WATER QUALITY AND PRODUCTIVITY OF THE REDWOOD CREEK ESTUARY

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ABSTRACT

Levee construction and sedimentation are judged to have decreased the productivity of the Redwood Creek estuary, Redwood National Park. Water quality is suitable for production of benthic organisms and juvenile salmonids but saltwater intrusions creating a true estuary occur only on an occasional basis. Production of benthic organisms is inhibited by substrate instability and limited development of a true estuary. Utilization of the estuary by juvenile chinook salmon *Oncorhynchus tshawytscha* and steelhead *Salmo gairdneri* is limited by the availability of estuarine habitat and cover when the mouth of the creek is open. Juvenile salmonids appear to migrate before the full productive potential of the estuary is realized. Food of the juvenile salmonids is primarily chironomid larvae and pupae, although amphipods *Corophium* spp. are the most abundant benthic organism when estuarine conditions occur.

INTRODUCTION

The estuarine habitat within the lower reach of Redwood Creek, Redwood National Park, California, has been degraded in recent years. Levee construction completed in 1968 altered the morphology and circulation patterns of the estuarine area (Figs. 1, 2). Additionally, 50% to 75% of the riparian habitat was lost (USFWS 1975). The south levee isolated the last meander of the creek creating the south slough. The west end of the south slough is contiguous with the main creek channel only during periods of high water. The altered flow pattern also isolated the north slough, a naturally abandoned creek channel by allowing sand deposition in an area where previously a free connection had existed (Ricks 1983). The present main channel now comprises the bulk of the estuarine area or embayment. True estuary conditions occur only periodically during summer and early fall. Pritchard (1967) defines an estuary as a semi-enclosed body of water which has a free connection with the open sea and within which sea water is measurably diluted with fresh water.

Aggradation in fish and invertebrate habitat within the lower reach of Redwood Creek has reduced salmonid productivity. The area between the levees is devoid of cover, providing migrating salmonids with little protection from predation. Historically Redwood Creek supported a substantial run of anadromous fish, but in recent years the run has declined as documented by the returns to Prairie Creek fish hatchery. Part of this decline can be attributed to the degradation of the estuarine area.

Reimers (1973) documented the importance of the estuary to fall chinook salmon, *Oncorhynchus tshawytscha*. Over 90% of the returning spawners in Sixes River, Oregon spent June, July, and August residing in the estuary as juveniles prior to outmigrating into the ocean, indicating enhanced survival of these fish. Healey (1980) emphasized the importance of the estuary as a rearing ground for juvenile chinook salmon in his studies on the Nanaimo River, British Columbia. Although not as well documented, it has been shown that juvenile steelhead trout, *Salmo gairdneri*, will spend rearing time in an estuary (Amend et al. 1980).

The purpose of this study was to provide baseline data concerning water quality and aquatic productivity including benthic productivity, fish utilization, and salmonid migration. Data were collected in 1980, 1981, and 1982.

