UTILIZATION OF THE REDWOOD CREEK ESTUARY,
HUMBOLDT COUNTY, CALIFORNIA
BY JUVENILE SALMONIDS

by

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ABSTRACT

The timing, duration and extent of utilization of the Redwood Creek estuary by juvenile chinook salmon (*Oncorhynchus tshawytscha*) and steelhead trout(*Salmo gairdneri*) were examined in 1980. All of the chinook were young-of-the-year, whereas the 79% of the steelhead were yearlings. The primary food items consumed by chinook and steelhead were Diptera larvae and pupae. Peak immigration into the estuary occurred in late May and early June for chinook salmon and steelhead trout. Both salmonid species appeared to reside in the estuary and did not immediately enter the ocean. Ocean entry of both salmonid species in early July was linked to the breaching of the sand berm that partially dammed the creek mouth. The breaching of the sand berm forced the juvenile salmonids to involuntarily enter the ocean and may have reduced survival.

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INTRODUCTION

A research program was conducted in 1980 to study downstream migrant salmonids in the Redwood Creek estuary, Humboldt County, California (Figure 1). The specific objectives of this study were to:

1. establish the time of the year when seaward migrating juvenile chinook salmon (*Oncorhynchus tshawytscha* Walbaum), coho salmon (*O. kisutch* Walbaum), steelhead trout (*Salmo gairdneri* Richardson) and cutthroat trout (*S. clarki* Richardson) enter the estuary;
2. estimate salmonid population sizes and durations of estuarine residency;
3. determine the sizes and ages of migrating salmonids utilizing the estuary;
4. describe and compare the growth of juvenile salmonids in the estuary and in the creek;
5. compare the food habits of juvenile salmonids in the estuary and in the creek, and;
6. establish baseline data for future evaluation of watershed rehabilitation efforts.

Redwood Creek was chosen as the study site because the circulation had been modified by flood control levee construction and sediment had aggraded much of the historical estuary. The levees may have affected the juvenile salmonid utilization of the estuary. Gathering baseline data was the first step in assessing levee construction impacts on juvenile salmonid utilization of the Redwood Creek estuary since no existing information was available. Redwood

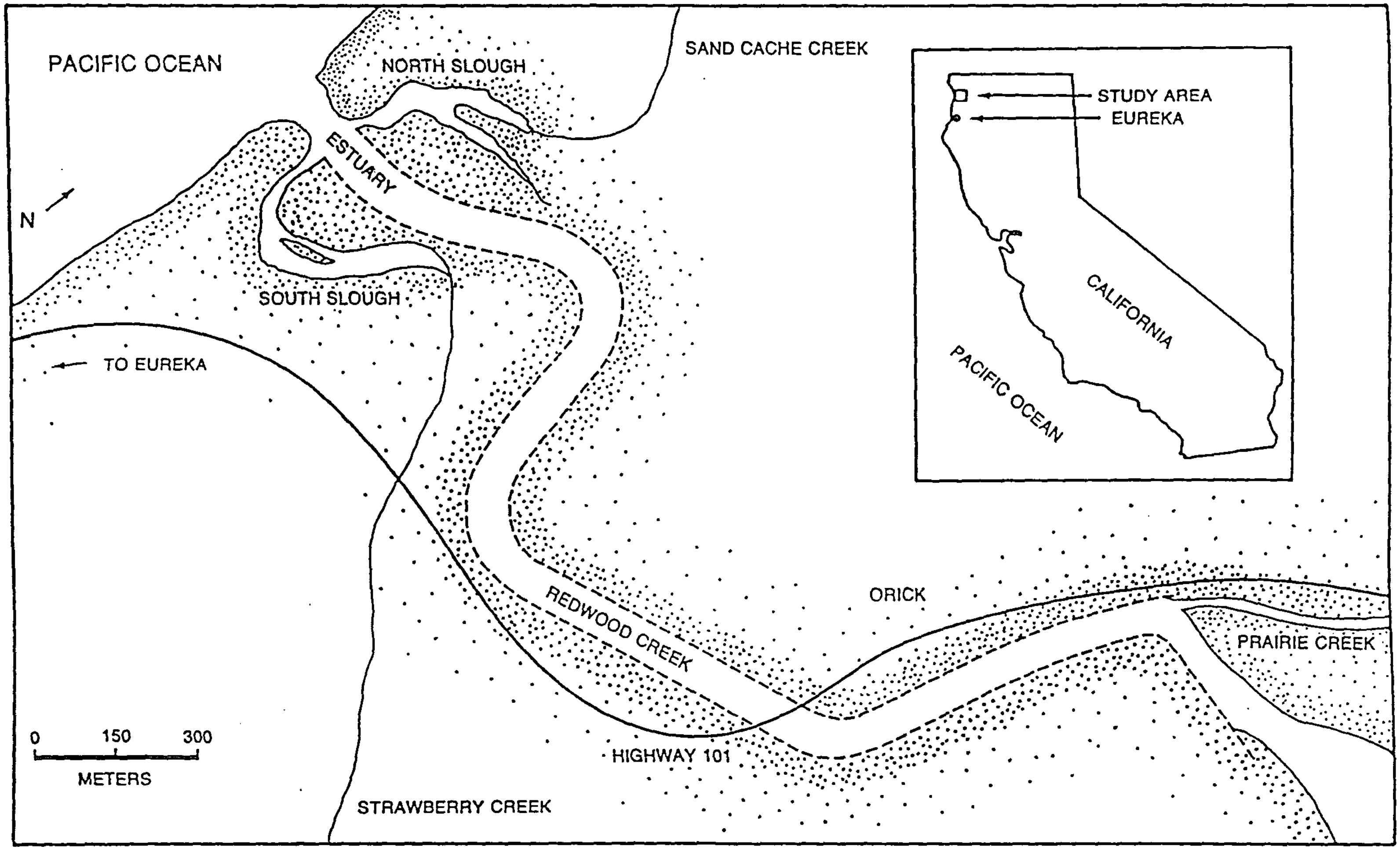

Figure 1. The Redwood Creek, California, study area configuration after levee construction with location map. The dashed lines represent the levees.

Creek was once known for its abundant run of large chinook salmon; however, the run has drastically declined from historical levels (Winzler and Kelly 1970). Even though no quantitative estimates of fish numbers exist, historical anecdotal accounts indicate that run sizes for all anadromous species have declined from historical levels (USFWS 1975).

Interviews by Feranna (1981) with local residents indicated that fishing for adult salmon in the estuary prior to the levee construction was good because salmon congregated there before migrating upstream. Fishing was extensive enough to support a small boat rental operation located in the north slough. The north slough and a deep hole adjacent to the headland were some of the more productive fishing areas. In the early 1900's, commercial fishing for salmon occurred in the estuary (USFWS 1960). Also, two Indian fishing villages were located near the creek mouth.

Present sport fishing intensity in the estuary for salmon adults is minimal because of poor fishing conditions and reduced success rates. Many explanations for the decline of adult salmon runs have been proposed. Various factors have likely contributed to the decline. Land use within the Redwood Creek watershed is generally thought to be the major cause for the decline (Winzler and Kelly 1970; Denton 1974). The geology of the watershed has been described as being very unstable and once protective ground cover has been removed or disturbed, already high erosion rates can be expected to increase (Janda et al. 1975). Eroded material moved into stream channels, filled pools and clogged interstices between rocks, and subsequently degraded the aquatic habitat (Janda 1978).

Redwood National Park was created in 1968 and expanded in 1978 to protect old-growth redwood trees (Sequoia sempervirens). The National Park Service has a further directive to rehabilitate the Redwood Creek watershed so as to protect the resources within its boundaries (Public Law 95-250). These efforts have consisted largely of stopping erosion caused by road building and logging activities that occurred within the park's boundaries prior to its establishment. An objective of rehabilitation has been to return the aquatic habitat to a natural condition and allow anadromous fish runs to increase. But, in the case of chinook salmon, Reimers (1978) stated the up-river habitat might not be the only limiting factor. His work on Sixes River, Oregon, showed that the estuary could limit the rearing capacity of the entire watershed. Rehabilitation of the upper watershed alone might do little to enhance salmon runs in Redwood Creek if the estuary was limiting.

Floods in 1953, 1955, and 1964 convinced the U.S. Congress of the need for the U.S. Army Corp of Engineers to build levees to protect the town of Orick, California (Hofstra 1983). Levees were constructed in 1968 beginning near the mouth of Prairie Creek (Figure 1) and ending 5.3 km downstream within 0.2 km of the ocean (U.S. Army Corps of Engineers 1966). Levee construction altered the creek course and changed the creek morphology, especially the estuarine portion. Levee construction was responsible for degrading and eliminating 50 to 75 percent of the estuarine habitat (USFWS 1975).

West coast estuaries have been recognized as providing a transition zone between fresh and salt water environments which allow the gradual physiological adaption of juvenile salmonids to the ocean environment (Hoar 1976). Cameron and Pritchard (1963) defined an estuary as "a semi-enclosed coastal body of water which has a free connection with the open sea and within which sea water is measurably diluted with fresh water derived from land drainage." Less recognized is the use of the estuary as a rearing area for some juveniles prior to emmigration (Healey 1980). Extended estuarine rearing may be required if some juveniles are to survive to become adults (Reimer's 1973). Snyder (1931) recognized that juvenile chinook spent an extended residence in the Klamath River estuary in Northern California and grew at a rate resembling ocean growth (as indicated by scale circuli spacing). Other researchers, including Taniguchi (1970), Healey (1980), and Levy and Northcote (1982), have documented that juvenile chinook may spend an extended period in the estuary prior to outmigration. In addition, Reimer's (1973) research documented the importance of estuarine growth for ocean survival. His research showed that 90 percent of the returning adult chinook salmon had spent June, July and August residing in the Sixes River estuary prior to outmigrating in September. Juveniles that spent less than 3 months in the estuary, the most abundant type of migration by juvenile chinook, contributed only 2.5 percent to the number of returning adult spawners.

Juvenile steelhead spend varying lengths of time in estuaries. Needham (1940) and Shapovalov and Taft (1954) indicated some juvenile steelhead in Waddell Creek, CA migrate downstream only as far as the estuary and reside there until returning upstream. Amend et al. (1980) reported that steelhead may reside in the estuary for an extended period before outmigrating. Their determination was based on a comparison of bacterial infection rates by vibriosis (Vibrio anguillarum) on coho salmon (Oncorhynchus kisutch) and steelhead. Water temperatures in estuaries provide optimum incubating conditions for vibriosis. Coho, which passed through the estuary quickly, were less severely affected by the bacterium than steelhead which spent an extended period in the estuary. Shapovalov and Taft (1954) concluded that steelhead experience rapid growth in the estuary before outmigrating, implying an extended residence time. Durkin et al. (1981) found that juvenile steelhead passed through the Columbia River estuary relatively quickly. Reimers (personal communication) felt that juvenile steelhead did not exhibit extended estuarine residence in Sixes River estuary.

Other species of salmonids, also found in the Redwood Creek drainage, utilized the estuary for varying lengths of time. Coho salmon juveniles will spend a few days to a few weeks in the estuary preparing for ocean life (Shapovalov and Taft 1954; Reimers 1978). Coastal cutthroat (Salmo clarki) utilization of estuaries has been documented as variable (Giger 1972; Hart 1973). Few wild coho and cutthroat were caught during the 1980 sampling in Redwood Creek (Appendix N) and no further analysis or discussion the role of the Redwood Creek estuary in the cutthroat and coho's life history is possible.

DESCRIPTION OF THE STUDY AREA

Watershed

The Redwood Creek watershed is relatively small (717 km^2), and is characterized as long and narrow, measuring 88 km long and 16 km at the widest point, excluding the Prairie Creek drainage. Maximum elevation in the watershed is 1600 m. The watershed receives an average of 200 cm of rain per year with most of the rain falling between December and March (Bradford and Iwatsubo 1978). Much of the rain falls during storm events which cause the flow to dramatically increase. Because of the low elevation, snow pack contributes only a minor amount of water to the creek flow. The maximum flow measured at Orick in 1980 was 549 m^3/s as compared to minimum summer flow of 0.34 m^3/s (USGS 1980). During the December 1964 flood, the peak flow at Orick was 1,559 m^3/s (USGS 1970).

Historical

Prior to construction of the levees in lower Redwood Creek, the creek course meandered through the coastal valley before entering the ocean. A 1948 photograph (Figure 2) showed that the creek above the main estuary was lined with vegetation, probably willows (*Salix* sp.) and alder (*Alnus* sp.). After the last meander but before the creek entered the ocean, the creek flowed north, parallel to the coastline. The flow was directed against the rocky headland before turning and flowing into the ocean. According to local residents, a deep pool was formed and maintained by the scouring action caused by the water

Figure 2. Aerial photograph of the Redwood Creek, California, estuary on September 7, 1948 showing the estuarine configuration before levee construction.

flowing against the rocky headland (Ricks 1985). The scouring also maintained the connection between the creek and the north slough. This connection was important in maintaining the circulation within the north slough which is a naturally abandoned creek channel.

