DOWNSTREAM MIGRATION, GROWTH, AND CONDITION
OF JUVENILE FALL CHINOOK SALMON
IN REDWOOD CREEK, HUMBOLDT COUNTY, CALIFORNIA

by

Joseph F. McKeon

A Thesis

Presented to

The Faculty of Humboldt State University

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

March, 1985

DOWNSTREAM MIGRATION, GROWTH, AND CONDITION

OF JUVENILE FALL CHINOOK SALMON

IN REDWOOD CREEK, HUMBOLDT COUNTY, CALIFORNIA

by

Joseph F. McKeon

Approved by the Master's Thesis Committee

Richard L. Ridenhour, Chairman	11 Mar 85
Richard L. Ridenhour, Chairman	Date
Terrence D. Hofstra	13 March 85
Terrence D. Hofstra	Date
Terry D. Roelofs	12 Mar 85
Terry D. Roelofs	Date
	18 March 85
Director, Natural Resources Graduate Program	Date

85/FI-29/03-08

Natural Resources Graduate Program Number

Approved by the Dean of Graduate Studies

Alba M. Gillespie	June 1985
Alba M. Gillespie	Date

ABSTRACT

Juvenile fall chinook salmon (Oncorhynchus tshawytscha) were trapped while migrating downstream in Redwood Creek in 1981-1983. Salmon were trapped while migrating downstream in Prairie Creek and sampled at Prairie Creek hatchery in 1983. Low flows and warm water temperatures in Redwood Creek in 1981, probably decreased rearing habitat in the river which resulted in an intense migration and early termination of downstream movement. High flows, and low water temperatures during early May in Redwood Creek in 1982, and 1983, may have supported in-river rearing, and temporally extended downstream migration. In all years fish migrated in late May through June. Migration may have been occurring in Prairie Creek prior to the start of sampling on 4 May, 1983. Migration occurred during the evening hours. Movement usually began 1.0 h to 1.5 h after sunset, and ended 1.0 h to 0.5 h prior to sunrise. Weir captures for Redwood Creek were adjusted for percentage of evening hours sampled, and percentage of stream width sampled. Factor analyses, indicated a positive correlation between discharge and adjusted number of fish captured in Redwood Creek, 1981, and a positive correlation between discharge and actual number of fish captured in Prairie Creek, 1983.

Linear models described growth rates of fish seined in Redwood Creek estuary from 27 July through 5 October 1983 [$\hat{Y}^{0.294} = 3.428 + 0.004(x)$, $R^2 = 0.559$, n = 177] and fish sampled at Prairie Creek hatchery from 1 June through 13 October 1983 [$\hat{Y}^{0.294} = 3.339 + 0.005(x)$,

$R^2 = 0.807$, $n = 194$]. Growth rates for estuary fish and hatchery fish were not significantly different ($F = 0.763$, df = 1 and 10, $P > 0.05$). Mean length of hatchery fish at time of release (23 November) was 138 mm, and mean length of the terminal estuarine fish (17 October) was 120 mm. Mean conditions of estuary and hatchery fish were similar during summer and fall, 1983. Scale analyses suggested that fish that spawned in Prairie Creek may have been larger in size than fish that spawned in Redwood Creek, and that fish remained in Redwood Creek estuary for a period of extended growth and not accelerated growth in summer and fall, 1983.

ACKNOWLEDGEMENTS

This study was conducted with funding provided by Redwood National Park, U. S. Department of the Interior, Arcata, California.

Dr. Richard L. Ridenhour, my major professor, helped throughout the study by providing assistance in the field and by offering his advice concerning analyses of data, and preparation of the manuscript. Mr. Terry Hofstra assisted in his effort at securing continued funding and needed personnel for the project, his advice concerning analyses of data, and his review of the manuscript. Dr. Terry Roelofs and Dr. Richard Golightly assisted through their suggestions, comments, and review of the manuscript.

I wish to thank the California Department of Fish and Game for their assistance in providing sampling equipment. I thank the Humboldt County, Public Works Department, and the California Department of Transportation for allowing the use of right-of-way. I thank the personnel of the Humboldt County, Prairie Creek Hatchery for allowing access to the facility, for the use of their equipment, and for their assistance in the collection of data.

I offer a special thanks to my colleagues in the Fish and Wildlife Resources Branch, Technical Services Division, Redwood National Park for their assistance in the field, and their willingness to share their insight and suggestions.

I thank my wife, Linda, for without her unending patience, and advice, this work may not have been accomplished.

TABLE OF CONTENTS

	Page
ABSTRACT	iii
ACKNOWLEDGEMENTS	v
LIST OF TABLES	viii
LIST OF FIGURES	ix
INTRODUCTION	1
STUDY AREA	4
MATERIALS AND METHODS	8
Sampling Methods and Locations	8
Stream Sampling	8
Estuary Sampling	14
Hatchery Sampling	15
Scale Measurements and Analyses	15
Statistical Analyses	17
Estimating Time of Migration	17
Estimating and Comparing Growth Rates	19
Estimating and Computing Condition of Fish	20
Statistical Computation and Testing	20
RESULTS	22
Stream Studies	22
Time of Migration	22
Species Composition ,Size, and Condition	36
Estuary and Hatchery Studies	40
Growth, Size, and Condition	40

TABLE OF CONTENTS (continued)

	Page
Scale Studies	46
Stream Samples	46
Estuary and Hatchery Samples	48
DISCUSSION	56
Trapping Efficiency	56
Factors Affecting Migration	57
Size and Condition	61
Scale Characteristics and Analyses	63
Growth Rate and Life History	64
CONCLUSIONS AND RECOMMENDATIONS	70
REFERENCES CITED	74
APPENDIX	
A. Date, Time, and Number of Juvenile Fall Chinook Salmon Captured in Redwood Creek Weir 1981-1983, and Captured in Prairie Creek Weir, 1983	80

LIST OF TABLES

Table		Page
1	Adjustments to Actual Catch of Juvenile Fall Chinook Salmon for Percentage of Evening Hours Fished, and Percentage of Creek Width Fished for Redwood Creek, 1981-1983, and Prairie Creek, 1983	24
2	Factors and Components of Environmental Parameters and Adjusted Evening Catches of Juvenile Fall Chinook Salmon after Verimax Rotation with Kaiser Normalization	35
3	Mean Platelet Diameter (mm), Mean Circuli Spacing (mm), and Mean Widths (mm) of the First and Second Bands of 5 Circuli at 114X Magnification for Prairie Creek and Redwood Creek Seine Site Juvenile Fall Chginook Salmon, 1983	49
4	Mean Riverine and Mean Estuarine Circuli Spacing (mm) at 114X Magnification on Scales of Juvenile Fall Chinook Salmon Captured in Redwood Creek Estuary from 27 July (day 88) through 5 October (day 158), 1983	54
5	Mean Riverine and Mean Estuarine Circuli Spacing (mm) at 114X Magnification on Scales of Juvenile Fall Chinook Salmon Captured in Redwood Creek Estuary from 27 July (day 88) through 5 October (day 158), 1983	55

LIST OF FIGURES

Figure		Page
1	Lower Redwood Creek Basin, Humboldt County, California Showing Locations of the Weirs, the Redwood Creek Estuary, and the Prairie Creek Hatchery	5
2	Redwood Creek Estuary Showing Several Locations of the 1983 Seine Sites	6
3	Inclined Plane Traps in Redwood Creek, 1981 (upper), and Weir in Prairie Creek, 1983 (lower)	10
4	Rear Section of Weir Showing Adjustable Panels with Inclined Plane and Removable Holding Bucket (upper), and Weir in Redwood Creek, 1983 (lower)	11
5	Relationship Between Cumulative Percentage of Juvenile Salmon Captured and Percentage of Evening (sunset to sunrise) Hours Fished for Redwood Creek, 1981-1983 . . .	27
6	Relationship Between Cumulative Percentage of Juvenile Salmon Captured and Percentage of Evening (sunset to sunrise) Hours Fished for Prairie Creek, 1983	28
7	Adjusted Number of Juvenile Salmon Captured, Lunar Phase, Mean Evening River Temperature, and Mean Daily River Discharge in Redwood Creek, 1981	29
8	Adjusted Number of Juvenile Salmon Captured, Lunar Phase, Mean Evening River Temperature, and Mean Daily River Discharge in Redwood Creek, 1982 . . .	30
9	Adjusted Number of Juvenile Salmon Captured, Lunar Phase, Mean Evening River Temperature, and Mean Daily River Dishcarge in Redwood Creek, 1983 . . .	31
10	Number of Juvenile Salmon Captured, Lunar Phase, Mean Evening River Temperature, and Mean Daily River Dishcarge in Prairie Creek, 1983 . . .	32
11	Length of Juvenile Salmon Captured in Redwood Creek, 1981 (upper), and 1982 (lower)	38

Figure		Page
12	Length of Juvenile Salmon Captured in Redwood Creek and Seined at Redwood Creek Seine Site, 1983 (upper), Captured in Prairie Creek, 1983 (lower)	39
13	Mean Condition Factors of Juvenile Salmon Captured in Prairie Creek and Redwood Creek and Seined at Redwood Creek Seine Site, 1983	41
14	Relationship Between Fork Length and Day of Capture for Juvenile Salmon Seined in the Redwood Creek Estuary 1983	43
15	Relationship Between Fork Length and Sample Day for Juvenile Salmon Sampled at the Prairie Creek Hatchery, 1983	44
16	Mean Condition Factors of Juvenile Salmon from Prairie Creek Hatchery, and Redwood Creek Estuary (after downstream migration), 1983	45
17	Relationship Between River Circuli and Day of Capture for Juvenile Salmon in Redwood Creek, 1981-1983	47
18	Relationship Between Number of Circuli Classified as Estuarine and Day of Capture for Juvenile Salmon in Redwood Creek Estuary 1983	51
19	Number of Riverine Circuli on Day of Capture for Juvenile Salmon in Redwood Creek Estuary, 1983	52

INTRODUCTION

Depending on race and geographic location, chinook salmon (*Oncorhynchus tshawytscha*) may rear in a riverine or estuarine environment for a few months to a year before entering the sea (Meehan and Siniff 1962; Reimers and Loeffel 1967; Reimers 1973, 1978; Healey 1980). Redwood Creek, Humboldt County, California, supports a fall run of chinook salmon, however, the abundance of salmon has declined dramatically in the last few decades (Division of Ecological Services 1975; Hofstra 1983). This decline has raised concern regarding the degradation of salmon spawning habitat and juvenile rearing habitat in Redwoood Creek basin. The decline in abundance of salmon has also raised concern regarding the altered estuarine environment at the mouth of Redwood Creek and its impact on growth and condition of juvenile salmon (Larson et al. 1981, 1983; Hofstra 1983). Logging in the upper watershed, and subsequent severe flooding has resulted in an aggraded stream channel. Levee construction and creek channelization near the mouth of the creek has modified the estuarine environment (Ricks 1983).

Biologists and managers need an understanding of biotic processes in order to properly manage a fisheries resource. Acknowledging this fact, Redwood National Park initiated a project in 1980, to determine abundance, distribution, and seasonal timing of use of Redwood Creek estuary by various fish species (Hofstra 1983).

Studies of estuarine habitats have shown the importance of the estuarine environment to chinook salmon (Reimers 1973; Healey 1980, 1982; Kjelson et al. 1982; Simenstad et al. 1982). Reimers (1978) suggested that the greatest use of estuaries by anadromous salmonids in terms of length of residence, and life history dependency, was made by fall chinook salmon.

Though temporally separated, both wild salmon and hatchery salmon contribute to the total outmigrant population in Redwood Creek. The growth and condition of juvenile salmon in Redwood Creek has not been well documented. Furthermore, knowledge is limited concerning the impacts of watershed perturbations on the downstream migration of juvenile salmon and the utilization of modified estuarine environments by juvenile chinook salmon.

This study described the time of downstream migration, growth, and condition of juvenile salmon in Redwood Creek in 1981, 1982, and 1983. The time of downstream migration for Prairie Creek fish was determined for 1983. Growth and condition of chinook salmon in Prairie Creek hatchery were compared to growth and condition of wild fish in Redwood Creek estuary. Scale characteristics were described for wild fish in Redwood Creek in each year. Scale characteristics were described for wild fish in Prairie Creek and in Redwood Creek estuary, 1983, and for fish in Prairie Creek hatchery, 1983.

This investigation provides an understanding of the life history patterns of wild chinook salmon in Redwood Creek. It establishes a data base to describe life history patterns of wild and hatchery reared salmon that return to spawn in the basin, and it complements the research goals of the National Park Service. Understanding the relationship between juvenile life history and survival to maturity for chinook salmon in Redwood Creek will give managers a rationale for providing and maintaining suitable rearing habitat near the mouth of the creek. The investigation provides managers with comparative information concerning growth and condition of wild and hatchery salmon enabling them to assess the benefits of hatchery supplementation. Knowledge gained by this investigation may support endeavors directed at rehabilitating or restoring the estuarine environment near the mouth of Redwood Creek.

STUDY AREA

Prairie Creek drainage and lower Redwood Creek drainage are within the coast redwood belt of the Humid Transition Life Zone (Briggs 1953) (Figure 1). Redwood Creek basin covers 73,038 ha in the northern Coast range of California. The basin is elongated in a north-northwesterly direction and is approximately 101.4 km in length and 2.8 km to 4.4 km in width. The altitude ranges from sea level at the mouth to 1615.4 m at the headwaters of the basin (Iwatsubo and Averett 1981). Redwood Creek enters the sea approximately 3.2 river km west of Orick, California.