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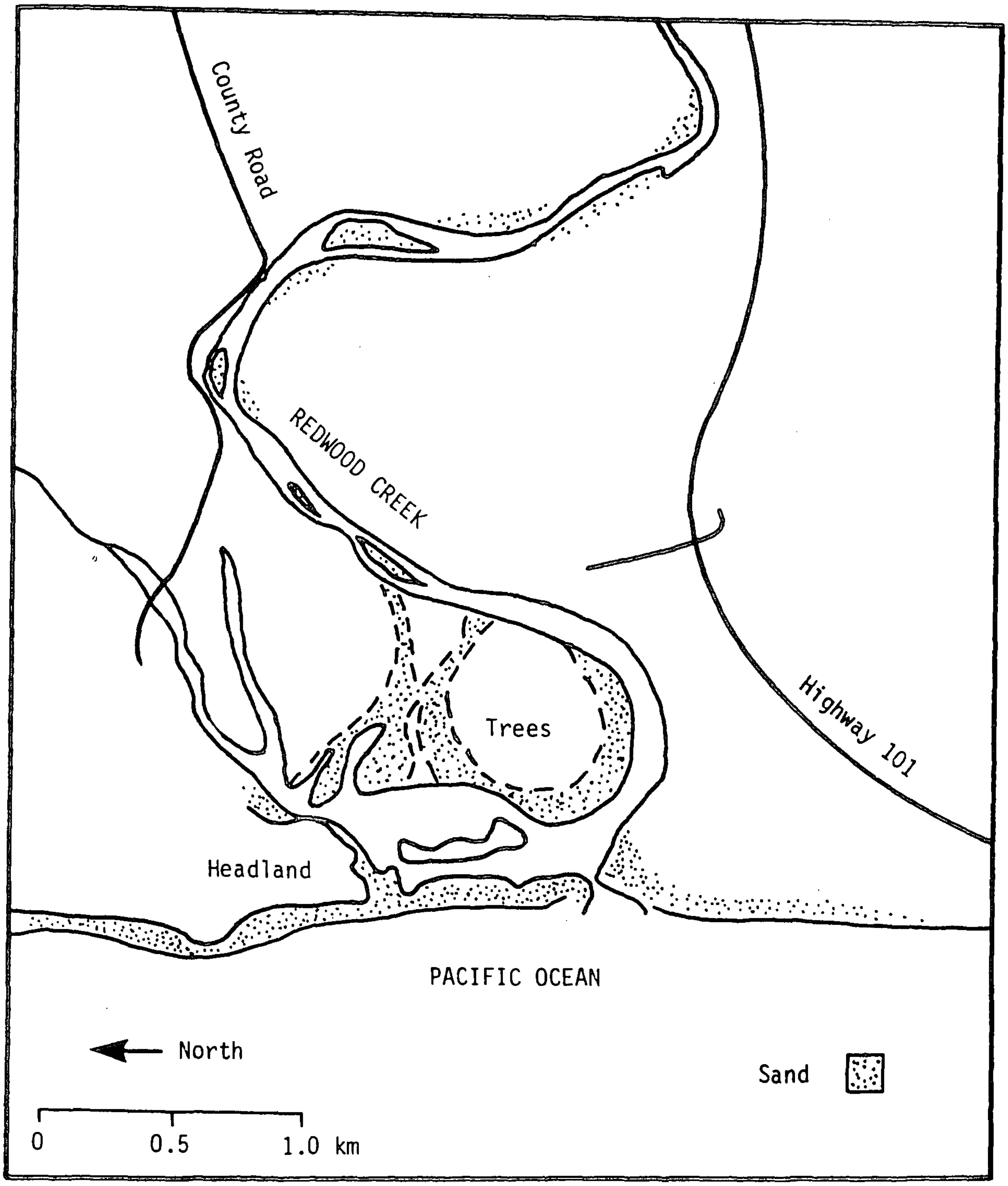

Figure 1

Configuration of Redwood Creek, Prior to Levee Construction, in 1962 (aerial photograph overlay 4/8/62)