Although there were no data to support the existence of an extensive estuary in Redwood Creek prior to levee construction, aerial and ground photographs and accounts by local residents suggested that estuarine conditions had existed. The estuarine character of the historical estuarine area of Redwood Creek was probably persistent because of the flow pattern and the deep pool near the headland. The flow gradient around the last meander would have been low and should have allowed salt water intrusion.

Present Day

The construction of the flood control levees radically changed the morphology and circulation patterns of lower Redwood Creek (Figure 1). Levees followed the original creek course downstream for 4.3 km beginning near the mouth of Prairie Creek. The final 1.0 km of levees then cut off the last meander of the original creek course, and aimed the creek flow directly out to sea. The east end of the last meander has been blocked from the creek by the levee while the west end has remained connected, creating what is now known as the south slough. With levee construction, lower Redwood Creek has been divided into four distinct areas which differ physically and chemically: Redwood Creek above the estuary, the estuary, the south slough and the north slough. These areas comprised the general sampling areas. Chemical parameters presented in the following sections were previously described by Gregory (1982).

Redwood Creek Above the Estuary

Redwood Creek within the study area but above the estuarine area flowed solely between the levees and little riparian vegetation existed. Willows grew on the sandbars and alders on the levees, but both were periodically removed to maintain the flood carrying capacity between the levees. Few pool areas existed but some deep areas, 1.0 m to 1.5 m deep, were found where the creek meandered against the levee or where willows have temporarily stabilized the bank habitat. During summer flows, all areas were very shallow and little cover existed for juvenile salmonids. The water temperature rarely exceeded 20 °C at the Highway 101 bridge although temperatures further upstream reached 25 °C. The lower water temperatures at Orick could be attributed to the cooling effect of the local coastal weather. Oxygen levels remained near saturation throughout the year (Gregory 1982).

Estuary

Unlike the upstream portion of the study area, which changed very little except for water volume, the estuary experienced marked seasonal changes. These seasonal variations created problems in defining the nature of the creek mouth. Calling lower Redwood Creek an estuary was strictly accurate for only a short span of time because the duration of saltwater intrusion was limited. The term estuary used throughout this thesis is meant more to describe the physical area of the creek being discussed rather than to suggest a chemical description of saltwater intrusion. The term embayment described the area when a sand berm partially or wholly dammed the creek mouth.

During the winter months, creek flow was high and the ocean had a relatively small effect on the creek discharge. The water flowed directly into the ocean although the mouth may have been moved either north or south by ocean processes (Bradford and Iwatsubo 1978). Salt water would enter the embayment at high tide, but all traces of salt water were flushed from the creek mouth as the tide receded (Gregory 1982). During extreme high tides, river water backed up and could enter either the north or south sloughs.

By June, reduced creek discharges and ocean wave intensity allowed an onshore movement of sand and the formation of a berm at the mouth of the creek. The berm prevented most sea water from entering the creek. After the berm formed, either of two events occurred depending on the ocean wave regime. In the absence of strong northwesterly winds, the berm remained intact and did not build higher. Water flowed directly into the ocean and salt water could intrude creating temporary estuarine conditions. However, more commonly a strong and persistent northwest wind pattern caused a sand berm to develop. The berm would partially or eventually completely dam the creek mouth and create a freshwater embayment. The embayment could fill with water to a level that caused surrounding pasture land to become flooded. If the berm development were allowed to progress, the water behind the berm might rise to the point where it would either spill over the berm and naturally create a new mouth or reach an equilibrium where inflow equaled evaporation and percolation.

Historically, the embayment was not allowed to evolve naturally. Ranchers who suffered from flooded pasture land would breach the berm to reduce the embayment water level (Ricks 1985). After breaching, a new mouth was created and the water level was reduced in deeper areas from a depth of 3 m to less than 1 m. Shallow areas became exposed gravel bars. After the berm breaching, berm development could begin again, if proper climatic conditions existed, and repeat the previous scenario. In 1980, the berm developed and was breached three times.

Major changes in salinity occurred when the berm was breached although flow played a significant role in determining whether the chemical changes persisted (Gregory 1982). During February, 1980, when discharge was 23 m^3/s, a salt wedge with a salinity of 18.8 $^o/oo$ moved upstream approximately 300 m from the mouth at high tide. At low tide all traces of salinity were flushed from the estuary. Under similar conditions in November 1980, except flow was only 4.0 m^3/s, a 28 $^o/oo$ salt wedge moved 1.0 km upstream and salt water remained in the estuary even at low tide. The effects of the berm on water chemistry were evident during the summer. In June when the embayment was fully formed, any salt water which entered the embayment was quickly flushed back to the sea. The dissolved oxygen level was 10.6 mg/liter and temperature was 19 ^oC at all depths. After the berm was breached in July, salt water freely entered the estuary and a bi-layered system was created. Salinity was 1.0 $^o/oo$ at the surface, 24.0 $^o/oo$ at 0.3 m and 30.5 $^o/oo$ at 1.3 m (the bottom). As the embayment reformed, the salt layer was gradually reduced and the surface freshwater lens increased in depth. During August, the most severe oxygen and temperature levels were recorded. Temperatures reached 19 ^oC and dissolved oxygen was measured as low as 6.7 mg/liter. By September, the embayment was almost entirely fresh, except for small isolated pockets of sea water on the bottom, consisting of salinities up to 21 $^{0}/oo$. When the fall rains began, all signs of estuarine conditions were eliminated. High creek flows prevented the berm from re-developing. Also, the ocean processes which built the berm ceased since prevailing winds shifted from northwest to southwest during storm conditions.

South Slough

The physical character of the south slough was basically unaltered from pre-levee Redwood Creek except that circulation was severely reduced. The west of end the slough remained connected with the creek, although the connection was reduced because sand and sediment were deposited at the confluence of the creek and slough (Ricks 1985). Bottom characteristics were changed because flow velocities were reduced. Fine sediments accumulated on the bottom where river flow previously scoured the bottom. Maximum depth varied between 2 and 3 m, depending on tides and creek discharge.

The south slough was a freshwater system most of the year. A small creek flowed year round into the slough at the eastern end. In addition, freshwater backed into the south slough from Redwood Creek during extreme high tides or during flood conditions caused by either high creek discharge or berm formation. These freshwater sources prevented the slough from becoming anoxic and prevented saltwater from accumulating. Sea water could enter the slough, creating estuarine conditions, during the late summer or early fall when the berm was broken and a high tide pushed salt water into the slough. Sea water would kill the abundant aquatic plants, primarily Potamogeton pectinatus, which decayed and caused periods of low dissolved oxygen. Contributing to the low oxygen conditions was the runoff from the flooded pasture land which had an accumulation of cow excrement. The problem was most acute during summer flooding in 1980 after the berm formed and circulation was minimal. The dissolved oxygen level in the south slough decreased to near 3 mg/liter on September 30. At other times of the year, the oxygen level remained near saturation.

Water temperature within the slough was moderated by the local coastal weather. Fog and low clouds predominated and prevented the sun from heating the water much above 20 ^{o}C. Occasionally the temperature would reach 24 ^{o}C on the rare, sunny, summer day.

North Slough

The north slough is a naturally abandoned creek channel with an average depth of about 2.5 m. Since levee construction, the slough has become more isolated from the main creek because of aggradation of sediments and reduction of scouring at the confluence of the slough with the creek (Ricks 1985). Water could enter the north slough from the creek during extreme high tides, after the embayment formed, during winter storms, or during floods. The slough had a limited year round source of fresh water from Sand Cache Creek but it was not sufficient to maintain good circulation. Additional runoff entered the slough from surrounding hills and pasture, but was mainly restricted to the winter months. Large quantities of floating woody debris reduced wind mixing. Poor circulation coupled with an abundance of organic matter, consisting mainly of sunken logs and other woody debris, produced an anoxic layer of water on the bottom. The anoxic layer's stability was further enhanced by the presence of a saline lens below a depth of

1.5 m. The salinity of the anoxic layer remained around 20 $^{o}/oo$. These conditions restricted the growth of aquatic plants to the shoreline and shallower portions of the slough. The depth and topography of the slough bottom also contributed to the lack of aquatic vegetation. Since the sides of the slough were steep, little suitable substrate above the saline, anoxic layer was available for plant growth.

Even though the lack of aquatic vegetation reduced reoxygenation of the water and floating woody debris prevented wind mixing, the oxygen content of the upper water column generally remained near 7.0 mg/liter year round. Occasionally, ocean waves entered the slough during winter storms and caused the slough's bottom water to mix with the upper water column reducing the oxygen content at all levels to 3.0 mg/liter. An oxygen level of 7.0 mg/liter would be desirable for the health of salmonids (Ellis et al. 1946; Denton 1974). Even when the oxygen level dropped to near 3.0 mg/liter, no fish kill was observed. Extensive cover was provided by floating woody debris although the debris' contribution to reduced wind mixing and debris accumulation on the bottom lessened its desirability. Terrestrial vegetation, which consisted mostly of grasses and willows, overhung the water and provided additional cover.

Productivity

Productivity studies based on nutrient availability and invertebrate abundance, showed that the north and south sloughs were the most productive areas on a year round basis (Larson et al. 1981). Seasonally, the creek and the embayment became productive. Generally, peak invertebrate abundance in both areas occurred in the summer and was dependent on the establishment of stable substrate conditions. Dissolved nutrients (measured as phosphate, PO_4^-, and nitrate, NO_3^-) were not abundant in the creek until after the first fall rains (Gregory 1982). The occassional entrance of ocean water into the embayment boosted dissolved nutrient concentrations and primary productivity.

MATERIALS AND METHODS

Sampling Schedule

Seining was conducted twice monthly from April through September (the main migration period for juvenile salmonids) and once a month in February, March, October and November in 1980. During January and December of 1980, the water was too high to safely sample and no seining was conducted.

Sampling Stations

Initially the study area was divided into benthic invertebrate and water quality sampling stations (Figure 3). Since levee construction divided lower Redwood Creek into four distinct areas, it was logical to collect and interpret the salmonid catch, migration and food habits data in accord with these areas. Stations R-1, R-2 and R-3 defined the Orick station which was characterized by solely freshwater creek habitat, and was uninfluenced by estuarine conditions. Stations R-4 through R-8 were located within the transition zone between fresh and estuarine habitats and were not distinct enough to include in either area. Stations R-9 through R-15 and the area west to the ends of the levees defined the estuary. The sampling stations located within the north and south slough represented each of those areas.

Capture Gear

Beach seines were the primary means of capturing migrant salmonids. A small beach seine measuring 17 m long and 2 m deep with a

