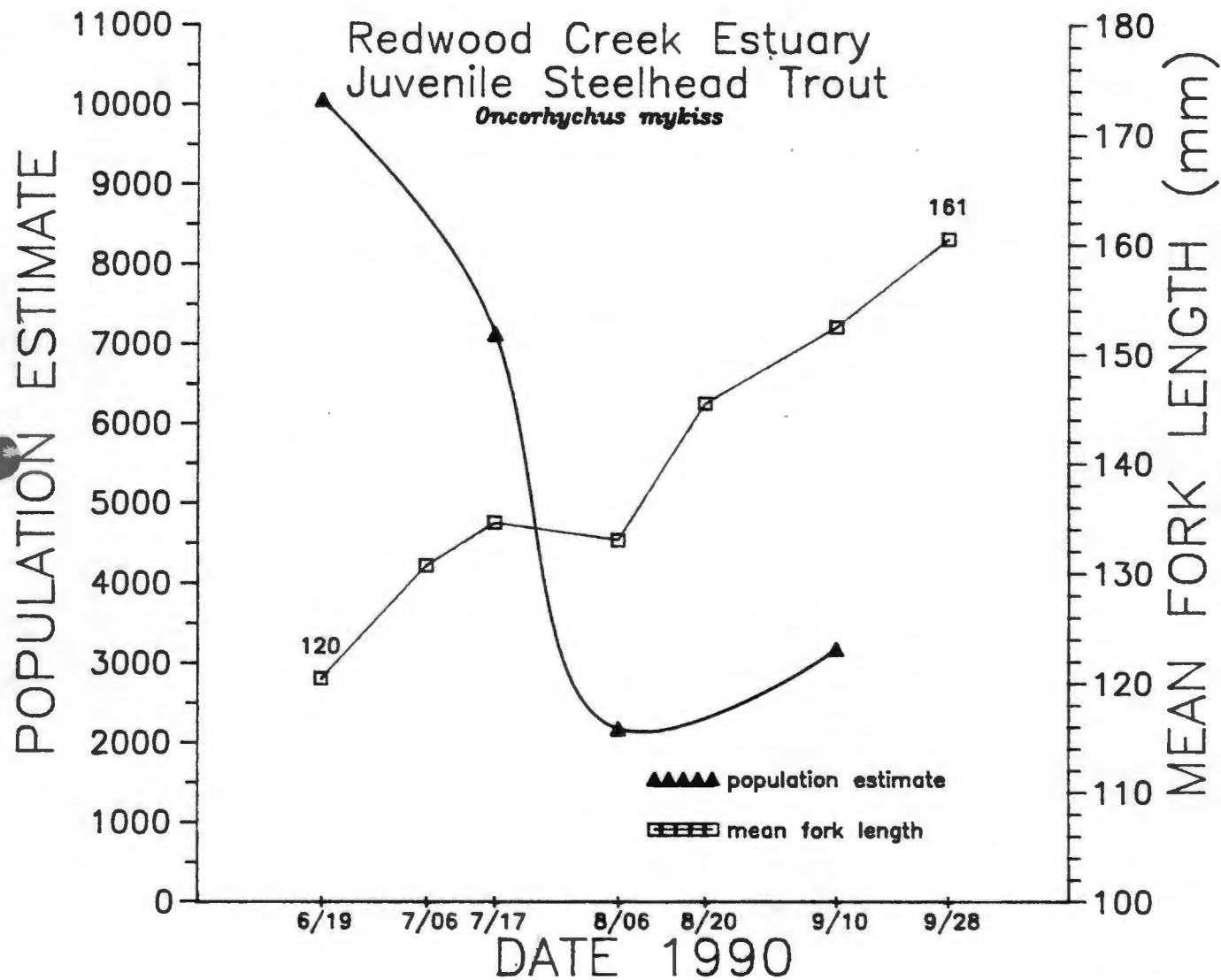


Figure 7. Mean fork lengths (mm) and population estimates for juvenile steelhead trout utilizing the Redwood Creek estuary, Humboldt County, California, during the summer and fall of 1990.

Redwood Creek Estuary
Juvenile Chinook Salmon
Oncorhynchus tshawytscha

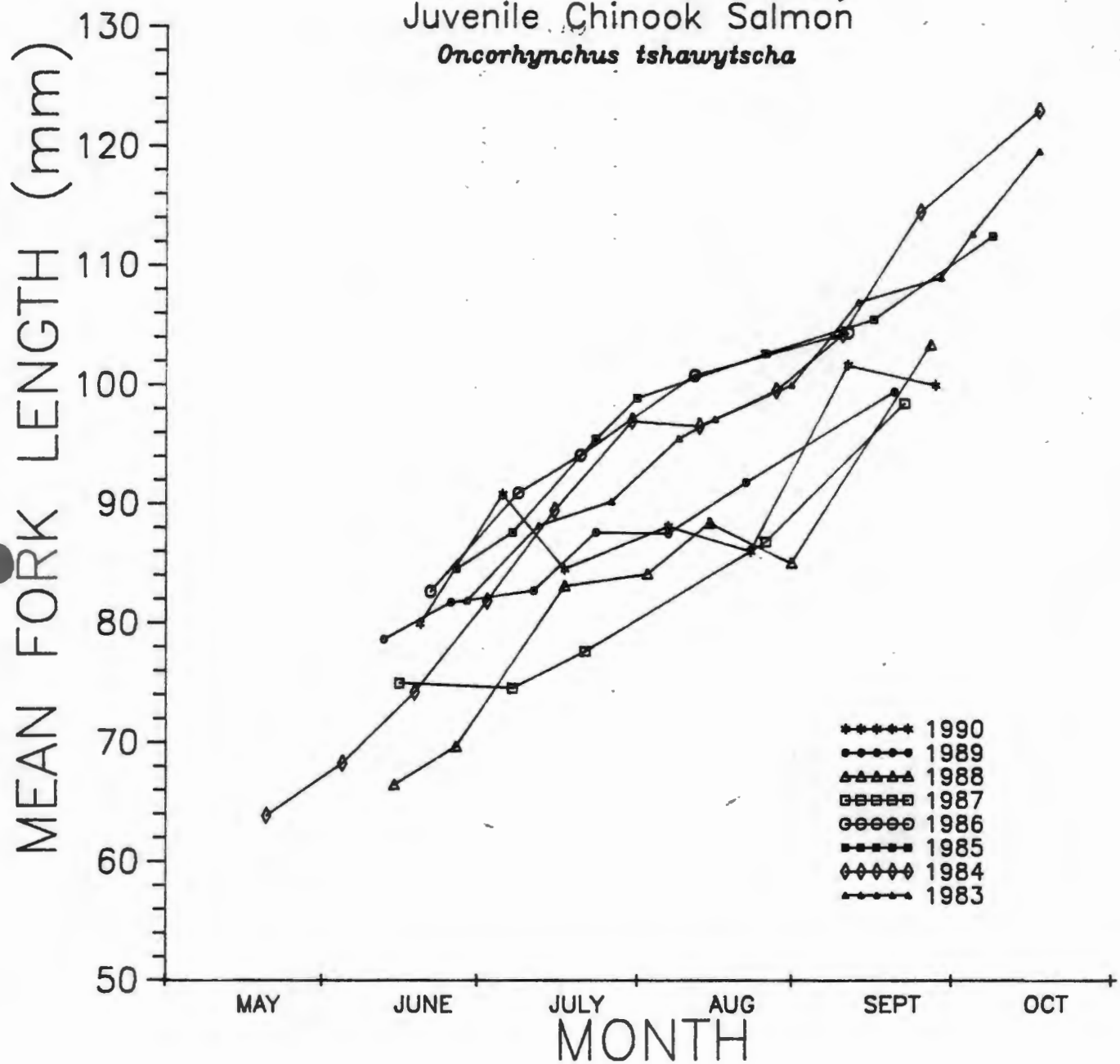


Figure 8. Mean fork lengths (mm) of juvenile chinook salmon utilizing the Redwood Creek estuary, Humboldt County, California, during the 1980 decade.

B. SOUTH SLOUGH

Methods

Methods were same as for south slough trapping and as embayment growth studies. However, no weights were measured or scales sampled.

Results

Mean fork length was 124.6 mm for the 36 steelhead (Std. Dev. 20.2, Range 58 - 162); 90.5 mm (Std. Dev. 12.1, range 71 - 110) for the 13 chinook; and 176 mm for the one cutthroat trout. Five of the chinook had partially blackened dorsal fins, indicating they possibly originated from the hatchbox enhancement project on Prairie Creek. Their mean fork length was 104.0 mm (Std. Dev. 3.7).

Discussion

South slough steelhead were smaller than embayment steelhead seined on July 17 and August 8. However, they fall within the confidence intervals of embayment fish. Additionally, three of the 36 steelhead were marked fish, indicating the south slough fish were from the same population as the embayment fish. South slough chinook were larger than chinook seined in the embayment on July 17 and August 8, but they too fall within their confidence intervals, and are probably from the same population.

III. WATER QUALITY

Methods

Water quality parameters were measured at one foot depth intervals at 12 sampling stations in the Redwood Creek estuary (Figure 1). The estuary was divided into four areas with three stations each. They were the main embayment, the south slough, the south slough neck, and the north slough. Parameters measured were depth (feet), water temperature (°C), salinity (o/oo), conductivity (μ mhos @ 25°C), dissolved oxygen (ppm), and pH. A YSI model no. 33 salinity-conductivity-temperature meter, a YSI model no. 57 dissolved oxygen meter, and a model no. 88 Markson Science portable pH digital meter were used. The dissolved oxygen meter had a range of 0 to 20 ppm, and the meter was 'pegged' when dissolved oxygen concentrations exceeded 20 ppm. An alpha bottle was used to retrieve bottom water samples for pH measurements. Generally, all embayment stations were measured on the outgoing tide. This was not by design, but an artifact of the time of day. Measurements were made every three to four weeks in summer-fall 1990.

Results

Graphic representations of measured values of temperature, dissolved oxygen, and salinity are presented for 10 stations (Figures 9 through 18). Two South Slough neck stations are presented in Table 6. Measured pH values are presented in Table 7. The north slough was anoxic and warm. The south slough exhibited high temperatures, pH, and dissolved oxygen values. In the embayment, temperatures were high, with sufficient dissolved oxygen concentrations. Both the embayment and south slough exhibited a saline layer at the lower depths. The south slough neck functioned as a shallow and very warm tidal influenced channel.

Discussion

North Slough

North Slough depths measured in the summer of 1990 (up to 16 feet) were the deepest in the entire estuary. These remnant depths have not been affected by sedimentation because the levee does not affect the north and south forks. The levee altered the direction of flow of Redwood Creek, causing greater sedimentation in the north slough neck, and isolating the north and south fork stations.

Sand deposited by previous winter storms has effectively isolated the North Slough from the embayment. The sand in the 'channel' (at the end of the north levee) of the North Slough, when surveyed in March of 1991, was 10.9 feet above mean sea level. At that height, surface tides can not flow into the North Slough, even at high tide. The amount of subsurface water percolation through the sand and its effect on water quality in the north slough is unknown.

Water was anoxic below 3 feet at the north fork (NS3) and fork (NS2) stations, and below 5 feet on the south fork (NS1). Surface temperatures were high, between 18 and 23.5°C, and decreased to more suitable levels for salmonids = 13°C at the bottom (Figures 9, 10, and 11). Because of negligible dissolved

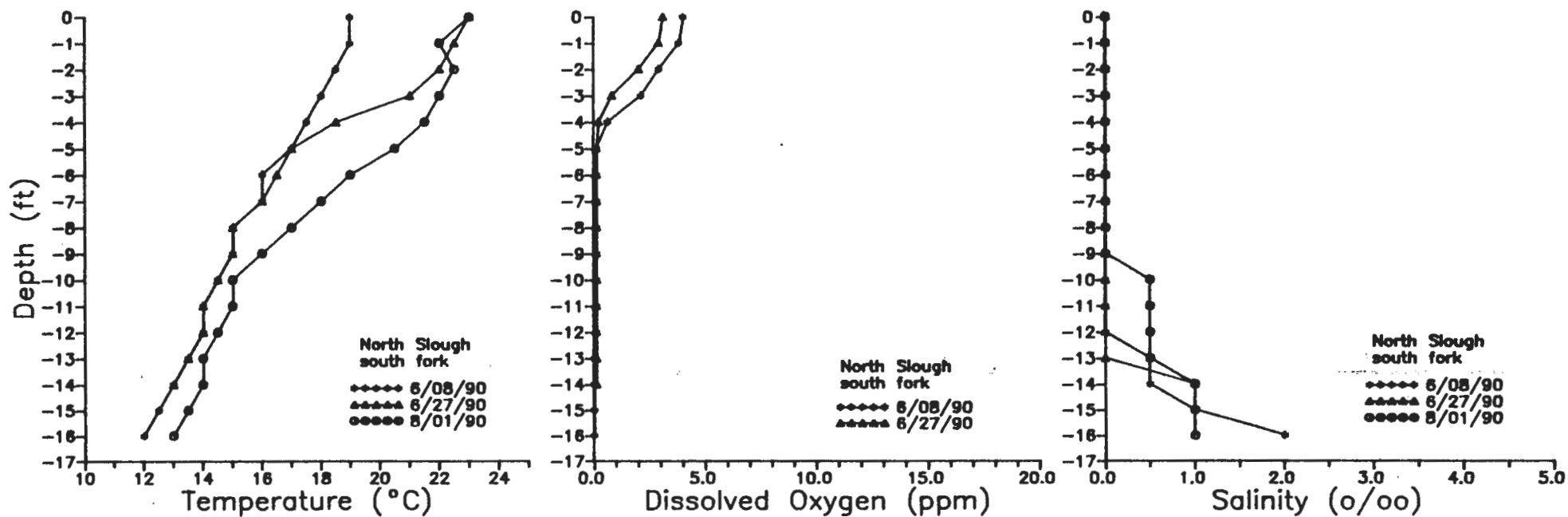


Figure 9. Water quality parameters, temperature (°C), dissolved oxygen (ppm), and salinity (o/oo), measured at one foot depth intervals in the south fork (NS1) of the north slough, Redwood Creek estuary, Humboldt County, California, during the summer of 1990.

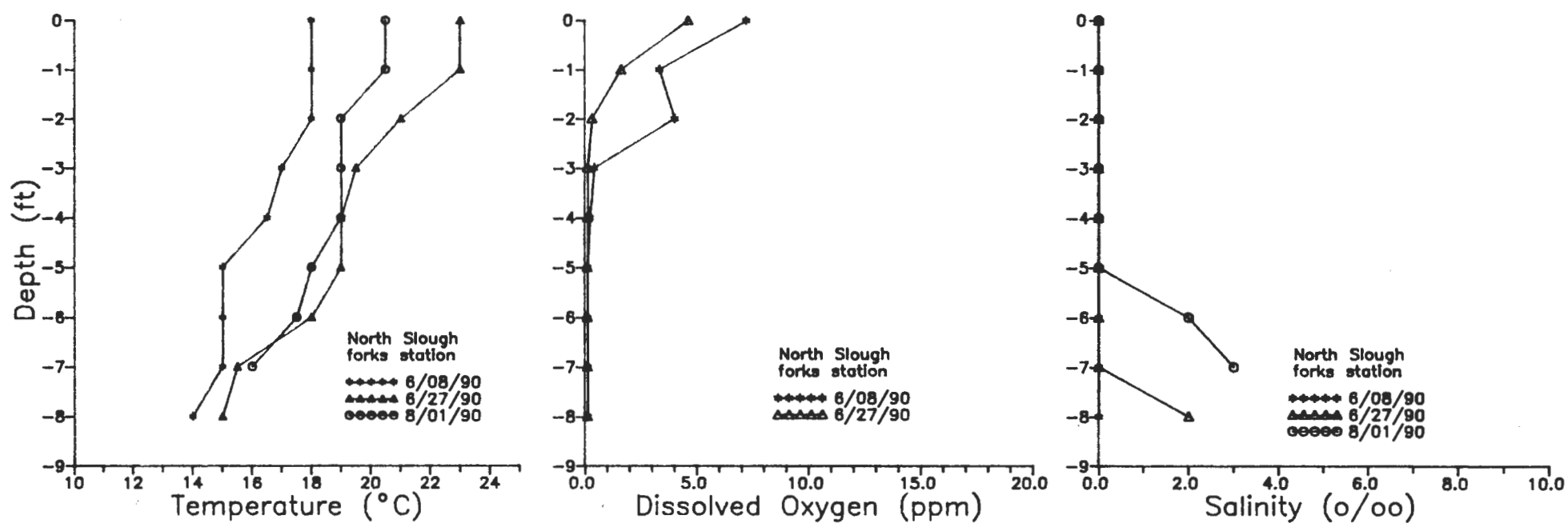


Figure 10. Water quality parameters, temperature ($^{\circ}\text{C}$), dissolved oxygen (ppm), and salinity (o/oo), measured at one foot depth intervals at the fork (NS2) of the north slough, Redwood Creek estuary, Humboldt County, California, during the summer of 1990.

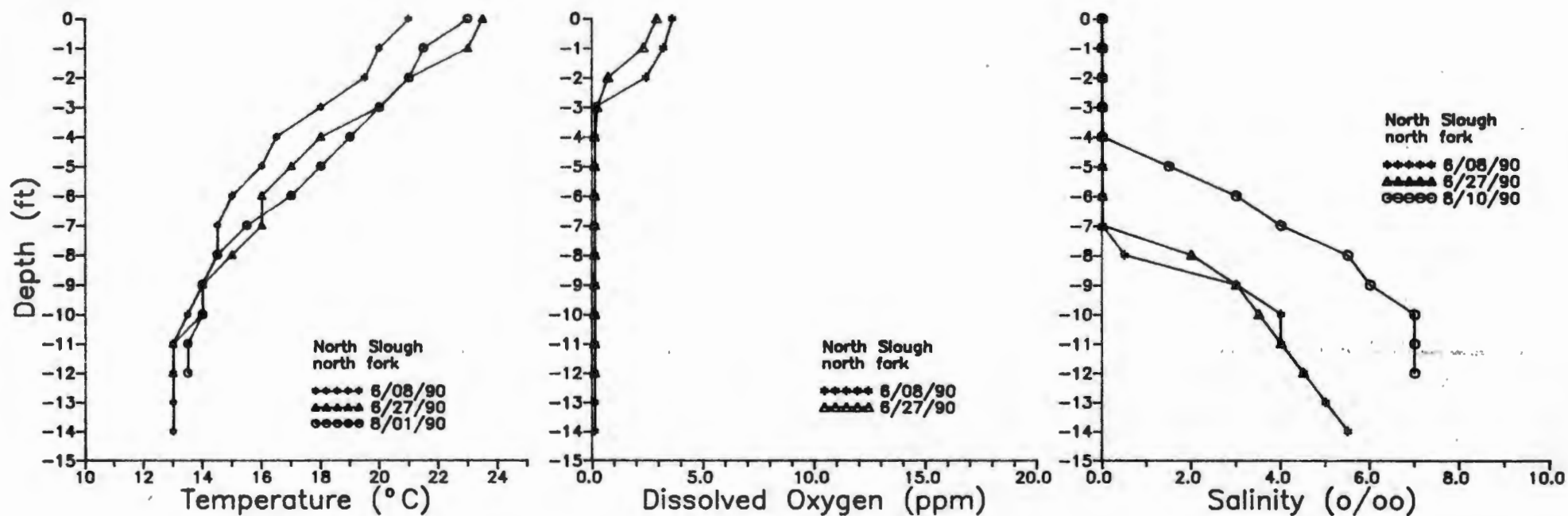


Figure 11. Water quality parameters, temperature ($^{\circ}\text{C}$), dissolved oxygen (ppm), and salinity (o/oo), measured at one foot depth intervals in the north fork (NS3) of the north slough, Redwood Creek estuary, Humboldt County, California, during the summer of 1990.