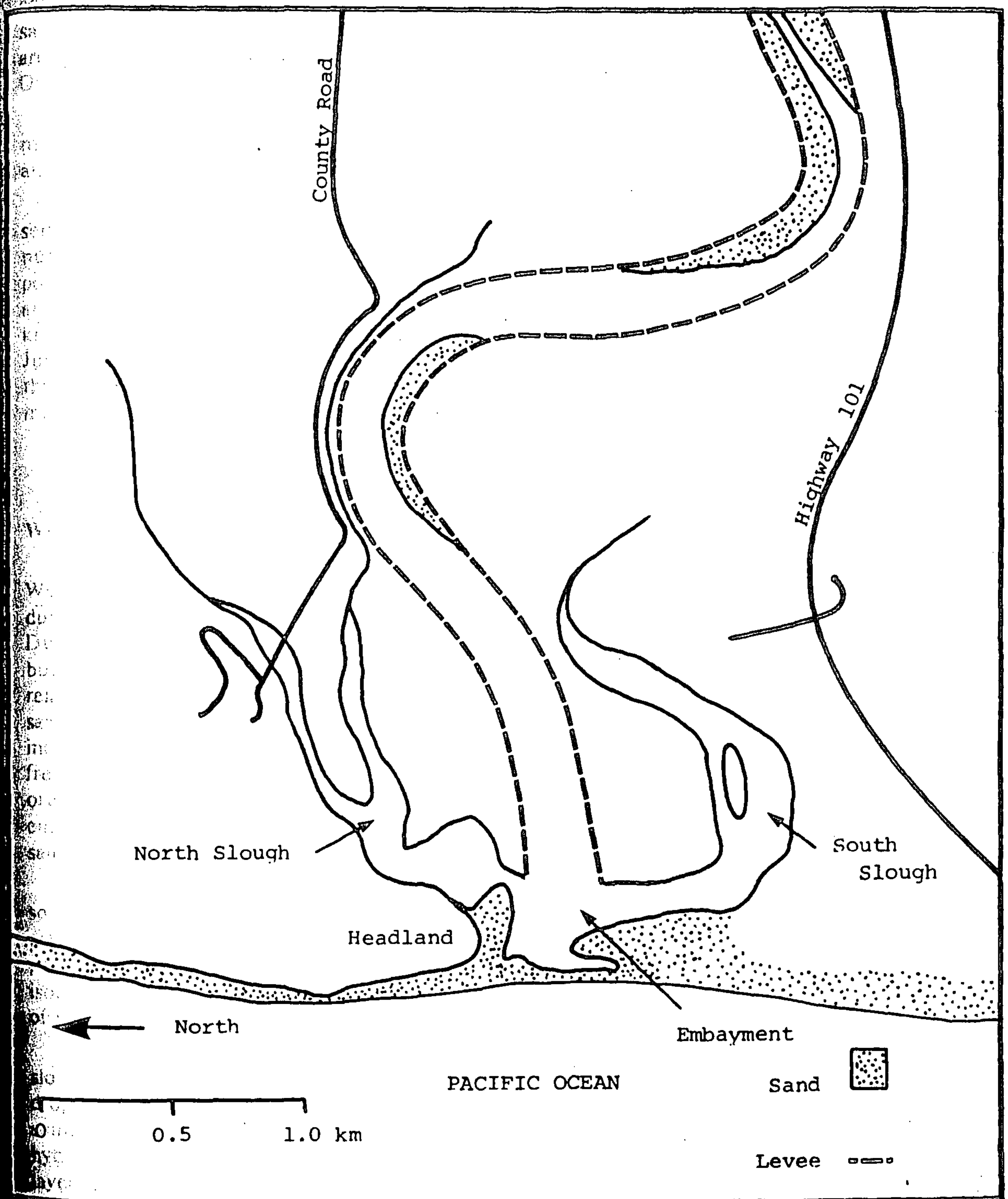

Figure 2

Redwood Creek, Post Levee Construction, 1978. Map of Study Area Showing Station Locations and Compartments (aerial photograph overlay 8/16/78)

METHODS

The study area encompassed the lower 4 km of Redwood Creek. Water quality data were collected during 1980. Salinity and temperature data were measured *in situ* with a salinometer. Water samples were collected for laboratory analysis of dissolved oxygen. Samples were taken from four areas: Redwood Creek near Orick, the embayment, south slough, and north slough. Samples from the Orick station provided a basis for comparison between river and ocean influences.

Invertebrate productivity was monitored once per month in 1980 using a kick net, dredges, and multiple plate samplers. Benthic and planktonic samples were collected from 15 sites for laboratory analysis of relative abundance and species composition of the invertebrate community.