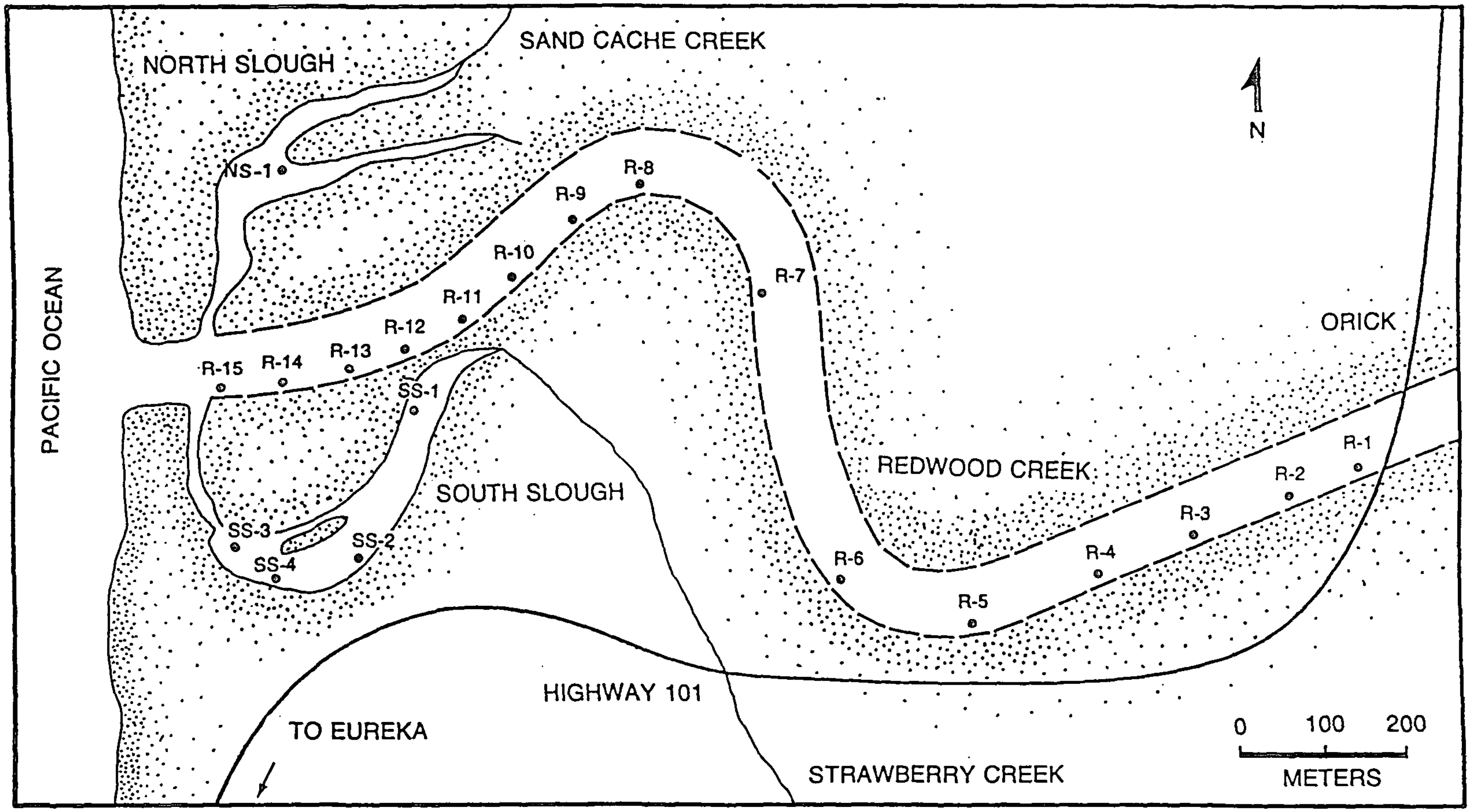

Figure 3. The station number and location of specific sampling stations within the study area of Redwood Creek, California. For data analysis, the general sampling stations were the Orick Station (R-1, R-2 and R-3), the Estuary (R-9 to R-15), the South Slough (SS-1 to SS-4) and the North Slough (NS-1).

mesh of 6.4 mm was used at the Orick station. This short seine was also used in the south slough and estuary, but its use was limited to shallow areas and proved not to be useful for sampling along the levees or for estimating relative abundance of the salmonid populations in these two areas. In June, a seine measuring 67 m long and 6.7 m deep with a mesh of 6.4 mm became the primary sampling gear used in the estuary and south slough. Because of the depth of the 67 m net, it could be landed on the levees with only a few unsuccessful sets caused by the net snagging on the rock riprap. A 45 m long and 2 m deep beach seine was used sporadically in the estuary and south slough prior to June; however, its large mesh (17.5 mm) allowed many juvenile chinook and steelhead to escape.

Gill nets 55 m long were used once in the south slough (May 2) and twice in the north slough (May 2 and July 22). Each gill net consisted of six panels of different size mesh. The stretch mesh sizes were: 5.0, 3.8, 3.1, 2.5, 2.0 and 1.3 cm.

Sampling Methods

Orick Station

Migrant juvenile salmonids were first captured before they entered the estuarine area to determine their relative abundance and the extent of river growth. Up to three passes were made each day sampled using the 17 m seine. Samples of up to five fish from each salmonid species captured on each sampling date were preserved in 50 percent isopropyl alcohol for food habits analysis. Fish to be handled were anesthetized using tricainemethane sulfonate (MS 222). Scale samples were taken from up to 25 of each salmonid species per sampling trip for age analysis. Scales were scraped from the area below the dorsal fin and above the lateral line. Fork lengths were measured from a maximum of 40 fish per trip. After measuring and taking scales, all fish to be released were marked. A mass marking technique described by Phinney (1967) was used. Inert fluorescent pigment was injected into the fishes' epidermis using compressed air and a sandblasting gun. The retained particles were readily visible when illuminated by ultraviolet light with a wave length of 3400 A. The technique had the advantage that many fish could be marked with a minimum of handling and mortality. A special viewing chamber was built which excluded most sunlight to make mark identification easier since the portable black light used (Ray-O-Vac, Model ML-49, Chicago, IL) was not powerful enough to illuminate the mark in direct sunlight. Fluorescent marking of juveniles was discontinued after June and a partial fin clip was substituted since the peak migration had occurred and fewer fish were available to be marked. In addition, the fin clip was easier to identify than the fluorescent mark.

Estuary

In general, more seining effort was directed toward the estuary than to other areas. Fish marked at the Orick station were first expected to be recaptured two weeks after marking. All fish caught were checked for marks, except on June 23 and 24 when time considerations allowed only 600 of the approximately 1,000 juveniles caught to be checked for a fluorescent mark. Fork lengths were measured from a random sample of juveniles if the catch exceeded 40 fish; otherwise all juveniles were measured. Scales were scraped from below the dorsal fin and above the lateral line from about 25 juveniles per sampling date. Samples of up to five fish of each salmonid species captured on each sampling date were retained for food habits analysis.

Marking in the estuary was begun in late June, when juvenile chinook and steelhead were congregating in the estuary, to determine the residence time of the two species and to estimate the population sizes. A different partial fin clip was used every two weeks which was different from the clip at the Orick station. The fin clip was repeated in 6 weeks if no recapture of that particular finclip occurred during that 6 week period. Using this criteria for repeating finclips, only single finclips were necessary during the study. The fins clipped during the study included the right and left pectoral fins, right and left ventral fins and upper and lower lobes of the caudal fin.

The chinook and steelhead population sizes were estimated on June 23 using the Petersen mark and recapture method (Ricker 1975). Fish for marking were initially captured using the 17 m and 67 m seines on June 23. Effort was spread throughout the estuary. Fish were marked with a partial fin clip and released after scales were taken and fork lengths measured. Recapture efforts were conducted the following day at evenly spaced intervals along the perimeter of the estuary. The 67 m seine was the only net used in recapture efforts. Juvenile chinook and steelhead were checked for fin clips and released. The Petersen method for estimating a fish population requires certain assumptions to be met. The assumptions are that marked fish do not suffer differential mortality when compared to the unmarked population, that no marks are overlooked when examined for recapture, that marked fish are caught at the same rate as unmarked fish, that the marked fish are randomly distributed, that there has been no additions to the population since marking and that if emmigration has occurred, both marked and unmarked fish leave the population at the same rate (Everhart et al. 1975). In this study, I feel that random mixing, no differential mortality and no additions to the population were the most difficult assumptions to satisfy. By conducting recapture efforts the day after marking the fish, I believe that violating the assumptions of no differential mortality and no additions to the population were minimized to point where they could be ignored. However, by conducting the estimate the day after marking, the assumption of random mixing of marked and unmarked fish was more difficult to meet. Because marked fish were captured in areas where no marked fish were released the day before, I believe the assumption of random mixing was also satisfied.

Sampling gear restrictions required pre-June effort to be limited to the shallow areas of the estuary. By late June more appropriate gear allowed sampling thoughout all portions of the estuary. Most effort was directed along the south levee where most of the fish seemed to be congregating and only two or three hauls per sampling date, was expended in the sandy areas near the mouth.

South Slough

Collecting in the south slough was limited to station SS-2 (Figure 3) using the 67 m seine. This station was the only area suitable for setting and landing a beach seine. Other areas either did not have a suitable site to land the net or the bottom had too much debris to allow retrieval of the net. Other seines were tried but were found to be of limited use. The 67 m seine was set one or two times at the site on each sampling date, depending on the success of the first set. All of the chinook and steelhead caught were checked for a fin clip or fluorescent mark. Fork lengths were measured and scale samples were taken from all salmonids. Samples of two or three specimens of each species caught were preserved in 50 percent isopropyl alcohol for food habits analysis.

A gill net was set on May 2, 1980 to sample the salmonids in areas where the beach seine could not be utilized. Scale samples were taken and fork lengths were measured for all fish caught. All fish were kept for stomach content analysis.

North Slough

Sampling in the north slough was limited to fishing with an experimental gill net. Beach and purse seines were fished in the slough but were ineffective because submerged logs snagged the nets. Scale samples were taken and the fork length measured for all fish caught. All fish collected were preserved for stomach content analysis.

Index of Abundance

Catch Per Unit Effort (CPUE) values were used to estimate the relative abundance of each salmonid species. A unit of effort in the estuary and south slough was defined as one haul with the 67 m seine. A unit of effort at the Orick station was defined as one haul with the 17 m seine. This method of estimating relative abundance assumes that the number of fish caught was proportional to the population size during the time sampling took place. Furthermore, to represent the relative population over time, the model assumes that the fish's catchability, due to changes in gear or the fish's susceptibility to a particular gear, does not change with time (Ricker 1975). By restricting the analysis of CPUE to the time period between April and

November at the Orick station when flow was relatively constant, I believe the assumptions for the model were met for chinook because the sampling gear remained constant, the effective area sampled was constant after flows stabilized and the size of the juvenile chinook captured did not radically change over the course of the season. The steelhead catch may not be representative because of the different age classes observed during the study. Older steelhead may not have been as susceptable to capture as the younger age classes. This reduced susceptability may have caused the proportion of older fish to be underestimated. By only comparing the CPUE within each age class, the bias caused by size differences can be minimized. The larger net used in the estuary and south slough should have reduced any biased assessment of the older age classes.

Scale Analysis

Aging of fish scales was accomplished by placing 12 scales between two microscope slides and projecting them using a microfiche reader (Quantor, Model 407, Burbank, CA) at a magnification of 48X. Ages were recorded as: 0+ for fish which had not formed a first annulus; 1+ for fish which had formed a first annulus but not the second; and 2+ for fish which had formed two annuli but not the third. Age composition was based on length-frequency analysis (Tesch 1971). Scale readings were used to estimate the lengths of fish in each age class for a given sampling date (Appendix O). The age composition of all measured fish was estimated for each day sampled and expressed as the percentage frequency at each age.

Stomach Analysis

Stomachs of collected salmonids were dissected and food items were identified and enumerated. Identification was made following Merritt and Cummins (1978), Pennak (1953), Smith and Carlton (1975) and Usinger (1956) to the at least the family level with most food item identified to genus or species. Because of the varying degrees of digestion of different organisms found in the stomachs, a system of reconstructed weight was used. Most of the soft bodied food items had sclerotized appendages which allowed identification of the food item. Estimation of reconstructed weight allowed consideration of those partially digested food items in the analysis (Popova 1967). Food items in an undigested condition were saved and used to establish a basis for estimating the restored dry weight of the stomach contents. A representative sample of undigested individual food items from each taxon from several fish were counted and combined, dried in an oven at 105 °C for one hour, and weighed on an analytical balance to the nearest milligram, and the average weight per individual was calculated. The average weights for each taxon weighed are listed in Appendix A. Where too few individuals were available for weighing or all specimens in the taxon were partially digested, food items of similar size and structure from another taxon were substituted. The taxa not weighable and their respective substitutions are listed in Appendix B. The average weight per individual food item was then multiplied by the count of the particular food item in each stomach. This estimate represented the total dry weight of each taxon found in a fish's stomach. Data were grouped according to the area the fish was captured and analyzed using the Index of Relative Importance (IRI) described by Pinkas et al. (1971). The IRI values for each area were summed and the percentage of total IRI calculated for each food group. The percentage of total IRI allowed comparison of food groups between areas and species using the Diet Overlap Index (DOI) described by Levins (1968). The DOI compares the similarity of the taxa consumed and the porportion of each taxa represented in the diet between two samples of fish. Results of the comparison lead to values between 0 and 1. A DOI result near 0 indicates that diets were completely different, whereas values that approached 1 indicates nearly identical food items were consumed. Although variance calculations and statistical analyses were not possible with either the IRI or DOI, Zaret and Rand (1971) and Mathur (1977) stated that if DOI $\geq$ 0.60, then there is probably a biologically significant overlap in food items consumed by the two groups of fish.

RESULTS

Chinook Salmon

Migration

All juvenile chinook migrating into the Redwood Creek estuary in 1980 were young-of-the-year. The main migration past the Orick station began in mid-May when the juveniles had an average length of 61.9 mm (standard deviation (SD) = 5.3, sample size (N) = 13) (Figure 4) and the Catch Per Unit Effort (CPUE) was only 7.0 chinook per seine haul (Figure 5). The population size, as indexed by CPUE using the 17 m beach seine, increased until the CPUE peaked at 32.0 chinook per seine haul in early June, when the average length had increased to 71.2 mm (SD = 6.2, N = 33). By early July, the CPUE had dropped to 4.5 chinook per seine haul and average length was 81.7 mm (SD = 9.0, N = 17). Few juvenile chinook were caught at the Orick station after July.