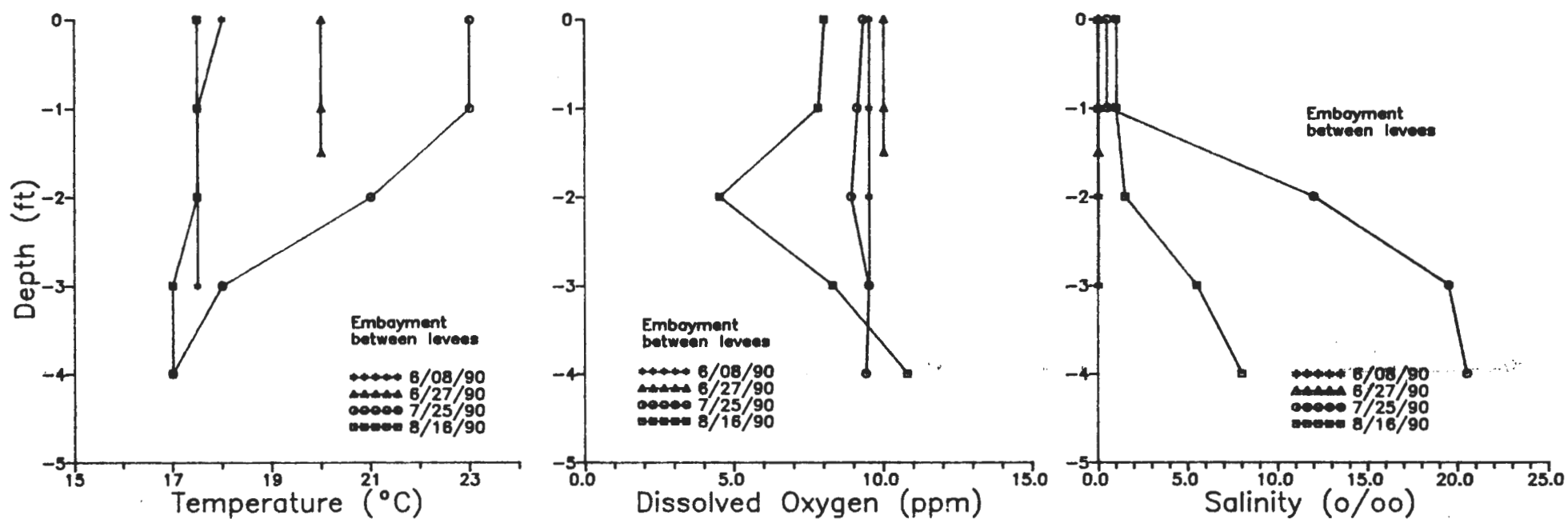


Figure 12. Water quality parameters, temperature (°C), dissolved oxygen (ppm), and salinity (o/oo), measured at one foot depth intervals between the levees (EMB4) in the embayment, Redwood Creek estuary, Humboldt County, California, during the summer of 1990.

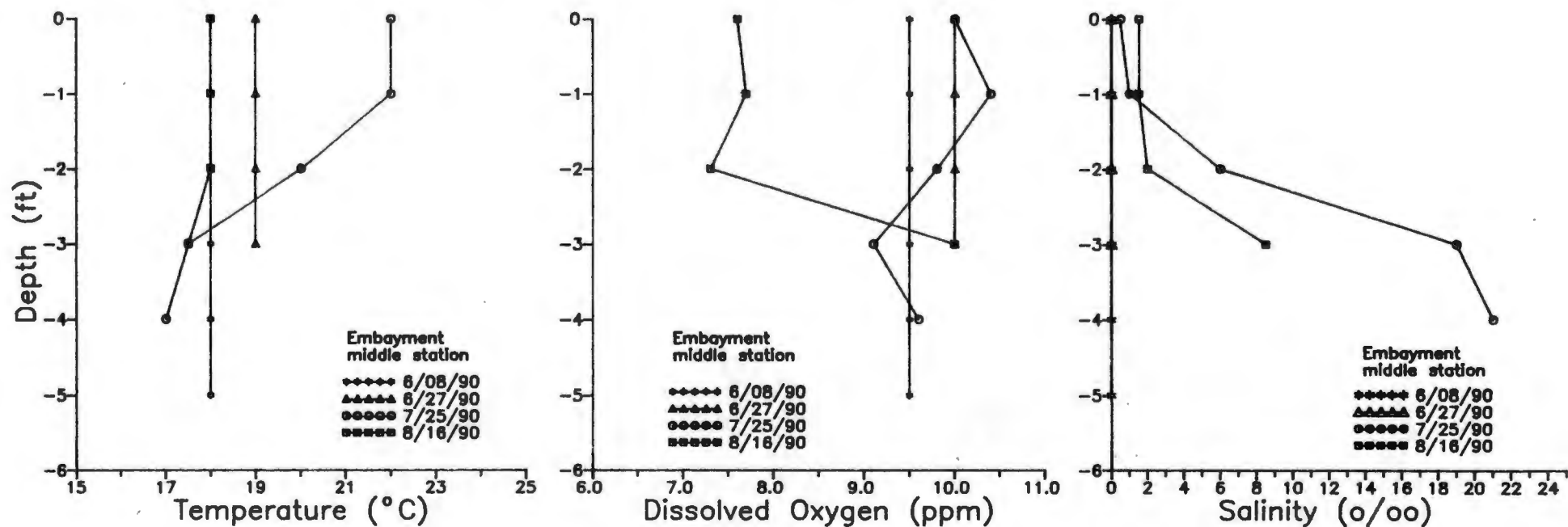


Figure 13. Water quality parameters, temperature (°C), dissolved oxygen (ppm), and salinity (o/oo), measured at one foot depth intervals in the middle (EMB5) of the embayment, Redwood Creek estuary, Humboldt County, California, during the summer of 1990.

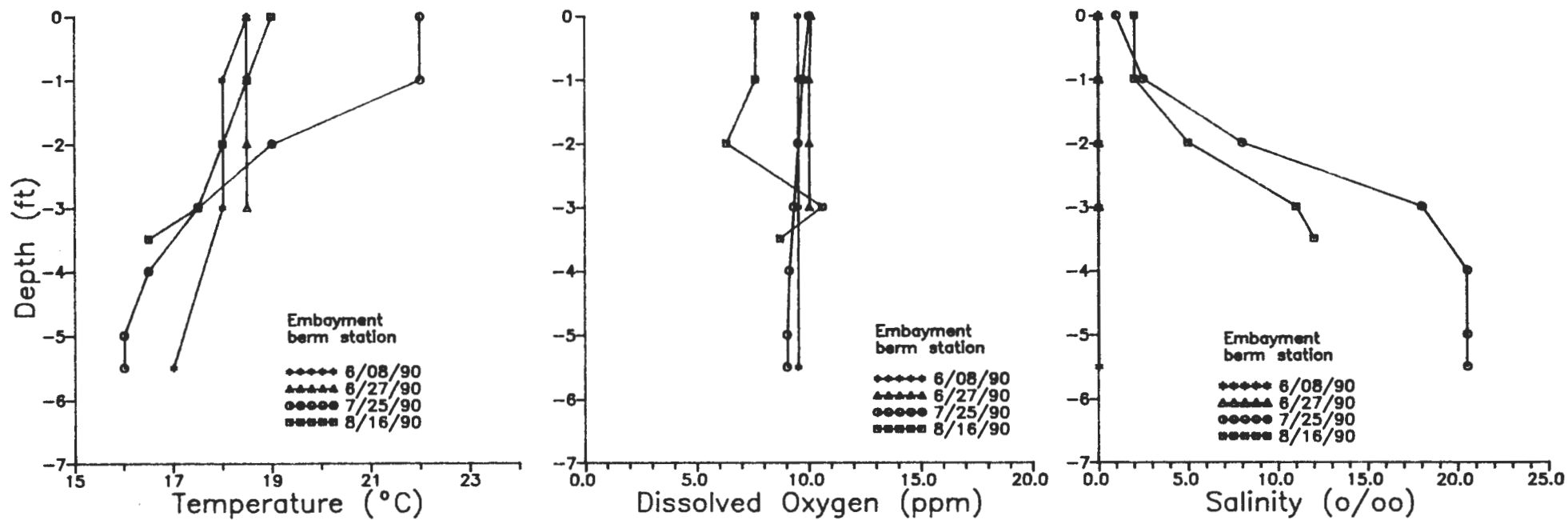


Figure 14. Water quality parameters, temperature (°C), dissolved oxygen (ppm), and salinity (o/oo), measured at one foot depth intervals at the berm (EMB6) of the embayment, Redwood Creek estuary, Humboldt County, California, during the summer of 1990.

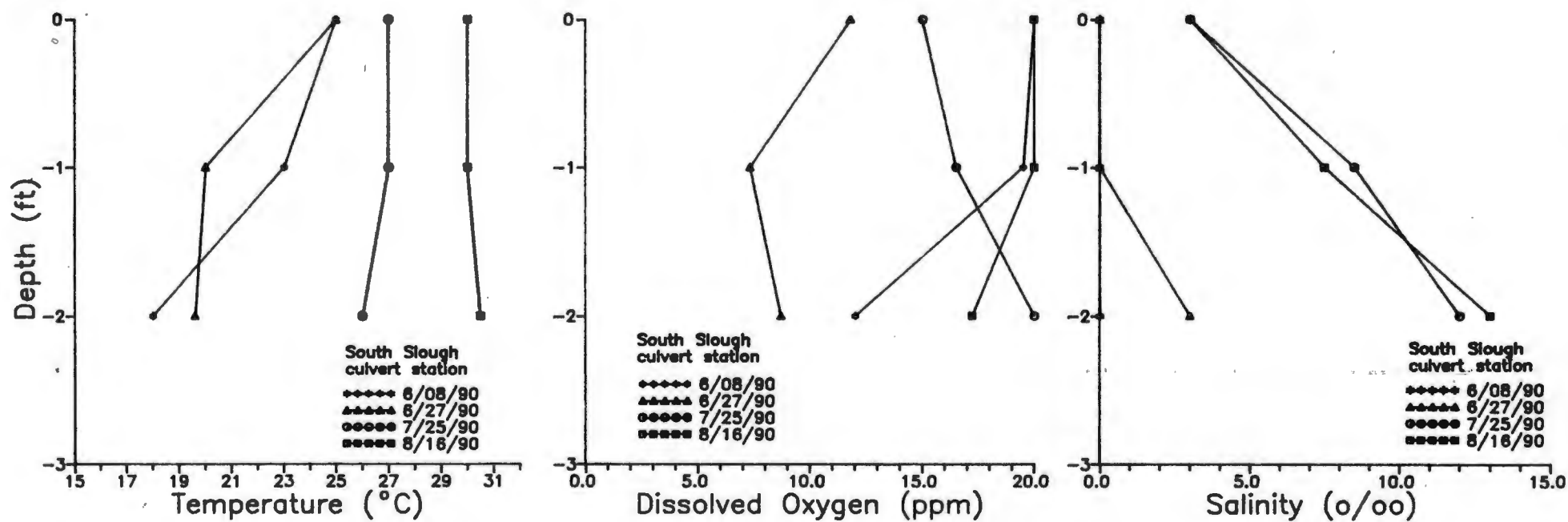


Figure 15. Water quality parameters, temperature (°C), dissolved oxygen (ppm), and salinity (o/oo), measured at one foot depth intervals near the culvert (SS10) of the south slough, Redwood Creek estuary, Humboldt County, California, during the summer of 1990.

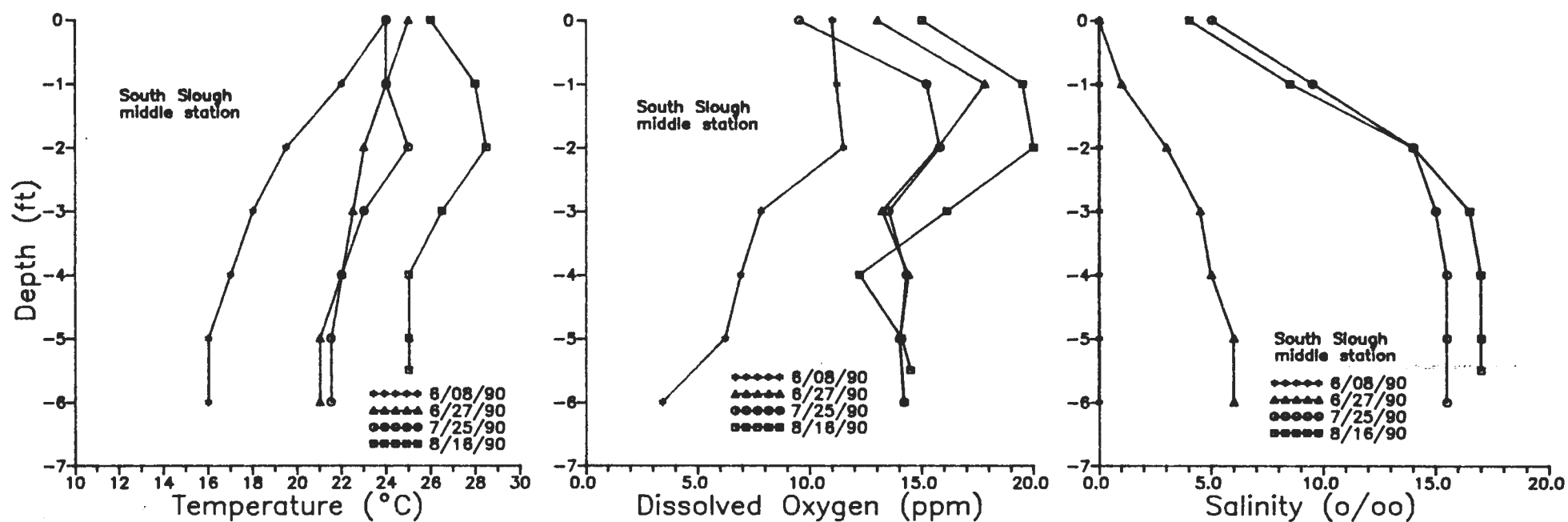


Figure 16. Water quality parameters, temperature (°C), dissolved oxygen (ppm), and salinity (o/oo), measured at one foot depth intervals in the middle (SS11) of the south slough, Redwood Creek estuary, Humboldt County, California, during the summer of 1990.

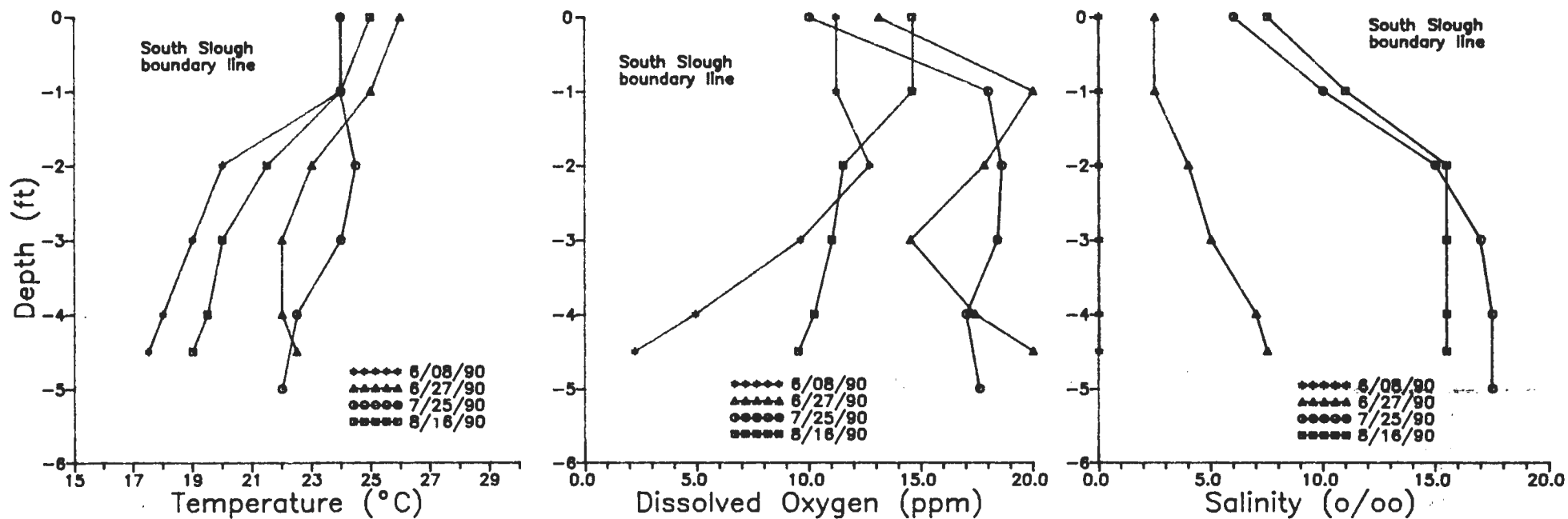


Figure 17. Water quality parameters, temperature (°C), dissolved oxygen (ppm), and salinity (o/oo), measured at one foot depth intervals at the RNP boundary (SS17) in the south slough, Redwood Creek estuary, Humboldt County, California, during the summer of 1990.

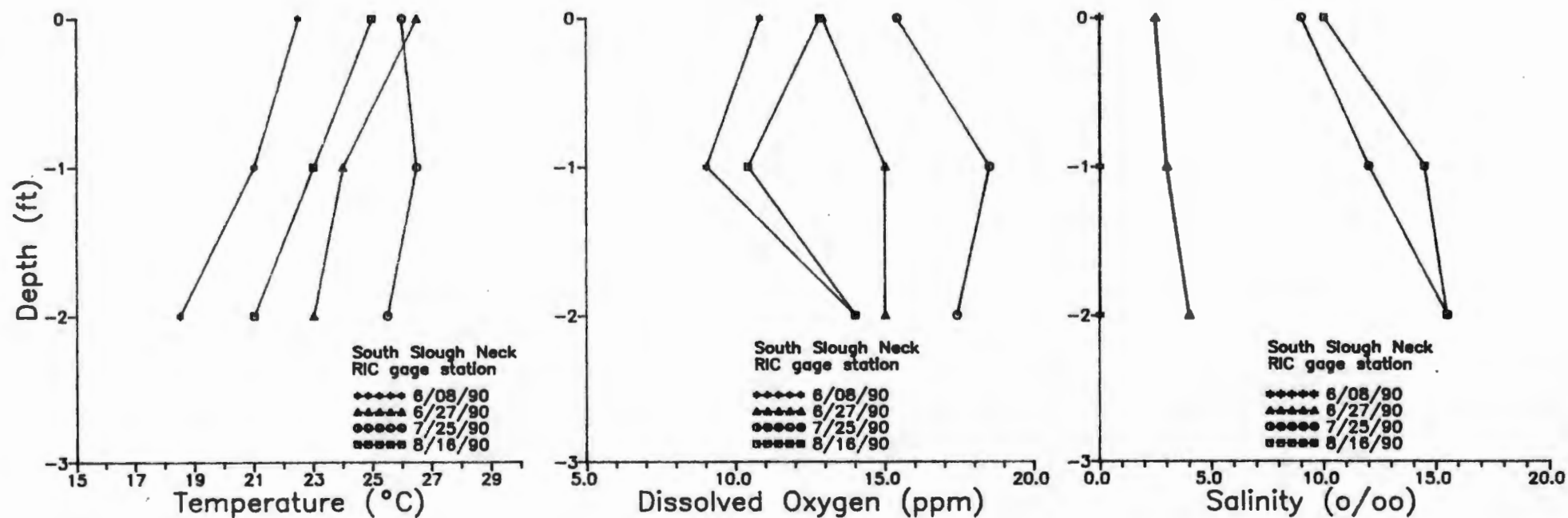


Figure 18. Water quality parameters, temperature (°C), dissolved oxygen (ppm), and salinity (o/oo), measured at one foot depth intervals at the RIC gage (§§7) in south slough neck, Redwood Creek estuary, Humboldt County, California, during the summer of 1990.

Table 6. Water quality parameters, temperature (°C), dissolved oxygen (ppm), salinity (o/oo), and pH, measured at one foot increments in the South Slough neck, stations 8 and 9, Redwood Creek estuary, Humboldt County, California, during the summer of 1990.

South Slough Neck - End of South Levee Station (SS9)

Date	Depth (ft)	Temperature (°C)	Dissolved Oxygen (ppm)	Salinity (o/oo)	pH
6/08/90	Surface	20.0	9.3	0.0	6.4
	1.0	20.5	9.3	0.0	
7/25/90	Surface	22.5	9.7	1.0	7.2
	1.0	22.5	9.8	1.0	
	2.0	22.0	10.0	12.5	
8/16/90	Surface	23.5	8.3	3.5	7.4
	1.0	24.0	8.4	3.5	

South Slough Neck - Stump Station (middle) (SS8)

Date	Depth ^a (ft)	Temperature (°C)	Dissolved Oxygen (ppm)	Salinity (o/oo)	pH
6/08/90	Surface	22.5	9.8	0.0	6.5
6/27/90	Surface	31.0	8.3	1.0	8.1
7/25/90	Surface	25.0	9.5	1.0	7.3
8/16/90	Surface	27.5	9.7	10.5	8.7

^a Depth < 0.5 ft

Table 7. pH values measured at the surface and bottom at 12 water quality sampling stations in the Redwood Creek estuary, Humboldt County, California, during the summer of 1990. () denotes bottom depth at which water sampled. Water level at South Slough RIC gage included.