Fish utilization was monitored every 2 wks during 1980 and 1982 with 50 m and 17 m beach seines. A selection of fish species caught were preserved for laboratory analysis of food habits. The number of fish caught per seine haul (CPUE) was recorded to provide information on changes in fish population density in 1980. Data on seasonal and diurnal salmonid migration were obtained in 1981 and 1982 using a downstream migrant trap. Two sampling sites within an area approximately 1.5 river km downstream from Orick were established. The trap was deployed once each week from 2 May to 24 July 1981 and from 3 May to 3 August 1982. During the period 30 June through 2 September 1982 the salmonid population in the embayment was estimated using the Peterson Index. Length measurements were taken on all captured fish.

RESULTS

Water Quality

During the first half of 1980, the embayment was almost totally influenced by freshwater input. Water quality parameters were similar to upstream values. Saltwater intruded into the embayment during extreme high tides, but all traces of seawater were quickly flushed out when the tide receded. During the same time period, the north and south sloughs were occasionally influenced by tidal action, but not by saltwater intrusion. The sloughs generally maintained their specific character indicating their relative isolation and lack of circulation. During the summer, seasonal oceanic processes may cause a sand berm to form across the creek mouth. As the berm builds, the water level in the embayment increases. An intact berm restricts saltwater intrusion to the point the embayment may be entirely fresh, although at times a thin salt water lens develops along the bottom. This saltwater is thought to originate from overwash and not direct tidal action. Ranchers have breached the berm to decrease the embayment water level. In July 1980, breaching allowed seawater to enter the embayment raising the salinity to 30 parts/thousand.

Salinity in the sloughs remained more stable than in the estuary. During winter and spring the south slough was entirely fresh, yet at other times saltwater would occasionally intrude through the estuary and into this area. Once saltwater entered the slough in summer, it remained for an extended period. A sand bar at the entrance to the slough dampened tidal influence. The north slough was more isolated and stable than the south slough. The upper water column was fresh while the bottom 0.5 m of water had a salinity of 14 parts/thousand.

Dissolved oxygen (DO) levels remained near saturation throughout the embayment and south slough. North slough DO levels were generally below saturation. Occasionally during summer, the DO dropped to 3 mg/l in the upper water column. The water column of the north, and periodically the south slough, was stratified. The saline layer in the north slough was anoxic and permeated with hydrogen sulfide. When circulation was reduced in the south slough during summer, a thin bottom layer of water would become anoxic because of poor mixing and decaying aquatic plants, primarily *Potamogeton pectinatus*.

Water temperatures within the study area were moderated by the coastal climate. The embayment had a maximum temperature of 20° C in late July. The north and south sloughs reached slightly higher maximum temperatures of 22° C and 25° C respectively. The minimum temperature for the entire study area was 9° C recorded in November.

ertebrate Productivity

Redwood Creek from the Highway 101 bridge to the mouth is characterized as crobenthically" poor. The sloughs supported a more stable invertebrate production throughout the which was limited to the margins and shallow portions. The south slough supported a higher ity of invertebrates than the main channel during spring and winter. However, these organisms e not found in or on the substrate of the deeper portions of the slough at least during late summer rly fall.

During the benthic sampling periods, there was an exception to the poor secondary production of ower creek. This was the appearance of extensive populations of the amphipod *Corophium.* These building detritivores attained an exceptionally large biomass per unit area. High winter and spring k flows kept the substrate in constant motion. It appeared that the filamentous algae, *Cladophora,* ed as a substrate and a food source.

In late June of 1980 an enclosed embayment became contiguous with the north and south ghs. This coincided with the reproductive cycle of *Corophium. Corophium salmonis,* which prefer ner silty-mud substrate, and *C. spinicorne,* which tolerates a coarser sand substrate (McCarthy 2), established mixed populations within the new habitat. Unfortunately the embayment was ned on 2 July before any extensive sampling could be performed. Within a month of the ching, the embayment was reestablished and the macrobenthos was monitored. *C. spinicorne* inated the populations upstream from the end of the levees, achieving a maximum biomass of 5 g dry wt/m^2. Mixed *Corophium* populations during the period of embayment persistence reached mass levels ranging from 1.4 to 13.4 g dry wt/m^2, 1.4 to 12.7 g dry wt/m^2, and 0.8 to 4.8 g dry m^2 on 22 August, 22 September, and 1 November, respectively. The decreasing biomass oughout this period was more a result of the abundance of smaller immature amphipods rather than ecrease in population size.