Prairie Creek enters Redwood Creek at a point approximately 6.1 river km from the sea. The altitude of Prairie Creek ranges from sea level to about 305 m. The Creek is approximately 22.5 km long and drains an area of 7500 ha (Briggs 1953).

Historically, the lower reach of Redwood Creek was characterized by a meandering channel with an extensive riparian zone, and a stable estuarine environment (Larson et al. 1983). Severe flooding in 1955 and again in 1964, prompted the County of Humboldt to seek support from the Army Corps of Engineers to construct a flood control project along the lower reach of the creek. The lower 6.3 km of the creek was considerably altered with completion of channelization and levee construction in 1968 (Ricks 1983) (Figure 2).

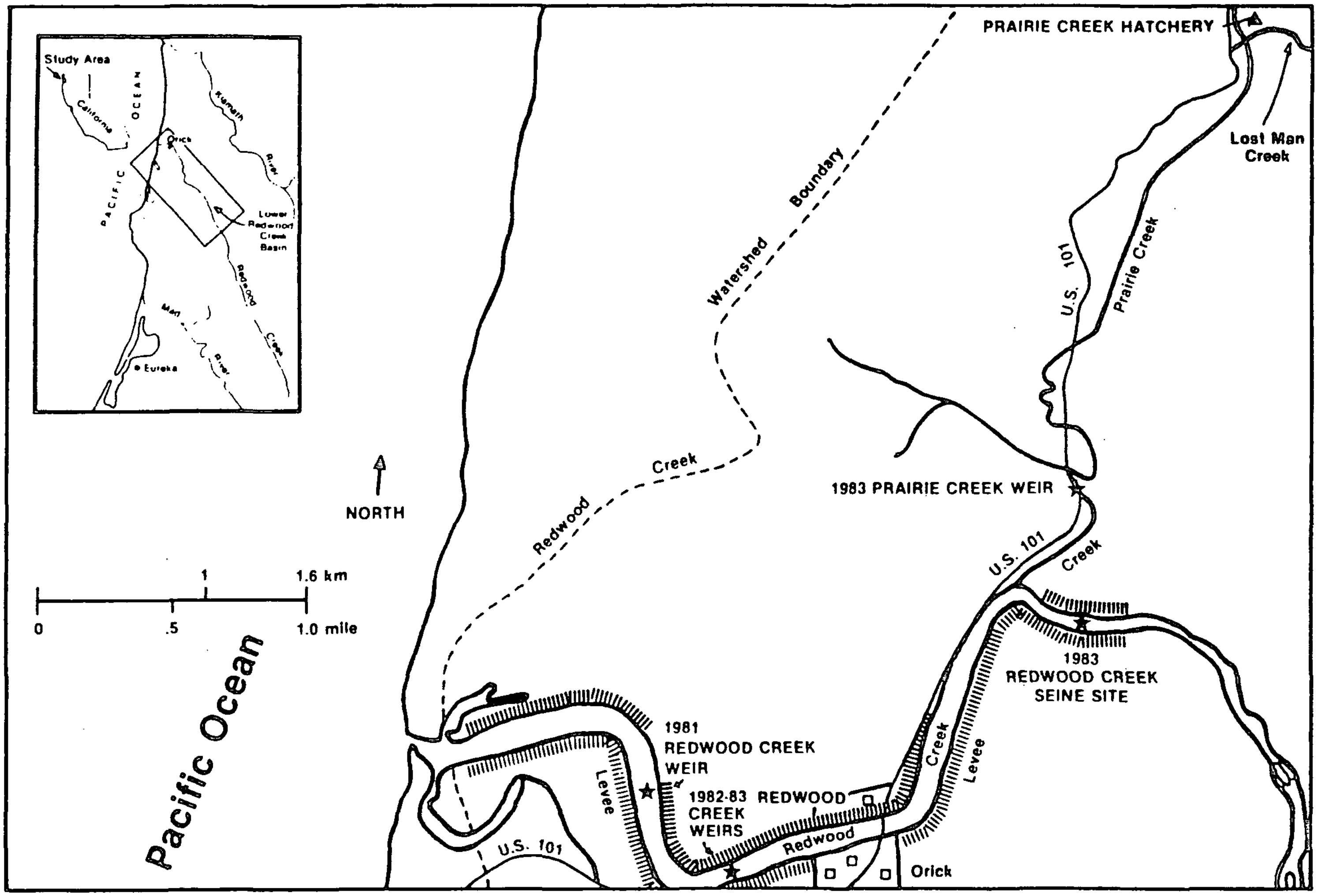


Figure 1. Lower Redwood Creek Basin, Humboldt County, California Showing Locations of the Weirs, the Redwood Creek Estuary, and the Prairie Creek Hatchery.

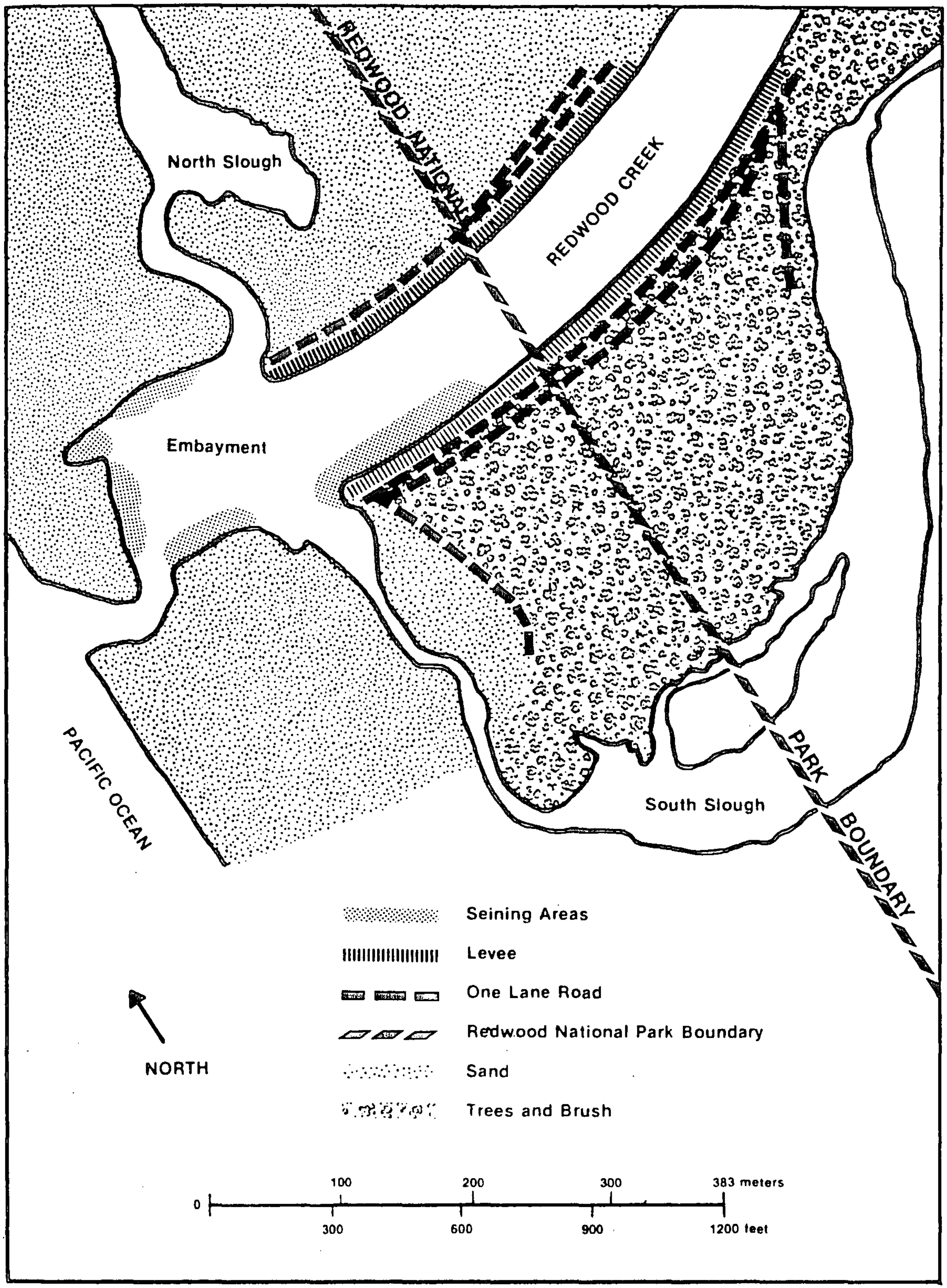


Figure 2. Redwood Creek Estuary Showing Several Locations of the 1983 Seine Sites.

Prairie Creek hatchery is located near the mouth of Lost Man Creek. Lost Man Creek joins Prairie Creek 4.75 km upstream from the mouth of Prairie Creek (Figure 1). The hatchery's primary purpose has been the propagation of coho (*Oncorhynchus kisutch*) and chinook salmon (*O. tshawytscha*), and steelhead trout (*Salmo gairdneri*). The hatchery began a program of extended rearing of chinook salmon in 1978. Since 1978, fish have not been released during the time of downstream migration of wild chinook salmon, but have been released at the time of the first fall freshets (S. Sanders, Superintendent, Prairie Creek Hatchery, Orick, CA 95555).

MATERIALS AND METHODS

Sampling Methods and Locations

Stream Sampling

A weir and seines were used to sample juvenile salmon in Redwood Creek, 1981-1983, and in Prairie Creek, 1983. Juvenile refers to fish without yolk sacs, and greater than 40 mm in length. Sample sites along Redwood Creek did not remain consistent in all years due to natural variation in the meandering thalweg, and year to year variation in size and depth of the embayment that develops near the mouth of the creek. Oceanic processes in spring and summer often cause a sand berm to form across the mouth of the creek, which can raise the water level in the embayment (Larson et al. 1983). The weir site established in 1981 was abandoned midway through 1982, and moved upstream to an area unaffected by the rising water level in the embayment.

It was assumed that all salmonids captured in the weir were migrating seaward. Ewing et al. (1980) made similar assumptions regarding the seaward migration of chinook salmon with seaward migration being defined as either active or passive movement from a point upstream to a point downstream. Hasler and Scholz (1983) described downstream migration incorporating the models of passive drift and directed movement.

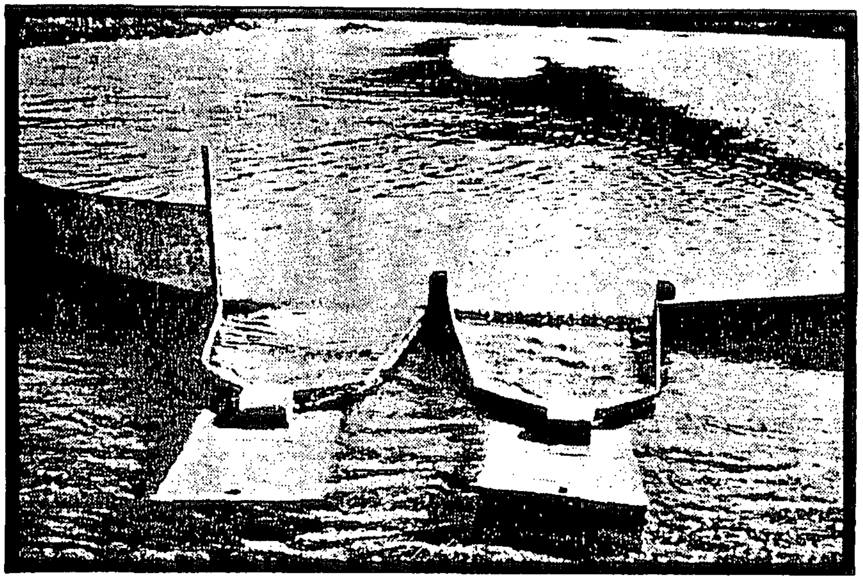
The 1981 weir site in Redwood Creek was at river km 2.6. The weir was located at river km 3.6 in 1982 and 1983 (Figure 1). The

Prairie Creek weir was located approximately 0.5 km upstream from the confluence with Redwood Creek in 1983.

Inclined plane traps at the terminal end of the weir were used to capture juvenile salmon in Redwood Creek in 1981. These traps were similar to the type described by Lister et al. (1969), Harper (1980), and Healey (1980). Two traps were deployed side by side at the edge of the creek. Additions to the trap assembly included 1.2 m by 3 m interlocked panels of 0.75 cm^2 wire mesh that acted as a barrier and guide for migrant fish (Figure 3).

A portable weir was constructed in 1982 for use in Redwood Creek using 1.27 cm rebar, 0.5 cm^2 wire mesh, perforated sheet steel, and 1.2 m by 3.0 m interlocked panels of 0.75 cm^2 wire mesh (Figure 3). This weir, modified for use in Redwood Creek and Prairie Creek in 1983, was 3.0 m long, and was 1.5 m wide at the mouth. The throat of the weir was fitted with hinged wire mesh panels, a hinged inclined plane, and a removable holding basket (Figure 4). It captured a wide size range of various fish species, and could be set in deeper, swifter portions of the creek (Figure 4). At high flows, only a portion of the total flow could be sampled. At low flows, the weir extended across the full width of the creek.