Date	Depth	NS1	NS2	WATER QUALITY STATION		EMB5	EMB6	
				NS3	EMB4			
6/08/90	surface	5.8	5.6	5.9	6.3	6.5	6.4	
	bottom	6.6 (16)	6.5 (14)	6.0 (8)	---	---	---	
6/27/90	surface	5.6	5.6	5.6	6.9	6.8	6.8	
	bottom	6.1 (14)	6.7 (12)	6.2 (8)	---	---	---	
7/25/90	surface	---	---	---	---	7.1	7.3	
8/01/90	surface	6.0	6.1	5.6				
	bottom	6.0 (16)	---	6.2 (7)				
8/16/90	surface	---	---	---	7.2	6.4	6.9	
	bottom	---	---	---	7.6 (4)	5.2 (3)	7.7 (3.5)	

Date	Depth	SS7	SS8	WATER QUALITY STATION		SS11	SS12	RIC WATER GAGE
				SS9	SS10			
6/08/90	surface	6.8	6.5	6.4	8.3	8.6	6.8	3.14 FT @ 1600
	bottom				---	5.4 (6)	5.8 (4.5)	
6/27/90	surface	9.3	8.1	---	8.3	8.6	9.4	3.05 FT @ 1642
	bottom				---	7.2 (6)	7.8 (4.5)	
7/25/90	surface	8.8	7.3	7.2	8.5	8.2	8.0	2.94 FT @ 1400
8/16/90	surface	8.9	8.7	7.4	9.3	9.2	9.2	2.89 FT @ 1440
	bottom				---	8.3 (5.5)	8.4 (4.5)	

NS1 = south fork of North Slough, NS2 = north fork of North Slough, NS3 = at fork of North Slough
 EMB4 = between ends of levees in Embayment, EMB5 = middle of Embayment, EMB6 = berm area of Embayment
 SS7 = near RIC gage in South Slough neck, SS8 = middle of South Slough Neck, SS9 = end of south levee in South Slough Neck
 SS10 = adjacent to culvert in South Slough, SS11 = middle of South Slough, SS12 = RNP boundary in South Slough

oxygen, there is absolutely no habitat for fish at lower depths. In a review of salmonid habitat requirements, Reiser and Bjornn (1977) reported 7.75 mg/l (= ppm) as a dissolved oxygen concentration above which fish can function without impairment, and at 4.25 mg/l, most fish were affected by a lack of oxygen. The highest dissolved oxygen concentration measured in the North Slough was 7.2 ppm. Accordingly, the north slough as fish habitat in the areas sampled is poor.

Salinity ranged from 0 to 7.5 o/oo. The highest concentrations were in the north fork. Since the north slough has been isolated from the rest of the estuary for years, the salinity may be a result of tidal exchange during previous years (1983-1988), or evaporation over time.

Freshwater inflow into the system is from Sand Cache Creek into the north fork of the slough. Fields adjacent to the North Slough and in the Sand Cache Creek watershed are used for pasture for cattle and dairy cows. At least two dairies are in the watershed. High nutrient concentrations in water and the greater demand for oxygen by organisms using the nutrients will lower oxygen concentrations. The amount of agricultural runoff or the biological oxygen demand (BOD) of the waters of the North Slough is unknown. However, dissolved oxygen concentrations in the north slough are very low.

Embayment

Embayment water depths among the water quality stations ranged between 1.5 to 5.5 feet during the summer. The deepest and most shallow stations were near the berm (EMB6) and between the levees (EMB4), respectively. Because of tidal fluctuation in the embayment, depths at each individual station varied 2 to 2.5 feet. As the measurements were taken on outgoing tides, depths probably reached higher levels. The depth in the embayment is affected by several factors; tidal extremes, height of the sill at the mouth, closure of the mouth, river flow, and the flood control levees. A sill was placed across the Redwood Creek channel between the ends of the levees to protect its structural integrity. The sill controls the amount of scour upstream and in the embayment, thereby affecting depths.

Temperatures were high, ranging between 16.0 and 23.0°C, well above the optimal range for juvenile salmonids. As the measurements were conducted on outgoing tides, temperatures may have been lower at high tides when cooler sea water enters the estuary, as appeared to have happened on July 25, 1990 (Figures 12, 13, and 14). The embayment was a fresh water body in June, most likely a result of runoff from the June 1, 1990 rain storm. Later in July, saline water was conspicuous at lower depths. Salt water intrusion into the estuary may have been more pronounced at flood tide. Dissolved oxygen ranged between 4.5 and 10.8 ppm, usually between 9 and 10 ppm. With few exceptions, it was typically the same for each depth. These concentrations are suitable for rearing salmonids. As a result of the open mouth, the embayment was very dynamic, and the measurements probably do not reflect the total range of conditions that occurred. The embayment had the best, even though substandard, water quality for fish, when compared to the sloughs.

South Slough

Sample station water depths ranged between 2 feet near the culvert (SS10) to 6 feet at the middle station (SS11). The deeper depths in the south slough are remnants of the old pre-levee Redwood Creek channel. Among the sample dates, the water level at the RIC gage varied about 0.25 feet (Table 7). This is an artifact of the elevated sedimented south slough neck channel acting as a sill. It acts similar to the sill that builds up at the mouth of Redwood Creek impounding water in the embayment. If the culvert gates had been opened, the water level would have varied more as the gates are about 1.5 feet lower than the south slough channel sill.

Water temperature in the south slough ranged between 17.5 and 20.5°C; the higher temperatures were at the shallow culvert station (Figures 15, 16, and 17). Water temperatures were cooler at the bottom depths. Most of the surface of the south slough was covered with floating, frothy, decomposing vegetation. This mat provided a solar sink, heating the surface. The temperature of the south slough increased over the summer. Dissolved oxygen concentrations exceeded 20.0 ppm several times (Figures 15, 16, and 17). The south slough had aquatic vegetation growing throughout the water column and the photosynthetic process (the release of oxygen as a byproduct) accounts for the high concentrations. The south slough probably experiences diel oxygen changes, though how anoxic it may become is unknown. No measurements were conducted at night when plant respiration would have noticeably decreased concentrations. The higher pH values measured in the south slough, up to 9.4 (range 5.4 to 9.4) are probably a result of photosynthesis, also (Table 7). Photosynthesis removes CO₂ from the water and increases the pH (Cole 1979). This level can be harmful to salmonids if it occurs over a long period of time (Committee on Water Quality Criteria 1972). Similarly at night, plant respiration would decrease pH, though to what extent is unknown. Salinity in the south slough increased over time, from a fresh water system to a saline one at lower depths (Figures 15, 16, and 17). The transport of salt water from the ocean (through the south slough channel), called the process of ectogenic meromixis, was responsible. The saline water settled at the lower depths of the slough, leaving a 2-foot lens of fresh water on the surface.

As fish habitat in 1990, the south slough was generally poor, exhibiting very high water temperatures. Operation of the culvert gates would have increased water circulation in the slough, but with an accompanying drop in water elevation and habitat. Temperature might have decreased to the lower levels of the embayment, but those too were not optimal for rearing fish.

South Slough Neck

The south slough neck, the long shallow channel connecting the south slough and the embayment acted like a tidal channel; most of the substrate became exposed at low tide and covered at high tide. However, at low tides, flow from the south slough created a narrow, shallow channel (< 0.5 ft). Although excavated in 1983, the neck has gradually filled in, and would probably do so if excavated again.

Temperatures were high, up to 31.0°C at the shallow middle station (SS8), and were some of the highest temperatures measured in the estuary. The warm substrate and direct solar radiation heated the water in the small channel.

Reiser and Bjornn (1979) report the upper lethal temperature for rearing steelhead trout and chinook salmon as 24.1 and 25.2°C, respectively. The neck was probably a thermal as well as low flow barrier to fish swimming into the south slough. Any fish in the south slough that originated from the embayment probably migrated in on the incoming tide. Dissolved oxygen concentrations were high, 8.3 to 18.5 ppm, and were not limiting to rearing fish (Table 6, Figure 15). Salinity concentrations reflect overall south slough values, shifting from fresh to saline water over time. As fish habitat, the south slough neck provides little cover in the form of depth, and is too warm.

IV. IMPORTANCE OF ESTUARY TO SALMONID SURVIVAL

Methods

Juvenile salmonid scales have been collected during summer population and growth monitoring in the estuary since 1980. Scales from 30 fish each of chinook salmon and steelhead trout were collected in conjunction with each estimate. During the winter redd and carcass surveys of Prairie, Lost Man, and Bridge Creeks, scales were collected from adult salmonids. The number of circuli representing freshwater rearing and their interspacing on adult salmonid scales will be measured and compared with their estuary cohort scale collection. From these comparisons, the early life history of the adult spawners will be determined. The method is described in more detail by Reimers (1973).

Results

No work has been done on this project since 1986, though scales continue to be collected. Some of the juvenile scales have been mounted on glass slides, projected, and the circuli traced on paper. In 1990, we foresee mounting the rest of the adult and juvenile scales, and digitizing the circuli pattern data directly into a computer with the aid of specialized software. It is hoped this study will illustrate the importance of the length of estuary rearing and its relationship to survival to spawning. Reimers (1973) reported that over 90% of the spawners in the Sixes River, Oregon, represented a life history pattern of combined riverine residence and estuarine residence during the period of improved growth.

V. WATER LEVEL MANAGEMENT

Methods

A detailed description of embayment formation is discussed in Ricks (1985) and Hofstra (1983). Estuary water level is managed for 5.6 - 6.0 ft above mean sea level. (In previous years, water level was managed at 5.0 feet, but a surveying error was discovered, and the true mean sea level was 0.6 feet lower). This management is accomplished by breaching the sand berm with a bulldozer when the river mouth closes. The berm is breached at the southern end where the channel gradient will be less than if breached in the center. The objective is to slowly lower the water to the desired level. Frequently, offshore physical processes close the channel again. Thus, controlled breaching may have to be repeated several times during the summer and fall depending on stream flow. The method is not an exact science and rapid declines in estuary water levels can result. The method of water level regulation is described in more detail in Hofstra (1983).

Results

The mouth of Redwood Creek remained open most of the summer and was artificially breached three times in the fall. In early summer, the mouth was blown straight out because of the June 1, 1990 rain storm. The mouth migrated to the north and remained there much of the summer. In late summer, it began to migrate slowly to the south. There was no stage recorder in the estuary this year. However, our visual records show that the mouth was open from at least May 15, 1990 until about September 14, 1990. The RNP D-4 dozer breached the berm on September 26. Estuary water level declined from 6.7 feet to 3.3 feet the following day. On October 2, the mouth closed and remained closed until we breached it again on October 31. Water level slowly declined from 8.1 feet to 4.8 feet two days later. The mouth closed again on November 5, and we breached it a third time on November 6. The water level fell from 6.7 feet to 3.2 feet 24 hours later. The mouth then closed November 13, naturally opened on November 14, and remained open the rest of the year (1990). It had closed once before the last September 28, 1990 fish growth estimate. The water in the estuary reached 8.1 feet above mean sea level prior to the second breaching. With the landowner's concurrence, partial flooding was allowed on an adjacent private parcel adjoining the south slough.

Discussion

The south slough was only connected to the embayment during high tide. The north slough was not connected at any time during the summer because of winter storm sand deposition in the neck at the end of the north levee. Although, daily tidal fluctuation in the ocean reached 10.7 feet (Table 8 and Figure 19), the estuary probably did not approach this level of fluctuation. The small transport capacity of the mouth, volume of the tidal prism, lag times in water momentum, and height of the sill in the channel mouth probably dampened the fluctuation range. However, the water level in the estuary did lower with the ebb tide, subsequently decreasing the amount of fish rearing habitat available. When the mouth was open, the Redwood Information Center (RIC) gage in the neck of the South Slough read approximately 3 feet above mean sea level. However, because the south slough water level is controlled by the elevation of the south slough neck channel, water levels in the estuary were

Table 8. Extreme Humboldt area ocean tidal fluctuations (feet) for the summer and fall months of 1990.

Month	FEET		
	High	Low	Difference
May	8.5	- 2.1	10.7
June	8.5	- 2.2	10.7
July	8.2	- 1.8	10.0
August	7.7	- 1.1	8.8
September	7.4	- 0.2	7.6
October	7.9	- 1.1	9.0

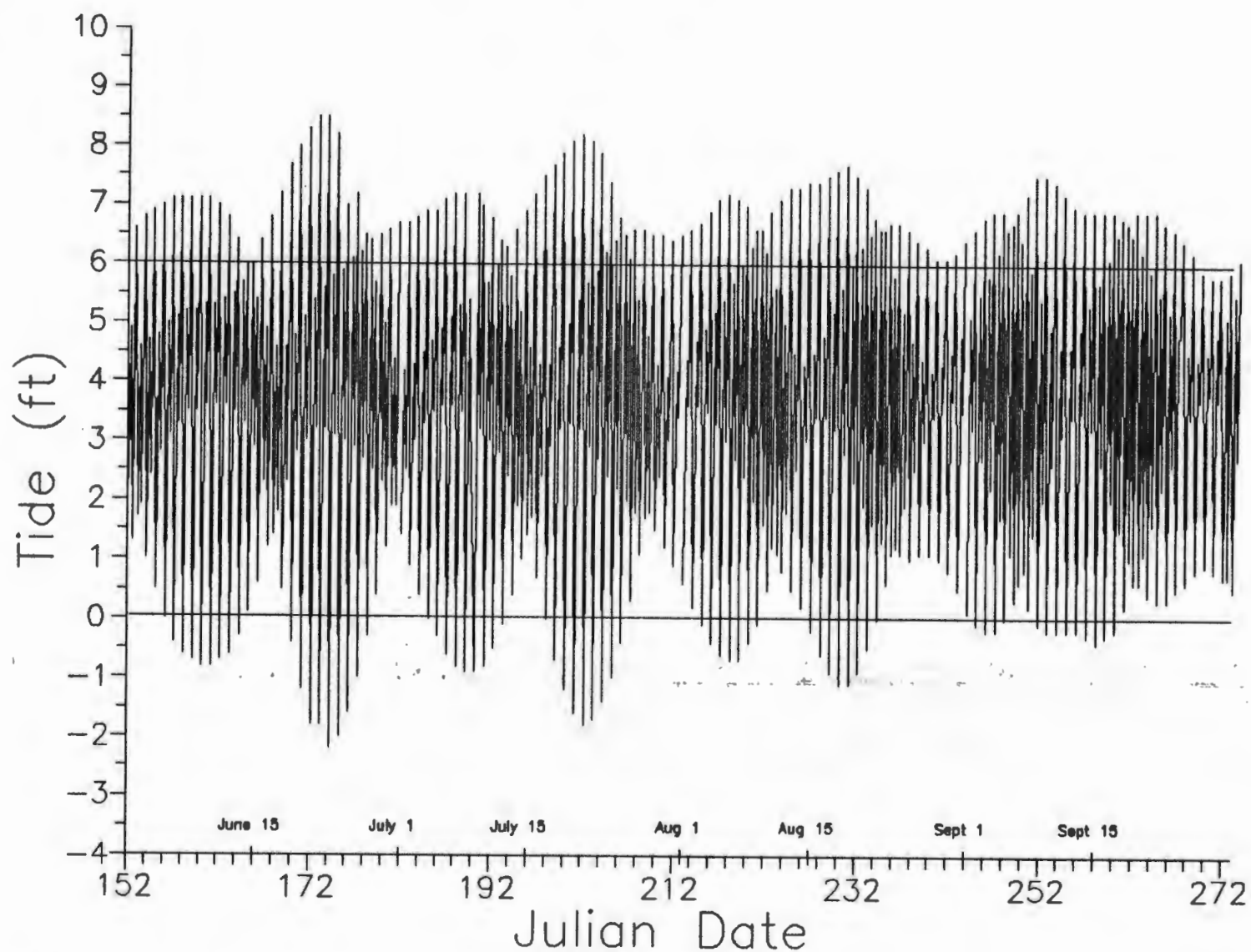


Figure 19. Humboldt area high and low tides for the period of June 1 (Julian date 152) to September 30, 1990 (Julian date 273). The Redwood Creek estuary is managed at a water level of 5.6 - 6.0 feet above mean sea level.

even lower. It is likely the mouth remained open most of the summer because it had migrated north against the adjacent northern headland after the June 1, 1990 rain storm. The northern headland sheltered the mouth and prevented it from migrating to the south and eventually closing to form a larger embayment. It is also likely that because of the estuarine tidal prism, and ocean conditions (eg. prevailing winds, and direction of waves and swells), the mouth remained open and migrated slowly to the south.

There was no need for breaching until late September because the mouth remained open most of the summer. The majority of the salmonid population utilizing the estuary were gone prior to the mouth closing and breaching activities. However, breaching did decrease the amount of habitat, and probably affected the fish remaining in the embayment.

Artificial breaching probably maintained the embayment longer than if it had been allowed to breach naturally. Allowed to breach by itself, a mouth would have broken through the center of the berm, a location much farther to the north of the artificial channel we dug. Being open to the north, it would have taken longer for the channel to migrate to the south, if at all, and close again.

VI. ESTUARINE RESTORATION

Restoration alternatives were investigated by Redwood National Park in 1983 (Hofstra 1983). Of those, the culvert through the south levee was implemented in 1987. The 'short-term' alternative of controlled breaching of the berm to manage water estuary levels has been conducted each summer since 1982. A Redwood Creek Estuary Working Group has been meeting over the years to discuss other restoration alternatives.

In 1990, the Redwood Creek Estuary Working Group met January 12. Representatives from Redwood National Park, U.S. Army Corps of Engineers, California Department of Fish and Game, Humboldt State University, and Humboldt County Department of Public Works were in attendance. Six primary improvement alternatives and three other alternatives were developed. They were: 1) levee removal (complete or partial; 2) levee relocation; 3) flood gate in north levee; 4) land acquisition; 5) diversion of low flood flows to South Slough; 6) improvement of flow characteristic at the necks of sloughs; 7) boulder placement in Redwood Creek channel; 8) reduced operation and maintenance of the flood control project; and 9) drainage structure placement at mouth of Redwood Creek. Potential evaluation factors such as engineering, environmental/ecological, and legal/political/social aspects were formulated.

On June 18, 1990, a U.S. Army Corps of Engineers representative discussed with Redwood National Park personnel a potential north slough culvert project and the use of Section 1135 of the Water Resources Development Act of 1986 to improve existing environmental conditions in the Redwood Creek estuary. Section 1135 allows for projects, such as the potential culvert project, to be funded on a 75% Federal - 25% local non-federal sponsor basis. The California Department of Fish and Game (CDFG) was identified as a potential local sponsor and steps to initiate the project process were discussed. Also discussed, was the use of Section 216 of the 1974 Flood Control Act to restudy the environmental features of the Redwood Creek Flood Control Project. On March 6, 1991, the working group discussed the Section 1135 proposal (Appendix A). Excavation of the north slough neck and construction of a seasonal dam to divert summer flows into the north and south slough culverts were added to the project. CDFG agreed to become the non-federal local sponsor if funding became available from fish restoration funds. A fishery project grant proposal (Appendix B) was submitted to CDFG funding sources to cover the 25% non-federal cost. This proposal describes the project and predicted fishery benefits in more detail.

On December 14, 1990, Redwood National Park submitted a permit application to the U.S. Army Corps of Engineers (Corps) to renew a permit for continued water level management, widening and deepening the channels of the north and south, and construction of a seasonal gravel dam in Redwood Creek to divert summer water flow into the south slough. The permit is presently undergoing public and agency review. Several federal agencies, including EPA, USFWS, and NOAA are recommending the Corps deny the permit.

A fencing project is underway on land adjacent to the north slough. A landowner (Thelma Hufford), CDFG, the California Conservation Corps, and the Six Rivers Chapter of Trout Unlimited, are cooperating on the project. The fence will protect the banks of both forks of the north slough from grazing cattle and create a riparian vegetation zone. Driftwood that was deposited on

the fields by high water was burned. Some of the driftwood floating on the surface of the slough was removed and burned. Presently, RNP has no valid permit to lower the water level in the north slough. They are waiting for us to breach the north slough neck or for the water level to naturally recede before constructing the fence.

Restoration of the Redwood Creek estuary is being pursued on a short-term and long-term basis. Controlled breaching is on short-term alternative. This alternative has been used since 1982. However, the detrimental effects of our breaching on estuary fish continue, though these effects are not as severe as when the adjacent landowners managed water levels by draining the embayment and sloughs. Another short-term alternative implemented in 1988, the south slough culvert (and possibly the north slough culvert in 1992 depending on funding) only provides for improved water quality and does not alleviate the need for controlled breaching to prevent summer flooding of adjacent private land. The excavation in 1983 of the slough necks, particularly the north slough neck, is temporary in nature. Presently sand in the north slough neck is approximately 11 feet above mean sea level. It is the opinion of this author, that the problem will be solved only with the complete removal of the levees to a point where their influence on the estuary is eliminated and the purchase of flood easements or land. This is a long-term solution that has many obstacles to hurdle; financial (acquisition funds need to be available), social (willing sellers needed), and political (Congressional authorization is required to remove the levees).