h Productivity

In 1980 and 1981 the peak seasonal downstream migration of juvenile chinook and steelhead was ate May, and continued through June. The peak seasonal downstream migration in 1982 was yed, beginning in the latter part of June, and continuing through mid-July (Fig. 3). In each of the rs, some steelhead continued to migrate into the estuary throughout the summer, while chinook sed migrating from freshwater nursery areas soon after the peak. The mean length and size range of nstream migrant chinook are presented in Table 1. In 1980 the CPUE on 22 July for steelhead eased considerably (Fig. 3A). Mark and recapture data indicated that these fish were not migrating the embayment but rather, were holding in the creek above the embayment.

Table 1

Mean Length (mm) and Size Range (mm) of Downstream Migrant Chinook Salmon in Redwood Creek for 1980, 1981, and 1982

Year	Mean Length (mm)	Range (mm)
1980	73.5 (FL)*	53 - 97 (FL)
1981	64 (TL)*	41-86 (TL)
1982	66 (TL)	51 - 105 (TL)

*FL = Fork Length; TL = Total Length

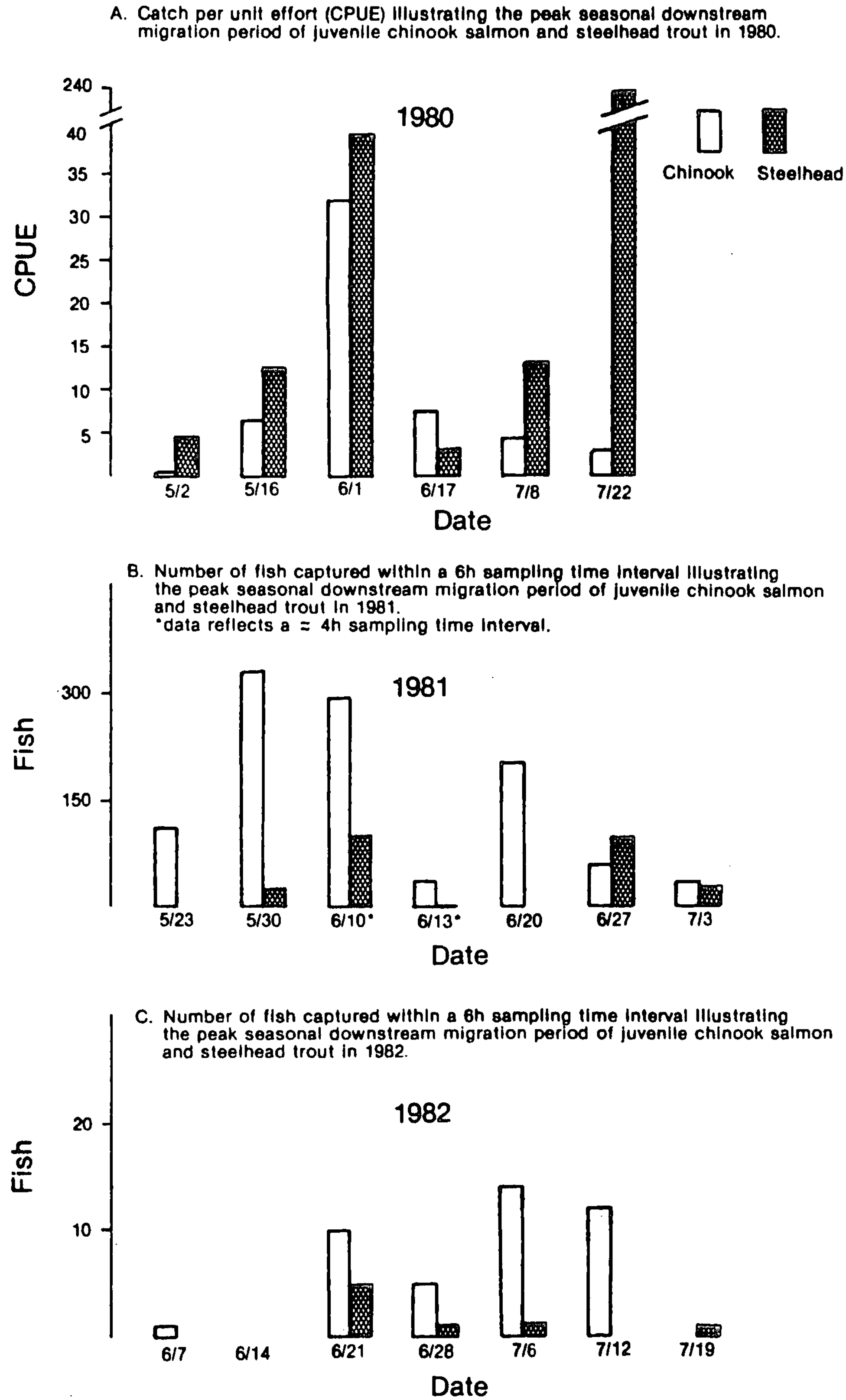

Figure 3

Peak Seasonal Downstream Migration of Juvenile Salmonids for 1980, 1981 and 1982 in Redwood Creek

The downstream migration of salmonids was restricted to evening hours. During the peak seasonal downstream migration in 1981, 75% of the salmonids were captured during the first half of the sampling period (1900 - 0100). Though a similar trend in 1982 was apparent at the onset of the seasonal downstream migration, it did not persist. The percentage of migrants captured during the first 6 hrs of the sampling period was comparable with those captured during the latter part of the sampling period (0100 - 0700).

The population in the estuary was estimated after the peak migration in 1980 to be 20,000 juvenile salmonids. The CPUE on 24 June was 200 fish per seine haul. Sampling on 7 July, 5 dys after the berm had been breached, yielded a CPUE of near zero.