Sampling in the estuary was not standardized until June 23 when the 67 m seine began to be used exclusively to catch juvenile salmonids. No attempt was made to correlate CPUE data between sampling dates in the estuary before and after June 23, because the 45 m and 17 m seines did not give comparable results. On June 23, the CPUE using the 67 m net was 136.8 chinook per seine haul (Figure 5), and the average length of the fish was 79.8 mm (SD = 5.7, N = 39) (Figure 4). The Peterson estimate conducted at that time provided an estimate of 9,422 juveniles with a 95% confidence interval of 7,106 < N < 12,738. On July 7, too few fish were caught to allow another estimate to be

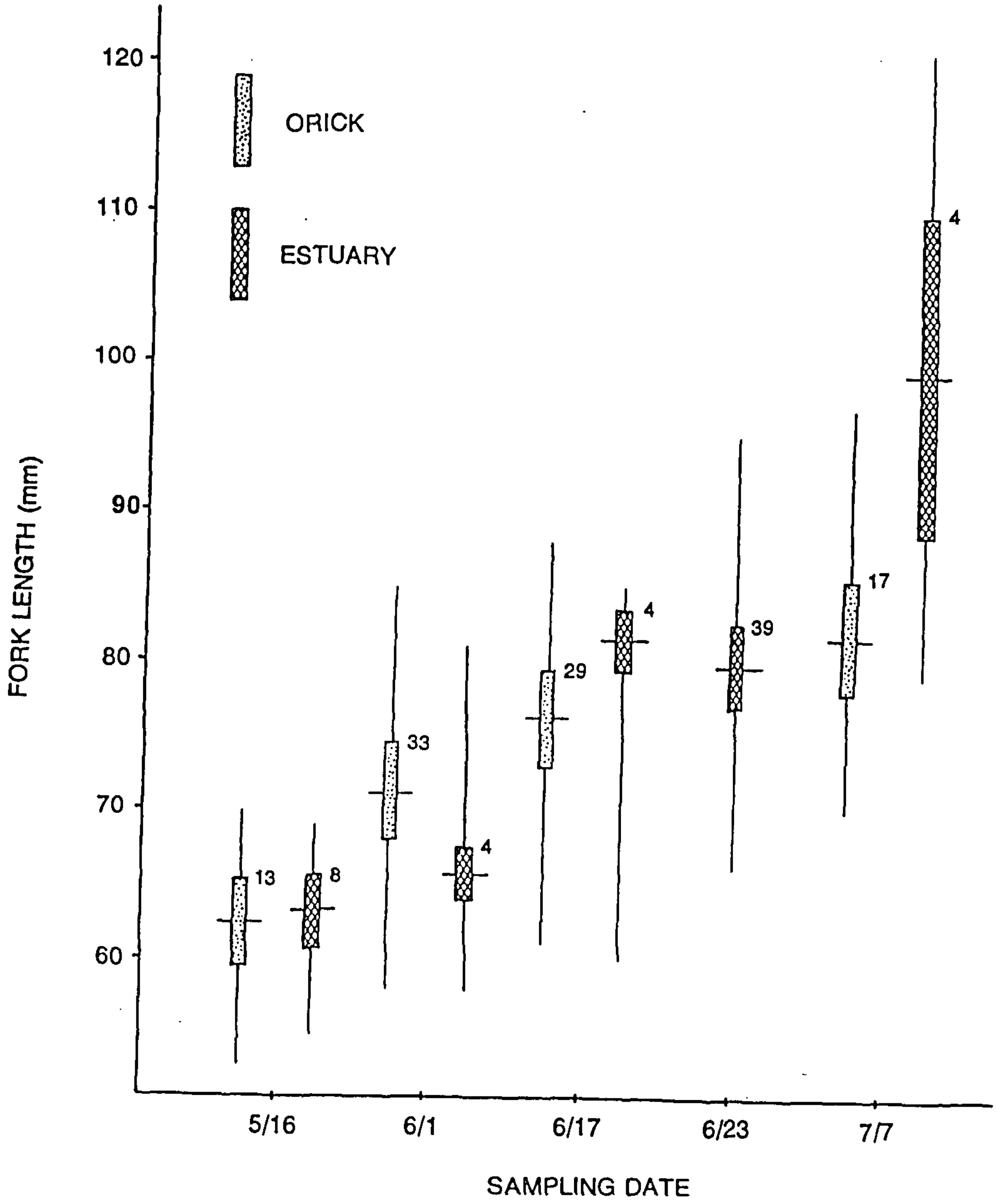

Figure 4. Mean fork length (horizontal line), range (verticle line), ± 1 standard deviation (vertical rectangle) and sample size (numerals) for juvenile chinook caught at the Orick station and in the estuary, Redwood Creek, California, 1980.

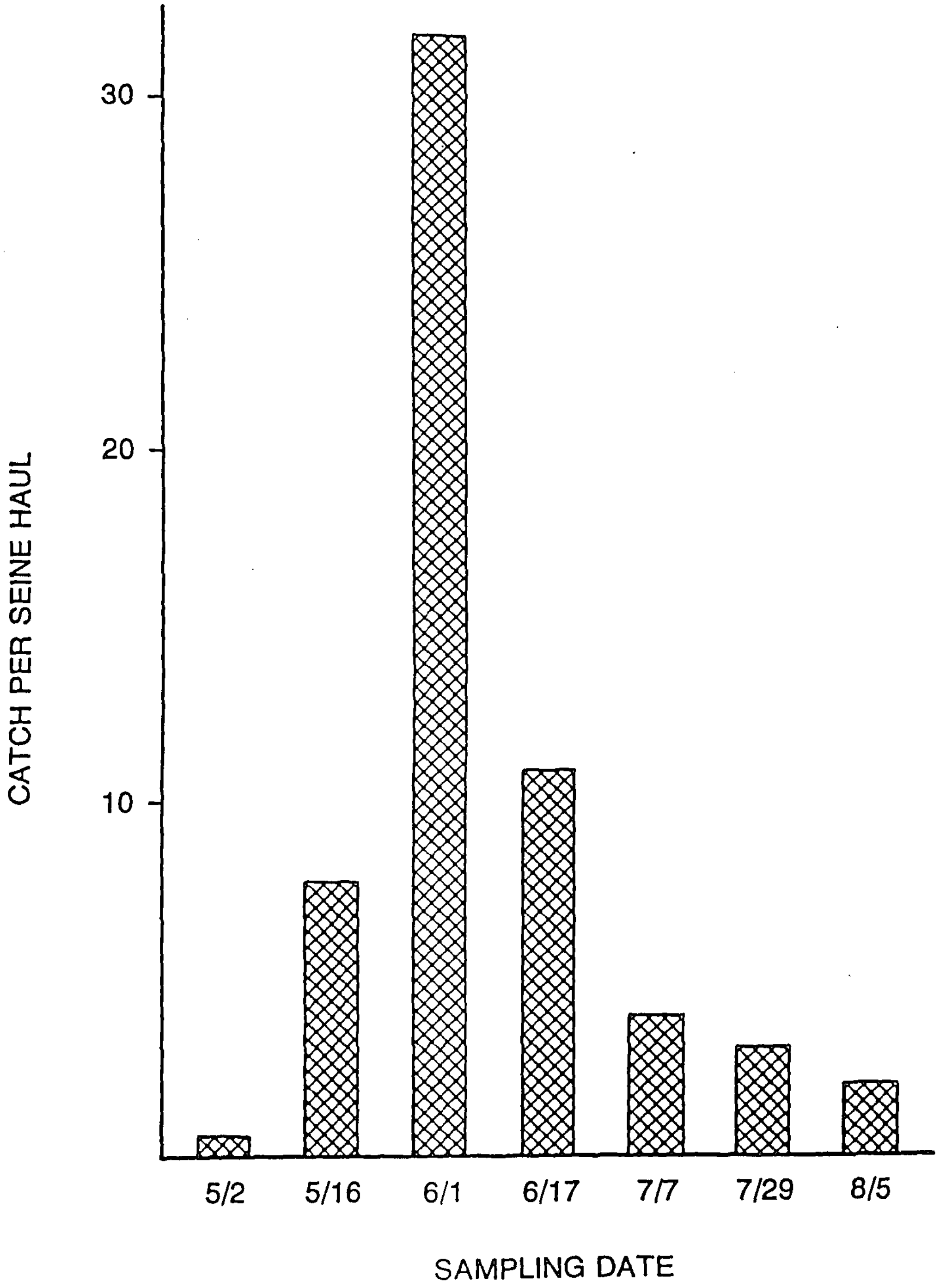

Figure 5. Catch per Unit Effort (CPUE) using the 17 m beach seine for chinook captured at the Orick station, Redwood Creek, California. Sampling extended from March to November, 1980.

attempted and the CPUE was only 2.5 chinook per seine haul. After July 7, less than 2 chinook were caught per sampling period in the estuary.

The catch data on June 23 and 24 showed that the chinook were concentrated near the end of the south levee and near the outlet while the embayment persisted (Figure 6). On July 7, the chinook concentrated only near the outlet (Figure 7).

Seining was not standardized in the south slough until after July 7 and no attempt was made to correlate the CPUE between different nets used because the 17 m and 45 m nets used prior to July 7 did not give comparable results. The CPUE on July 7 using the 67 m net was 5.0 chinook per seine haul. The CPUE dropped to 1.0 and 2.0 chinook per seine haul on July 22 and August 18 respectively.

Length Comparison

The mean lengths of chinook caught on the same date at the Orick station and in the estuary (May 16, June 1, June 17 and July 7) were compared using Student's t-test. None of the comparisons indicated a significant difference ($P < 0.05$).

Marking

Of the 115 juvenile chinook marked at the Orick station, none were recovered in the estuary (Table 1). Also, none of the 827 juveniles marked during the June 23 population estimate were recovered on or after July 7.

Food Habits

The food habits of juvenile chinook were compared from three general areas: the Orick station, the estuary and the south slough. In terms of percentage of the total Index of Relative Importance (IRI) for

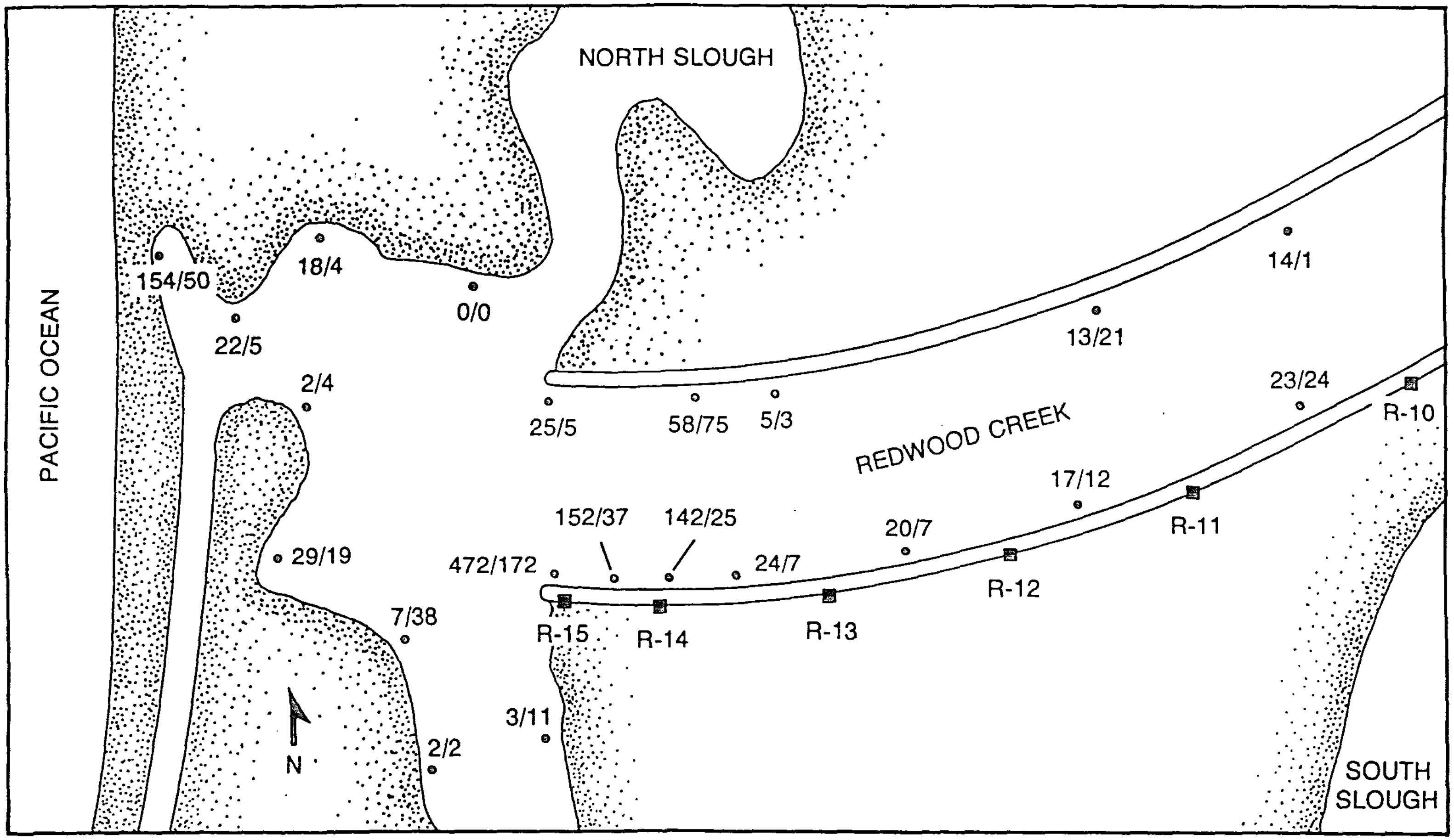

Figure 6. Catch per seine haul (chinook/steelhead) using the 67 m beach seine by location on June 23 and 24, 1980 in the estuary of Redwood Creek, California.