In all years the weir was deployed on the same day once each week, usually from 1 May until 1 August. High flows resulting in equipment failure prevented sampling prior to 1 May in all years. Sampling dates in Redwood Creek were from 2 May 1981 through 24 July 1981, from 3 May through 2 August 1982, from 2 May through 8 August 1983, and in Prairie Creek from 5 May through 3 August 1983.



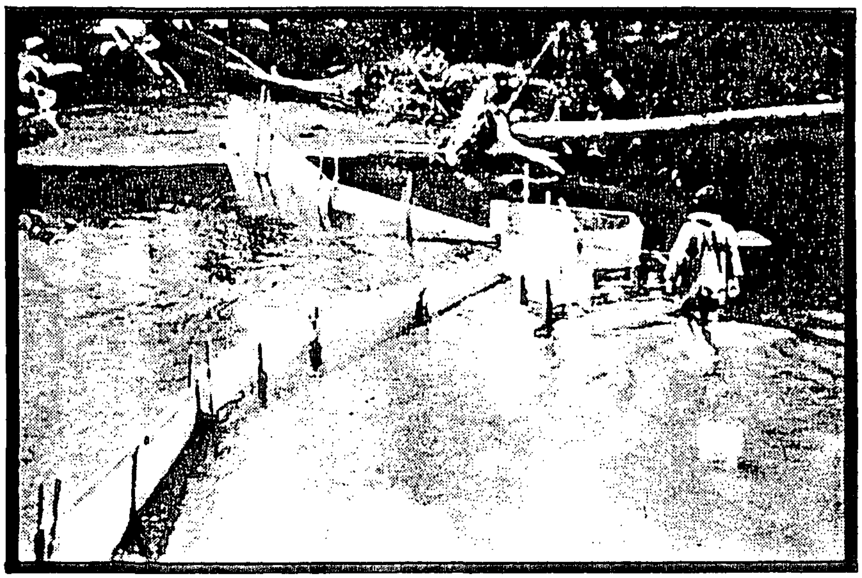
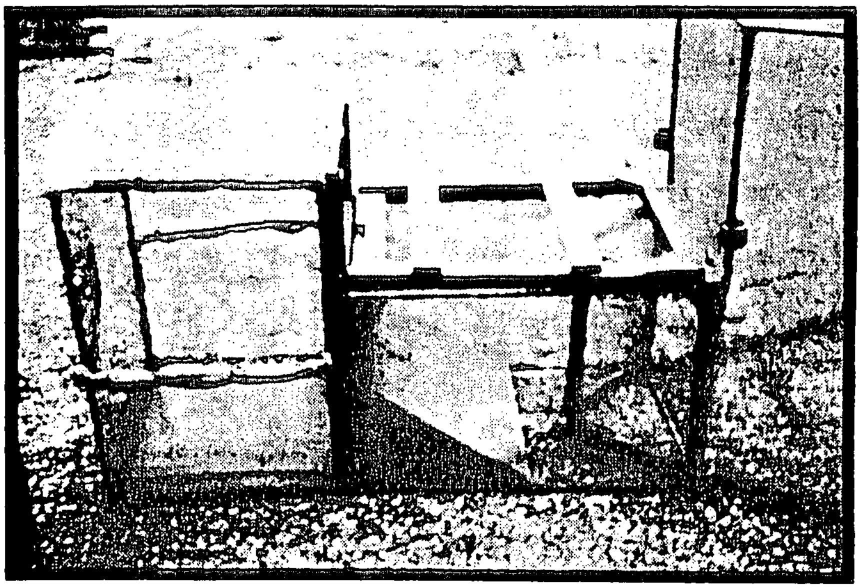


Figure 3. Inclined Plane Traps in Redwood Creek, 1981 (upper), and Weir in Prairie Creek, 1983 (lower).



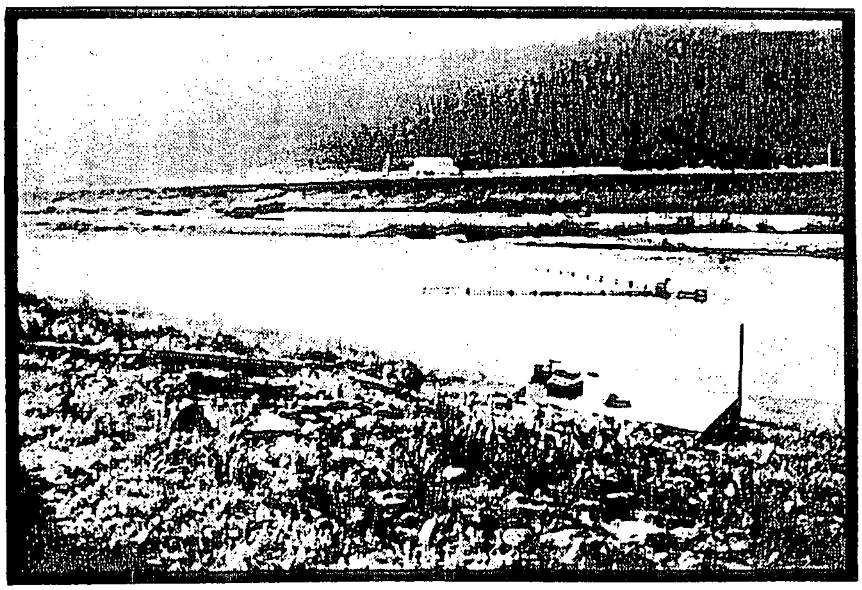


Figure 4. Rear Section of Weir Showing Adjustable Panels with Inclined Plane and Removable Holding Bucket (upper), and Weir in Redwood Creek, 1983 (lower).

In 1981 the weir was usually in place at sunset and was removed 1.0 h after midnight. Periodically it was in place from sunset on one day until sunrise on the following day. The weir was always in place and functioning from 1900 h to 0800 h the following day in 1982 and 1983. The studies of Meehan and Siniff (1962), Reimers (1973), and Mason (1975) provided evidence that juvenile salmonids migrate nocturnally.

The weir was in place in Redwood Creek during the day on two occasions in 1981 and 1982, and on one occasion in 1983 to determine if salmon were migrating during daylight hours. In 1981 the weir was in place on 2 May and 9 May from approximately 12 noon until sunset. In 1982 the weir was in place on 14 June and 15 July from approximately 0800 h until sunset, and in 1983 the weir was in place on 31 May from 0800 h until sunset.

In 1981 the weir was cleared of debris using a large wire brush, and fish were removed usually every four hours. In 1982 and 1983, the weir was similarly cleared of debris, and fish were removed usually every three hours. In all years, wind and rain caused an increase in the drift of leaves and woody debris, resulting in the need to clean the weir at more frequent intervals.

Captured fish were anaesthetized with Tricane Methanesulfonate (MS-222), scale samples were obtained, and field measurements of length and weight were made prior to release. With the exception of 1981, total length and fork length of each fish was recorded to the nearest millimeter, and total weight was recorded to the nearest 0.1 gram. Total length to the nearest millimeter was recorded in 1981. Fish captured in the Redwood Creek weir in 1983 and seined at Redwood Creek seine site in 1983 were used to generate a regression equation to estimate the fork length of fish captured in 1981.

In 1982 and 1983, if more than 10 fish were present in the weir at the time they were to be removed, the first 10 fish, and every fifth fish thereafter were measured and weighed and scale samples were obtained. With the capture of 10 or fewer fish, all fish were usually measured and weighed, and scale samples were obtained. Fish were not systematically sampled in 1981, but were occasionally measured and weighed, and scale samples were obtained. All enumerated fish, regardless of hour of capture, were said to be captured on the date that sampling began.

In every year, the Redwood Creek weir was located downstream from the mouth of Prairie Creek. A seine site was established immediately upstream from the mouth of Prairie Creek in 1983 (Figure 1). An 18.0 m by 1.8 m seine with 4.0 mm stretched mesh was used to sample fish at this location.

Fish were seined downstream from the weir in each year. These fish, and fish captured in the weir, were periodically marked and released upstream from the weir sites to estimate capture efficiency. A panjet tattooing device (Wright Dental Group, Dundee, Scotland), and dorsal and ventral caudal clips were used to provide variable color and variable fin marks (Hart and Pitcher 1969). On days that capture efficiency was tested, fish were marked and released early in the evening. Trap efficiency for each year was calculated by determining the percentage of recapture for all marked fish released during each year (Miller 1970).

Water temperature was recorded when fish were removed from the weir. Mean water temperature for each sample date was determined. Daily water discharge measurements for Redwood Creek were available from the U. S. Geological Survey, Eureka, California (U. S. Geological Survey 1981, 1982, 1983). Measurements were made at the Highway 101 bridge in Orick, California, approximately 1.0 km upstream from the 1982 and 1983 weir site, and 1.5 km upstream from the 1981 weir site. Discharge in Prairie Creek was recorded at a location immediately upstream from the weir using a Weather Measurement flow meter (Model F581-DR, Weather Measurement Corporation, Sacramento, California).

Number of evening moonlight hours ($\pm$ 0.17 h) was calculated for a point near the mouth of Redwood Creek at 41° 17" North latitude and 124° 05" West longitude (Astronomical Almanac for Year 1981, 1982, 1983; Royal Astronomical Society of Canada 1981, 1982, 1983). Evening refers to the period from sunset on one day to sunrise on the following day.

Estuary Sampling

Estuary fish were captured in 1983 using a 49.0 m by 3.6 m beach seine with 1.0 cm stretched mesh. Seine hauls were made in the same general locations on each sampling date. Sample sites were located along the edge of the south levee, and along the berm near the mouth of the creek (Figure 2). Estuary sampling began on 29 June 1983 and terminated on 17 October 1983. Random samples of approximately 30 fish were obtained from the seine catches, usually at two week intervals, on 10 sampling dates. Fork length to the nearest millimeter and scale samples of each fish were obtained on all sample dates. Weights were obtained on three dates.

Hatchery Sampling

Sampling of hatchery fish began on 1 June 1983, and terminated on 23 November 1983. Sampling occurred at 15 to 20 day intervals, with the exception of the last two sampling intervals which were 51 and 41 days respectively. A scale sample, fork length to the nearest millimeter, and weight to the nearest 0.1 gram were obtained and recorded for approximately 30 fish on each sampling date. The same group of fish was sampled throughout the season. These fish were from the earliest spawn, and were the oldest fish (approximate age of 110 days) at the start of sampling. On 30 May 1983, fish were divided between two rearing ponds, and on 4 August 1983 a few of the larger, younger fish were combined with the sampled group.

Fish were reared at a constant temperature of 11° C, and were fed a ration of Oregon Moist Pellet (OMP). At the end of sampling on 23 November 1983, this group was estimated to number 10,500, which was approximately 50 percent of the total chinook salmon released by the hatchery in 1983.

Scale Measurements and Analyses

Scale samples were obtained from the left side of each fish in an area immediately above the lateral line and slightly posterior to the origin of the dorsal fin (Bohn and Jensen 1971). Scales were mounted and examined in a manner similar to the methods used by Bohn and Jensen (1971), Reimers (1973), and Schluchter and Lichatowich (1977). Scales from each fish were mounted on a glass slide, and were projected to a table top at a magnification of 114X using a Bausch and Lomb microprojector. Counts of circuli, and measurements, were made for two scales from each fish. All measurements were made on the anterior portion of each scale at two anterior 20° radial lines. A paper overlay with a focus, a horizontal and vertical axis, and an anterior 20° dorso-radial line and an anterior 20° ventro-radial line, was oriented over each scale image. The inner and outer edge of the first circulus, the outer edge of all subsequent circuli, and the outer edge of the scale, were marked along each anterior 20° radial line. Enumeration of irregular circuli followed the method used by Clutter and Whitsel (1956). The greatest platelet diameter regardless of horizontal/vertical orientation was measured to the nearest 0.1 mm using vernier calipers.

A total circuli count for each fish was determined from the scale with the highest circuli number. Each fish was assigned a discrete total circuli number. If the difference in circuli counts between scales was greater than two, the scale sample was discarded (Clutter and Whitsel 1956). Measurements to the nearest 0.1 mm were made from the outside edge of the first circulus, to the outer edge of the last circulus for each scale (Bilton 1975). Mean platelet diameter, mean circuli spacing, and width of the first two bands of five circuli of Prairie Creek and Redwood Creek fish were measured to the nearest 0.1 mm for analyses to identify stocks (Martin 1978). The inner edge of the first circulus was often difficult to clearly differentiate. To increase precision, the measurement was made from the outside edge of the first circulus to the outer edge of the fifth circulus. The second band included the sixth through the tenth circuli, and a measurement was made from the outside edge of the fifth circulus, to the outer edge of the tenth circulus.

Circuli of fish captured in the estuary in 1983 were classified into two zones: riverine, or estuarine. Circuli formed in freshwater are often finer in structure, of lesser height, and closer together than circuli formed in seawater (Clutter and Whitsel 1956). Mean circuli spacing for each zone was determined by dividing the measured river growth zone and the measured estuary growth zone by their respective number of intercirculi spaces (Clutter and Whitsel 1956; Reimers 1973; Schluchter and Lichatowich 1977).

Statistical Analyses

Estimating Time of Migration

Factor analyses were used to detect interrelationships among variables which could explain and describe peaks in downstream migration of fish. The statistical package for the social sciences (SPSS), was used to perform factor analyses involving adjusted number of trapped fish, mean daily river discharge, mean evening water temperature, and evening moonlight hours (Nie et al. 1975).