Summary Report on Estuary Monitoring and Management during the 1980 Decade

Previous annual reports need to be summarized, and 1988 and 1989 data (Appendix C) needs to be incorporated into an summary report on estuary monitoring and management during the 1980's. The results will be interpreted in relation to ecological functions of the estuary, fish, and wildlife, and management effectiveness.

References

- Cole, G. 1979. Textbook of Limnology. C.V. Mosby Company: St. Louis. 426 pp.
- Committee on Water Quality Criteria. 1972. Water Quality Criteria 1972. Environmental Studies Board, National Academy of Sciences and National Academy of Engineering. EPA-R3-73-0333. Washington, D.C. 594 pp.
- Gregory, R. 1982. Physical and chemical parameters of Redwood Creek estuary. Directed Study, Department of Oceanography, Humboldt State University, Arcata, California. 43 pp.
- Hofstra, T. 1983. Management alternatives for the Redwood Creek estuary. Redwood National Park, Arcata, California. 43 pp.
- Larson, J. 1987. Utilization of the Redwood Creek estuary, Humboldt County, California by juvenile salmonids. M.S. Thesis, Humboldt State University, Arcata, California. 79 pp.
- McKeon, J. 1985. Downstream migration, growth, and condition of juvenile fall chinook salmon in Redwood Creek, Humboldt County, California. M.S. Thesis, Humboldt State University, Arcata, California. 90 pp.
- Pauley, G.B, K. Oshima, K.L. Bowers, and G.L. Thomas. 1989. Species profiles: life histories and environmental requirements of coastal fish and invertebrates (Pacific Northwest) -- sea-run cutthroat trout. U.S. Fish and Wildlife Service Biological Report 82(11.86). U.S. Army Corps of Engineers TR EL-82-4. 21 pp.
- PCFFA-Trinidad Fishermen's Salmon Enhancement. 1990. Prairie Creek Project 1989-1990 Final Report. 29 pp.
- Redwood National Park. 1984. Estuarine management and research activities mouth of Redwood Creek 1983. Redwood National Park, Crescent City, California. 17 pp.
- Redwood National Park. 1985. Estuarine management and research activities mouth of Redwood Creek 1984. Redwood National Park, Crescent City, California. 15 pp.
- Redwood National Park. 1986. Estuarine management and research activities mouth of Redwood Creek 1985. Redwood National Park, Crescent City, California. 14 pp.
- Redwood National Park. 1987. Estuarine management and research activities mouth of Redwood Creek 1986. Redwood National Park, Crescent City, California. 11 pp.
- Redwood National Park. 1988. Estuarine management and research activities mouth of Redwood Creek 1987. Redwood National Park, Crescent City, California. 7 pp.

Redwood National Park. 1991. Monitoring the impacts and persistence of fine sediment in the Prairie Creek watershed 1989 -1990. Redwood National Park, Arcata, California. 101 pp.

Reimers, P. 1973. The length of residence of juvenile fall chinook salmon in Sixes River, Oregon. Research Reports of the Fish Commission of Oregon. 4(2). 42 pp.

Reiser, D., and T. Bjornn. 1979. Influence of forest and rangeland management on anadromous fish habitat in Western North America: Habitat requirements of anadromous salmonids. Pacific Northwest Forest and Range Experimental Station. U.S.D.A. Forest Service General Technical Report PNW-96. 54 pp.

Ricks, C. 1985. Flood history and sedimentation at the mouth of Redwood Creek, Humboldt County, California. Technical Report No. 15, Redwood National Park, Arcata, California. 156 pp.

Salamunovich, T. 1987. Fish food habits and their interrelationships in lower Redwood Creek, Humboldt County, California. M.S. Thesis, Humboldt State University, Arcata, California. 173 pp.

Youngs, W. and D. Robson. 1978. Estimation of population number and mortality rates. Pages 137 - 164 In Methods for Assessment of Fish Production in Fresh Waters. Third Edition. (ed.) T. Bagenal. Blackwell Scientific Publications: Oxford. 365 pp.

**Appendix A. U.S. Corps of Engineers Section 1135 of the Water Resources
Development Act of 1986 proposal for the Redwood Creek estuary,
Humboldt County, California.**

MEMORANDUM FOR THE RECORD

SUBJECT: Redwood Creek Section 1135 Project, Interagency Meeting

1. The technical manager, Scott Miner, and Continuing Authority Program manager, Bill Brick, met with representatives of the National Park Service (DPW), California Department of Fish and Game (CDFG), and Humboldt County Department of Public Works (DPW) on 7 March 1991 at the NPS offices in Arcata. A list of attendees is attached (Enclosure 1). The purpose of the meeting was to discuss the Corps' Section 1135 project and, in particular, to discuss cost-sharing requirements and project alternatives.

2. Scott Miner discussed the purpose and background of the Section 1135 program and the status of the Redwood Creek project. The San Francisco District has \$40,000 to conduct a feasibility study to select a plan, estimate costs and benefits, and prepare an environmental assessment and a local cost-sharing agreement. Although no cost-sharing is required to complete the feasibility study, a 25% non-Federal cost-share is required to continue the project beyond the feasibility study. A copy of the District's budget and schedule for completion of the project was distributed (Enclosure 2). It was noted that Corps headquarters would prefer to have construction of the project start this fiscal year. The final construction cost is limited to 150% of the current estimate.

3. Potential sources of non-Federal funds were discussed. To obtain CDFG funds in the coming State fiscal year, a grant application must be submitted to CDFG by 29 March 1991. It was agreed that the Corps would provide cost estimates for each of the alternative plans to be considered by 22 March. Carolyn Meyer, NPS, will then prepare and submit a grant application for each alternative. Dave McLeod, CDFG, noted that the CDFG funds can only be used for construction. Scott Miner suggested that it may be possible to apply the entire 25% non-Federal share of the overall project to the construction stage. Dave McLeod agreed to provide a letter of intent stating that CDFG will be willing to cost-share the project if an acceptable plan is developed and funds are available. Terry Hofstra, NPS, offered to investigate other sources of non-Federal funds.

4. The concerns of the owner of the private lands adjacent to the North Slough regarding flooding were discussed. It was stated that a culvert in the north levee would tend to reduce water elevations in the north slough if the mouth of the slough is scoured open, since the current ponding level in the North Slough is higher than the level of the creek.

5. It was noted that the NPS has cross-sections and profiles for the North Slough, as well as water quality and biological data.

6. After discussion of several other possibilities, it was agreed that the Corps would begin the feasibility study by developing cost estimates for the following four alternatives:

a. Culvert in the north levee.

b. Culvert in the north levee with a summer dam to divert water into both the North and South Sloughs.

c. Enlargement of the existing culvert in the south levee.

d. Removal of both levees to a point above the upper end of the North Slough, and construction of a new sill at the end of the levees.

7. It was also agreed that the Corps would determine the cost of investigating these four alternatives and determine whether the available study funds are adequate. If additional funds are needed, the Corps could: (1) seek additional Corps funds, (2) potentially use the remaining portion of the NPS funds previously transferred to the Corps, or (3) reduce the scope of the study.



SCOTT MINER
Ecologist
Environmental Branch

Copies furnished:

Attendees of 7 March 1991 interagency meeting

REDWOOD CREEK SECTION 1135
FUNDING ESTIMATE
(\$1,000)

<u>ACTIVITY</u>	<u>FY 91</u>	<u>FY92</u>	<u>FY93</u>	<u>TOTAL</u>
Letter report	40			40
Plans and specifications	55.5			55.5
Construction	291.2			291.2
Evaluation		13.3	13.3	26.6
TOTAL	386.7	13.3	13.3	413.3
FEDERAL (75%)	290	10	10	310
NON-FEDERAL (25%)	96.7	3.3	3.3	103.3

Encl. 2

MEMORANDUM FOR THE RECORD

SUBJECT: Redwood Creek Section 1135 Project, Status of Project

1. This memorandum summarizes the work which has been completed since 7 March 1991.

2. The Corps of Engineers prepared preliminary cost estimates for four alternatives. The four estimates, including planning, design, construction, and monitoring costs, are:

- a. Culvert in the north levee: \$603,907.
- b. Culvert in the north levee with a summer dam: \$899,760.
- c. Removal of both levees: \$2,939,343.
- d. Enlargement of existing south levee culvert: \$1,072,784.

Each of these estimates includes substantial contingencies due to the preliminary nature of the estimates. Nonetheless, it is clear that the third and fourth alternatives would greatly exceed the current limit on Corps funding for the project. The limit on Corps funding is 150% of the currently scheduled Federal funds, or \$461,250. With a 25% non-Federal cost-share, this results in a maximum project cost of \$615,000. The second alternative would fall within this limit only if most of the contingencies are not required.

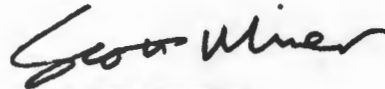
3. In response to a Congressional inquiry regarding a possible FY 1991 Federal Jobs Bill, the San Francisco District has proposed that the scope of the Section 1135 project be expanded to cover the costs of studying and constructing the second alternative. Because the Jobs Bill proposals are subject to screening by the Corps and require Congressional approval, the chances of obtaining additional funds through a Jobs Bill are very uncertain.

4. The Corps is currently developing detailed study cost estimates for the four alternatives. Although the estimates are incomplete, it is apparent that the cost of studying the first alternative alone will exceed the Corps funding currently available for the feasibility study (\$40,000). Therefore, the Corps will need to seek additional study funds. The chances of obtaining additional Corps funds through the Section 1135 program are not known.

5. Carolyn Meyer of the National Park Service has prepared and submitted a grant proposal to the California Department of Fish and Game (CDFG) for non-Federal funds for the project. Based on the Corps' estimated costs for the alternatives and the

anticipated benefits to fisheries, it was agreed by Carolyn and myself that only the second alternative (north culvert with summer dam) would be submitted to CDFG. Because the first alternative (north culvert alone) is a portion of the second alternative, the first alternative should also be covered by the grant proposal.

6. Issue to be resolved: After the Corps completes its study cost estimates, a decision regarding the scope of the feasibility study (i.e., which alternatives to consider and at what level of detail) will need to be made. That decision will be made after coordination with the Park Service, CDFG, and the County Department of Public Works.



SCOTT MINER
Ecologist
Environmental Branch

Copies furnished:

Attendees of 7 March 1991 interagency meeting

Appendix B. Redwood Creek estuary fishery grant proposal to restore rearing salmonid habitat in the north slough by placing a culvert in the levee and a summer dam between the levees.

FISHERY PROJECT GRANT PROPOSAL

SUMMARY SHEET

1. Contractor: Redwood National Park
2. Type of Contractor: Public Agency
3. Street Address: Redwood National Park, 1125 16th St.
4. City: Arcata
5. State: CA
6. Zip Code: 95521
7. Contact Person: Carolyn Meyer
8. Telephone Number: (707) 822-7611
9. Project Title: Redwood Creek Restoration Project
10. Funding Request: \$224,940
11. Objective: Restore salmonid rearing habitat in the north slough of Redwood Creek estuary by placing a culvert in the levee and a summer dam between levees.
12. Species Benefitted: Coho Salmon, Chinook Salmon, Steelhead
13. Work Schedule: 6 months from May to October 1992
14. County: Humboldt
15. Stream: Redwood Creek
16. Tributary to: Ocean
17. Assembly District: 2
18. Senate District: 2
19. Past Contractor: Yes

REDWOOD CREEK ESTUARY RESTORATION PROJECT
ADDITIONAL INFORMATION

BACKGROUND

Redwood Creek drains a long, narrow 720 km² basin in northern California (Fig. 1). Bankfull discharge at Orick is estimated to be 17,000 cfs. Historically, Redwood Creek was known for its abundant runs of large chinook salmon, coho salmon, steelhead trout, and cutthroat trout. Since the early 1900's, anadromous fish returns have declined precipitously (U.S. Fish and Wildlife Service 1975). Since 1960, local hatchery records show chinook salmon have declined by 70-80%, coho salmon by 60%, and steelhead trout by 50% (Hofstra 1983). These declines have been largely attributed to land use practices in the basin and channelization of formerly excellent salmonid rearing habitat in the estuary. The Army Corps of Engineers constructed flood control levees from 1966-68 on lower Redwood Creek and its estuary to prevent a repeat of the severe flooding in 1953, 1955, and 1964. These levees isolated both the last downstream meander bend (south slough) of Redwood Creek and the estuary's north slough. The levees also altered sediment deposition patterns. Consequently, up to 50% (Ricks 1984) of the once deep estuary embayment has filled with sediment (compare Fig. 2 to Fig. 3).

After the levees were built, water quality deteriorated in the north and south sloughs. Because of poor water circulation, dissolved oxygen frequently dropped to 0 ppm at lower depths during the summer, turning these areas into unsuitable salmonid habitat. Juvenile salmonids were forced to rear in a small relic of the original embayment located between and at the end of the levees.

A sand berm naturally builds across the estuarine mouth in the summer, flooding more land. However, the mouth is frequently artificially breached to alleviate flooding. This reduces the volume of water available to fish in the embayment, causing premature fish losses to the ocean.

The National Park Service has been monitoring water quality and population size and growth of juvenile salmonids since 1980. Up to 35,000 juvenile chinook salmon (Fig. 4a) and 46,000 steelhead trout (Fig. 4b) have been estimated to utilize the embayment during good years in June. In summers when the mouth has remained open for long periods (e.g., 1988 and 1990), numbers have been low. In 1980, the estuary water level dropped drastically following sandbar breaching by local landowners. Following this, fish numbers were so low a population estimate was not possible.

In Redwood Creek, good quality rearing habitat for chinook salmon is limited to the estuary. Sedimentation and woody debris loss throughout the extensively logged Redwood Creek basin have eliminated most instream chinook salmon rearing habitat. Therefore, almost all chinook salmon juveniles in the entire watershed depend on the estuary as rearing habitat. Restoration of the sloughs would provide more of this desperately needed habitat. Additionally, anadromous cutthroat trout utilize the estuary and would benefit greatly from its restoration.

The National Park Service is endeavoring to restore the estuary to a naturally functioning ecosystem, including its fish, wildlife, and riparian habitat. In

1981, the Service began managing summer estuarine water levels by controlling sand berm breaching activities. We have strived to breach the sand berm across the mouth as conservatively as possible to lessen impacts on the anadromous fishery. In 1983, the sand-plugged slough outlets were excavated to improve water and fish exchange between the embayment and sloughs. Within a few years, the outlets filled in again. For a more long-term solution, we placed a gated culvert in the south levee in 1988 to improve water circulation into the south slough. Studies have shown this alteration improved dissolved oxygen from 0 to 8 ppm at lower water depths, thus improving fish habitat. Some fish have been found using both the embayment and the south slough. All these restorative actions have been conducted in cooperation with the following agencies: CA Department of Fish and Game, CA Department of Transportation, U.S. Army Corps of Engineers (Corps), Humboldt County, Humboldt State University, and Redwood National Park.

Although not a complete blockage, the south slough outlet is at present still aggraded with sediment. Removal of this sediment would further improve fish access. Placement of a low flow dam between the levees just downstream of the south levee culvert would divert more flow into the south slough and possibly scour out this sediment.

The north slough is completely separated from the embayment by a large buildup of sand. Summer water quality in this slough continues to be poor. The next logical step (other than removal of the levees, which is not an option at this time due to landownership) is restoration of the north slough by placing a gated culvert through the north levee. We anticipate this would restore water quality and reduce north slough flooding, allowing riparian vegetation to return to the banks. Due to the small size of the opening, the culvert alone would probably not facilitate fish entry into the north slough, however. Additionally placing the low flow dam between the levees just downstream of the south slough culvert (Fig. 5) would divert low flows into the north as well as the south slough, achieving two desired results: scour the slough outlets and divert more fish into each slough. To assist scouring processes, the north slough outlet would be excavated when the culvert is constructed.

Under the Water Resources Development Act of 1986 (P.L. 99-662, Sec. 1135), the U.S. Army Corps of Engineers is authorized to modify water resource projects to improve quality of the environment. Projects must be cost-shared 25% with a non-federal local government sponsor. The Corps has obtained \$40,000 to conduct a feasibility study on the option of constructing a north levee culvert and low flow dam. If funding is provided by a local sponsor, the Corps is authorized to fund up to \$450,000 of the project cost. This project was one of 18 projects in the nation (only 2 were in CA) selected for funding in FY 91 under Section 1135. If a non-federal sponsor is not found, the federal funding will become unavailable.

Funding this proposal would establish CA Department of Fish and Game as the local project sponsor. Even if the Department could not fund the full 25%, partial funding may be of assistance if other local sponsors also contribute. As a federal agency, Redwood National Park can not fund this portion. Therefore, the Park is seeking funding from non-federal sources, including submission of this funding proposal.

OBJECTIVE

The objective of the project is to work toward restoring Redwood Creek estuary to a more naturally functioning ecosystem. The project's emphasis is on restoration of summer rearing habitat for juvenile chinook salmon and steelhead. We propose placing a gated culvert through the north levee and a low flow (summer) dam between the levees to improve water circulation, water quality, and juvenile fish access, thereby making the north slough available for rearing. In the south slough, we anticipate fish access would also improve due to projected scouring of sand presently deposited at the south slough western outlet.

This project does not preclude ultimately removing the levees, which may be an option at some time in the future. Presently it is not feasible as it requires landowner cooperation, congressional authorization, and over \$2 million. Until levee removal is feasible, this project will greatly increase the very limited supply of rearing habitat presently available to juvenile salmonids, in particular for chinook salmon. Increased rearing habitat should help increase salmon and steelhead runs in the creek in the long term.

LOCATION

The location of the project is on Redwood Creek near its mouth. Location of the culvert in the levee and the low flow dam are shown in Fig. 5.

PROCEDURE

The Corps will conduct a feasibility study which will include an environmental assessment of the project. Corps engineers will design the project and be responsible for its construction. The gated culvert will be similar in design to the south levee culvert (Fig. 6), except smaller in size. Figure 7 shows a sketch of the low flow dam design. Redwood National Park would maintain these structures. The low flow dam would be removed at the beginning of the rainy season and reinstalled in early spring. The Corps will be responsible for monitoring after the project is completed and will prepare a follow-up report on the project.

SCHEDULING

The feasibility study is being conducted in the spring 1991. The construction work would be accomplished during a 6 month low-flow period from May to October, 1992. A decision as to whether this project proposal will be funded is needed as soon as possible, and definitely before the end of the federal Fiscal Year 1991 (September 30, 1991).

Hofstra, T.D. 1983. Management alternatives for the Redwood Creek estuary. Redwood National Park. 50 pp.

Ricks, C.L. 1984. Flood history and sedimentation at the mouth of Redwood Creek. M.S. Thesis. Humboldt State University, Arcata, CA 166 pp.

U.S. Fish and Wildlife Service. 1975. Environmental summary of existing information relating to past and present resources at Redwood Creek, California. Division of Ecological Services Memorandum on File at California Department of Fish and Game Office, Eureka, CA.

ESTIMATED BUDGET
REDWOOD CREEK RESTORATION
NORTH SLOUGH CULVERT AND SUMMER DAM
FISCAL YEAR 1992

PERSONNEL COSTS

Level of Staff	Numbers of Hours	Hourly Rate	Total
Labor	8,600	30.75	264,450
Staff Benefits as 19%			50,246
TOTAL PERSONEL COSTS			314,696

MATÉRIALS AND SUPPLIES

	Quantity	Units	Unit Cost	Total
Construction materials:				
Slide gate	1	each	35,000	35,000
Riprap, 12-inch	315	tons	19	5,985
Filter material	158	tons	25	3,950
Concrete, structural	88	c.y.	76	6,688
Concrete, lean mix	18	c.y.	64	1,152
Fence, chain-link	228	lin. ft.	11	2,508
Planks	19600	bd. ft.	0.51	9,996
Pipe casing, 15" dia.	198	lin. ft.	60	11,880
Support pipe, 12" dia.	460	lin. ft.	48	22,080
Bolts and nuts, 3/4"	490	each	4	1,960
Neoprene	4900	sq. ft.	1.46	7,154
Miscellaneous materials				21,700
Construction supplies				92,100

TOTAL MATERIALS AND SUPPLIES 222,153

OPERATING EXPENSES

Equipment				115,500
Fuel	43,000	gal.	0.80	34,400

TOTAL OPERATING EXPENSES 149,900

Administrative Overhead at 7% 48,072

TOTAL ESTIMATED BUDGET 734,821
Construction Only

ESTIMATED FEDERAL COST (donated)
75% of Total Project Cost 674,820
(includes planning, design, construction, and monitoring).