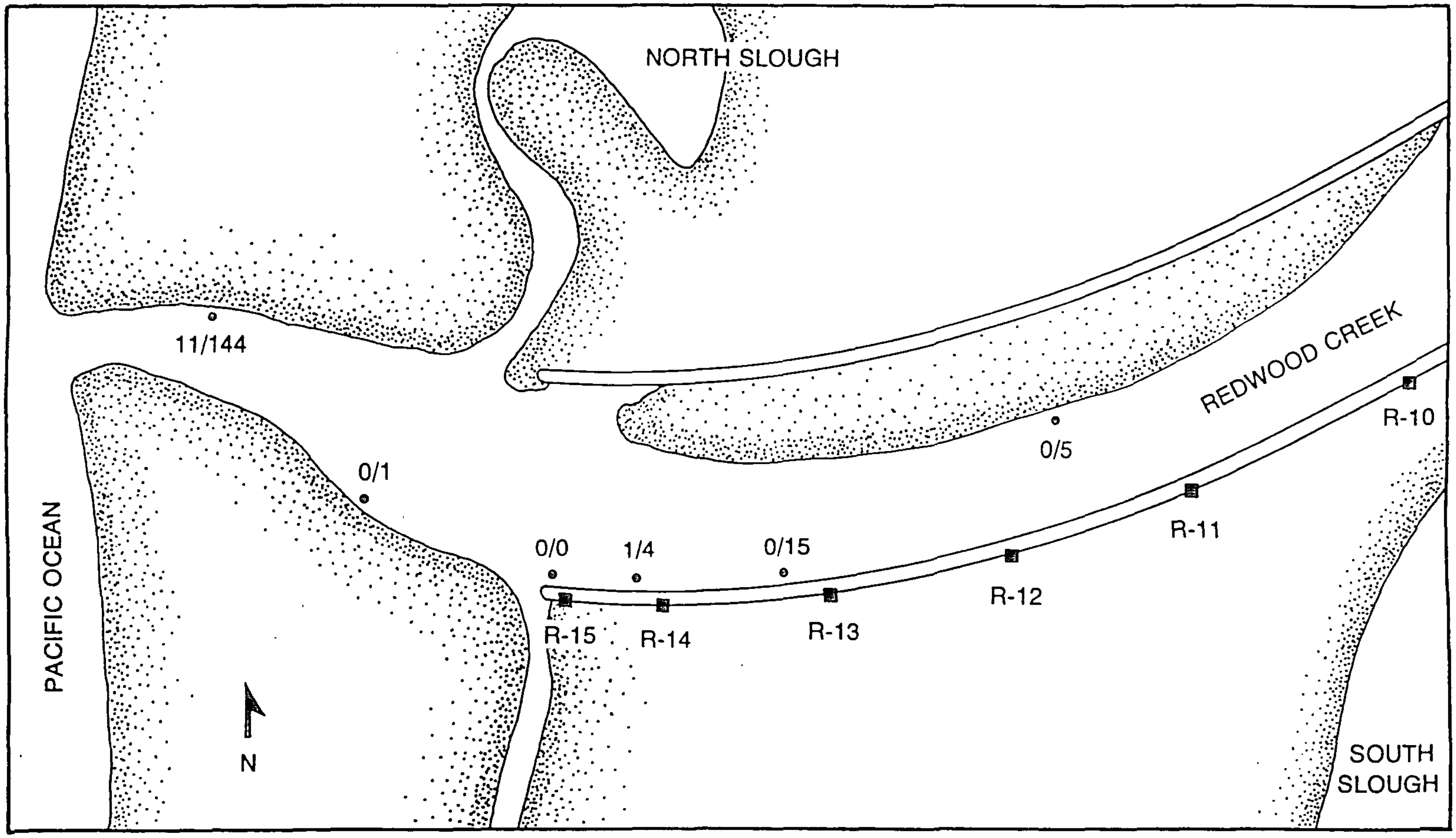

Figure 7. Catch per seine haul (chinook/steelhead) using the 67 m beach seine by location on July 7, 1980 in the estuary of Redwood Creek, California.

Table 1. Mark and recapture data for juvenile chinook caught in the estuary and near Orick in Redwood Creek, California, 1980.

MARKED			RECAPTURED			
Date	Number	Station	Total Number caught	Number Exhibiting Marks	Station Initially Marked	Date Marked
5/2	5	Estuary	-	-		
5/2	1	Orick	-	-		
5/16	5	Estuary	8	0		
5/16	10	Orick	13	0		
6/1	1	Estuary	4	0		
6/1	62	Orick	64	0		
6/17	1	Estuary	4	0		
6/17	27	Orick	30	0		
6/23	827	Estuary	840	0		
6/24	0	Estuary	373	28	Estuary	6/23
7/7	12	Estuary	15	0		
7/8	14	Orick	17	0		
7/22	0	Estuary	1	0		
7/22	1	Orick	3	0		
7/29	0	Orick	2	0		
8/5	0	Orick	1	0		
9/15	0	Estuary	1	0		
10/1	0	Estuary	2	0		
TOTAL	115	Orick	132	0		
TOTAL	851	Estuary	1255	28		

each respective category, Diptera larvae (52.4%) and pupae (33.8%) were the predominate food items at the Orick station (Sample size (N) = 11) (Figure 8). Ephemeroptera Larvae (7.0%) comprised the third most important group consumed. In the estuary (N = 27), Diptera larvae (41.3%) and pupae (50.1%) were also the major food source; but unlike the upriver station, Diptera adults (4.9%) comprised the third most important food group. In the south slough (N = 5), a greater variety of food items contributed a larger porportion to the chinook's diet than in either the estuary or at the Orick station where two food items dominated the chinook's diet. *Corophium salmonis* (37.1%) and *C. spinicorne* (18.2%) were the dominant food items in the south slough, as opposed to the estuary where dipterans dominated. Mysids (9.4%) made up the third most important food group. A list of food items eaten, the actual IRI value for each food item and percentage of the total IRI are reported in Appendix C. The diet overlap index (DOI) showed only chinook in the estuary and at the Orick station (DOI = 0.91) had similar diets (DOI ≥ 0.60). Chinook in the south slough consumed different food items (DOI < 0.60) than those in the estuary (DOI = 0.09) or at the Orick station (DOI = 0.07). Seasonal food habit comparisons were not attempted because of the short duration of chinook movement.

Steelhead

Migration

At the Orick station, juvenile steelhead were caught throughout the sampling season from March to November. The CPUE gradually increased to 11.0 age 1+ steelhead per seine haul on June 1 then

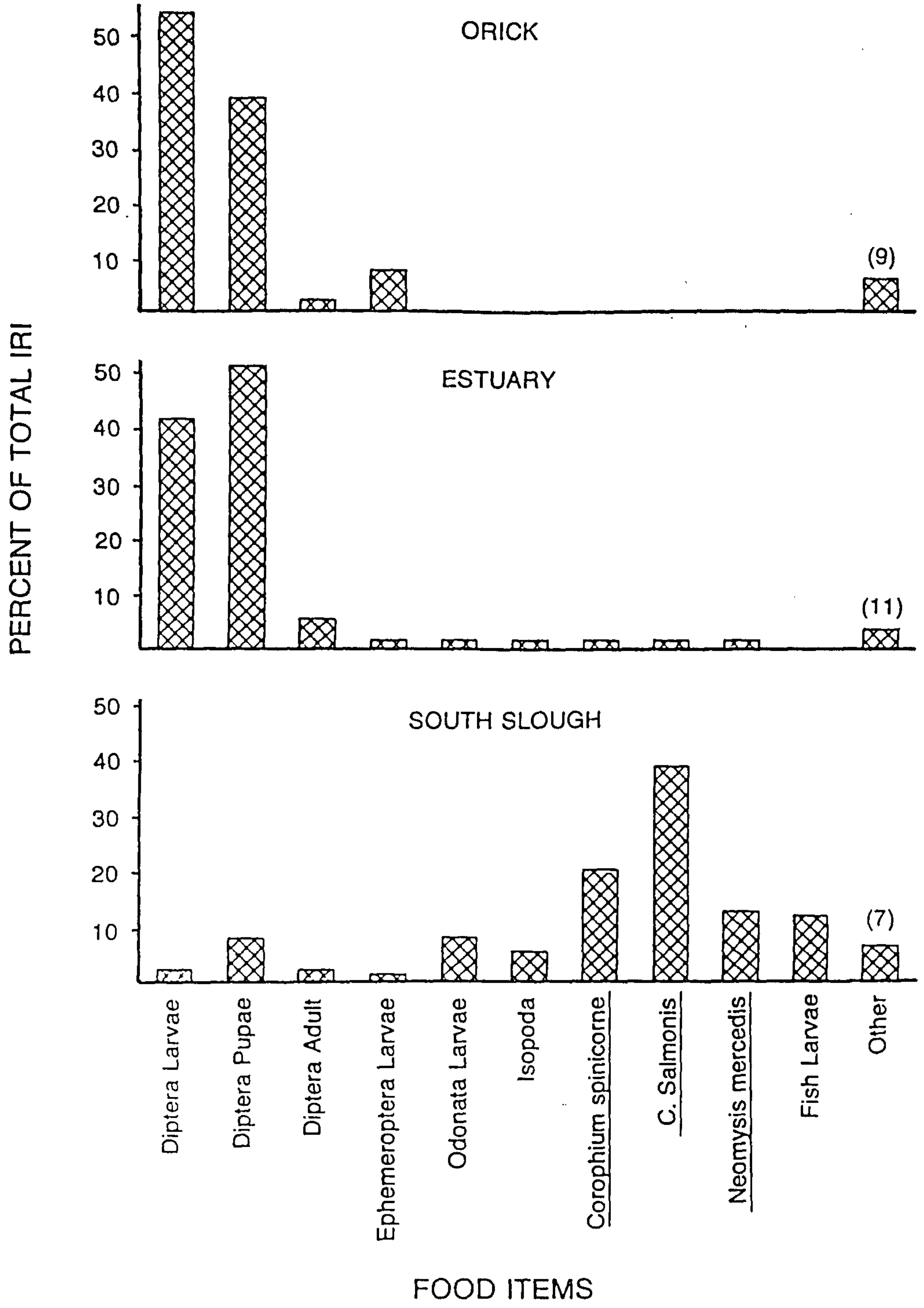

Figure 8. Major food items eaten by juvenile chinook in Redwood Creek, California, 1980, expressed as the percentage of the total Index of Relative Importance (IRI) for each general sampling area. Numbers in parantheses indicate the number of minor food items included in the "other" category.

decreased to 3.0 age 1+ steelhead per seine haul on June 17 (Figure 9). The CPUE increased on July 22 to 103.0 age 1+ steelhead per seine haul and remained high until September when the CPUE decreased to 1.0 age 1+ steelhead per seine haul. For age 0+ steelhead, the CPUE peaked at 109.0 steelhead per seine haul on July 22, then decreased to 34.0 age 0+ steelhead per seine haul on July 29 and August 5. On September 2, the CPUE dropped to 6.0 age 0+ steelhead per seine haul. No age 0+ steelhead were caught after September 2.

As was the case with chinook, sampling in the estuary for steelhead was not standardized until June 23. The peak CPUE after the method was standardized in the estuary was recorded on June 23 at 20.5 age 1+ steelhead per seine haul (Figure 10). The population was estimated using the Petersen method on June 23 to be 19,000 steelhead. Because of the small number of juveniles marked and recaptured, the estimate can only give a rough idea of the order of magnitude of the steelhead population. On July 7 another population estimate was attempted but too few juvenile steelhead were caught for marking. The CPUE for most areas sampled on July 7 in the estuary was near 0 except for the area nearest the outlet where 144 juveniles were caught in one seine haul (Figure 7). From July 7 until the end of the sampling season in November, the average CPUE was 1.9 age 1+ steelhead per seine haul in the estuary.