The population of chinook declined slowly throughout the summer of 1982 (Table 2). The steelhead population in the embayment remained fairly stable. Chinook salmon showed a significant increase in size in the embayment throughout the summer of 1982 (Fig. 4). Steelhead also experienced a significant but less drastic growth. Fish marked early in the sampling period were still being recovered by 2 September 1982.

Table 2

Population Estimates for Chinook Salmon and Steelhead Trout in the Redwood Creek Estuary in 1982

Date (1982)	Species	
	Chinook	Steelhead
1 July	17,342	17,685
21 July	17,112	18,229
3 August	8,118	17,937
20 August	12,699	25,900
2 September	11,992	19,950

Preliminary food habit analyses were carried out on fish seined from February through November of 1980. Salmonid food habit analyses indicated freshwater aquatic insects, primarily chironomid larvae and pupae, were the most important food items in the main channel prior to July. During this same period Diptera were also the preferred forage for other resident fish species, the threespine stickleback *Gasterosteus aculeatus*, prickly sculpin *Cottus asper*, and Humboldt sucker *Catastomus occidentalis humboldtianus*. The estuarine fishes, starry flounder *Platichthys stellatus*, and staghorn sculpin *Leptocottus armatus*, fed almost exclusively on crustacean prey such as amphipods, isopods, and mysids. After July, when stable conditions prevailed, the brackish water amphipods *C. spinicorne* and *C. salmonis* became the primary diet of the fish species residing in the lower creek, except for the sticklebacks, which continued to feed intensively on chironomid larvae.

Analysis of fish captured in the south slough indicated that the non-salmonids relied on amphipods, isopods, and mysids for the greatest share of their forage. Salmonids showed a more diverse food habit, consuming a combination of adult and larval insects in addition to brackish water crustaceans.