In all calculations and graphical illustrations, sample dates were denoted as Julian date minus a constant (K), with K = 121. In all years, 1 May was coded as day one. In Redwood Creek in 1981, the weir was often in place for only part of the evening. In 1982 and 1983, the weir was in place throughout the whole evening. During high flows in

Redwood Creek, only a portion of the total flow could be sampled. Adjustments to actual catch of juvenile salmon for percentage of evening hours fished, and percentage of the creek width sampled, were made for Redwood Creek in 1981. Adjustments to actual catch of fish for percentage of creek width sampled were made for Redwood Creek in 1982, and 1983. No adjustments were necessary for Prairie Creek weir captures in 1983. In Prairie Creek the weir extended across the full width of the creek, and was always in place throughout the whole evening. A graph of cumulative percentage of fish captured versus cumulative percentage of evening hours fished was constructed for Redwood Creek in 1981, 1982, and 1983, and for Prairie Creek in 1983. Each graph was developed from data obtained on dates when the weir was in place throughout the whole evening (Appendix A). The total catch on dates when the weir was in place for only part of the evening was estimated by use of the graphs. The graphs also provided a way to assess similarities and differences in diurnal downstream movement of salmon among years in Redwood Creek, and in Prairie Creek in 1983. A composite graph was constructed using data obtained in all three years in Redwood Creek.

In Redwood Creek in 1981 when the weir was in place for only part of the evening, adjustments to actual catch for percentage of the evening fished were obtained from the composite graph of cumulative percentage of fish captured versus cumulative percentage of evening hours fished. Adjustments to actual catch for percentage of creek width fished were based on the assumption that the population of migrant fish was evenly distributed across the width of the creek at each weir location. Adjusted catches were used in factor analyses of Redwood Creek data for 1981, 1982, and 1983. Actual catches were used in the factor analysis of Prairie Creek data for 1983.

Estimating and Comparing Growth Rates

Growth rates of wild fish seined in the estuary and fish sampled at the hatchery in 1983 were compared. Growth rates were determined from regressions of fork length on sample date using individual fish as observations. Only fish captured after river migration had terminated were used to determine growth rate in the estuary.

Mean platelet diameter, mean circuli spacing, and widths of the first and second bands of five circuli were compared from a sample of 49 Prairie Creek and 49 Redwood Creek fish captured in 1983 using two sample t-tests. A significance level of P=0.05 was used.

Fish captured in the estuary were stratified by sample date and number of riverine circuli. Comparisons between the spacing of riverine circuli and the spacing of estuarine circuli were made using two sample t-tests, at a significance level of P=0.05.

Regressions of scale circuli number on sample date were calculated for migrant fish in Redwood Creek for years 1981, 1982, and 1983 (Buckman and Ewing 1982). Regressions of total number of scale circuli on sample date for estuary fish (after downstream river migration) and hatchery fish were calculated and compared. Regressions of number of riverine circuli on sample date, and number of estuarine circuli on sample date were calculated for fish captured in the estuary from 27 July (day 88) through 5 October (day 158), 1983. All regressions were calculated using individual fish as observations.

Estimating and Computing Conditon of Fish

Mean coefficient of condition (condition factor) was calculated for hatchery fish, and wild fish sampled at all locations in 1983. Mean coefficient of condition (Fessler and Wagner 1969; Ricker 1975; and Bagenal and Tesch 1978) was computed using the formula:

$$\bar{K}_{FL} = \frac{\sum_{i=1}^{n} K_{FL}}{n}$$

Where: K_{FL}=coefficient of condition for individual fish, n=sample size, and $\bar{K}_{FL}$=mean coefficient of condition (condition factor). Approximate tests of equality among all pairs of mean condition factors were made using the Games and Howell Method to determine significant differences in condition between Prairie Creek and Redwood Creek fish, and estuary and hatchery fish (Sokal and Rohlf 1981). A significance level of P=0.05 was used.

Statistical Computation and Testing

The Scheffe-Box test was used to test for heteroscedasticity in 1983 samples of fork length for estuary fish and hatchery fish. Bartlett's test for homogeniety of variance was used to test for heteroscedasticity among samples used in scale analyses. In all regression analyses the Box-Cox transformation was used to provide for homogeneity of variances (Sokal and Rohlf 1981). F-tests were used to compare regression coefficients, and t-tests were used to compare Y-intercepts (Brownlee 1965; Zar 1974; Sokal and Rohlf 1981). All tests were made using the P=0.05 significance level.

The Minitab statistical computing system was used to collate raw data, and estimate simple descriptive statistics (Ryan et al. 1976). BIOM, a package of statistical computer programs, was used in the more advanced statistical computations (Rohlf 1982). Graphs and plots were constructed using the Interactive Graphing Package and Minitab (Ryan et al. 1976; Tektronix, Inc. 1977).

RESULTS

Stream Studies

Time of Migration

In Redwood Creek in all years, sampling was incomplete at high flows. As the flows receded, the weir extended across a greater portion of the creek. Sampling in Redwood Creek was usually incomplete when flows exceeded 7 cms. At flows below 7 cms the entire creek was sampled. The weir extended across the entire width of Prairie Creek at all times, and maximum flow at the start of sampling in 1983 was estimated to be 2.5 cms. Trap catches described the time of downstream migration and peaks in migration of migrant chinook salmon.

The recapture of marked fish released upstream of the weir provided a measure of overall trapping efficiency. There were 29 recaptures of 208 fish that were marked and released in Redwood Creek during 1981. In 1982, there were 31 recaptures of 168 fish that were marked and released. In 1983, there were 13 recaptures of 37 fish that were marked and released. There were 42 recaptures of 157 fish that were marked and released in Prairie Creek during 1983. Recapture percentages for Redwood Creek in 1981, 1982, and 1983, and for Prairie Creek in 1983, were 13.9 percent, 18.5 percent, 35.1 percent, and 26.8 percent, respectively.

The adjusted catches for percentage of evening hours fished and percentage of creek width fished in Redwood Creek in 1981, 1982, and 1983, and Prairie Creek in 1983, were determined (Table 1).

Cumulative catches of chinook in Redwood Creek and Prairie Creek did not exceed 20 percent of total catch for the night until approximately 50 percent of the evening hours had passed (Figure 5, 6). Fish tended to migrate earlier in the evening in Redwood Creek in 1981 than in 1982 and 1983. A greater percentage of fish were captured during the first half of the evening in Prairie Creek than in Redwood Creek in 1983 (Figures 5, 6).

Fish were not captured on dates when the weir was in place throughout the daylight hours in Redwood Creek (Appendix A). On many occasions in both Redwood Creek and Prairie Creek, the weir was still in place following sunrise. It was assumed that fish present in the weir after sunrise had been captured during the evening hours. This assumption was supported by the fact that fish were not captured during daylight sampling times and fish were not present in front of the weir after sunrise.

During 1981, fish in Redwood Creek tended to exhibit a bimodal pattern of migration, with peaks near 30 May (day 30), and 20 June (day 51) (Figure 7). Peaks in migration in 1982 occurred near 10 May (day 10), and near 21 June (day 52) and 5 July (day 66) (Figure 8). As in 1982 the migration was somewhat trimodal in 1983 with peaks occurring near 31 May, 20 June, and 11 July (days 31, 51, and 72) (Figure 9). A broader trimodal pattern was evident for migration of Prairie Creek fish in 1983 (Figure 10). Peaks in migration occurred near 18 May, 1 June,

Table 1. Adjustments to Actual Catch of Juvenile Fall Chinook Salmon for Percentage of Evening Hours Fished, and Percentage of Creek Width Fished for Redwoood Creek, 1981-1983, and Prairie Creek, 1983. Adjustments to the actual catch for percentage of evening fished in Redwood Creek, 1981 were derived from the composite curve in Figure 5.

					Adjustments		
Site/Year	Date	Coded date	Actual catch	Percent night hours fished	Fraction of fish catch/night	Fraction of creek width fished	Adjusted catch[a]
Redwood Creek							
1981	5-2	2	0	37.8	0.227	0.437	0
	5-9	9	4	37.7	0.227	0.437	40
	5-16	16	6	41.4	0.287	0.437	48
	5-23	23	114	100.0	1.000	0.653	175
	5-30	30	330	56.7	0.600	0.909	605
	6-10	41	381	100.0	1.000	1.000	381
	6-13	44	34	44.9	0.390	1.000	87
	6-20	51	263	100.0	1.000	1.000	263
	6-27	58	101	100.0	1.000	1.000	101
	7-3	64	33	100.0	1.000	1.000	33
	7-11	72	2	42.9	0.340	1.000	6
	7-18	79	0	45.8	0.413	1.000	0
	7-24	85	0	42.0	0.320	1.000	0
							1739
Redwood Creek							
1982	5-3	3	2	100.0	1.000	0.056	36
	5-10	10	4	100.0	1.000	0.056	71
	5-17	17	2	100.0	1.000	0.056	36
	5-24	24	5	100.0	1.000	0.049	102
	5-31	31	8	100.0	1.000	0.049	163
	6-7	38	5	100.0	1.000	0.049	102
	6-14	44	0	100.0	1.000	0.049	0
	6-21	52	17	100.0	1.000	0.268	63

Table 1. Adjustments to Actual Catch of Juvenile Fall Chinook Salmon for Percentage of Evening Hours Fished, and Percentage of Creek Width Fished for Redwoood Creek, 1981-1983, and Prairie Creek, 1983. Adjustments to the actual catch for percentage of evening fished in Redwood Creek, 1981 were derived from the composite curve in Figure 5. (Continued)

Site/Year	Date	Coded date	Actual catch	Percent night hours fished	Adjustments: Fraction of fish catch/night	Adjustments: Fraction of creek width fished	Adjusted catch[a]
	6-28	59	10	100.0	1.000	0.732	14
	7-6	67	54	100.0	1.000	0.732	74
	7-12	73	18	100.0	1.000	0.554	32
	7-19	80	0	100.0	1.000	0.554	0
	7-26	87	0	100.0	1.000	0.616	0
	8-2	94	0	100.0	1.000	0.616	0
							693
Redwood Creek 1983	5-2	2	2	100.0	1.000	0.222	9
	5-9	9	3	100.0	1.000	0.148	20
	5-16	16	11	100.0	1.000	0.415	27
	5-23	23	7	100.0	1.000	0.159	44
	5-31	31	41	100.0	1.000	0.281	146
	6-6	37	10	100.0	1.000	0.281	36
	6-13	44	8	100.0	1.000	0.281	28
	6-20	51	41	100.0	1.000	0.410	100
	6-27	58	4	100.0	1.000	1.000	4
	7-4	65	2	100.0	1.000	1.000	2
	7-11	72	42	100.0	1.000	1.000	42
	7-18	79	5	100.0	1.000	1.000	5
	7-25	86	5	100.0	1.000	1.000	5
	8-1	93	0	100.0	1.000	1.000	0
	8-8	100	1	100.0	1.000	1.000	1
							469

Table 1. Adjustments to Actual Catch of Juvenile Fall Chinook Salmon for Percentage of Evening Hours Fished, and Percentage of Creek Width Fished for Redwoood Creek, 1981-1983, and Prairie Creek, 1983. Adjustments to the actual catch for percentage of evening fished in Redwood Creek, 1981 were derived from the composite curve in Figure 5. (Continued)

					Adjustments		
Site/Year	Date	Coded date	Actual catch	Percent night hours fished	Fraction of fish catch/night	Fraction of creek width fished	Adjusted catch[a]
Prairie Creek							
1983	5-4	4	43	100.0	1.000	1.000	43
	5-11	11	51	100.0	1.000	1.000	51
	5-18	18	123	100.0	1.000	1.000	123
	5-25	25	34	100.0	1.000	1.000	34
	6-1	32	130	100.0	1.000	1.000	130
	6-8	39	70	100.0	1.000	1.000	70
	6-15	46	60	100.0	1.000	1.000	60
	6-22	53	14	100.0	1.000	1.000	14
	6-29	60	6	100.0	1.000	1.000	6
	7-6	67	31	100.0	1.000	1.000	31
	7-13	74	21	100.0	1.000	1.000	21
	7-20	81	8	100.0	1.000	1.000	8
	7-27	88	3	100.0	1.000	1.000	3
	8-3	95	0	100.0	1.000	1.000	0
							594

[a]Adjusted catch = (Actual catch)/(fraction of fish catch/night) (fraction of creek width fished)