ESTIMATED NON-FEDERAL COST (funding requested)
25% of Total Project Cost 224,940

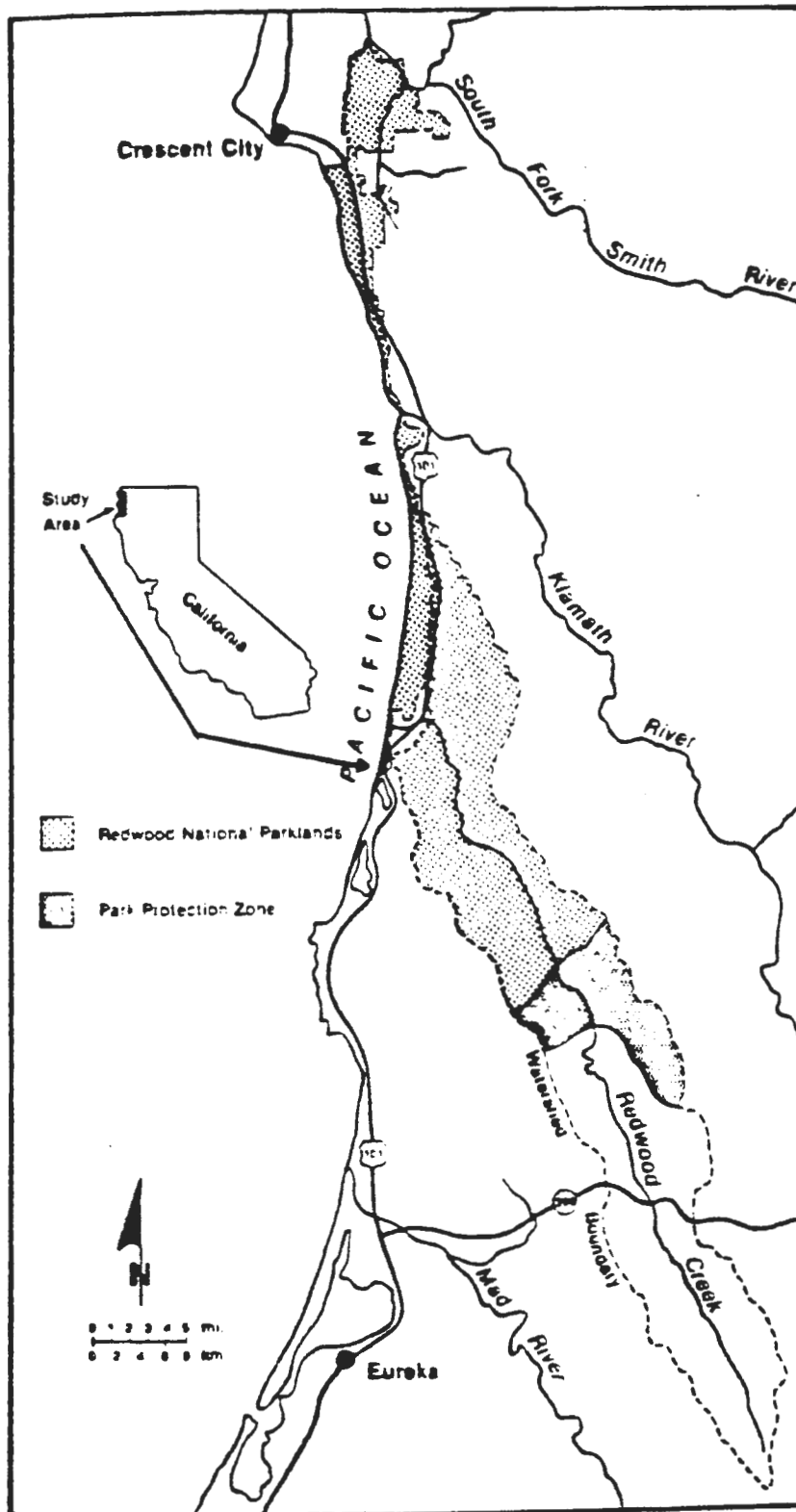


Figure 1. Northern California Location Map.

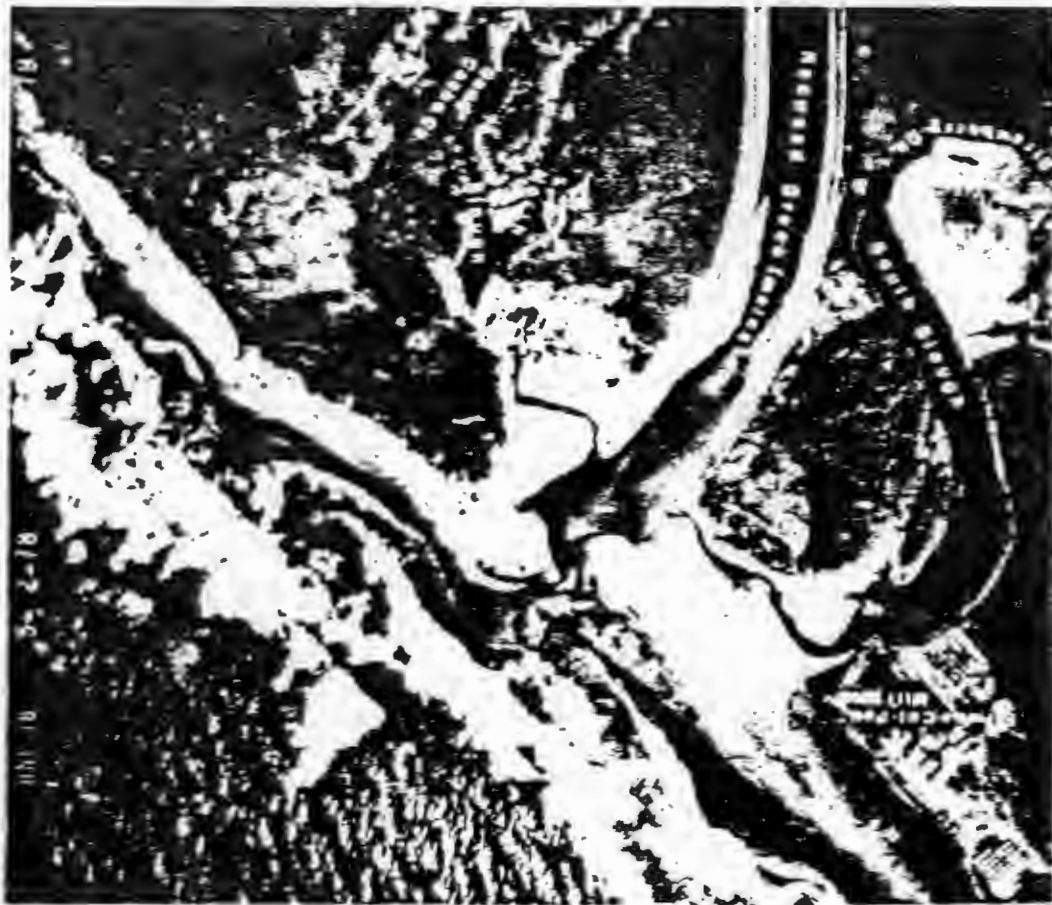


Figure 2. Present estuarine configuration. (RNP photo, May 2, 1978).

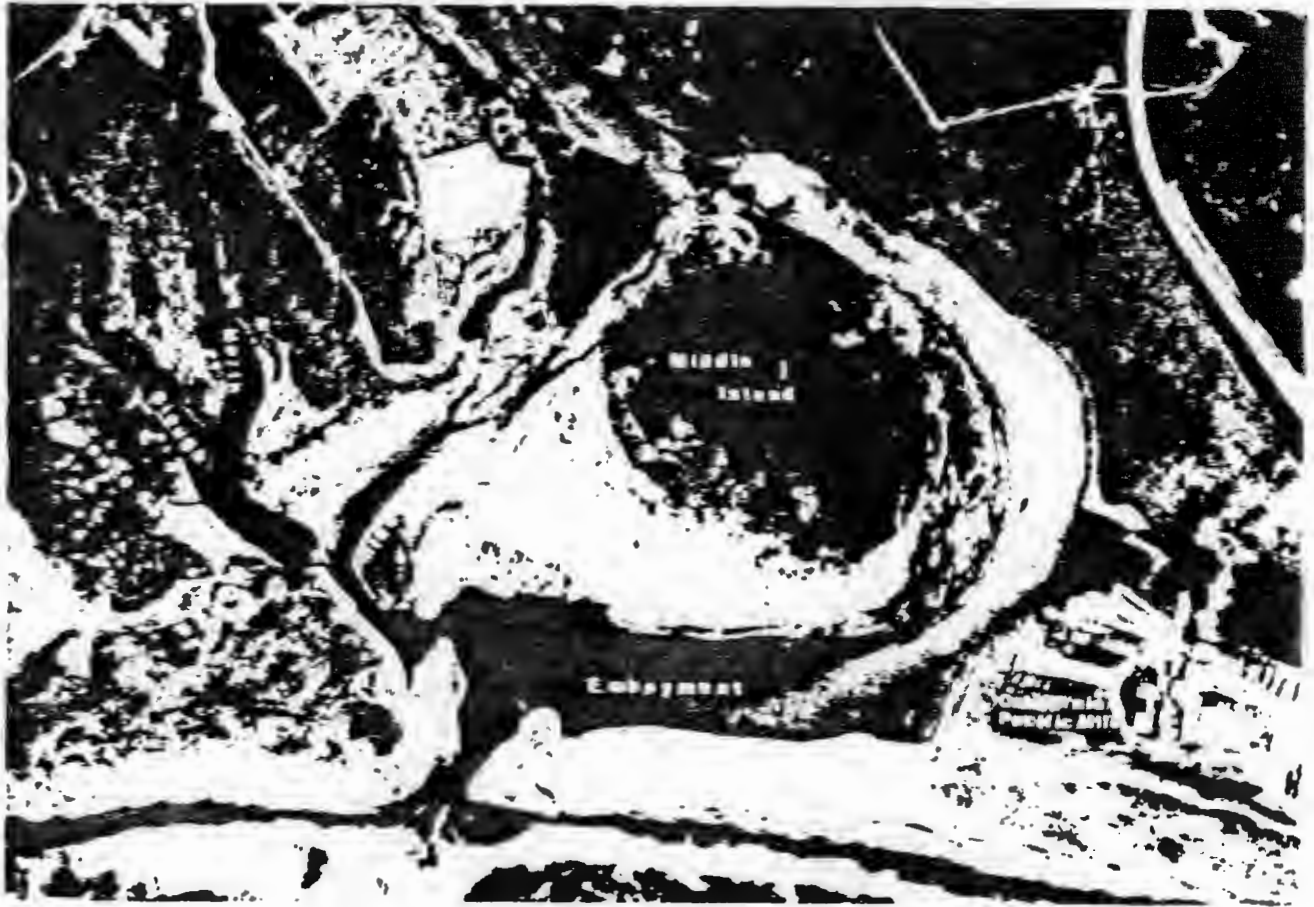


Figure 3: Historic estuarine features. (COE photo, June 30, 1966).

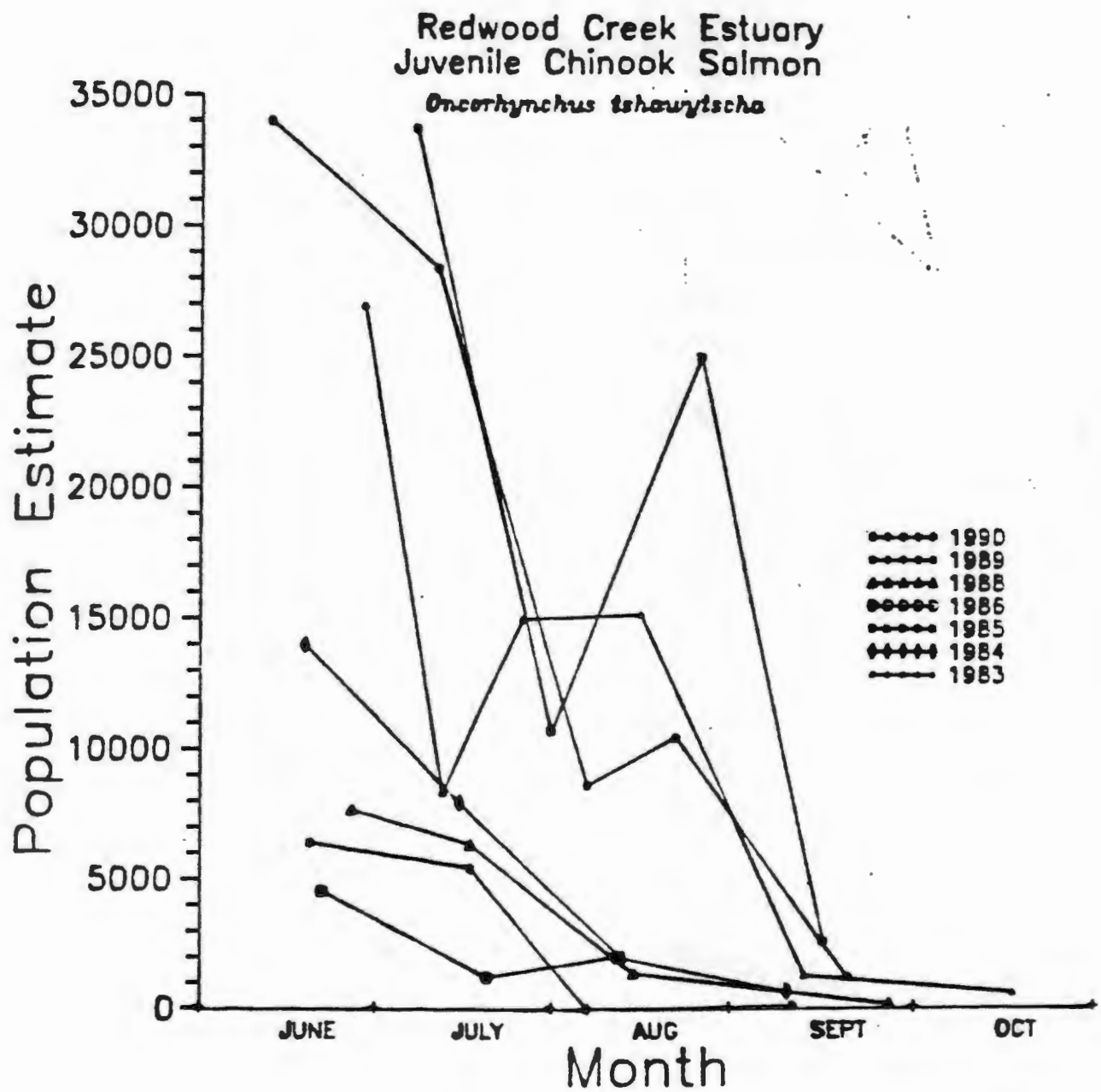


Figure 4a. Population estimates of juvenile chinook salmon utilizing the Redwood Creek estuary, Humboldt County, California.

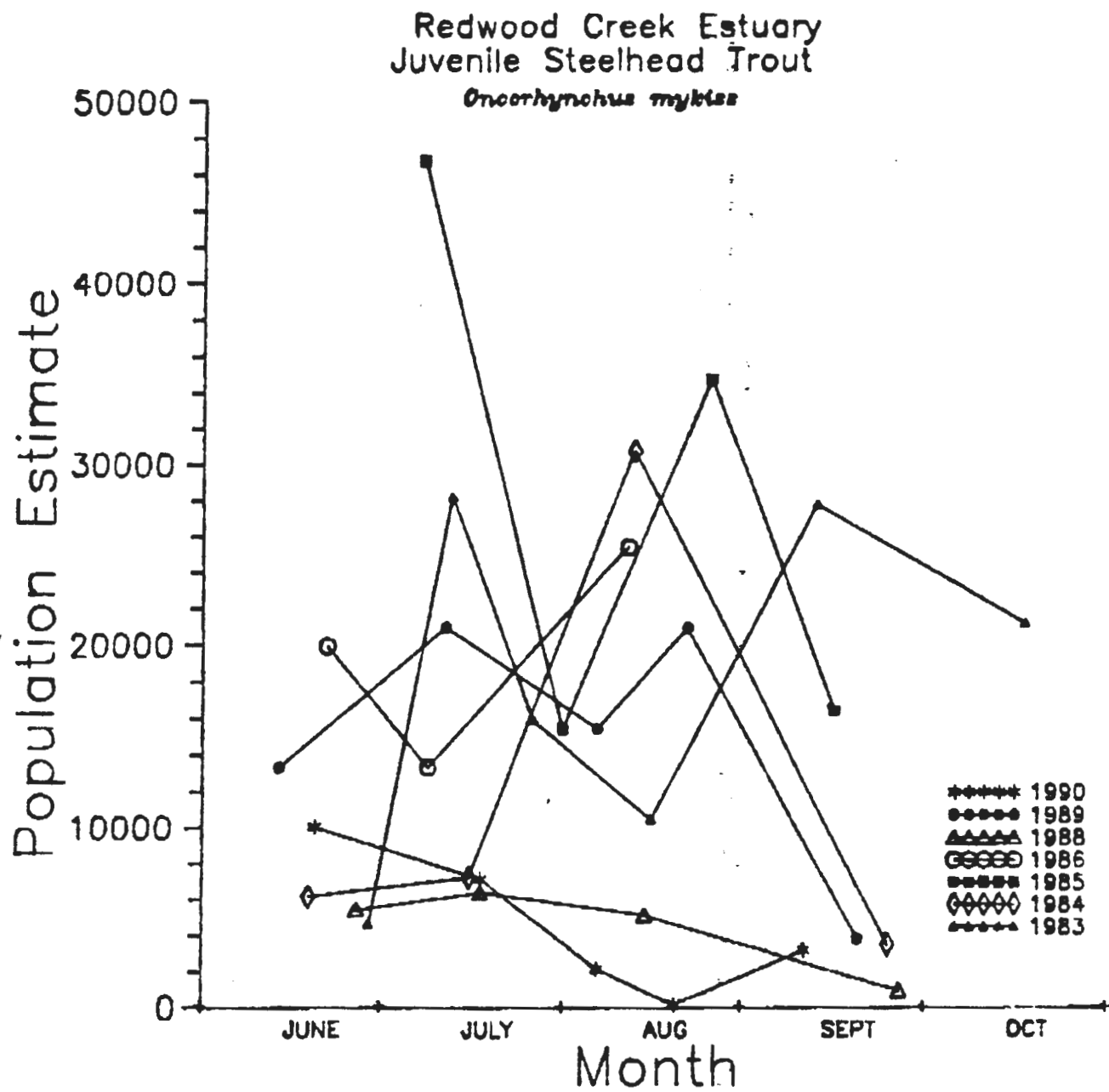


Figure 4b. Population estimates of juvenile steelhead trout utilizing the Redwood Creek estuary, Humboldt County, California.