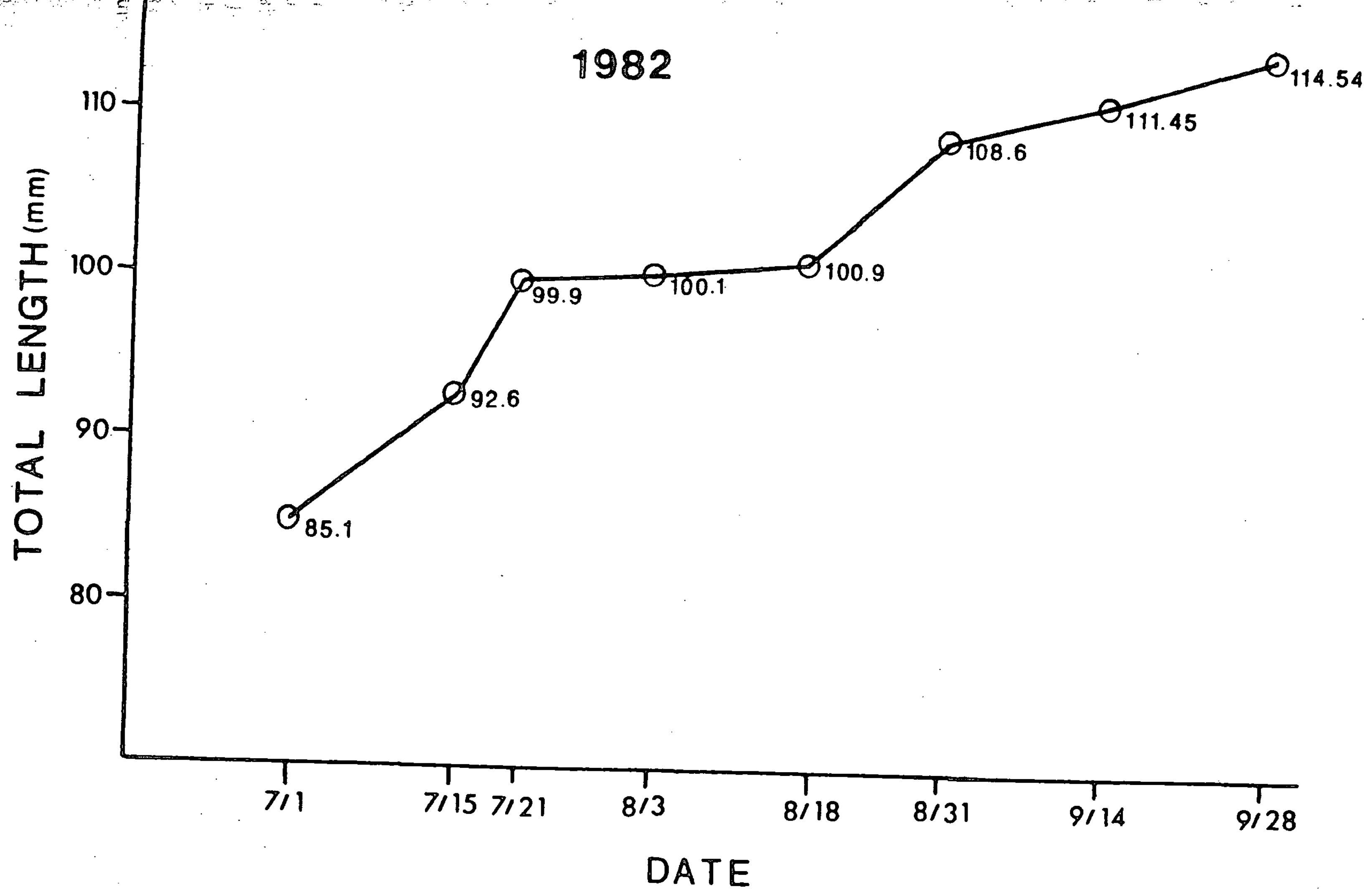

Figure 4

Growth of Juvenile Chinook in the Redwood Creek Estuary, 1982

Cannibalism was documented for the prickly sculpin and stickleback. In spring and summer the stickleback larvae were the most popular forage fish of finned predators. Observation of salmonids as forage species was noted in March, when a large cutthroat trout, *Salmo clarki*, was seined, with the caudal fin of a salmonid still protruding from its mouth. Another case of salmonid predation was of a 2 yr old steelhead that had consumed three juvenile chinook migrants.