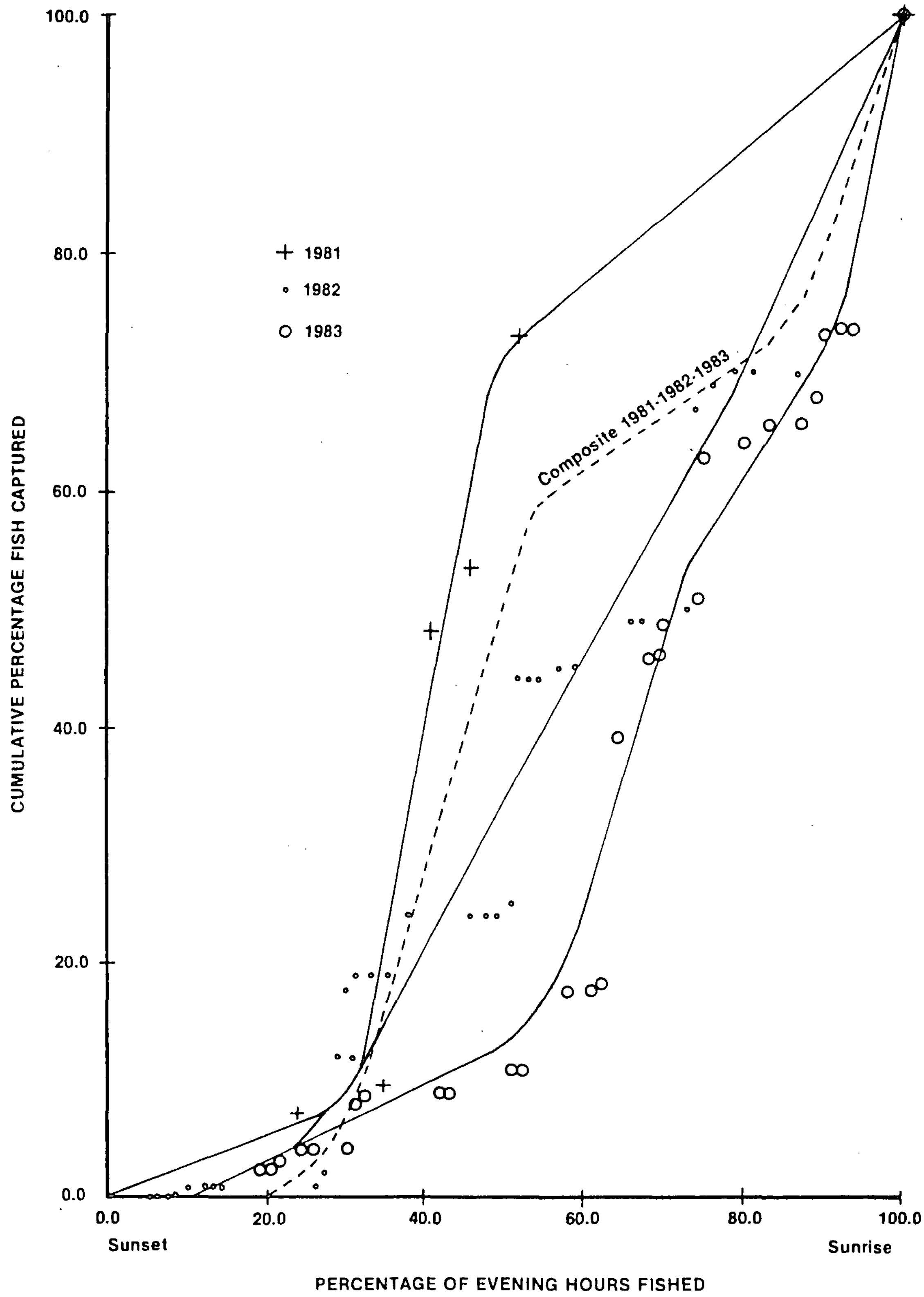


Figure 5. Relationship Between Cumulative Percentage of Juvenile Salmon Captured and Percentage of Evening (sunset to sunrise) Hours Fished for Redwood Creek, 1981-1983.

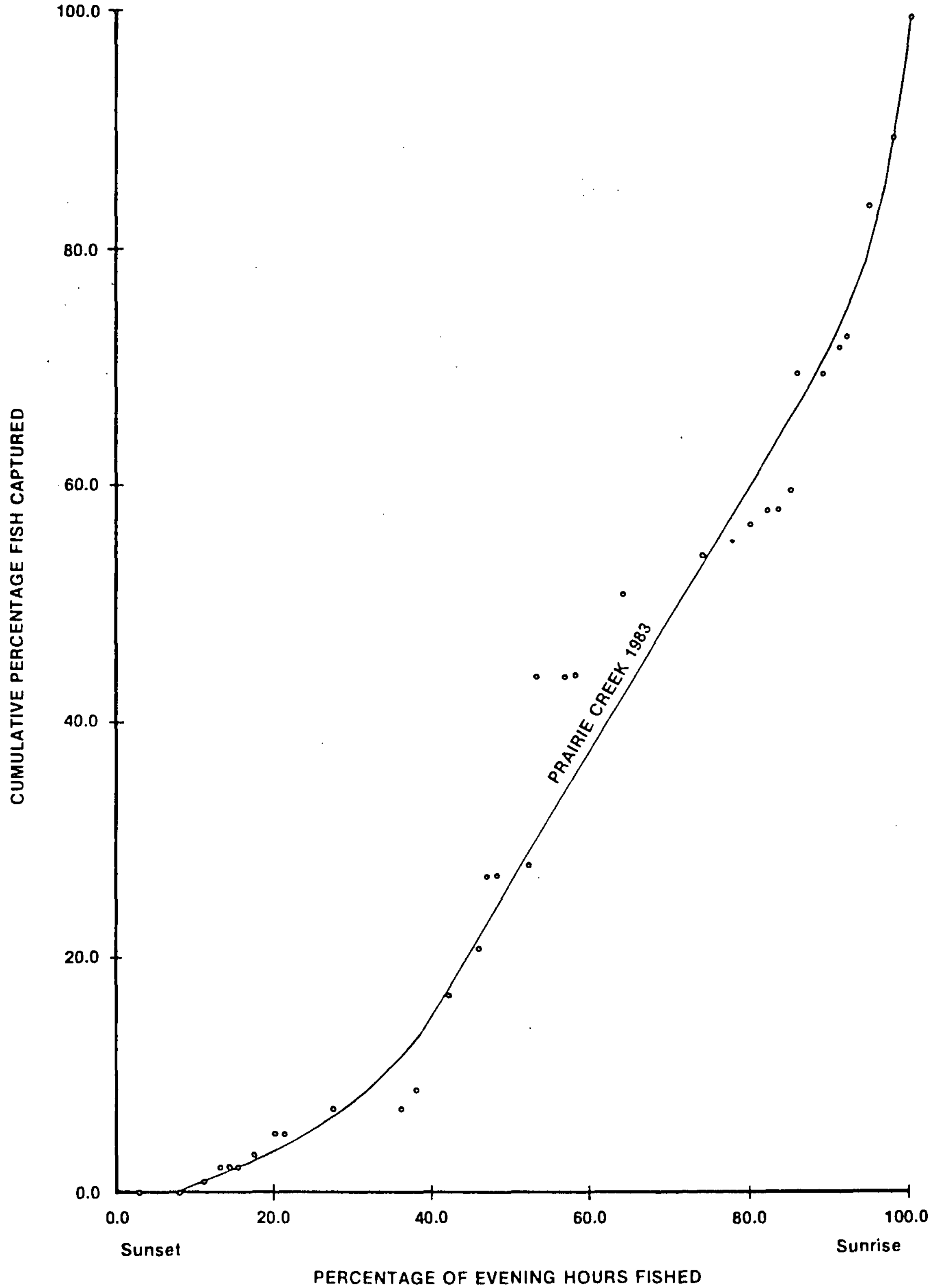


Figure 6. Relationship Between Cumulative Percentage of Juvenile Salmon Captured and Percentage of Evening (sunset to sunrise) Hours Fished for Prairie Creek, 1983.

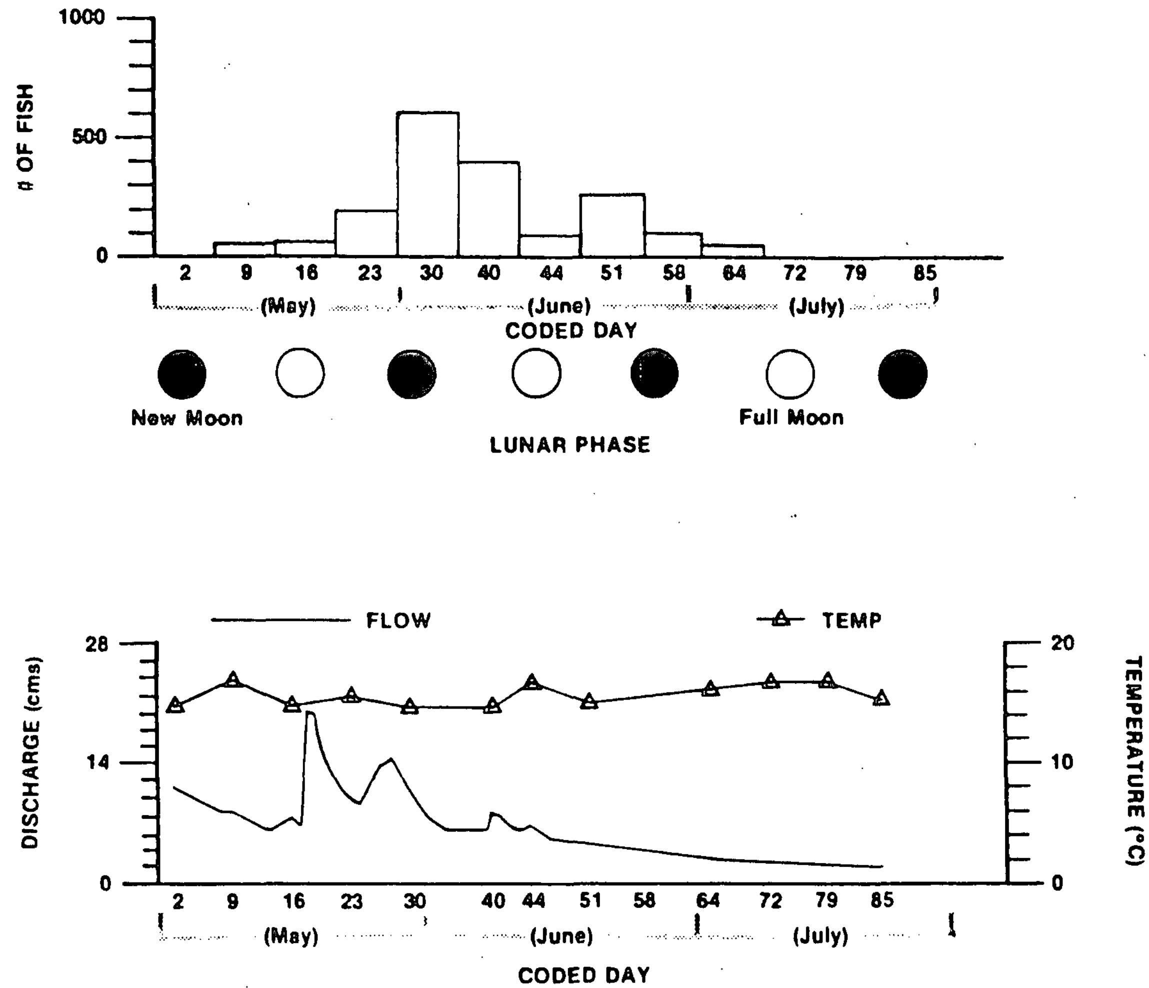


Figure 7. Adjusted Number of Juvenile Salmon Captured, Lunar Phase, Mean Evening River Temperature, and Mean Daily River Discharge in Redwood Creek, 1981.

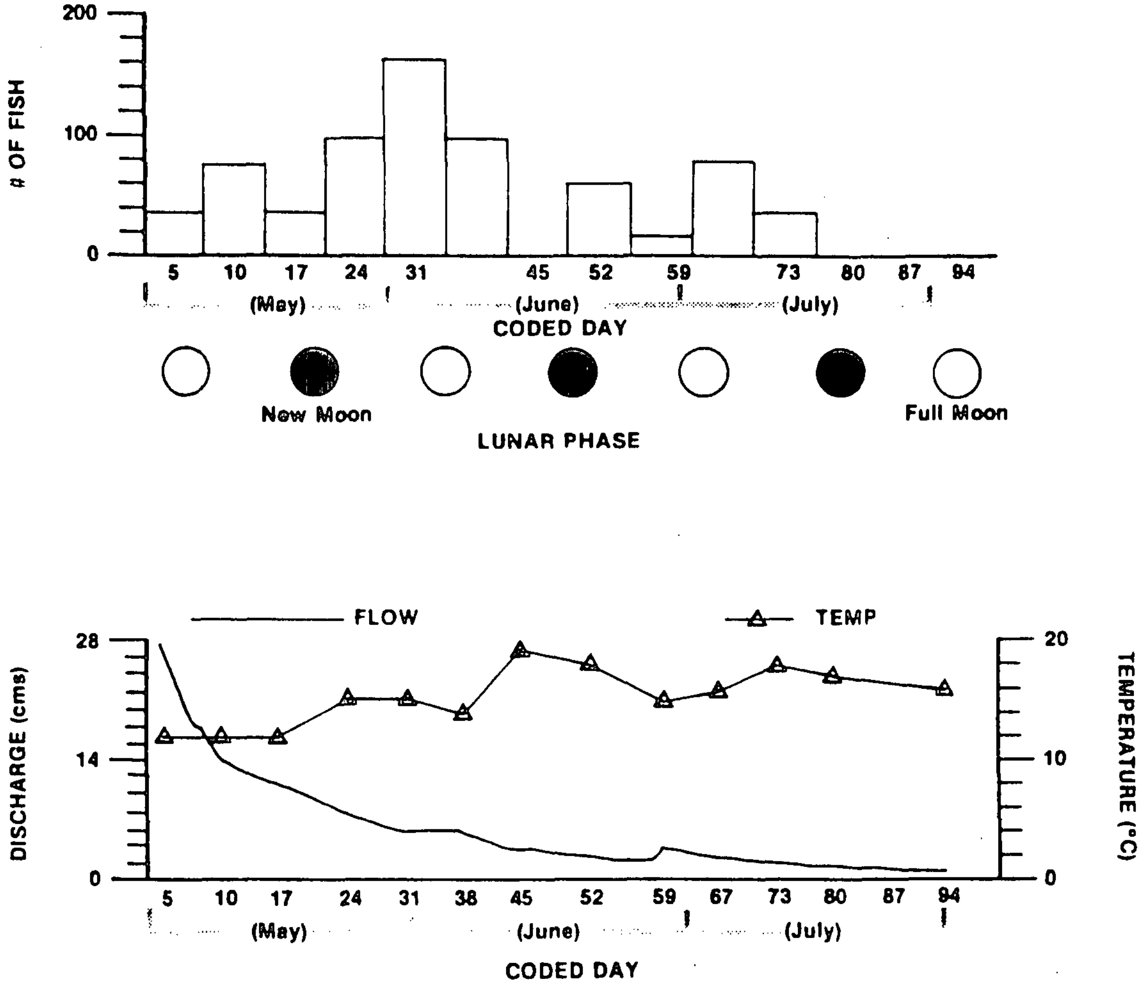
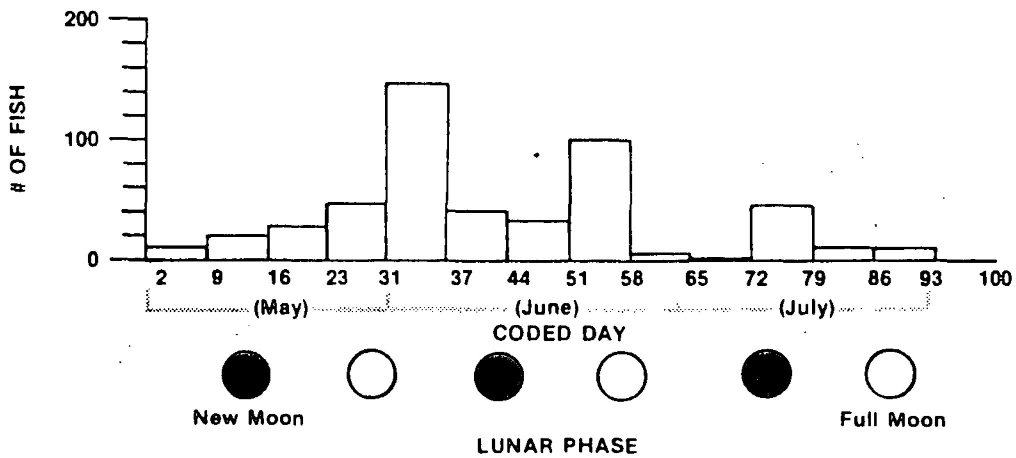