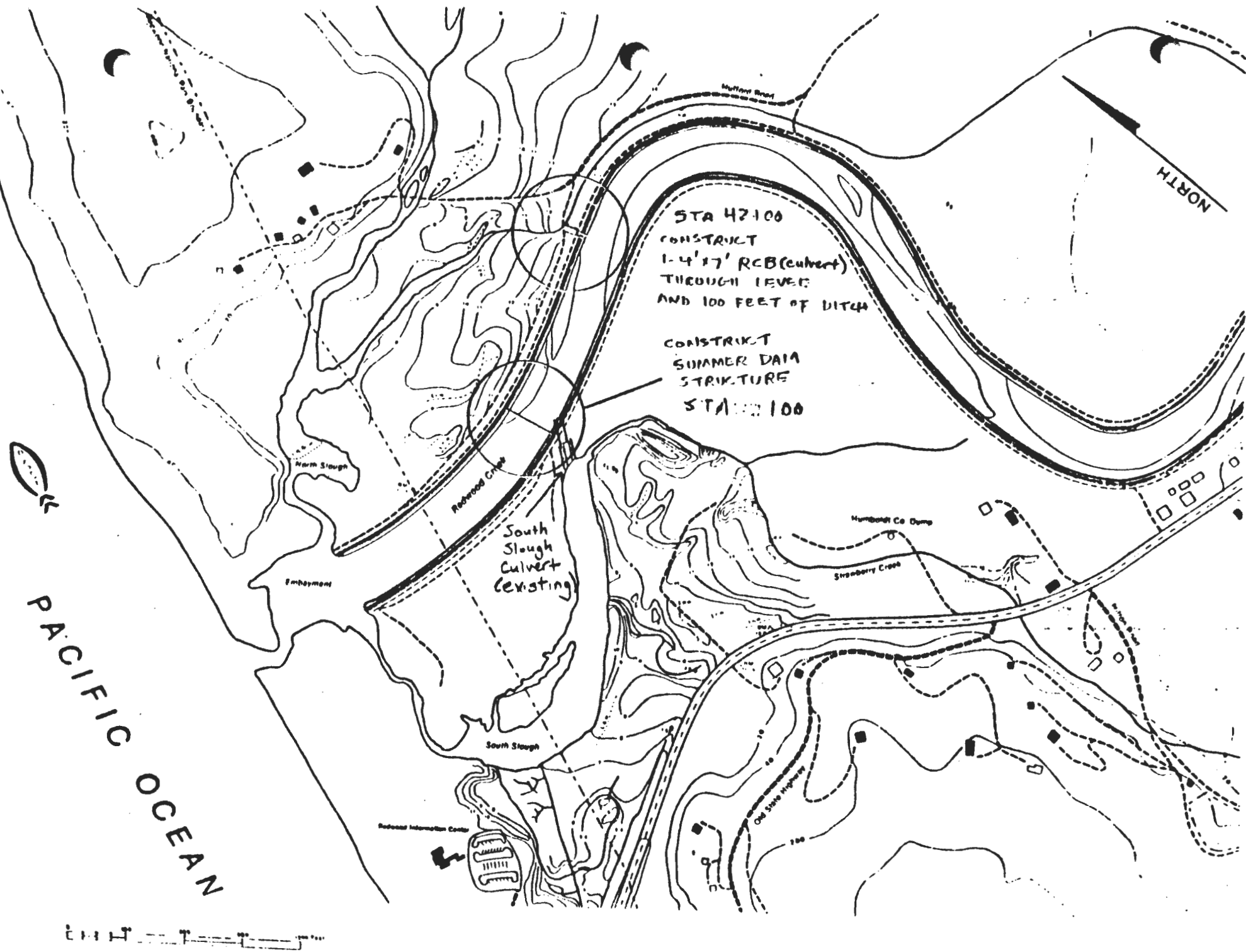
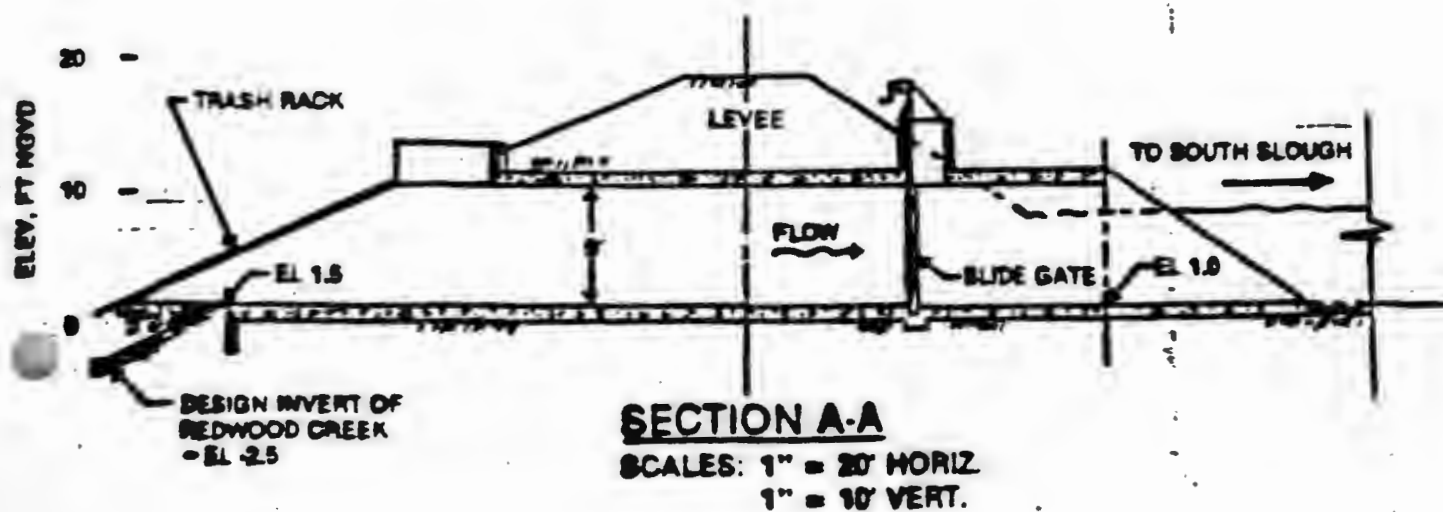
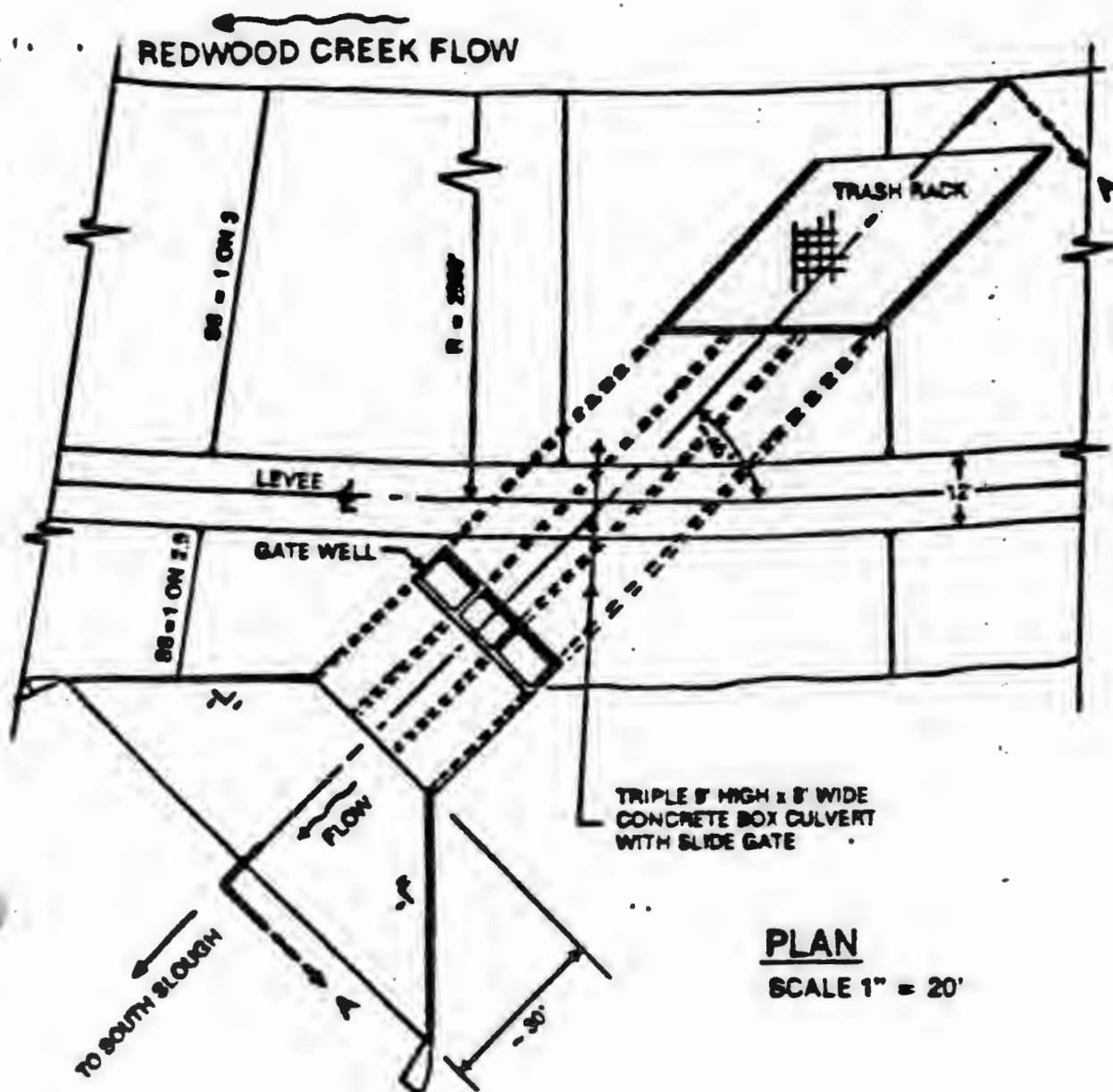
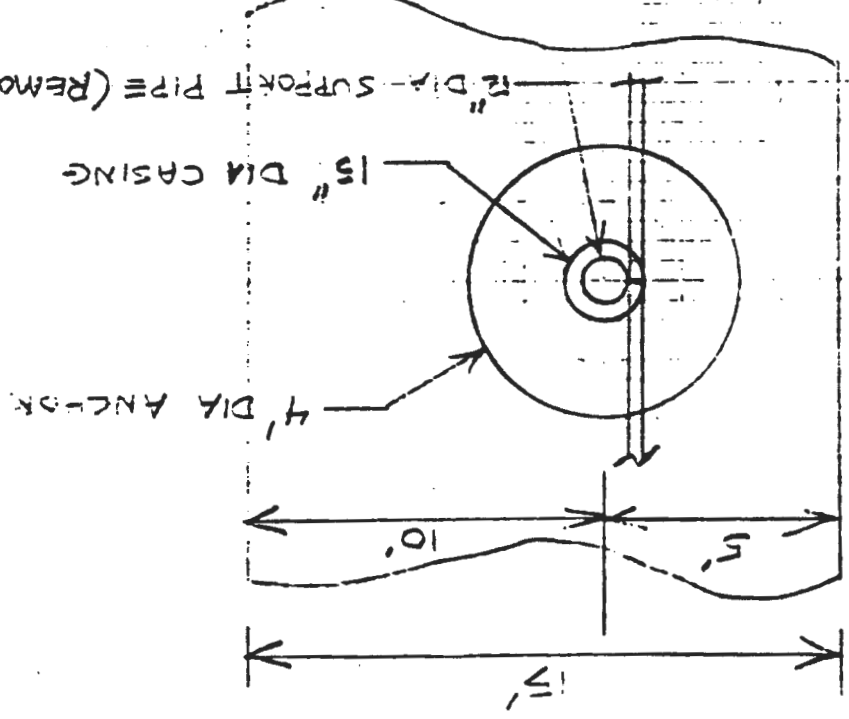
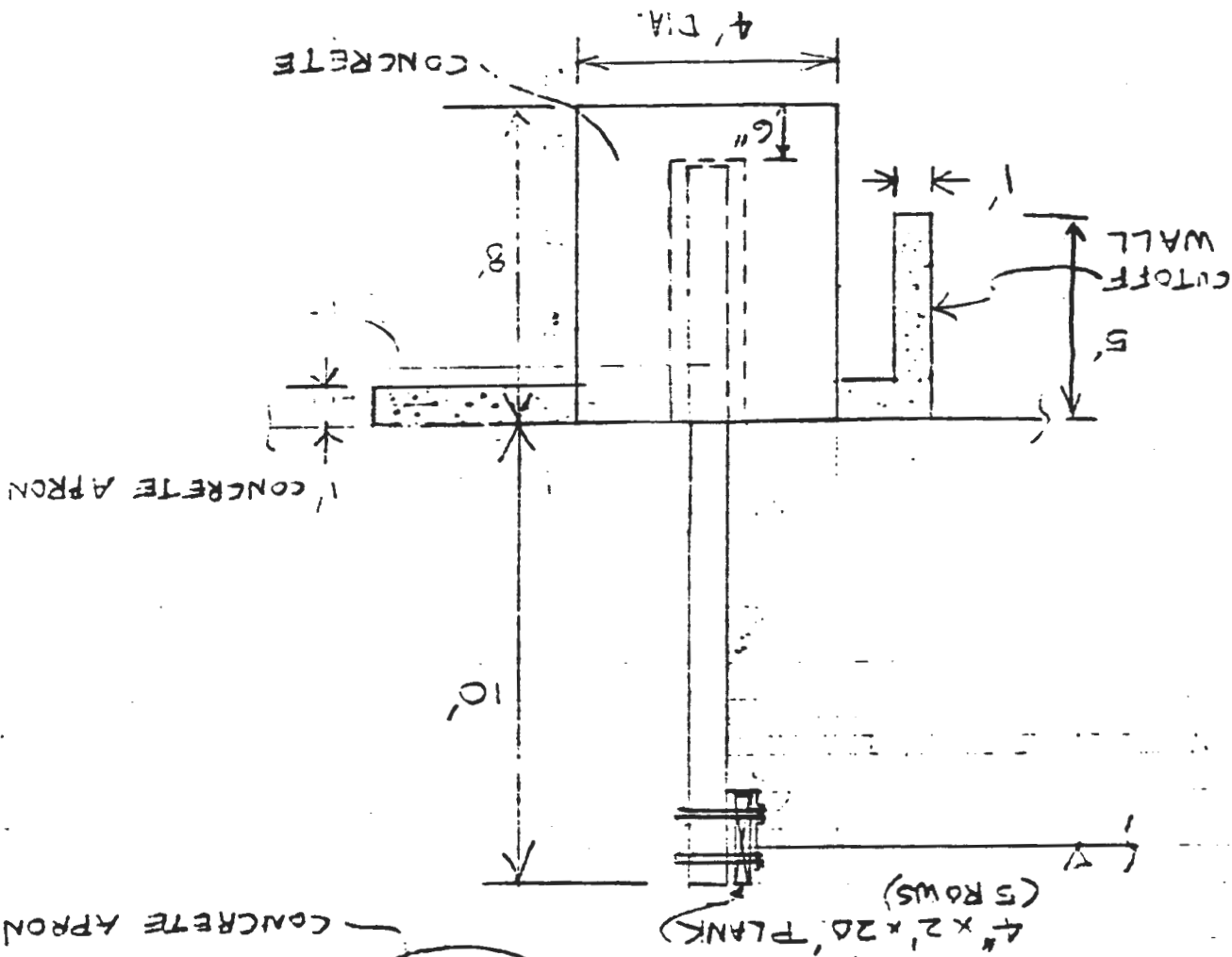
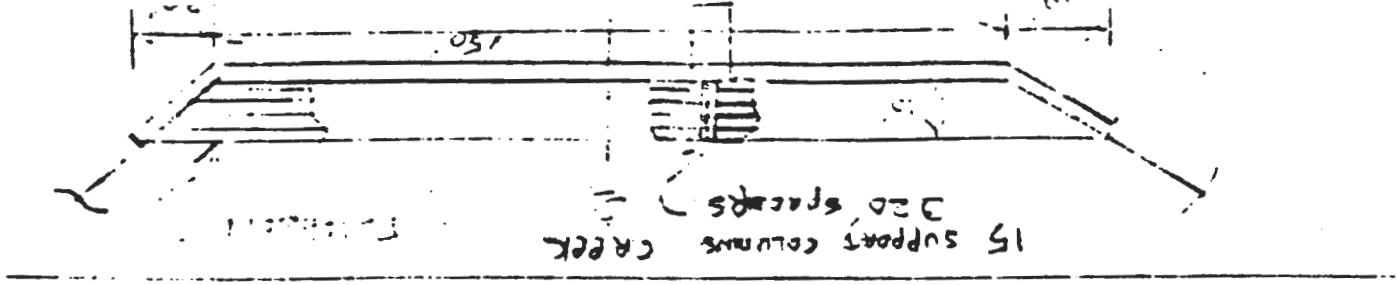


Figure 5. Location of proposed north levee culvert and summer dam.





Appendix C. Redwood Creek estuary fishery data, population estimates and confidence intervals, and mean fork lengths and weights of salmonids utilizing the estuary during the summers of 1988 and 1989.

Appendix C. Population estimates and 95% confidence intervals for juvenile salmonids utilizing the Redwood Creek estuary during the summer of 1989, Humboldt County, California.

	Population Estimate	95% Confidence Interval
<u>Chinook Salmon</u>		
6/14/89	33,970	25,190 - 42,750
7/11/89	28,340	22,030 - 34,640
8/07/89	8,570	1,240 - 15,900
8/21/89	10,440	357 ^a - 22,040
9/19/89	1,210	220 - 2,190
<u>Steelhead Trout</u>		
6/14/89	13,320	4,850 - 21,790
7/11/89	20,950	7,560 - 34,350
8/07/89	15,400	9,360 - 21,440
8/21/89	20,910	15,820 - 26,000
9/19/89	3,810	2,380 - 5,230

^a Actual number caught

Appendix C. Mean fork lengths (mm) and weights (g) of juvenile chinook salmon and steelhead trout utilizing the Redwood Creek estuary, Humboldt County, California during the summer and fall 1989.

Date	No.	Mean Fork Length (mm)	S.D.	Min - Max	No.	Mean Weight (g)	S.D.
<u>Chinook Salmon</u>							
6/13/89	228	78.6	6.7	56 - 105	31	5.6	1.4
6/26/89	248	81.7	6.5	60 - 95	30	5.9	1.3
7/11/89	205	82.7	6.3	53 - 98	30	5.6	1.4
7/24/89	215	87.6	5.2	70 - 100	30	7.6	1.5
8/07/89	200	87.5	5.8	64 - 104	30	9.4	1.7
8/21/89	200	91.8	5.5	77 - 109	29	8.4	1.5
9/19/89	152	99.5	5.1	83 - 113	30	11.9	1.7
<u>Steelhead Trout</u>							
6/13/89	231	120.7	20.2	63 - 195	29	24.4	12.6
6/26/89	218	121.6	25.6	52 - 265	29	19.0	6.5
7/11/89	219	116.0	22.5	59 - 186	30	19.5	9.7
7/24/89	220	113.4	24.9	59 - 170	30	19.0	9.7
8/07/89	211	129.4	22.6	70 - 184	30	28.3	11.3
8/21/89	200	130.1	19.7	68 - 181	30	24.0	9.3
9/19/89	205	124.2	28.1	75 - 181	30	21.1	13.9

Appendix C. Mean fork lengths (mm) of coastal cutthroat trout, coho salmon, and adult steelhead trout utilizing the Redwood Creek estuary, Humboldt County, California during the summer and fall of 1989.

Date	No.	Mean Fork Length (mm)	Std. Dev.	Range Min - Max
<u>Cutthroat Trout</u>				
6/13/89	3	201.1	2.6	199 - 204
6/26/89	10	284.9	101.0	184 - 445
7/11/89	12	260.8	84.5	166 - 410
7/24/89	0	---	--	---
8/07/89	12	245.1	22.2	203 - 278
8/21/89	20	247.4	30.7	182 - 307
9/19/89	20	271.4	30.5	211 - 320
<u>Coho Salmon</u>				
6/13/90	4	135.0	8.0	125 - 142
7/11/89	2	76.0	7.1	71 - 81
8/21/90	3	141.3	5.8	138 - 148
9/19/90	2	155.0	19.8	141 - 169
<u>Adult Steelhead</u>				
7/11/89	6	560.0	52.9	470 - 630

Appendix C. Population estimates and 95% confidence intervals for juvenile salmonids utilizing the Redwood Creek estuary, Humboldt County, California during the summer and fall of 1988.

	Population Estimate	95% Confidence Interval	
<u>Chinook Salmon</u>			
6/27/88	7,670	2,160	13,170
7/18/88	6,300	5,260	7,350
8/15/88	1,350	1,110	1,590
9/27/88	150	100	190
<u>Steelhead Trout</u>			
6/27/88	5,420	2,700	8,130
7/18/88	6,370	5,340	7,400
8/15/88	5,100	4,450	5,740
9/27/88	950	180	1,720
<u>Cutthroat Trout</u>			
6/27/88	42 ^a		
7/18/88	80	40	650
8/15/88	1 ^a		
9/27/88	none captured		

^a Actual number caught

Appendix C. Mean fork lengths (mm) and weights (g) of salmonids utilizing the Redwood Creek estuary, Humboldt County, California during the summer and fall of 1988.