Age

The juvenile steelhead migrating past the Orick station were dominated by age 1+ fish. During the peak of the run in June, 79 percent of the juveniles were age 1+. The average length of these juveniles was 107.3 mm (SD = 10.4, N = 22) with a range of 87 mm -

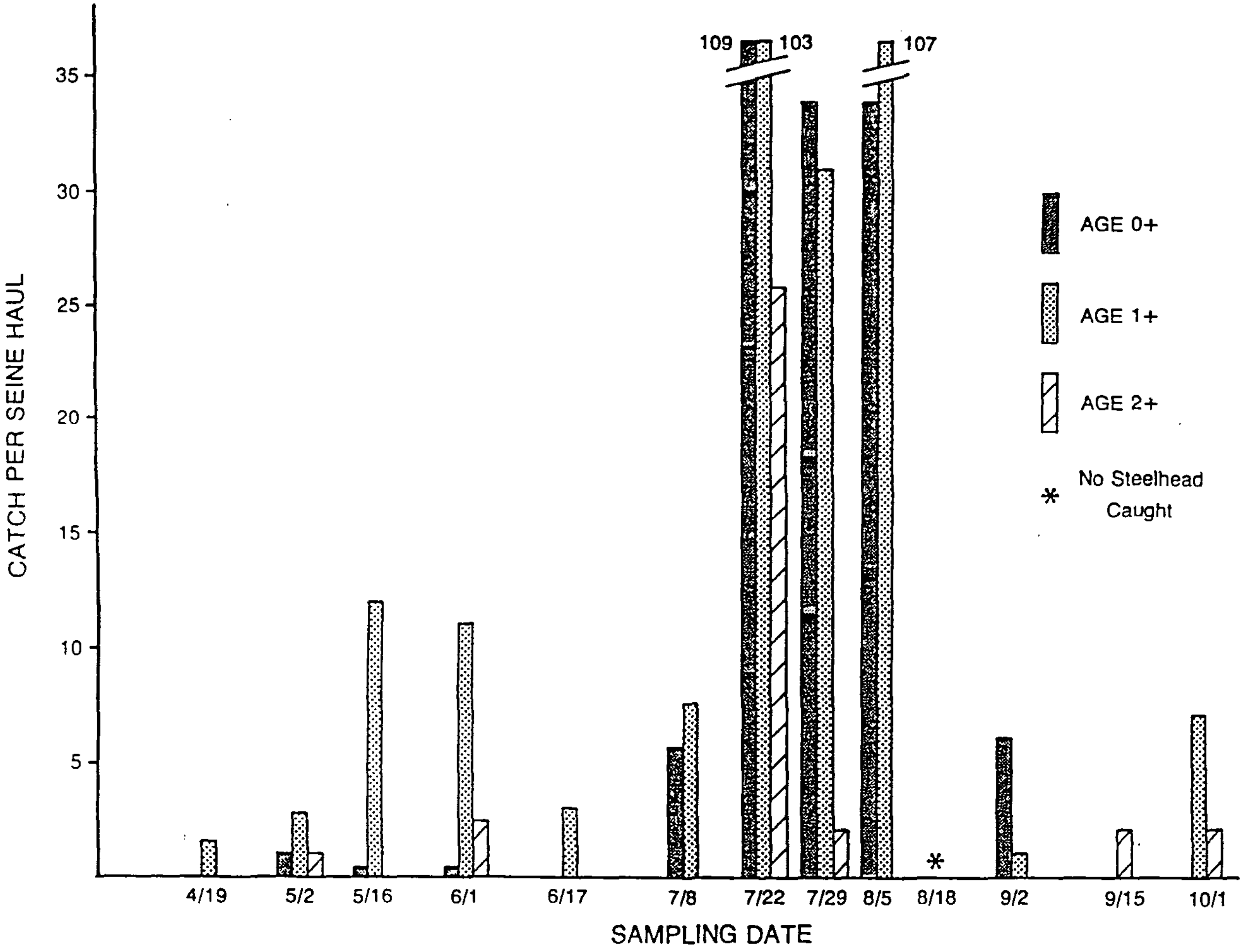

Figure 9. Steelhead catch per seine haul (17 m x 2 m beach seine with 6.4 mm mesh) at the Orick station, Redwood Creek, California, 1980, separated by age class.

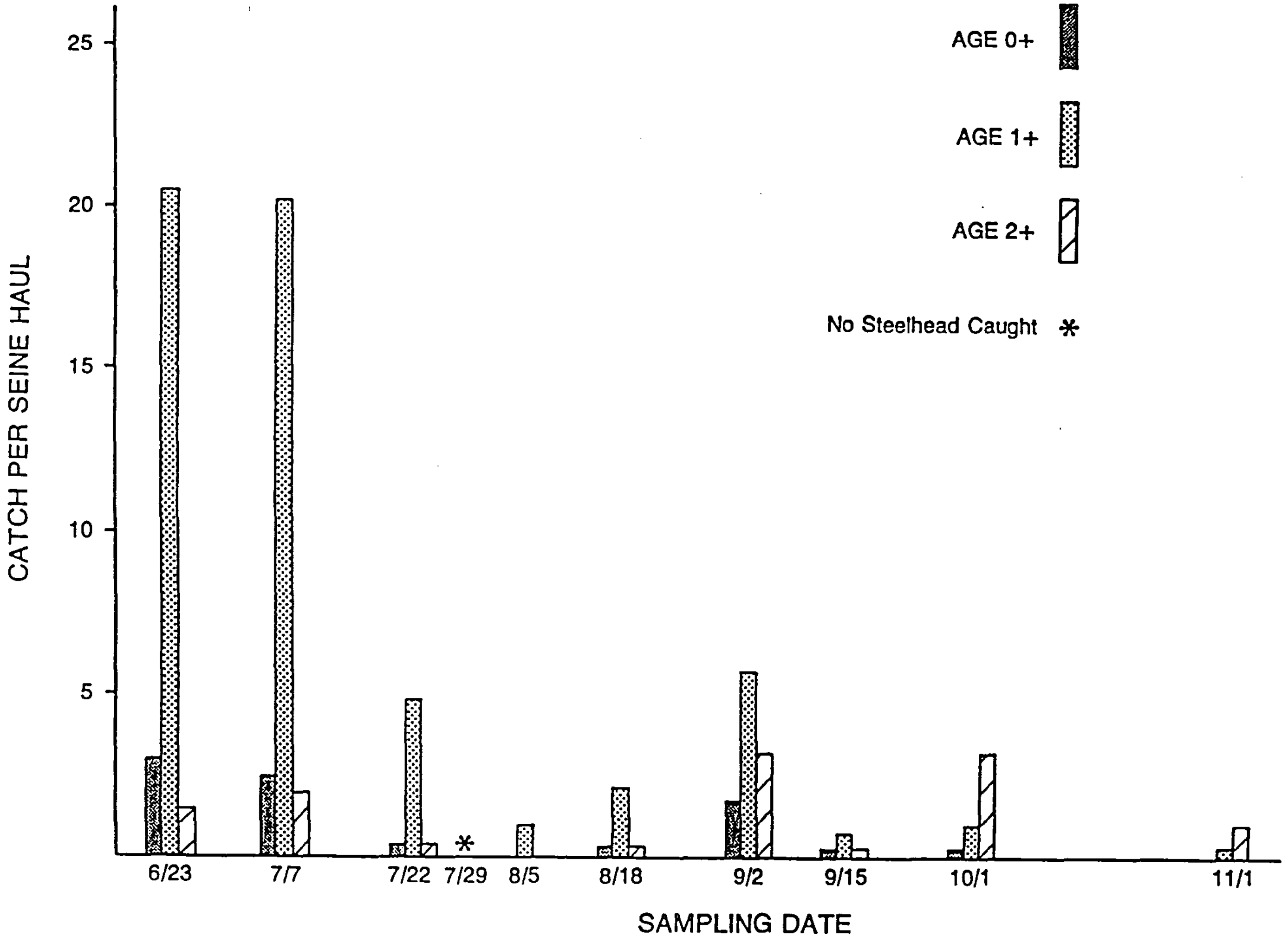

Figure 10. Steelhead catch per seine haul (67 m x 6.7 m beach seine with 6.4 mm mesh) in the Redwood Creek estuary, California, 1980, separated by age class.

132 mm (Figure 11). While age 1+ juveniles comprised the bulk of the migrating steelhead throughout the sampling year, definite trends in the timing of migration for age 0+ and 2+ fish were noted. Age 0+ juveniles did not begin migrating until late June when they contributed about 10 percent to the total number of steelhead migrating at that time. Average length of these fish was 76.1 mm (SD = 4.6, N = 3) with a range of 71 mm - 80 mm. From July 8 to August 5, 41 percent of the fish caught were age 0+. Age 2+ steelhead were represented in small numbers throughout the sampling year; however, the majority of age 2+ fish migrated after mid-August when approximately 37 percent of the catch was age 2+ juveniles. During the peak migration in June, only 9 percent of the steelhead caught was age 2+. Average length in June for age 2+ fish was 137.6 mm (SD = 2.4, N = 5) with a range of 135 mm - 141 mm. By November, age 2+ steelhead had an average length of 186.7 mm (SD = 10.7, N = 6) with a range of 177 mm - 203 mm.

Marking

Of the 537 steelhead marked at the Orick station, only one was recovered in the estuary (Table 2). This fish was marked on August 5 and recaptured 2 weeks later on August 18. Of the 520 steelhead marked for the population estimate on June 23 in the estuary, none were recaptured after June 24. Several steelhead marked at the Orick station were recaptured at the Orick station. On July 22, one steelhead marked on July 8 was recaptured; on July 29, four steelhead marked on July 22 were recaptured.

South Slough

Juvenile steelhead were found in the south slough throughout the

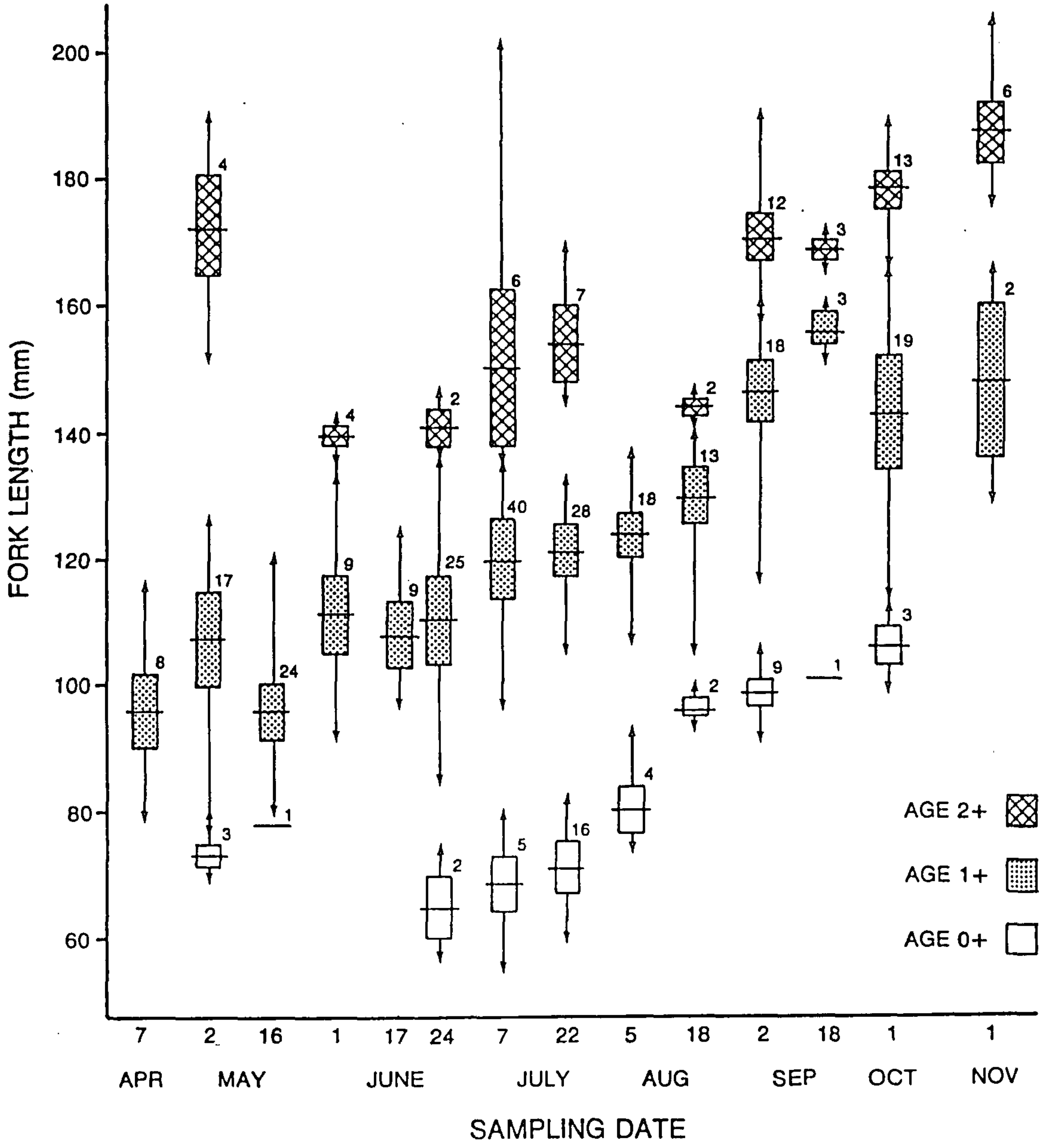

Figure 11. Mean fork length (horizontal line), ± 1 standard deviation (verticle rectangle), number of fish aged (numerals), age (rectangle shading) and size range (arrows) for juvenile steelhead aged by scale reading and captured at the Orick station or in the estuary, Redwood Creek, California, 1980.