Figure 8. Adjusted Number of Juvenile Salmon Captured, Lunar Phase, Mean Evening River Temperature, and Mean Daily River Discharge in Redwood Creek, 1982.



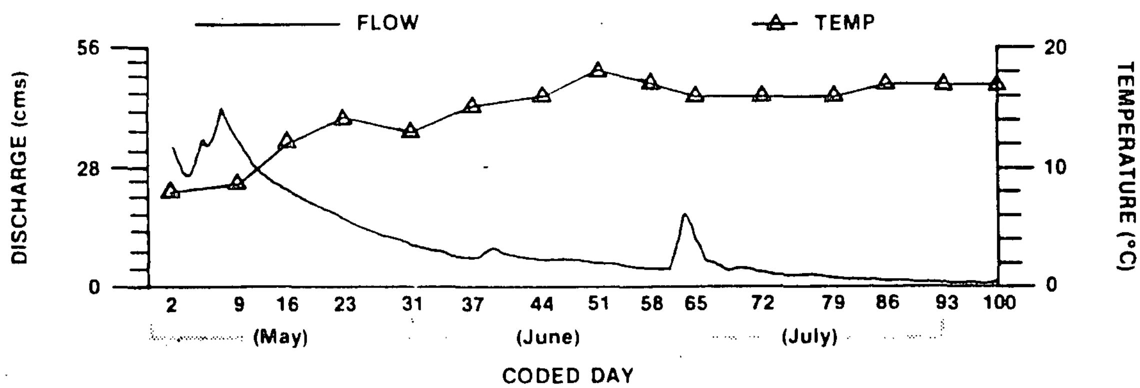


Figure 9. Adjusted Number of Juvenile Salmon Captured, Lunar Phase, Mean Evening River Temperature, and Mean Daily River Discharge in Redwood Creek, 1983.

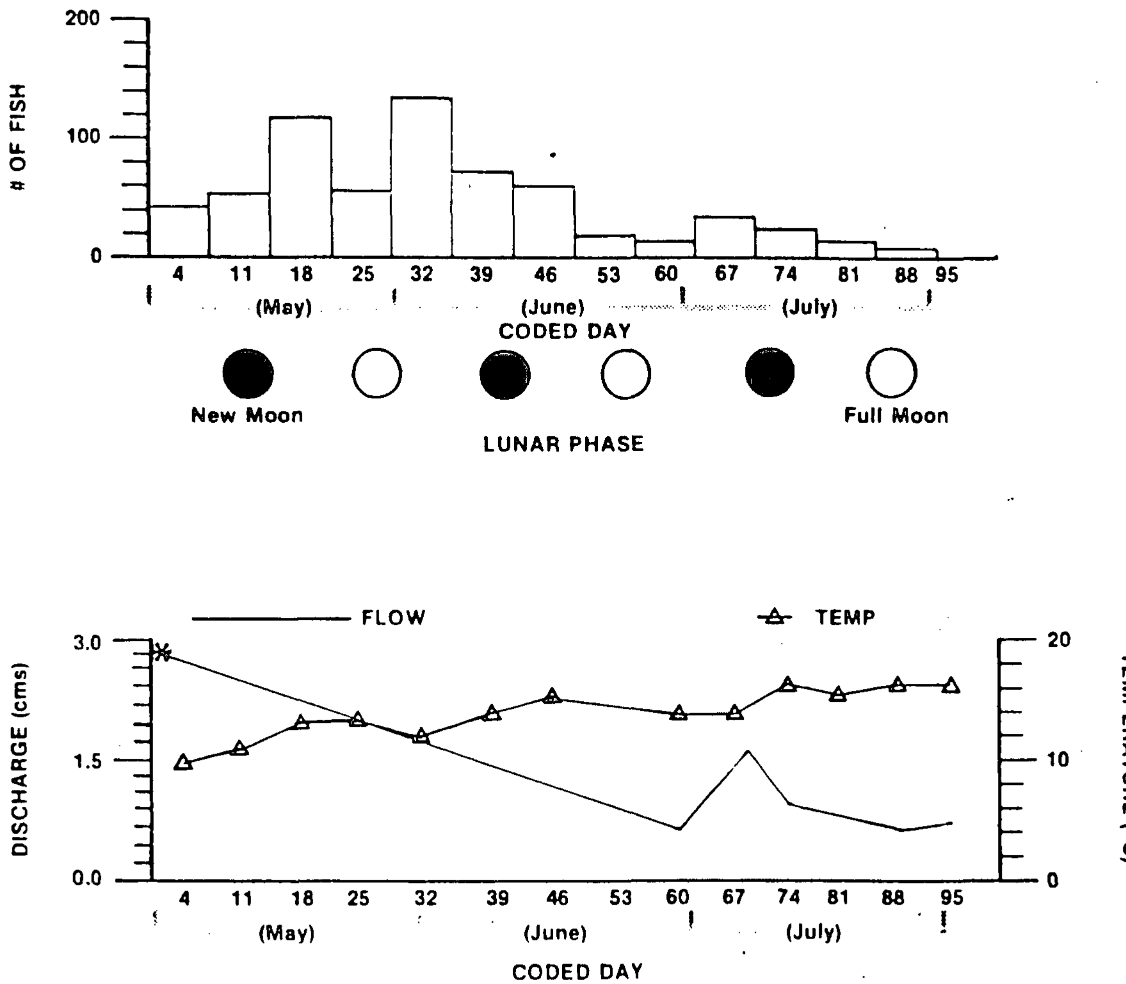


Figure 10. Number of Juvenile Salmon Captured, Lunar Phase, Mean Evening River Temperature, and Mean Daily River Discharge in Prairie Creek, 1983.

and 6 July 1983 (days 18, 32, and 67), respectively, and tended to correspond with Redwood Creek migration patterns (Figures 9, 10).

Migration of fish in Redwood Creek had terminated near 11 July (day 72) 1981, and near 19 July (day 80) 1982. Migration was prolonged in 1983, ending near 27 July (day 88) in both Redwood Creek and Prairie Creek.

Redwood Creek water temperatures in 1981 ranged from 15^{o} to 17^{o} C, and were higher at the onset of migration than in 1982 and 1983. In 1981 water temperatures remained relatively stable throughout the season (Figure 7). Water temperature ranges for Redwood Creek in 1982, and 1983, and Prairie Creek in 1983 were from 12^{o} to 19^{o} C, from 8^{o} to 18^{o} C, and from 10^{o} to 16^{o} C, respectively. Temperature fluctuations in Redwood Creek appeared to follow similar patterns in the three years (Figures 7 - 9).

River discharge during the period of migration varied among years in Redwood Creek, with seasonal declines from 21.0 to 1.5 cms in 1981, from 23.0 to 1.0 cms in 1982, and from 42.0 to 1.9 cms in 1983. Prairie Creek discharge into Redwood Creek in 1983 ranged from an estimated 2.7 to 0.62 cms. In each year in Redwood Creek, and in Prairie Creek, there was a trend toward an increase in migration during or following intervals of increased flow. This trend was evident near 30 May (day 30) and 9 June (day 40) 1981, shortly after 28 June (day 59) 1982, and following 9 May (day 9) and 30 June (day 61) 1983 (Figures 7-10). It was also evident near 6 July (day 67) 1983 in Prairie Creek (Figure 10).

Peak migration in Redwood Creek near 30 May (day 30) 1981 coincided well with the new moon phase. The low number of fish captured on 13 June (day 44) coincided with the full moon phase (Figure 7). In Redwood Creek a peak in migration on 31 May (day 31) and 6 July (day 67) 1982 coincided with a near full moon phase (Figure 8). In Redwood Creek peaks in migration tended to occur around the full moon phase on 31 May (day 31), and 20 June (day 51) 1983. Late in the season a peak occurred near the new moon phase on 11 July (day 72) 1983 (Figure 9).

Peaks in migration in Prairie Creek near 11 May, 8 June, and 6 July (days 11, 39, and 67) 1983 coincided with the new moon phase. Low numbers of fish captured on 25 May (day 25) and 22 June (day 53) coincided with the fullmoon phase (Figure 8).

Factors and components of environmental parameters and adjusted evening catches of salmon for each year in Redwood Creek and for Prairie Creek (using actual catch), 1983 were calculated (Table 2). Factor loading scores represent regression coefficients between variables and factors. Kaiser normalization and varimax rotation of the original matrix simplified patterns of relationships, while having no effect on the original correlations between variables. Total variance of a variable accounted for by a factor is equal to the squared factor loading score. Total variance of a variable (expressed as a percentage) accounted for by the combination of all common factors, is usually referred to as the communality of the variable. The mean of the communalities represents the percentage of total variation in the data accounted for by all factors in the matrix (Nie et al. 1975). As an example, total variance of the variable discharge for Redwood Creek,

Table 2. Factors and Components of Envrionmental Parameters and Adjusted Evening Catches of Juvenile Fall Chinook Salmon after Varimax Rotation with Kaiser Normalization. Factor analyses are for Redwood Creek, 1981-1983, and Prairie Creek, 1983. Values are rounded to the nearest one hundredth.

Location/Year	Variable	Factor 1 Loading score	Factor 2 Loading score	Communality
Redwood Creek/1981	Number of fish	+0.50	-0.12	0.25
	Discharge	+0.81	+0.09	0.65
	Mean evening water temperature	+0.08	+0.67	0.45
	Number of evening moonlight hours	-0.38	+0.50	0.39
				$\bar{X}$ = 0.43
Redwood Creek/1982	Number of fish	+0.46	+0.34	0.33
	Discharge	+0.54	-0.21	0.33
	Mean evening water temperature	-0.11	+0.51	0.28
	Number of evening moonlight hours	+0.55	-0.08	0.31
				$\bar{X}$ = 0.34
Redwood Creek/1983	Number of fish	-0.01	+0.19	0.04
	Discharge	-0.96	+0.01	0.91
	Mean evening water temperature	+0.99	+0.16	1.00
	Number of evening moonlight hours	+0.14	+0.58	0.36
				$\bar{X}$ = 0.58
Prairie Creek/1983	Number of fish	+0.58	+0.04	0.34
	Discharge	+0.79	+0.31	0.71
	Mean evening water temperature	-0.06	-0.59	0.36
	Number of evening moonlight hours	-0.42	+0.25	0.24
				$\bar{X}$ = 0.41

1981 accounted for by Factor 1 was $(0.81)^2 = 0.65$, and by Factor 2 was $(0.09)^2 = 0.008$. These two values summed represented the communality, 0.658 (Table 2).

Factor analysis of data for Redwood Creek in 1981 detected a positive correlation between discharge and adjusted number of fish captured, with loading scores of 0.81 and 0.50, respectively (Table 2). Factor analysis of data for Prairie Creek using actual fish catches detected a positive correlation between discharge and number of juvenile chinook captured, with loading scores of 0.79 and 0.58, respectively (Table 2). Factors or components related to number of migrant fish with factor loading scores of greater than 0.50 were not apparent in analyses of Redwood Creek data for years 1982 and 1983.