Date	n	Mean Fork length (mm)	S.D.	n	Mean Weight (g)	S.D.
<u>Chinook Salmon</u>						
6/15/88	133	66.4	5.9			
6/27/88	198	69.6	8.6	30	3.5	1.5
7/18/88	220	83.1	7.0	30	6.6	1.5
8/03/88	199	84.4	5.6	30	6.8	1.6
8/15/88	200	88.4	6.1	30	7.9	1.7
8/31/88	3	85.0	5.3	3	7.4	1.4
9/27/88	89	103.4	8.1	30	13.0	3.1
<u>Steelhead Trout</u>						
6/15/88	13	75.8	25.0			
6/27/88	200	118.1	24.4	30	9.5	6.9
7/18/88	200	130.6	21.8	30	29.5	15.1
8/03/88	206	111.8	26.6	30	17.7	11.4
8/15/88	205	141.3	19.4	30	31.4	11.5
8/31/88	88	118.8	24.4	30	18.8	12.2
9/27/88	141	125.7	20.9	31	23.5	12.6
<u>Cutthroat Trout</u>						
6/27/88	35	230.3	48.4			
7/18/88	30	232.4	36.1			
8/03/88	none captured					
8/15/88	1	240.0	----			
8/31/88	1	250.0	----			
9/27/88	none captured					
<u>Steelhead Trout Half Pounder</u>						
8/31/88	2	281.5	7.8			
9/27/88	1	439.0	----			
<u>Coho Salmon</u>						
9/27/88	1	82.0	----	1	10.5	----

APPENDIX: D

EVALUATION OF EFFECTIVENESS OF CULVERT

HYDROLOGIC RESTORATION OF THE REDWOOD CREEK ESTUARY¹

Randy D. Klein and William E. Weaver²

ABSTRACT: The ecological structure and functioning of the Redwood Creek estuary and surrounding lowlands have been vastly altered over the last several decades due to: 1) conversion of riparian habitat to pasturelands, 2) excessive sedimentation from upstream land use and large floods, 3) annual, multiple artificial breaches of the barrier beach, and, most importantly, 4) channelization for flood control. Sedimentation associated with levee construction has reduced tidal circulation and caused periodic isolation of two sloughs which compose potentially valuable components of the estuarine rearing habitat for juvenile salmonids. Resultant water quality and accessibility problems limit habitat for fish each summer. Restoration efforts undertaken by Redwood National Park include measures to partially restore hydrologic and geomorphic processes responsible for maintaining a productive estuarine ecosystem. A large, gated culvert was recently constructed through a levee section, re-establishing water circulation to the landward end of the largest slough. Results of initial field experiments on culvert operation show marked improvement in estuary water quality and hydrologic function.

INTRODUCTION

Located about 480 kilometers north of San Francisco, the Redwood Creek estuary (Fig. 1) is one of many on the Pacific Coast. Redwood Creek drains a long narrow basin 725 square kilometers (km) in area flowing to the Pacific Ocean near the town of Orick, California. The basin is largely underlain by the Franciscan assemblage, which consists of tectonically deformed belts of sedimentary and metamorphic rocks (Baily et al. 1964). For most of its length, Redwood Creek follows the northwest-trending Grogan Fault. A combination of rapid tectonic uplift, highly erodible terrain, and intense winter rainstorms is responsible for the relatively high rates of natural erosion and sedimentation characteristic of the region (Janda et al. 1975).

Local tides range to about two meters (m) in amplitude with a mean of about 1.4 m and are classified as mixed semidiurnal (two high tides and two low tides per day with consecutive highs and lows being of different height, as described in Bascom 1964, p. 89). Swells in excess of 8 m in height occur several times each year, usually during the winter.

HISTORICAL CHANGES

Most estuaries in developed areas have been directly affected to varying degrees by human activities such as clearing of woody debris, diking, land filling, dredging, and

¹Presented at the Society for Ecological Restoration and Management Annual Meeting; January 16-20, 1989, Oakland, California. A manuscript based on this subject has also been submitted to Environmental Management Journal, Springer-Verlag, N.Y.

²Hydrologist and Engineering Geologist, respectively, Redwood National Park, U.S. Department of the Interior, Orick, Calif.

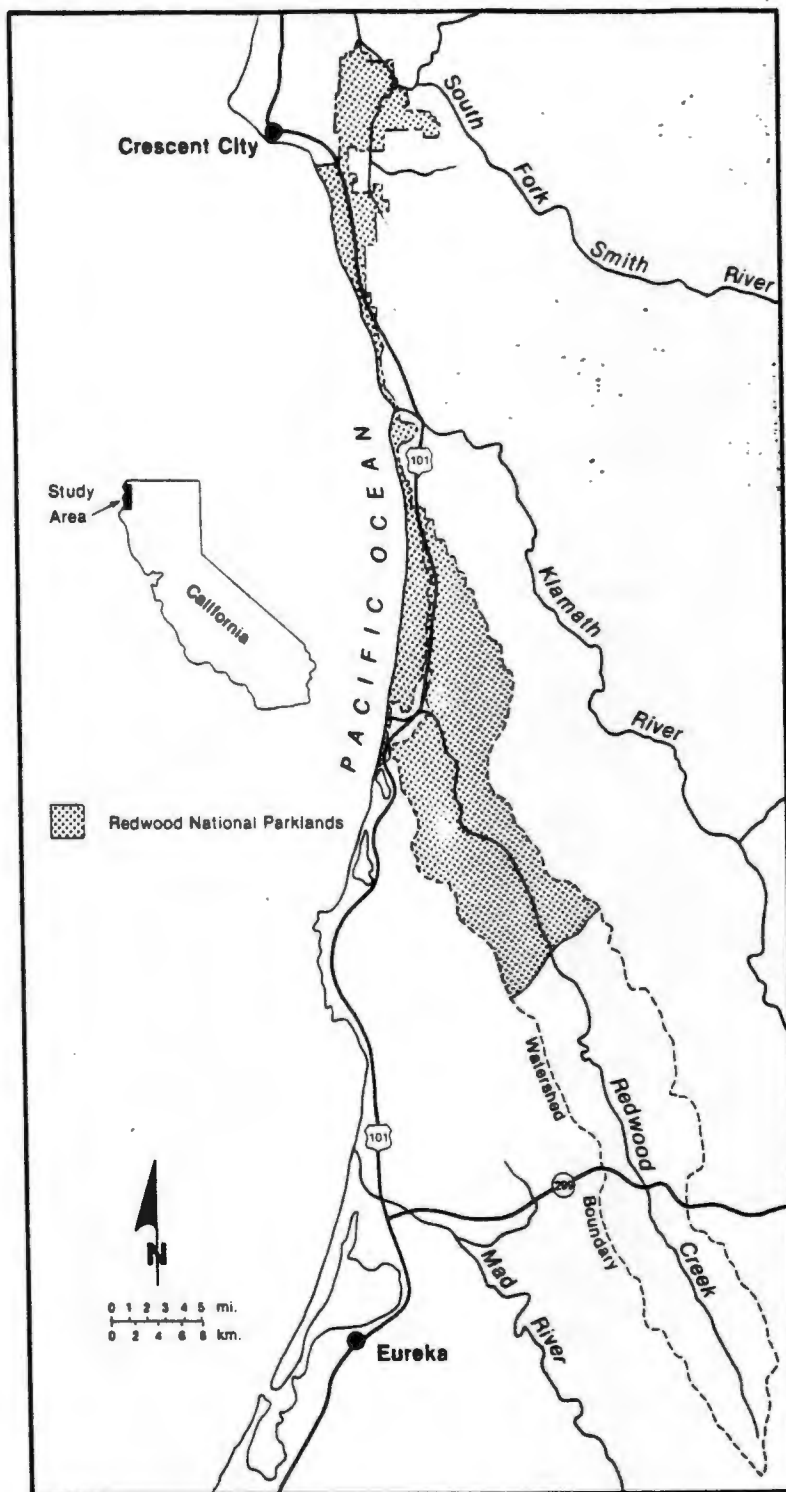


Figure 1--Location map of the western U.S. showing Redwood Creek basin in northwestern California.

artificial channelization for navigation and flood control. These activities restrict or prevent the interaction of streams with their floodplains, sloughs, and side channels and greatly simplify the remaining aquatic habitat (Sedell and Luchessa 1981). Indirect impacts from human activities involve increased sedimentation in low gradient,

downstream areas from accelerated hillslope and channel erosion processes occurring upstream. Channelization and sedimentation can greatly reduce tidal prism volumes in estuaries, thereby reducing the effectiveness of tidal currents in maintaining the dimensions and productivity of estuarine sloughs.

In Redwood Creek, extensive timber harvest in the contributing watershed, followed by large floods in 1964, 1972, and 1975, resulted in greatly increased sediment loads which caused aggradation and channel widening in the low gradient floodplains of the lower valley (Janda et al. 1975). Flood control levees were completed in 1968 which channelized the lower 5.1 km of Redwood Creek from the apex of the alluviated Orick valley to within 200 m of the surf zone (Fig. 2).

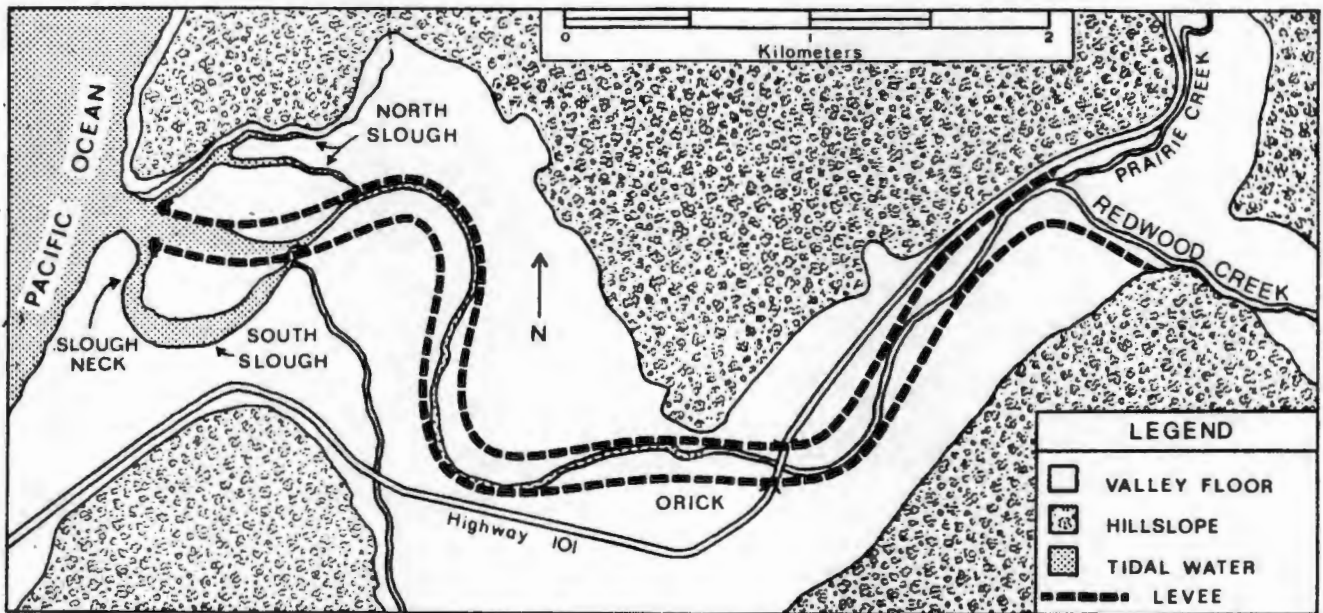


Figure 2--Local geography of lower Redwood Creek in the Orick valley.

Since channelization, Redwood Creek's floodwaters and sediment loads have been totally confined between levees (Fig. 2) and routed directly into the Pacific Ocean through the main embayment (that part of the estuary exclusive of the North and South Sloughs). Both the South Slough (which was formerly the main channel of Redwood Creek) and the North Slough (which formerly functioned as a high flow distributary) have experienced increased sedimentation in their oceanward ends since levee construction. Ricks (1985) estimates that approximately fifty percent of the volume of the lower estuary (between 0 and 1.2 m above mean sea level (MSL)) has been filled in or become isolated from the main embayment since 1966.

Sedimentation has been primarily caused by marine processes of beach berm overwash and flood tidal currents enhanced by surf-derived wave bores (FitzGerald 1988, p. 207) translating through the river mouth. Both processes transport and deposit sand in the lower sloughs of Redwood Creek (Ricks 1985). Because wave bore-enhanced flood tidal currents translate up through the river mouth with great frequency (even during periods of moderate surf, and occasionally with great force), this process has resulted in much more sedimentation since 1981 than beach berm overwash (which occurs relatively infrequently, only during periods of extremely high tides and wave heights). The landward orientation of megaripples (Horne and Patton 1989, p. 814) on the channel beds

of the lower sloughs suggests that flood tides dominate sediment transport processes in these areas during periods of low river discharge.

The mouth of Redwood Creek commonly closes during summer low-flow periods (late summer through early fall) when coastal nearshore processes can build a berm at the river mouth higher than estuary water levels. The mouth may re-open prior to the onset of fall rains if the estuary water level rises enough to cause the berm to be overtopped (depending on the elevation of the beach berm relative to the rate of accretion of fresh water in the embayment). If the mouth closes late in the dry season, when Redwood Creek discharge is very low, it will usually remain closed (unless mechanically opened) until the first fall rains increase river discharge.

While the mouth is closed, estuary waters can rise to the point where flooding occurs on adjacent private properties. Prior to management by Redwood National Park, landowners commonly breached the mouth, causing the estuary to empty almost completely and prematurely with respect to the natural occurrence of hydrologic conditions which caused breaching. Because the late summer and early fall estuary habitat is especially important for the physiological development of juvenile salmonids about to make the transition to the marine environment, the artificial breaches became an important management concern for Redwood National Park (Hofstra and Sacklin 1987).

As an interim method of improving estuarine rearing conditions for fish, Redwood National Park has actively managed summer water levels in the estuary since 1982. When water levels approach flooding conditions on adjacent private lands (at about 1.6 m in elevation, MSL), a "controlled breach" is performed. This is accomplished by cutting an outflow channel at the river mouth by bulldozer in a configuration and during tidal conditions which are likely to prevent the estuary from completely draining (Hofstra and Sacklin 1987). The variability in hydrologic and coastal processes which control river mouth closures and natural breaches necessitates different numbers of controlled breaches from year to year. For example, twenty breaches were necessary in 1987, while in 1988 the mouth remained open virtually all summer and no artificial breaches were needed.

PRESENT CONDITIONS AND PROCESSES

Except for the aggraded "neck", the South Slough retains a relict pattern and hydraulic geometry typical of a meander bend (its fluvial role from the pre-levee period). Aggradation in the slough neck now physically limits the lower tidal range for the slough while the river mouth is open, causing a substantial decrease in tidal water circulation. Hydrologic isolation of the slough occurs when tidal water levels in the main embayment drop lower than the elevation of aggraded sediments in the slough neck. During the summer and early fall, the limited circulation and isolation results in elevated water temperatures and depressed levels of dissolved oxygen as eutrophication progresses. Because the South Slough composes a large portion of the potential (and historic) rearing habitat for juvenile salmonids, improving water quality and accessibility is a major restoration goal (Hofstra and Sacklin 1987).

Continuous monitoring of water levels in the main embayment and South Slough since 1987 has provided insights into the hydrologic functioning of the Redwood Creek estuary. Figure 3 shows a plot of water level fluctuations at the two locations for calendar days 251-265, 1988 (September 7 through 21). During the period preceding day 258 (September 14), water levels in the main embayment fluctuated within a 1 m tidal range while water level fluctuations in the South Slough were limited to a 0.3 m range above

the maximum thalweg elevation in the aggraded slough neck (0.8 m above MSL). Surf conditions closed off the river mouth on day 258 (September 14), after which water levels rose gradually in both the main embayment and the slough.

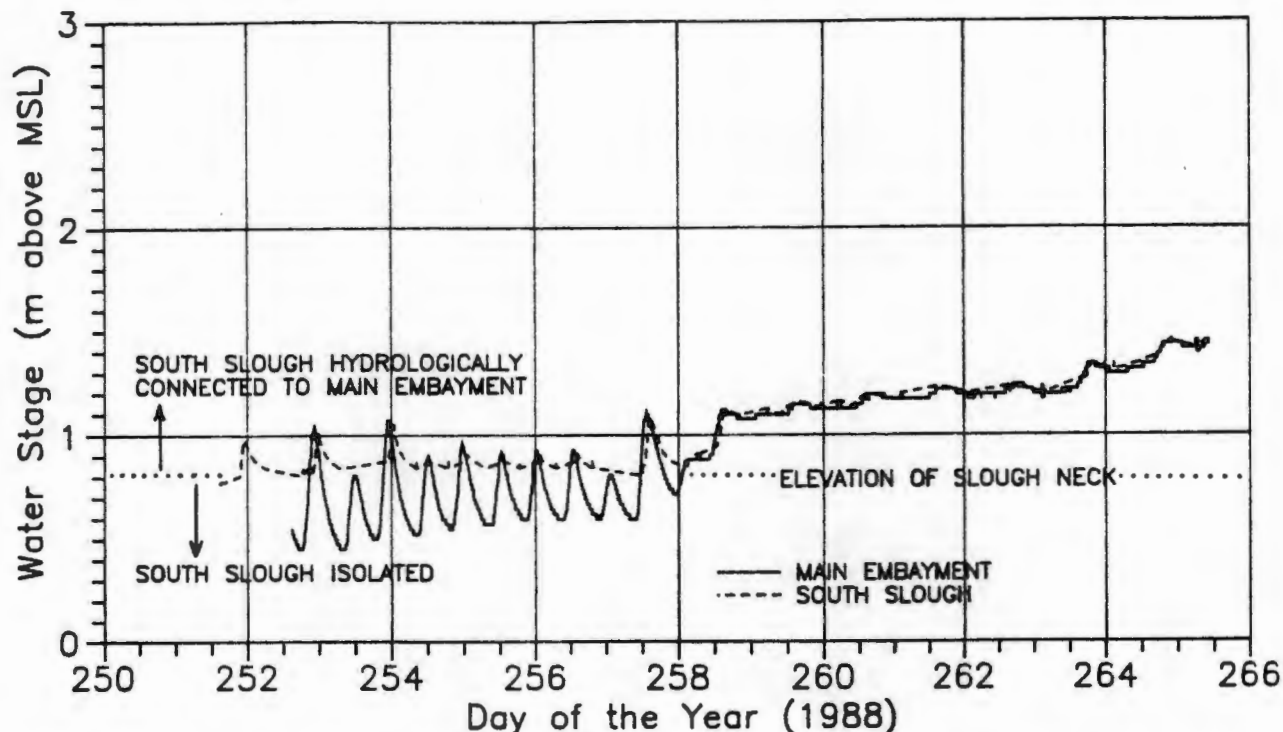


Figure 3--Plot of water levels in the South Slough and the Main Embayment of Redwood Creek for calendar days 251-265 (September 7 through 21, 1988).

When hydrologic gains and losses in the estuary are approximately equal, water levels become nearly static or rise gradually in a stepwise fashion related to the tides (Fig. 3, days 259 through 265). Such conditions reflect a near balance between surface and subsurface hydrologic contributions from the watershed, evapotranspiration losses, and ocean conditions (which affect both the rate and direction of groundwater seepage through the barrier beach and seawater inputs from wave overwash). Under these conditions, the river mouth will remain closed (unless artificially opened) until the first fall rainstorm increases river discharge.

Figure 4 shows estuary water levels for calendar days 304 through 312, 1988 (October 30 through November 7, 1988), encompassing a rainy period which caused the mouth to breach. Prior to day 307 (November 2), water levels were nearly static, showing only minor fluctuations corresponding to higher-high tides. A rainstorm which began on day 307 (November 2) increased discharge in Redwood Creek, which caused estuary water levels to rise sharply. The river mouth breached on day 309 (November 4) when embayment water levels overtopped and eroded through the sand berm, returning tidal fluctuations to the estuary.

Figures 5a and 5b show the estuary immediately before and after functional closure of the mouth in August and September of 1988. When the mouth is closed, the consistently higher water levels improve fish accessibility to the sloughs, however only slight improvements in slough water quality occur due to the absence of tide-driven circulation (Hofstra and Sacklin 1987). When the estuary water level reaches the crest elevation of the sand sill at the mouth, water from the embayment spills into

the ocean and the sill is breached by rapid erosion. Water levels can drop two to three meters in a few hours (see Fig. 4) as the spilling water cuts a deep channel through the sand.