Table 2. Mark and recapture data for juvenile steelhead caught in the estuary and near Orick in Redwood Creek, California, 1980.

MARKED			RECAPTURED			
Date	Number	Station	Total Number Caught	Number Exhibiting Marked	Station Initially Marked	Date Marked
4/19	3	Estuary	-	-		
4/19	1	Orick	-	-		
5/2	0	Estuary	10	0		
5/2	17	Orick	19	0		
5/16	0	Estuary	10	0		
5/16	22	Orick	25	0		
6/1	0	Estuary	1	0		
6/1	25	Orick	28	0		
6/17	0	Estuary	7	0		
6/17	7	Orick	9	0		
6/23	274	Estuary	280	0		
6/24	0	Estuary	251	2	Estuary	6/23
7/7	144	Estuary	149	0		
7/8	23	Orick	26	0		
7/22	27	Estuary	28	0		
7/22	235	Orick	238	0		
7/29	64	Orick	67	4	Orick	7/22
8/5	4	Estuary	4	0		
8/5	131	Orick	141	1	Orick	7/29
8/18	14	Estuary	17	1	Orick	8/5
9/2	39	Estuary	43	0		
9/2	5	Orick	7	0		
9/15	2	Estuary	5	0		
9/15	0	Orick	2	0		
10/1	17	Estuary	20	0		
10/1	7	Orick	9	0		
11/1	6	Estuary	8	0		
TOTAL	537	Orick	574	5		
TOTAL	780	Estuary	824	3		

year. A peak CPUE of 5 steelhead per seine haul was recorded on July 7. The CPUE dropped, then remained stable after July. The average CPUE from July 22 to October 1 was 2.3 steelhead per seine haul. Sampling in the south slough yielded a mixture of wild and hatchery steelhead. The Prairie Creek County Fish Hatchery occasionally planted catchable trout in the south slough to support a limited sport fishery. During the May gillnetting, 50 percent of the catch were hatchery trout. Hatchery trout were identified by either a fin clip or fin degeneration. Hatchery fish averaged 180.6 mm (SD = 11.6, N = 8) and were significantly larger than wild steelhead which averaged 142.8 mm (SD = 7.8, N = 3) (t-test, $p \leq 0.05$).

North Slough

Sampling in the north slough was limited to the use of a gill net because of the extensive woody debris on the bottom and the lack of suitable sites to land a seine. A 3-hour set with the gill net on May 2 yielded 14 steelhead. The average length was 206.7 mm (SD = 47.0, N = 14) with a range of 148 mm - 326 mm. Age composition, based on scale reading, was 57 percent age 1+, 36 percent age 2+ and 7 percent age 3+ steelhead. On July 22 the gill net was again set but only one age 2+ steelhead, measuring 250 mm, was caught during the 2.5 hour set.

Food Habits

The food habits of juvenile steelhead were compared from three general areas: the Orick station, the estuary and the south slough. Results from the estuary and Orick station were stratified by date to reflect seasonal changes in organism availibility (Figure 12). In terms of the percentage of the total Index of Relative Importance (IRI)

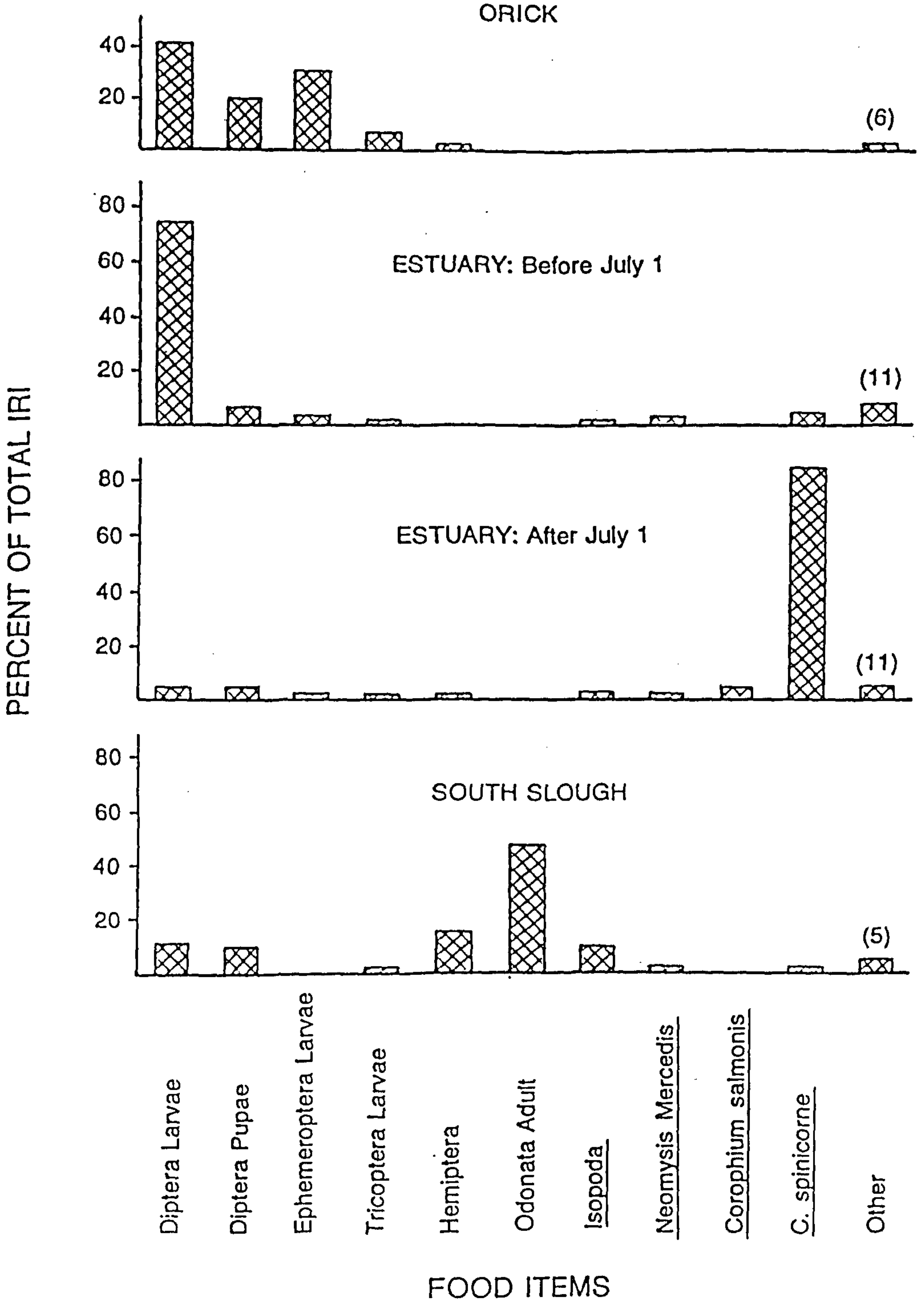

Figure 12. Major food items eaten by juvenile steelhead expressed as the percentage of the total Index of Relative Importance (IRI) for each general sampling area Redwood Creek, California, 1980. The number in parentheses indicates the number of minor food items included in the "other" category.

for each respective category, Diptera larvae (52.9%), Diptera pupae (25.0%) and Ephemeroptera larvae (14.4%) were the main food items at the Orick station before July 1 (N = 8). After July 1 at the Orick station (N = 10), the main food items were Ephemeroptera larvae (40.8%), Diptera larvae (29.7%), Trichoptera larvae (14.6%) and Diptera pupae (13.6%). In the estuary prior to July 1 (N = 16), Diptera larvae (74.3%) dominated the steelhead's diet with Diptera pupae (7.0%) and mysids (4.0%) the next most important groups. In the estuary after July 1 (N = 30), Corophium spinicorne (84.8%) was the most important food item. Diptera pupae (4.9%) comprised the second most important group. Steelhead in the south slough (N = 8) fed on a variety of different major food groups. Odonate adults (46.2%) comprised the most important food group. Other major groups in descending order of importance were Hemiptera (15.2%), Diptera larvae (10.5%), Diptera pupae (10.0%) and isopods (10.0%). A list of food items eaten, percent of total IRI, and actual IRI value for each food item are reported in Appendix D.

The diet overlap index (DOI) showed that steelhead diets were biologically similar (DOI $\geq$ 0.60) for two comparisons: the estuary before July 1 versus the Orick station before July 1 (DOI = 0.90) and the Orick station before July 1 versus after July 1 (DOI = 0.76). The DOI demonstrated that steelhead food habits were biologically dissimilar (DOI $\leq$ 0.40) for the following six comparisons: the estuary after July 1 versus the Orick station after July 1 (DOI = 0.03), the estuary after July 1 versus the south slough (DOI = 0.03), the estuary after July 1 versus the estuary before July 1 (DOI = 0.08), the estuary before July 1 versus the south slough (DOI = 0.21), the Orick station before July 1 versus the south slough (DOI = 0.26) and the Orick station after July 1 versus the south slough (DOI = 0.17). The comparison of the estuary before July 1 and the Orick station after July 1 (DOI = 0.57) failed to demonstrate any biological similarity or dissimilarity (0.40 < DOI < 0.60).

DISCUSSION

Chinook

During 1980, juvenile chinook were observed in lower Redwood creek from May to August and the peak migration past the Orick station occurred on approximately June 1 (Figure 5). The peak population in the estuary occurred in June although the exact time of peak occurrence could not be determined because sampling was not standardized until late June. On July 2, 1980 the sand berm at the mouth was breached. The release of water reduced the available habitat in terms of area and depth so dramatically that the estuarine area no longer provided suitable conditions for fish habitation and essentially forced the chinook to move into the ocean. The change in population number could easily be seen in the catch data. The CPUE was reduced by 98 percent from 136.8 chinook per seine haul on June 23 to 2.5 chinook per seine haul on July 7. Since the bottom was barren, comprised primarily of sand and gravel, cover in the estuary was minimal. Before the breaching, some cover was provided by virtue of the increased water depth, approximately 3.0 m. While the embayment persisted, the chinook concentrated near the deep areas along the end of the south levee and near the outlet, although a few juveniles were caught throughout the embayment (Figure 6). After breaching the few remaining chinook were found only in the deep portion of the estuary near the mouth (Figure 7). Crevises between the rocks forming the levee could provide cover when the water was deep, but observations while snorkeling in the embayment indicated that salmonids were only occasionally utilizing interstices between rocks. After the water level was reduced by breaching, crevices in the levee were not available for cover.

Because the chinook could not continue habitation of the estuary or move into the south slough after the berm was breached, the fish were forced to enter the ocean. Chinook in the Redwood Creek estuary averaged 83 mm when the berm was breached in July. Wagner et al. (1969) conducted seawater survival experiments on two groups of juvenile chinook of similar size and age. Their results showed chinook with average lengths of 86 mm and 88 mm had survival rates of 20 percent and 46 percent respectively when transferred from fresh water (0 ⁰/oo) to sea water (30 ⁰/oo) without acclimation. The difference between survival rates was not attributed to any specific cause. They also found that size alone did not determine osmoregulatory ability. An accelerated growth rate or acclimation allowed juvenile chinook to osmoregulate at a smaller size and younger age. Applying the results from Wagner et al. (1969) to the Redwood Creek chinook suggested that immediate and abrupt transition from fresh to sea water because of the berm breaching probably decreased survival of the young chinook. The Redwood Creek chinook, which were smaller than the test fish used by Wagner, were not provided a period of acclimation.