Species Composition, Size, and Condition

In all years chinook salmon captured in the weir did not have visible yolk sacs. Of 12 fish captured at the Redwood Creek seine site on 28 April 1983 one fish, 42 mm long, had a visible yolk sac. Late in the sampling season at each weir, and in each year, many captured fish exhibited a silvery, smolt-like appearance.

A total of 4,537 fish was captured in the weir during the study. The species composition of all fish captured during the study was juvenile chinook salmon (47.0 percent); threespine stickleback, *Gasterosteus aculeatus* (22.5 percent); sculpins, *Cottus* sp. (15.2 percent); steelhead trout, (11.0 percent); coho salmon, (0.01 percent); Humboldt sucker, *Catostomus humboldtianus* (0.009 percent); coast cutthroat trout, S. *clarki clarki*, (0.008 percent); and Pacific lamprey, adult and ammocete, *Lampetra tridentata* (0.002 percent).

Total lengths for 1981 fish were converted to fork lengths by substituting the given total length of each fish into the regression equation:

$$\hat{Y}=1.92 + 0.893(x),\ R^2=0.975,\ \text{and}\ n=275.$$

where $\hat{Y}$=estimated fork length, a=Y intercept, b=slope of the line, and x=measured total length.

The eight fish captured in Redwood Creek weir at the start of sampling on 9 May 1981 (day 9) had a mean fork length of 44 mm, and and at the end of sampling on 11 July (day 72), the mean fork length of two fish was 73 mm (Figure 11). Two fish captured in the Redwood Creek weir in 1982 had a mean fork length of 56 mm, at the start of sampling on 10 May 1982 (day 10) and, at the end of sampling on 12 July (day 73), the mean fork length of nine fish was 66 mm (Figure 11). The one fish captured in the Redwood Creek weir at the start of sampling on 2 May 1983 (day 2) was 53 mm fork length. However, on 9 May 1983 (day 9), the mean fork length of three fish was 51 mm. At the end of sampling in Redwood Creek on 8 August 1983 (day 100), the one fish captured had a mean fork length of 100 mm while on 25 July 1983 (day 86) mean fork length of four fish was 87 mm (Figure 12).

The mean new fork length at sample date for Redwood Creek fish seined in 1983 was greater than migrant fish captured in the weir on four of six sample dates (Figure 12). Twelve fish captured at the Redwood Creek seine site at the start of sampling on 28 April 1983 had a

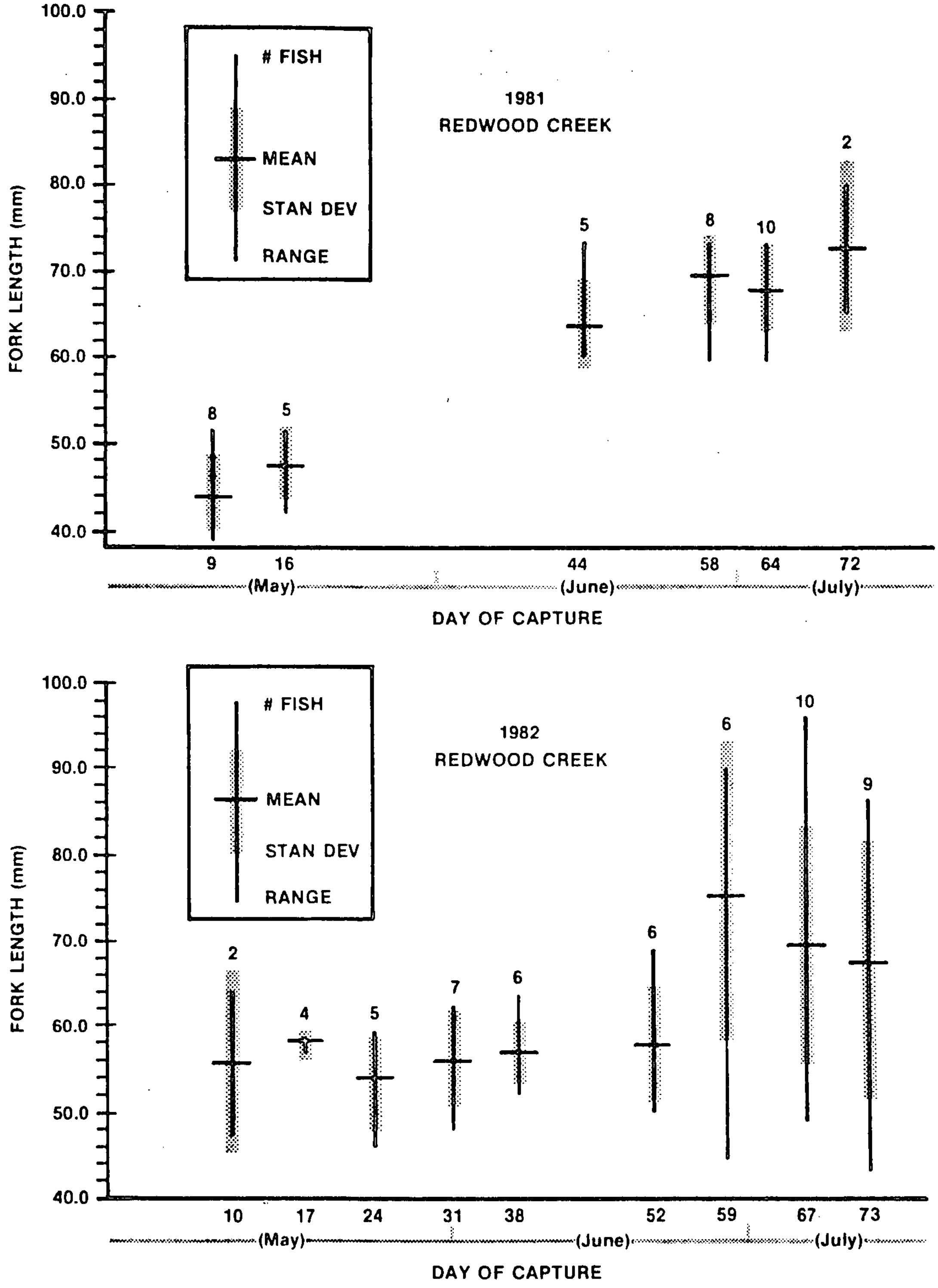
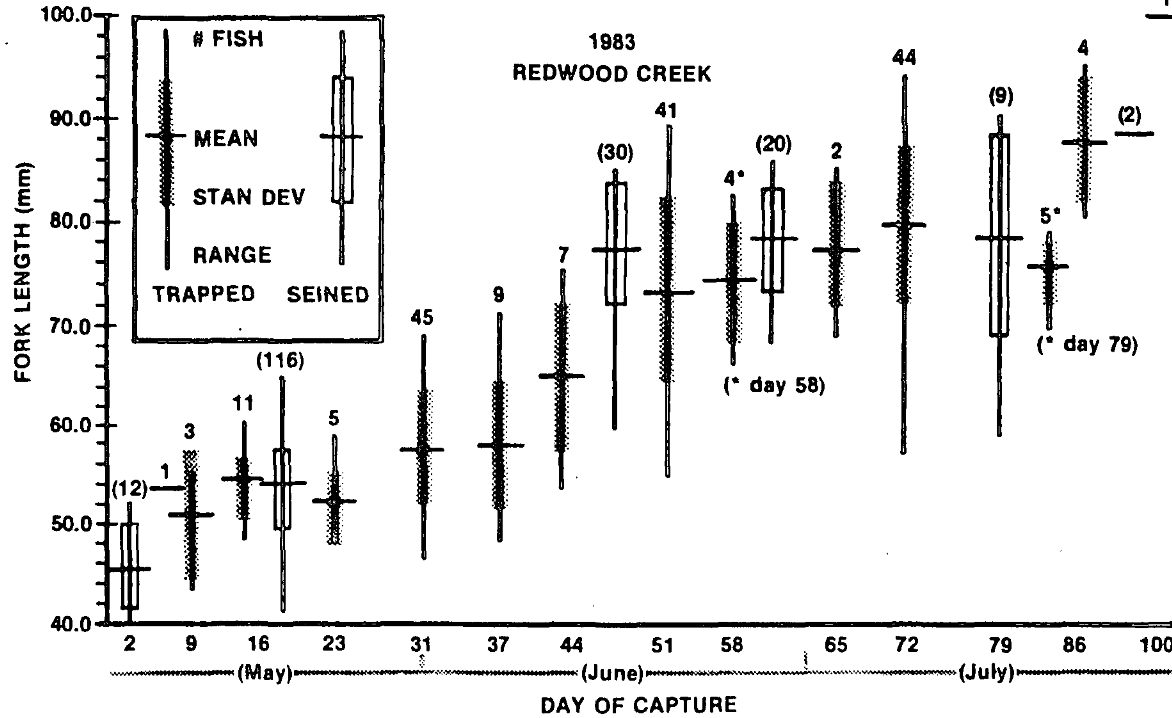


Figure 11. Length of Juvenile Salmon Captured in Redwood Creek, 1981 (upper), and 1982 (lower).



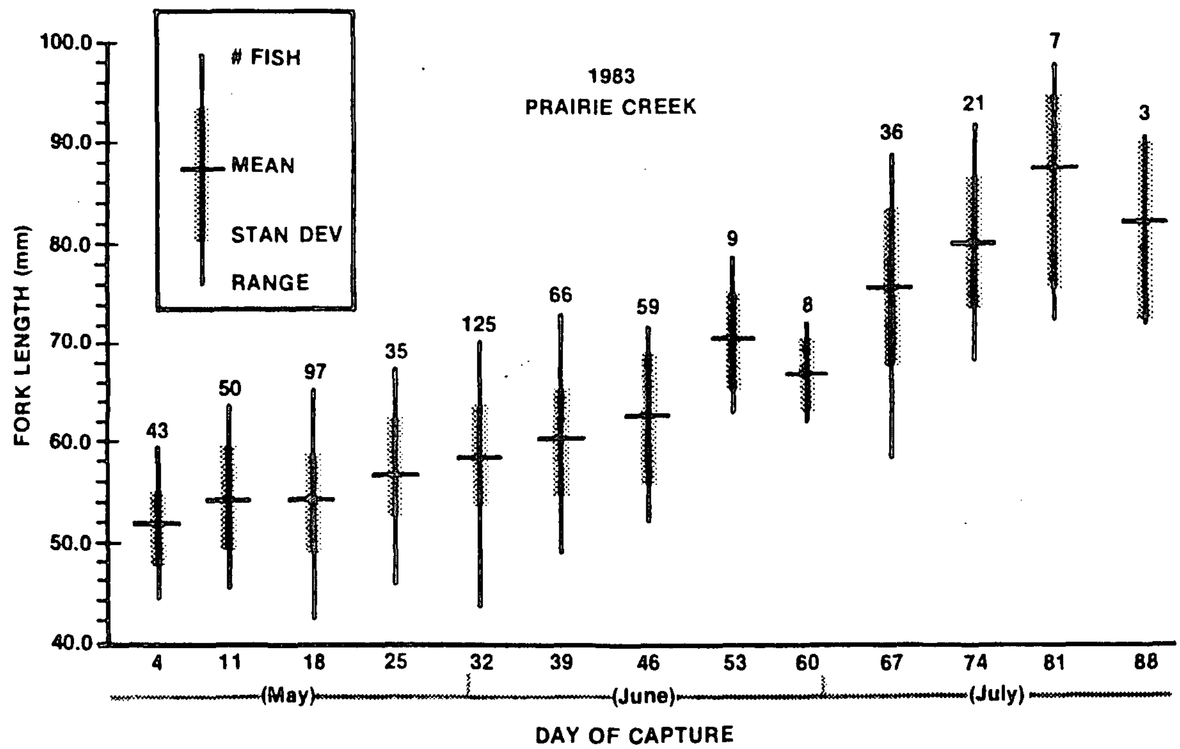


Figure 12. Length of Juvenile Salmon Captured in Redwood Creek and Seined at Redwood Creek Seine Site, 1983 (upper), Captured in Prairie Creek, 1983 (lower).

mean fork length of 45 mm. At the end of sampling on 3 August 1983 (day 95), the two fish captured had fork lengths of 88 mm (Figure 12).

The mean fork length of 43 fish in Prairie Creek at the start of sampling on 4 May 1983 (day 4) was 51 mm. The mean fork length at the end of sampling on 27 July (day 88) was 81 mm (Figure 12).

The majority of Prairie Creek fish had left the watershed by 22 June (day 53), with a few, large fish migrating from 6 July (day 67) through 27 July (day 88) (Figures 10, 12). The general length and range of Prairie Creek fish from 4 May (day 4) through 15 June (day 46) was reflected in Redwood Creek trap captures from 9 May (day 9) through 3 June (day 44) (Figure 12).

Mean weekly condition factors of Prairie Creek, Redwood Creek, and Redwood Creek seine site fish were not significantly different. Changes in weekly condition of Redwood Creek fish appeared to parallel changes in weekly condition of Prairie Creek fish from 8 June (day 39) through 13 July (day 74) (Figure 13). When comparing condition factors it was hypothesized that heavier fish of a given length were in better condition (Ricker 1975; Bagenal and Tesch 1978). Greatest mean condition of all riverine fish captured was 1.85 on 18 May 1983 (day 18) in Prairie Creek, and lowest mean condition was 0.99 on 18 July 1983 (day 79) in Redwood Creek (Figure 13).