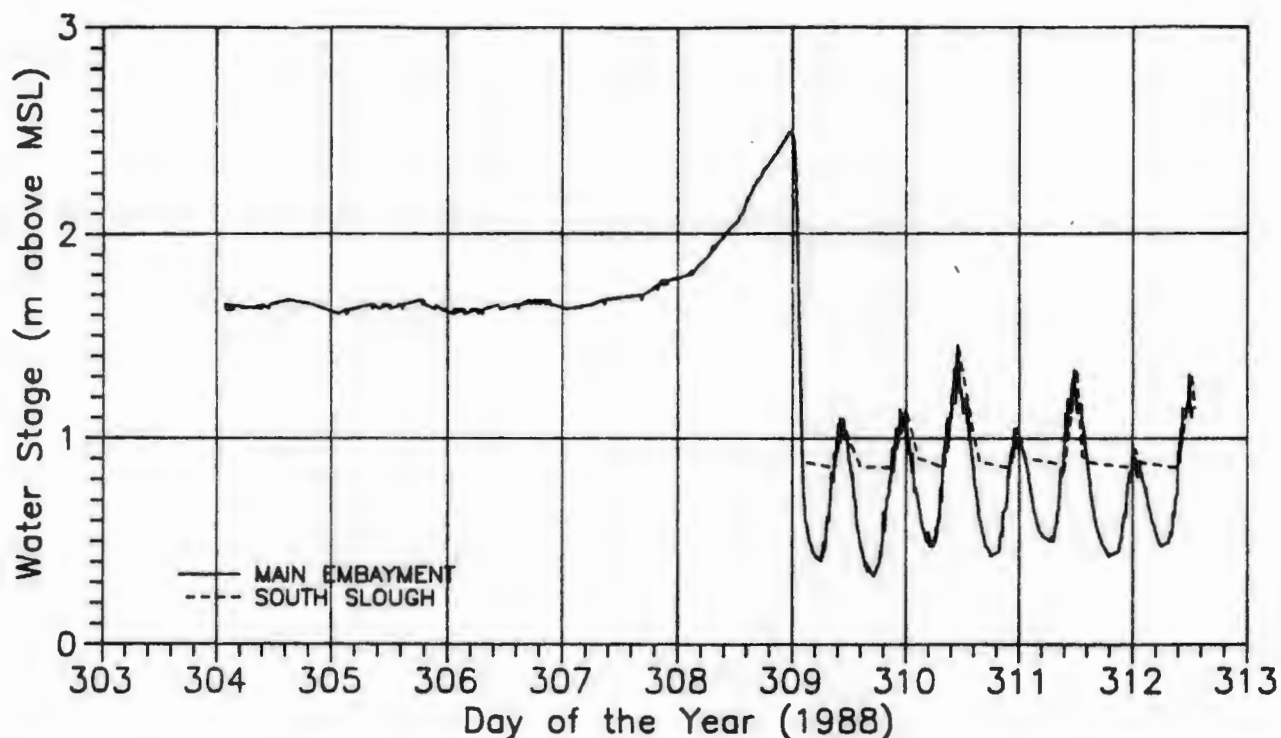


Figure 4--Plot of water levels in the Main Embayment and South Slough for calendar days 304-312 (October 30 through November 7, 1988).



Figure 5--Aerial photographs of the estuary of Redwood Creek during August (a) and September (b), 1988; before and after river mouth closure, respectively.

RESTORATION EFFORTS

The focus of recent restoration efforts has been to partially restore natural hydrologic and geomorphic processes to the South Slough. To re-establish low stage communication between the main embayment and the South Slough, sediment was excavated from the slough neck by bulldozer in summer, 1983. Removal of the sediment temporarily improved circulation by allowing more of the slough water to be exchanged with new water from the main embayment on each tidal cycle. Following the 1983 excavation, however, the slough neck had re-filled with sand to its former elevation of 0.8 m MSL by the summer of 1988. Because there was no significant beach berm overwash during this period, re-filling was due primarily to wave bore-enhanced flood tidal currents which carried sand up into the neck.

To help provide a long term solution to the sedimentation and water quality problems of the South Slough, a large diversion culvert was constructed through the south levee in 1988 (Fig. 5). Funding for the project was provided by the California Department of Transportation as mitigation for anticipated loss of fishery values resulting from a nearby highway construction project. Design and construction supervision of the structure was provided by the U.S. Army Corps of Engineers.

The culvert (Fig. 6) consists of three 2.5 m square chutes, each with its own manually operated gate, connecting the main channel of Redwood Creek with the landward end of the South Slough. The structure was designed to 1) increase tidal water circulation during the summer for improving water quality in the South Slough, and 2) scour sediment from the slough neck by routing winter stormflows of up to 97 cubic meters per second (cms) from Redwood Creek through the slough.

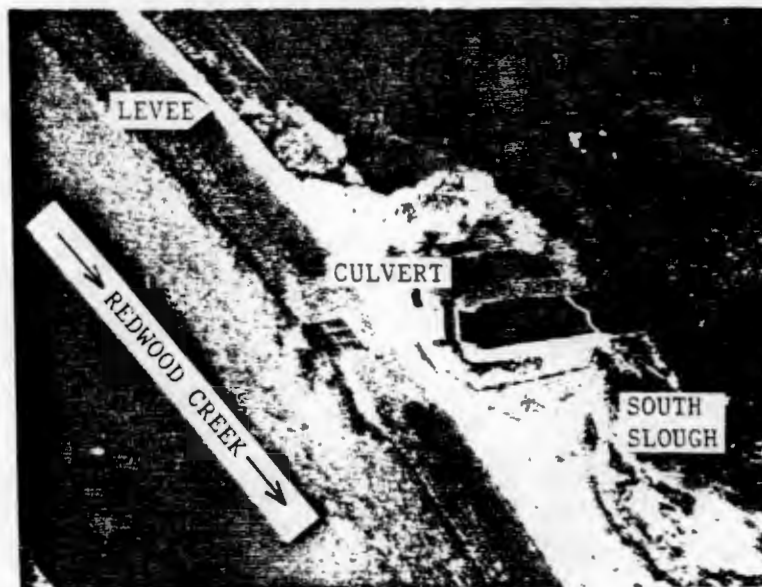


Figure 6--Gated culvert drainage structure built through the south levee of Redwood Creek in 1988.

Tidal Circulation

Several trials were conducted during the summer of 1988 to quantify the effects of culvert gate opening on increasing tidal circulation within the South Slough. Without the gates open, the lower end of the tidal range in the slough is determined by the

elevation of aggraded sediments in the slough neck. Continued aggradation further elevates the lower end of the tidal range in the slough, making it increasingly narrow. The volume of slough water exchanged on any given tide cycle, then, is determined by the slough's bathymetry between the maximum water level at high tide and the elevation of aggradation in the slough neck.

Figure 7 is a plot of water surface elevation versus water volume retained in the South Slough, derived from a map of the slough's bathymetry. The bathymetric configuration of the South Slough (wide cross section with very gently sloping bottom topography) causes large increases in water volume with slight increases in water surface elevation. Because the culvert bottom is 0.3 m lower than the elevation of the aggraded slough neck, opening the culvert gates caused the base water level in the slough to be effectively lowered by about 0.3 m in 1988. This slight lowering of the slough's base water level was responsible for an additional 12,000 m³ of potential tidal water exchange (Fig. 7), which represents approximately 37 percent of the water remaining in the slough at low tide. In addition to increasing the volume of tidal water exchange, opening of the culvert gates also allows tidal circulation at the landward end of the slough, thereby improving dispersion of new water as well.

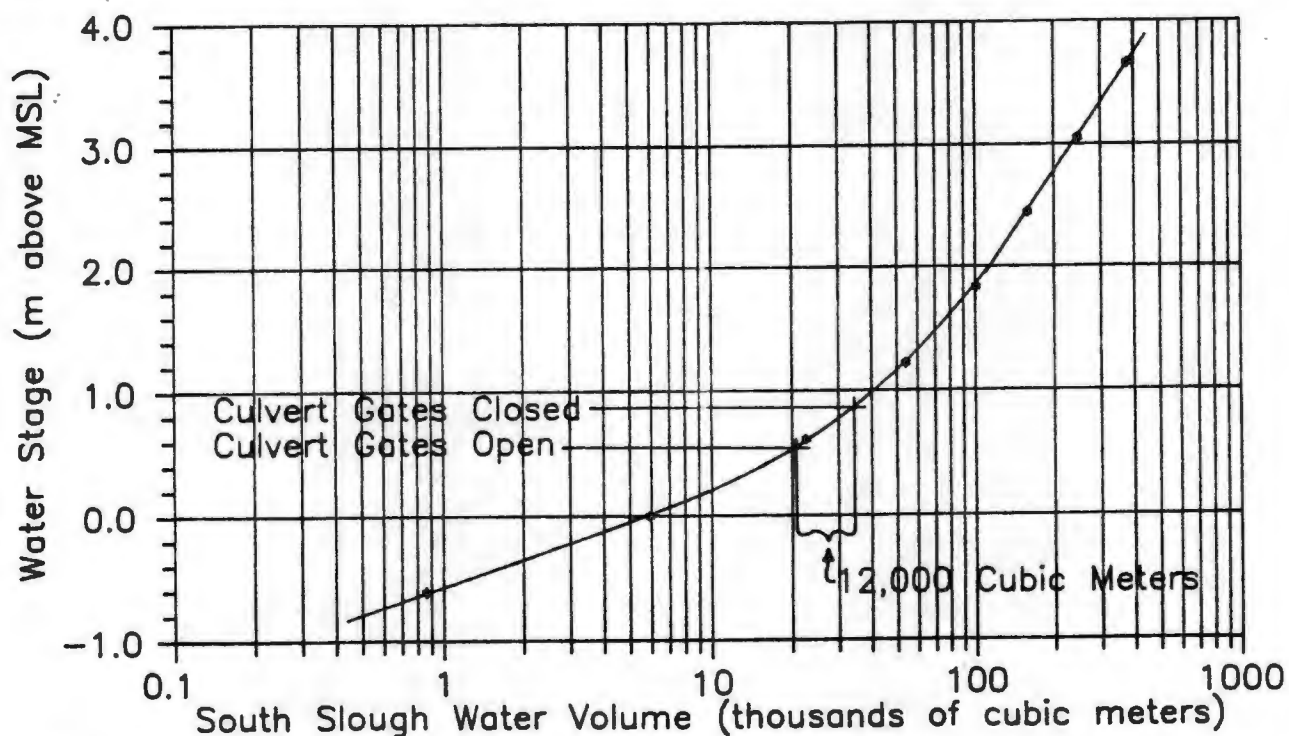


Figure 7--Plot of water surface elevation versus water volume in the South Slough, showing the effect of opening the culvert gates on increasing volumetric water exchange between the main embayment and the South Slough.

Preliminary results of water quality monitoring in the South Slough showed substantial improvements in temperature and dissolved oxygen following gate installation and opening.³ On June 29, 1988 (prior to opening the gates), depth-averaged water temperature near the middle of the slough had risen to 17.4 degrees Centigrade (C),

³Data on file with Terry Hofstra, Ecologist, Redwood National Park, Arcata, CA.

ranging from 22.5 degrees C near the surface to 14.5 degrees C near the bottom. Depth-averaged dissolved oxygen was 3.5 parts per million (ppm), ranging from 9.5 ppm near the surface to 0.3 ppm near the bottom, on the same day. The gates were opened on July 1, 1988, and these same water quality parameters improved markedly over the next several weeks. By July 29, 1988, depth-averaged temperature dropped to 15.8 degrees C, ranging from 18 to 14.5 degrees C, top to bottom. Depth-averaged dissolved oxygen rose to 8.0 ppm, ranging from 10.6 to 7.4 ppm, top to bottom.

To illustrate the effect of culvert opening on the hydrology of the South Slough, Figure 8 shows tidal hydrographs encompassing one complete tidal cycle which occurred August 2, 1988. Discharge rates are plotted which represent water entering both ends of the slough on the flood tide and leaving the slough on the ebb tide (ebb flow rate is shown as discharge in the negative range). Because it is lower in elevation than the slough neck, flood tidal water begins entering the slough earlier and ebb tidal water continues leaving the slough later at the culvert. The peak flood and ebb tidal discharge rates were highest at the slough neck due to its far greater cross sectional area, although the greatest velocities were measured at the culvert. Particularly strong wave bore action in the slough neck precluded reliable measurements at this location between 15:30 and 17:30 hours. It is estimated that the peak ebb flow rate through the slough neck was about 3 cms as the tide fell (the dashed line in Figure 8 indicates the estimated portion of the slough neck tidal hydrograph).

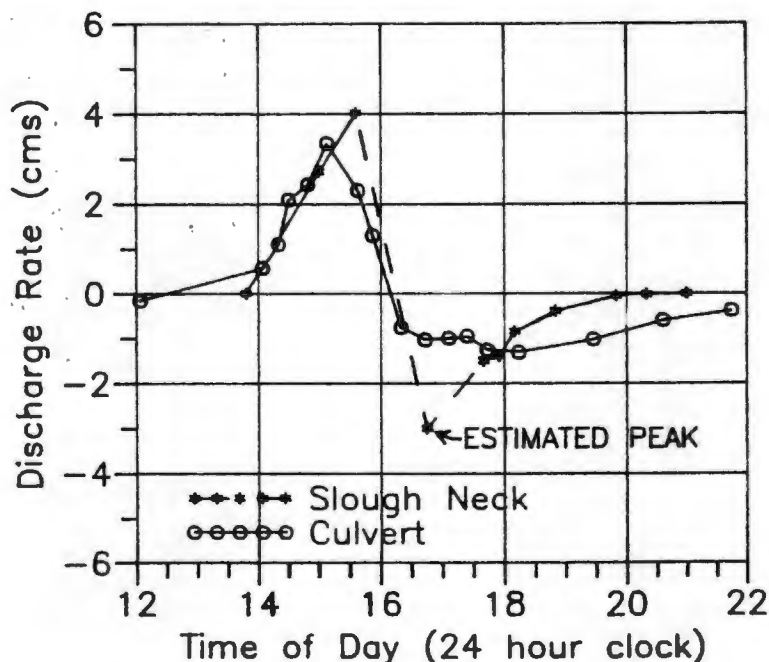


Figure 8--Hydrographs spanning one complete tidal cycle for the South Slough. With the culvert gates open, flood tidal flow (shown as positive discharge) and ebb tidal flow (negative discharge) can occur at the landward as well as the seaward end of the slough.

By calculating the area under the tidal hydrographs in figure 8, the volumes of water exchanged at both ends of the South Slough can be compared. Table 1 shows flood tidal and ebb tidal water volumes, as well as peak discharge rates, from the hydrographs. Although peak rates of both flood and ebb tidal flow were lower at the culvert, the greater ebb flow water volume passing through the culvert is accounted for by the longer duration of flow (see Fig. 8). Similar flood flow volumes for the slough neck

and the culvert indicate the effects of surf-derived wave bores, which apparently enhance flood tidal currents and retard ebb tidal currents at the slough neck (FitzGerald 1988). Because it is further upstream, wave bore effects were minimal at the culvert inlet.

Table 1--Peak discharge rates and water volumes for the South Slough from a complete tidal cycle on August 2, 1988.

	Peak discharge (cms)		Water volume (m ³)		
	Slough Neck	Culvert	Slough Neck	Culvert	Total
Flood flow	4.0	3.3	16,500	16,400	32,900
Ebb flow	3.0	2.7	13,200	19,700	32,900

¹Estimated

Sedimentation

Fulfilling the second objective of culvert operation (scouring aggraded sediments from the slough neck) is a far more complicated task than that of improving summer tidal circulation. Mobilizing and flushing sediments from the slough neck is dependent on generating shear stresses great enough to entrain and transport these materials against the force of wave bores and backwater effects present in the estuary during stormflow events. Predicted culvert discharge rates at various discharge rates and return periods for Redwood Creek are shown in Table 2 (from U.S. Army Corps of Engineers 1989):

Table 2--Predicted discharge rates of water diverted through the culverts.

Redwood Creek discharge rate (cms)		Culvert design discharge rate (cms)
	return period (years)	
550	1.5	36.5
662	2	46.4
986	5	55.8
1206	10	62.9
1489	25	67.1
1702	50	69.4
1916	100	71.4
2181	500	96.7

Backwater effects in the estuary result from the combination of both river stage and ocean height (a product of the combination of tides, storm surges, and swells). Although predicted culvert discharges increase with increasing discharge in Redwood Creek (as shown in the tabulation above), the scouring ability of higher culvert flows is largely offset by increased backwater effects due to rising river stage on Redwood Creek near the mouth. Optimal hydraulic conditions for scour exist just before and during low tide. Two interrelated conditions occur at low tide which increase the hydraulic effectiveness of stormflows routed through the culvert: 1) backwater effects in the estuary are lessened, and 2) the surf zone moves seaward and down in elevation.

The first of these conditions allows steepening of the energy slope in the slough neck, and the second causes a reduction or elimination of wave bore energy reaching the slough neck and opposing slough outflows.

During a stormflow event which occurred on November 22, 1988, the first culvert trial was conducted for attempting to scour sediment from the South Slough neck. Discharge in Redwood Creek was about 510 cms while the culvert gates were open, a relatively moderate event of about 1.5 years return period. The gates were left open for a falling tide period of six hours, during which a peak of 22 cms was diverted into the slough. Because of a build-up of storm debris on the inlet of the culvert (on the Redwood Creek side of the levee), the maximum possible rate was not attained for the existing hydraulic conditions.

A subsequent topographic survey of the slough neck showed no significant scour as a result of the first trial. Because of its wide, shallow hydraulic channel geometry, unit streampowers are about an order of magnitude smaller in the slough neck than at the culvert. In order to increase the hydraulic effectiveness of flows diverted through the neck of the South Slough, various alternatives are being considered which include structural measures to dissipate wave bore energy at the seaward end of the South Slough and construction of a morphologically stable channel (with respect to stream pattern and hydraulic channel geometry) through the slough neck which would be capable of being maintained by culvert design flows.

SUMMARY

The task of restoring estuarine environments requires an understanding of complex interactions between highly variable and sometimes violent processes. Monitoring of these processes in the estuary of Redwood Creek has led to insights used to develop and refine management and restoration strategies. Although implementation of restoration measures has improved physical conditions and resulting aquatic habitat, these activities can only hope to restore a fraction of the historic biological productivity to the Redwood Creek estuary. Ongoing field experiments using a gated culvert to route both tidal water and stormflows into the South Slough of Redwood Creek are aimed at refining operational techniques to be employed in active estuary management. Although each estuarine system is unique in structure and function, results of studies and experiments conducted in Redwood Creek may have direct application in other estuary restoration and management programs.

ACKNOWLEDGEMENTS

We wish to express our appreciation to the various agencies that cooperated to implement restoration alternatives in the Redwood Creek estuary: the County of Humboldt, California Department of Transportation, U.S. Army Corps of Engineers, and Redwood National Park. Also, we thank Cindy Ricks, U. S. Forest Service, and Terry Hofstra, Redwood National Park, for their geomorphic and aquatic investigations, respectively, which illuminated much about historical and modern-day processes at work in the estuary. Thanks also go to Ron Sonnevill of Redwood National Park for expert field assistance and manuscript review and to Professors Mack McKee and Charles Chamberlain of Humboldt State University and their students for field assistance with collecting the tidal hydrographic data. Last but not least, we thank Fred Booker for his skilled and undaunted help throughout the late hours and bad weather.

REFERENCES

- Baily, E.H., W.P. Erwin, and D.L. Jones. 1964. Franciscan and related rocks, and their significance in the geology of Western California. Calif. Div. Mines and Geology. Bull. 183. 177pp.
- Bascom, W. 1964. Waves and beaches. Doubleday and Co., Inc. Garden City, N.Y. 267 pp.
- FitzGerald, D.M. 1988. Shoreline erosional-depositional processes associated with tidal inlets. Pages 186-225 in: Hydrodynamics and Sediment Dynamics of Tidal Inlets. D.G. Aubrey and L. Weishar, eds. Springer-Verlag Inc. New York.
- Hofstra, T.D., and J.A. Sacklin. 1987. Restoring the Redwood Creek estuary. Pages 812-825 in: Coastal Zone '87. WW Div., ASCE. Seattle, WA.
- Horne, G.S., and P.C. Patton. 1989. Bedload-sediment transport through the Connecticut River estuary. Geological Society of America Bulletin. v. 101. June. pp. 805-819.
- Janda, R.J., K.M. Nolan, D.R. Harden, and S. M. Coleman. 1975. Watershed conditions in the drainage basin of Redwood Creek, Humboldt County, California, as of 1973. U.S. Geological Survey Open-File Report 75-568. 266 pp.
- Ricks, C.L. 1985. Flood history and sedimentation at the mouth of Redwood Creek, Humboldt County, California. Redwood National Park Tech. Rpt. No. 15. National Park Service, Redwood National Park. Arcata, CA. 155 pp.
- Sedell, J.R., and K.J. Luchessa. 1982. Using the historical record as an aid to salmonid habitat enhancement. Pages 210-223 in: Proceedings of a Symposium on Acquisition and Utilization of Aquatic Habitat Inventory Information. N.B. Armantrout, ed. Western Division, American Fisheries Society. Portland, OR.
- U.S. Army Corps of Engineers. 1989. Draft operation and maintenance manual, Redwood Creek culvert project, Redwood National Park, Humboldt County, California. Attachment 4 - Redwood Creek Drainage Structure Rating Curves.