Preventing the chinook from utilizing the estuary through the summer may have reduced the number of juveniles surviving to become adults. In streams similar in size to Redwood Creek, chinook appear to move into the ocean after growing to a threshhold length of 120 mm (Reimers 1973; Taniguchi 1970). Survival is dependent on reaching this length before entering the ocean and may be achieved by growing either in the estuary or in fresh water (Reimers 1973). Reimers and Loeffel

(1967) found fresh water residence time to be variable and dependent on fresh water rearing conditions. Under harsh conditions (for example, high water temperatures), juveniles move out of the rearing stream at a smaller size (Reimers 1978). Estuarine growth compensated for reduced fresh water growth and allowed the chinook to reach the threshhold length. The Reimers (1973) found that fish which had spent the summer in the Sixes River estuary and outmigrated in the fall at approximately 120 mm comprised 90 percent of the returning adult chinook. Reimers work consisted of studing both the juvenile and adult life history patterns. Since the work on Redwood Creek consisted of studing only the juvenile life history, caution must be exercised when comparing the importance of the estuarine environment of Sixes River and Redwood Creek. A thorough examination of the adult life history of Redwood Creek fall chinook is necessary before conclusions on survival may be presented.

Food habit analysis indicated that the estuary did not provide a feeding environment distinctly different from that observed at the Orick station. The primary food items before the berm was breached were Diptera larvae and pupae (Figure 8). Chinook in the estuary were consuming similar food items as at the Orick station (Diet Overlap Index (DOI) = 0.91) not brackish water invertebrates typically associated with estuary environments such as amphipods, isopods, and mysids. Variable food habits have been reported for juvenile chinook in other west coast estuaries. Investigations of the Fraser River estuary (Anderson et al. 1980) and Columbia River estuary (Lipovsky 1977) showed that chinook consumed mostly chironomid larvae. In contrast, investigations at Grays Harbor, Washington (Herrman 1971), the Fraser River estuary (Dunford 1975), the Dumwash River estuary, Washington (Meyer et al. 1980) and the Sixes River estuary (Bottoms 1980) indicated that Corophium were the most important component in the chinook's diet. Pearce et al. (1982) further noted that chinook less than 70 mm ate mostly dipterans and spiders, while chinook larger than 70 mm consumed mostly crustaceans including Corophium, Neomysis mercedis and Cumella. Healey (1980) noted spacial and temporal differences in juvenile chinook food habits in the Naniamo River estuary, British Columbia. Juvenile chinook consumed mostly invertebates (copepods, amphipods, mysids and insect larvae) in the intertidal areas, whereas their diet shifted to predominately fish as they move out of the intertidal areas. Their diet within the intertidal area was dependant on seasonal food abundance. Whether the food habits of Redwood Creek's chinook salmon would have shifted to estuarine organisms as the season progressed is unclear. Steelhead did exhibit a seasonal shift in food habits in the Redwood Creek estuary. After July 1, steelhead consumed primarily Corophium sp. whereas prior to July 1 the steelhead ate Diptera larvae and pupae.

Length data further indicated that the estuary had not provided conditions different than at the Orick station. If the embayment were providing an expanded food base, chinook would have shown an accelerated growth rate and average lengths would have been expected to be different. However, chinook caught in the estuary were not significantly ($p \leq 0.05$) longer than fish caught at the Orick station on comparable sampling dates. This comparison assumed first that migration timing was not size dependent and second that the juvenile chinook resided in the estuary instead of outmigrating into the ocean.

Evidence was available to support these assumptions. First, if migration timing was strictly dependent on the length of the fish and a threshhold size triggered migration, then the mean lengths of all juveniles chinook sampled at the Orick station would not change regardless of the sampling date. However, a steady increase in mean length was evident at the Orick station as the sampling season progressed (Figure 4). Second, catch data suggested juvenile chinook did not immediately outmigrate from the estuary until the berm was breached.

Construction of flood control levees further impacted historical use of the estuary by juvenile chinook. The USFWS (1975) estimated that the flood control levees eliminated 50 - 75% of the estuarine habitat. Juvenile chinook access into the north and south sloughs for rearing was restricted because a sand bar blocked entry at low water levels. The south slough provided an attractive rearing habitat because of the expanded food base and diverse forms of cover. The food habits of chinook caught in the south slough were quite different from those fish feeding in the embayment. Their diet shifted from one dominated by fresh water Diptera in the embaymemt to one of estuarine derivation (Figure 8). Typical estuarine organisms, primarily Corophium and mysids, were the most important food items. In addition to a broader food base, the slough had a variety of structures, primarily sunken logs and overhanging riparian vegetation, which provided ample cover. However, the connection between the estuary and the south slough was shallow at best even during high water. As the water in the estuary drained following the breaching, the slough became isolated. While the water level was high, a few juvenile chinook entered the slough, but the concentration of juveniles appeared to be small. The CPUE was 5.0 chinook per seine haul on July 7 and was probably linked to poor access caused by the shallow connection and extensive growth of pond weed (*Potamogeton pectinatus*). Once the fish negotiated the shallow connection, access was hindered by the pond weed. The west end of the slough, the entrance, had the densest growth of aquatic plants and only the deep areas had open water. Better circulation within the slough would reduce the pond weed abundance. Water entered the slough via Strawberry Creek, but the flow was minimal and not enough to disturb the growth of aquatic plants. Increased flow could eliminate the silt which provided a growth substrate for the pond weed.

Denton (1974) concluded that the lack of rearing habitat was the most significant factor affecting steelhead and salmon runs in northern California streams. In Redwood Creek low flows coupled with the loss of riparian vegetation aggravated by aggradation resulted in poor living conditions due to decreased food production, increased competition for living space, higher summer water temperatures and increased vulnerability to natural enemies. The combination of altered circulation, reduced habitat, and berm breaching has decreased the Redwood Creek estuary productivity for juvenile chinook salmon.

Steelhead

Juvenile steelhead were captured during the entire sampling year in Redwood Creek but the peak migration occurred from May through early June. Sampling in lower Redwoood Creek in subsequent years further corroborate these findings (McKeon 1985). Research in

Waddell Creek, California showed the same basic pattern: the peak migration occurred in April through June with minor emmigration the entire year (Shapovalov and Taft 1954). The CPUE data (Figure 9) from the Orick station provided a misleading picture of steelhead migration in Redwood Creek. The CPUE data indicated a large number of juvenile steelhead were moving past the Orick station and into the estuary in late July and August. If the peak migration had occurred in late July and August, as the data suggest, a corresponding increase in CPUE should have been observed in the estuary. Catch data in the estuary indicated that peak population abundance of steelhead occurred in late June. In addition, recapture of steelhead at the Orick station marked up to a month earlier at the Orick station (Table 2) indicated that the population had temporarily halted migration. Some of the fish caught at the Orick station during late July and August were probably moving into the estuary, but a majority were apparently not migrating. Prior to July and after mid September, none of the steelhead marked were recaptured at the Orick sampling site suggesting the steelhead were moving past the sampling station and into the estuary at those times.

After migrating past the Orick station, the steelhead population appeared to be residing in the estuary. Evidence that the steelhead were not immediately entering the ocean was inferred from the catch data by comparing peak migration timing past the Orick station with the peak CPUE in the estuary. The peak past the Orick station occurred approximately June 1, while a high CPUE persisted in the embayment until the berm was breached in July. The exact time of peak steelhead occurrence in the estuary could not be absolutely determined because the sampling method was not standardized until late June. However, since the juvenile steelhead appeared to be residing in the estuary in June, peak occurrance would be assumed to have occurred in late June.

The berm breaching terminated any possibility of determining the length of residence of juvenile steelhead in the estuary. As was the situation with chinook, most steelhead present in the embayment prior to the breaching entered the ocean during or soon after the breaching. None of the steelhead marked during the June 23 population estimate were recovered during sampling on July 7. Catch data provided other evidence that the steelhead entered the ocean. The number of juveniles inhabiting the embayment prior to breaching was considerably larger than after breaching. The dramatic change in population numbers was demonstrated by the sharp decrease in the number of fish caught in individual seine hauls by area (Figure 6 and Figure 7). Most noticeable was the area near the end of the south levee where 172 steelhead were caught on June 23 and June 24. On July 7, no steelhead were caught in the same area. The water had become extremely shallow. Other areas showed similar trends although not as dramatic. Thus, the majority of juvenile steelhead were prevented from extended use of the estuary.

The role of the estuary in the steelhead's life history and its contribution toward the return of adults has been only slightly addressed in the literature. Shapovalov and Taft (1954) found that juvenile steelhead made the most rapid growth in lagoon and tidewater areas of Waddell Creek, California prior to entering the ocean. They also noted that ocean survival was size dependent. In Waddell Creek, the age structure of downsteam migrating juvenile steelhead was 40 percent age 0+, 40 percent age 1+, and 19 percent 2+ juveniles.

Approximately 57 percent of the returning adult spawners had migrated downstream as age 2+ juveniles emphasizing the age and, hence, size dependency on ocean survival. A small number of larger juveniles contributed greatly to the number of spawners. During the peak migration in Redwood Creek, 79 percent of steelhead migrants were age 1+ juveniles whereas age 2+ juveniles comprised only 9 percent of the number migrating. If only small numbers of steelhead do rear to age 2+ in the upper watershed, then spawner returns depend heavily on survival of age 1+ juvenile steelhead. A study of adult steelhead age at migration would be needed to draw any conclusions about the return of each juvenile age class as adults. Other reasons for the low abundance of age 2+ steelhead in the catch results might be either the peak migration occurred when Redwood Creek was not being sampled or that the age 2+ fish were not as susceptable to capture as the younger age classes. The sample was assumed to be unbiased but generally larger fish are more capable of evading capture by seines than small fish.

Size dependent ocean survival may also operate within a given age class; larger fish may have a better chance of survival (Hoar 1976). The embayment could have provided an environment for rapid growth for age 1+ steelhead before they entered the ocean had the breaching not occurred. The food habits of the juvenile steelhead indicated that productive conditions were established after the peak migration period. Steelhead caught before the breaching in June were feeding on freshwater aquatic insects, primarily chironomid larvae and pupae. After the breaching and reformation of the berm, typical estuarine food items, primarily *Corophium spinicorne*, became the dominant food. Only steelhead that emmigrated in late summer were able to take advantage of the productive conditions.

The berm breaching had consequences other than excluding steelhead from productive conditions. Steelhead survival was probably impacted by the abrupt displacement from freshwater into sea water. Forced entry into sea water by steelhead that have not undergone physiological adaption to the ocean environment, may cause poor growth and survival rates (Adams et al. 1973; Wagner 1974). Wagner found that sea water tolerance of juvenile steelhead was fully developed when fish exceeded approximately 120 mm. The average length of age 1+ steelhead in Redwood Creek in June was 105 mm. The degree that these juvenile steelhead had developed their ability to osmoregulate was not known. The impact of the rapid transition from freshwater to sea water can only be guessed.

Juvenile steelhead were captured in the south slough throughout the sampling year. Peak utilization probably occurred during the peak downstream migration. Adequate catch data were not collected to allow statistical testing to support this judgement. The food habits analysis indicated that the south slough provided a more stable estuarine environment than the embayment. Estuarine invertebrates comprised a portion of the juvenile steelhead's diet throughout the year. During the spring and summer, the amount of available habitat was reduced by the prolific growth of pond weed. More steelhead would probably have utilized the slough had the pond weed not been so abundant during the major migration period and had the slough been more accessable. The north slough was generally unavailable for utilization except to fish that migrated in winter and early spring.

Hatchery Production

The Prairie Creek Hatchery released 54,048 steelhead, 52,708 chinook and 209,081 coho juveniles in the 1979-1980 fiscal year (Sanders 1981). Chinook juveniles were released into a tributary of Prairie Creek as age 1+ fish in March and April (Sanders, personal communication). Only a few hatchery fish were caught during the sampling year. Hatchery fish, recognized by fin-clips and large size, were released before the migration of wild juvenile salmonids. One hatchery coho, identified by a fin clip, was caught in the north slough during a purse seining attempt on April 12. The hatchery coho was 160 mm long. Because of the release and migration timing difference between hatchery and wild salmonids, it appears hatchery fish were not impacting wild juvenile chinook and steelhead utilizing the estuary.

CONCLUSION

Changed estuarine conditions resulted from the construction of flood control levees and have probably contributed to decreased salmonid returns to Redwood Creek. The size of the estuary has been decreased and the north slough eliminated as rearing habitat. Circulation changes have decreased the extent and duration of estuarine conditions. Instead of the creek meandering through the coastal plain, the flow rushes between the levees and out to sea. Cover is virtually non-existent and juvenile rearing habitat poor.

Furthermore, berm breaching in 1980 forced chinook and steelhead to enter the ocean prematurely. Both chinook and steelhead were less than the average lengths described in the literature as being optimum for maximum osmoregulatory ability. The breaching may have reduced the number of juveniles which survived the transition from fresh to sea water. Restoring the historic circulation pattern would assist returning the estuary to a productive condition.

PERSONAL COMMUNICATIONS

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