DISCUSSION

Water Quality

Creek flow and estuarine water level appeared to be the most important factors affecting the productivity of the Redwood Creek estuary. Other water quality parameters, especially dissolved oxygen and temperature remained within acceptable limits throughout the year. Flow directly restricted saltwater intrusion and prevented productive estuarine conditions from being established. Berm building, also affected by flow, created the embayment.

Water quality conditions in both sloughs were affected by low flow and poor circulation. Anoxic conditions along the slough bottoms, especially the north slough, limited the available area for invertebrate colonization, thus decreasing invertebrate productivity. Reduction of these anoxic layers would reduce the effect occasional ocean waves had on the DO levels. Periodic mixing within the sloughs caused DO levels to drop precipitously and dispersed hydrogen sulfide throughout the water column stressing resident organisms. Reestablishing continuous flow and circulation patterns to include the sloughs would eliminate anoxic conditions.

Fish Productivity

Redirecting the river course reduced riparian and submerged habitat. In the area of the north and south sloughs a diverse habitat exists with overhanging trees, submerged logs, and deep water areas; however, since the levees were constructed, the sloughs have generally been isolated from the main creek and are unavailable to migrating salmonids except during high flows.

Conditions in the creek are different from those in the north and south sloughs. The creek margins and banks are devoid of any vegetative cover except for a filamentous algae bloom in the spring. This provided a suitable habitat for invertebrates but was too dense to provide cover for migrating salmonids. Juvenile salmonids were provided with cover only when the water depth increased. During low water the volume of habitat is decreased, subjecting migrant fish to predation.

In 1980 during the peak juvenile salmonid migration, the south slough was accessible from the main creek only in late June and migrating juveniles utilized the expanded habitat. Breaching of the berm on 2 July 1980 stranded these fish in the south slough.

Peak migration into the estuary in 1980 coincided with the formation of a deep water embayment. The juvenile salmonid population began to increase, indicating an extended utilization of the area since these fish were free to migrate into the ocean. The 1980 breaching released 75% of the water in the embayment (Larson et al. 1981) and caused the juvenile salmonids to involuntarily enter the sea. The juvenile salmonids did appear to be smolting before being flushed into the ocean as indicated by their silver appearance, but to what degree the smoltification process was completed is not known.

Breaching of the berm in 1980 occurred before the full food production potential was realized. It was not until after the embayment reestablished from the July berm breaching that the highly productive *Corophium* population became established. Steelhead entering the embayment after its reestablishment predominately fed upon the expanded food base provided by *Corophium*.

In mid April 1981 the berm was artificially breached. No embayment developed and the south slough remained inaccessible throughout the downstream migration period. Downstream migrant salmonids were involuntarily forced into the sea. Saunders and Henderson (1973), Adams et al. (1973), and Wagner (1974) have documented reduced survival and growth to salmonids after being involuntarily inducted into seawater before smolting. Had the berm not been breached in 1980 or

1981, the juvenile chinook and steelhead would have been afforded a period of improved growth before entering the ocean and therefore, an increased chance of survival.

The population estimates for 1982 reveal substantial chinook and steelhead populations. The berm had been artificially breached by the National Park Service a total of 16 times throughout the summer. These breachings were of a controlled nature with the water being released slowly. These data indicate that when habitat is available juvenile salmonids will spend an extended rearing time in the estuary. In addition, this extended rearing period apparently allows for increased growth.

CONCLUSIONS

Levee construction has decreased the biological productivity of the mouth of Redwood Creek. The extent and duration of estuarine conditions have been reduced because of altered flow characteristics. Uncontrolled artificial breaching of the berm has had a negative impact on utilization of the estuary by migrating salmonids.

Development of rehabilitation alternatives that can restore the estuary to a stable, productive system are warranted.

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