Estuary and Hatchery Studies

Growth, Size, and Condition

Mean fork length of fish seined in the estuary at the start of sampling on 27 July 1983 (day 88) was 81 mm and fork length ranged from

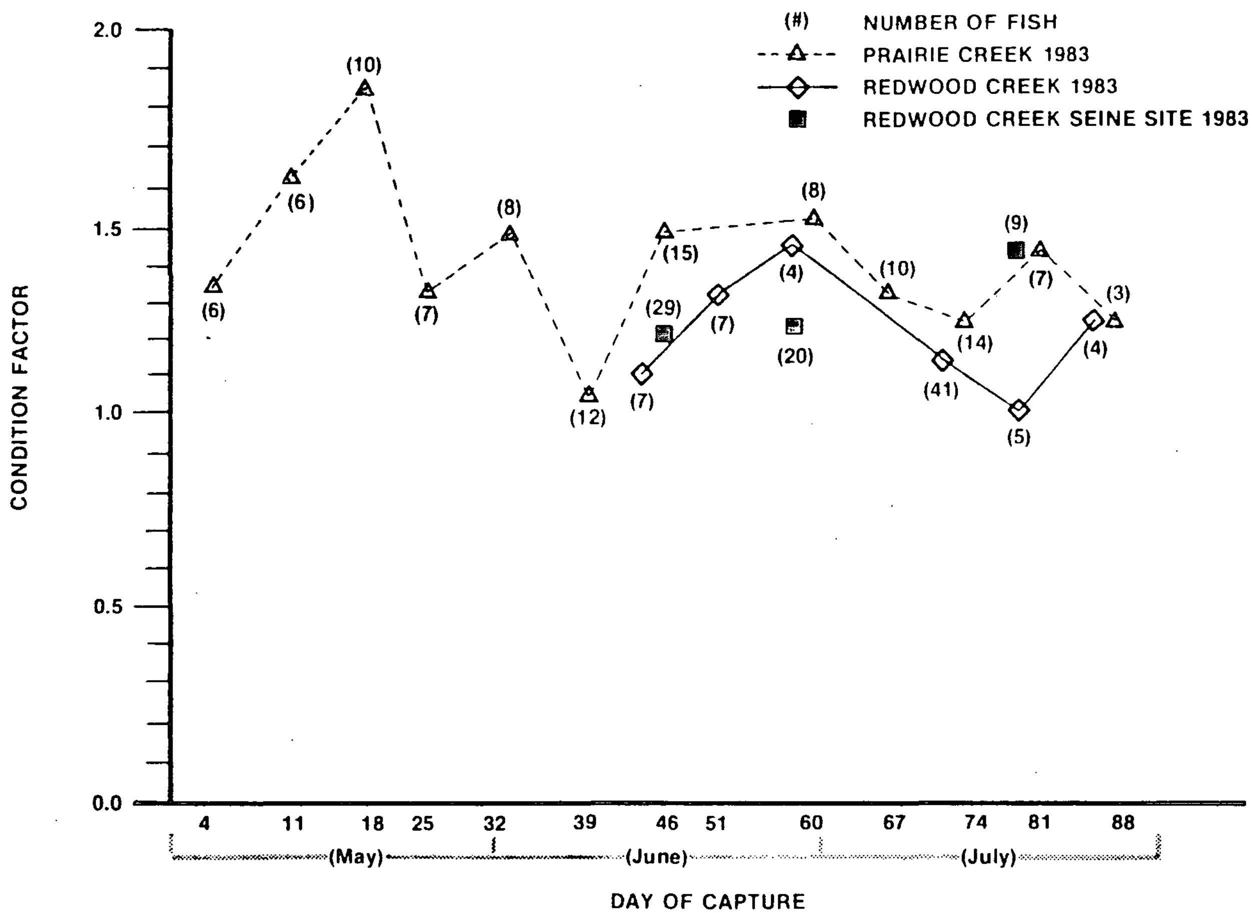


Figure 13. Mean Condition Factors of Juvenile Salmon Captured in Prairie Creek and Redwood Creek and Seined at Redwood Creek Seine Site, 1983.

69 mm to 92 mm. At the end of sampling on 17 October (day 170) mean fork length was 120 mm and fork length ranged from 107 mm to 133 mm. Mean fork length of hatchery fish at the start of sampling on 1 June 1983 (day 32) was 71 mm, and fork length ranged from 60 mm to 80 mm. At the end of sampling on 23 November (day 207) mean fork length was 138 mm, and fork length ranged from 111 mm to 153 mm (Figures 14, 15). Estuary sample sizes ranged from 6 to 39, and hatchery sample sizes ranged from 17 to 31. Growth rates for estuary fish were described by:

$$\hat{Y}^{0.294} = 3.428 + 0.004(X)$$

where $R^2 = 0.559$, $n = 177$, $\hat{Y}^{0.294}$ = estimated fork length, X = day of capture. Hatchery fish were described by:

$$\hat{Y}^{0.294} = 3.339 + 0.005(X)$$

where $R^2 = 0.807$, $n = 194$; (Figures 14, 15).

Regression coefficients of the lines were not significantly different ($F=0.763$, df=1 and 10, $P>0.05$). The elevation of the estuary line was significantly greater than the elevation of the hatchery line ($t=630.7$, df=368, $P<0.001$). Fork length was calculated at sample date for estuary and hatchery fish, and a curved line was fitted through values obtained (Figures 14 and 15).

There were no significant differences in comparisons of mean condition factors between hatchery fish and estuary fish from July through November, 1983 (Figure 16). Mean condition factors among the three samples of estuary fish remained consistent. Condition of estuary fish was not significantly different from condition of hatchery fish sampled at the same time of the season (Figure 16).

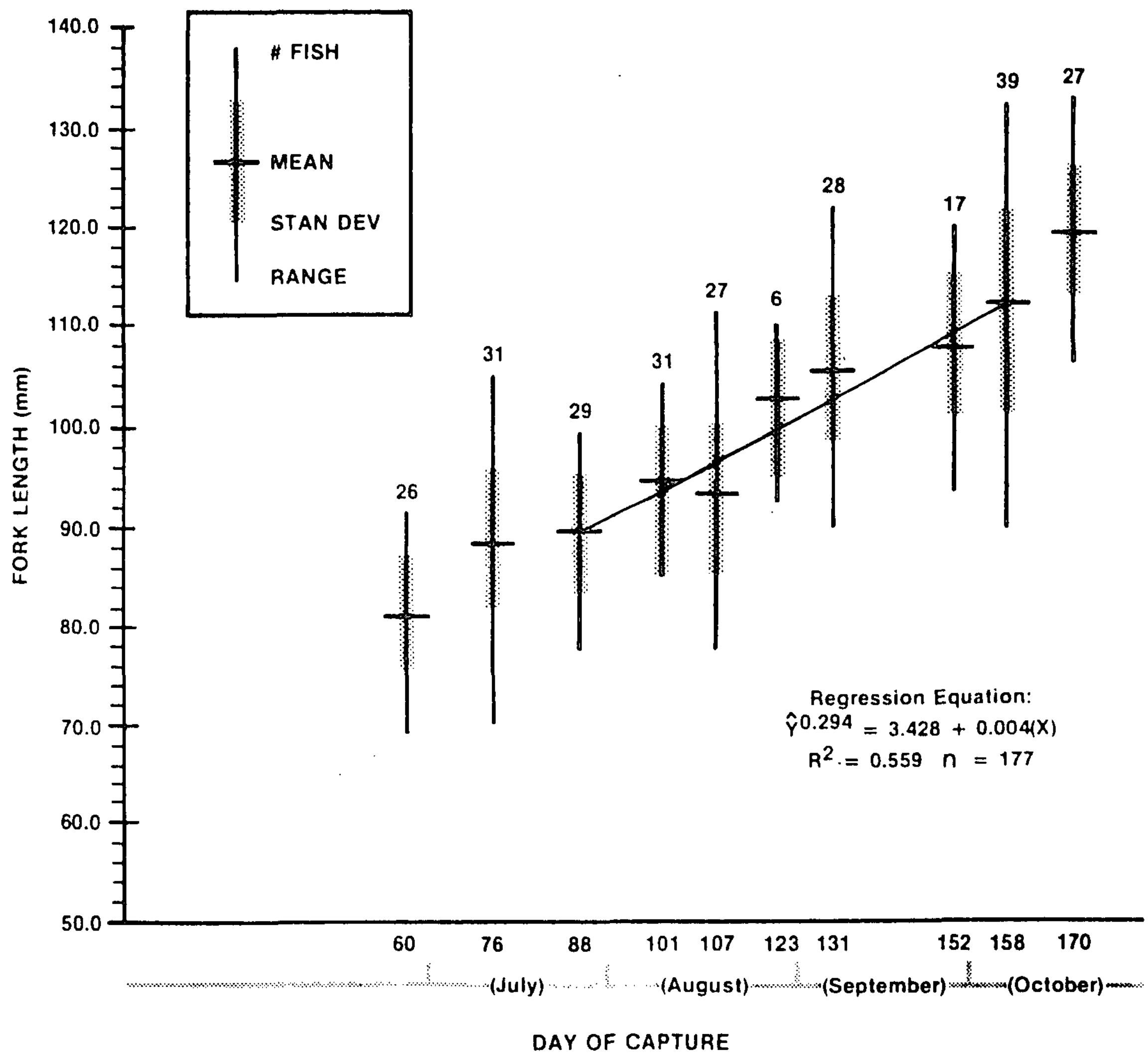


Figure 14. Relationship Between Fork Length and Day of Capture for Juvenile Salmon Seined in the Redwood Creek Estuary 1983.

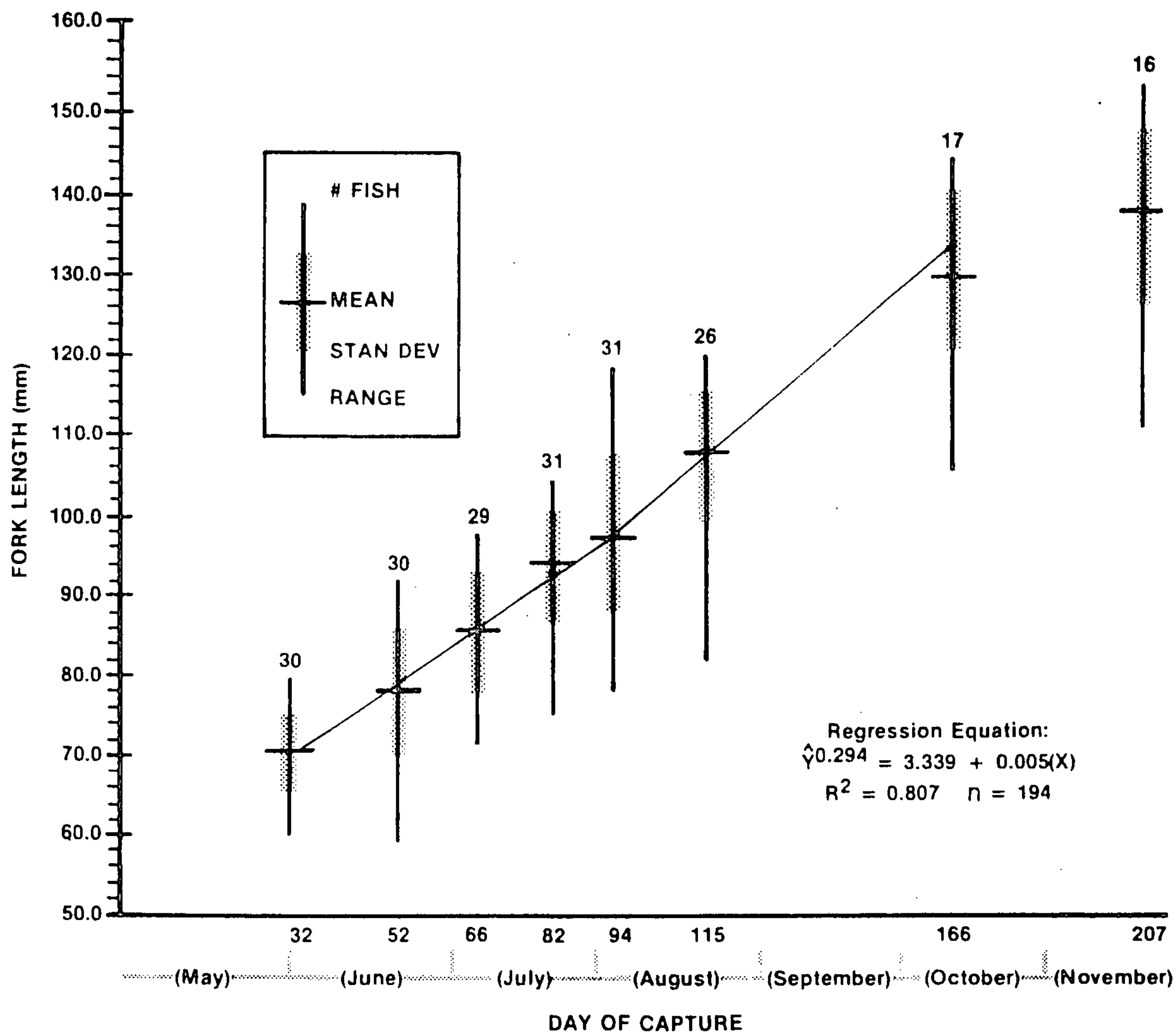


Figure 15. Relationship Between Fork Length and Sample Day for Juvenile Salmon Sampled at the Prairie Creek Hatchery, 1983.

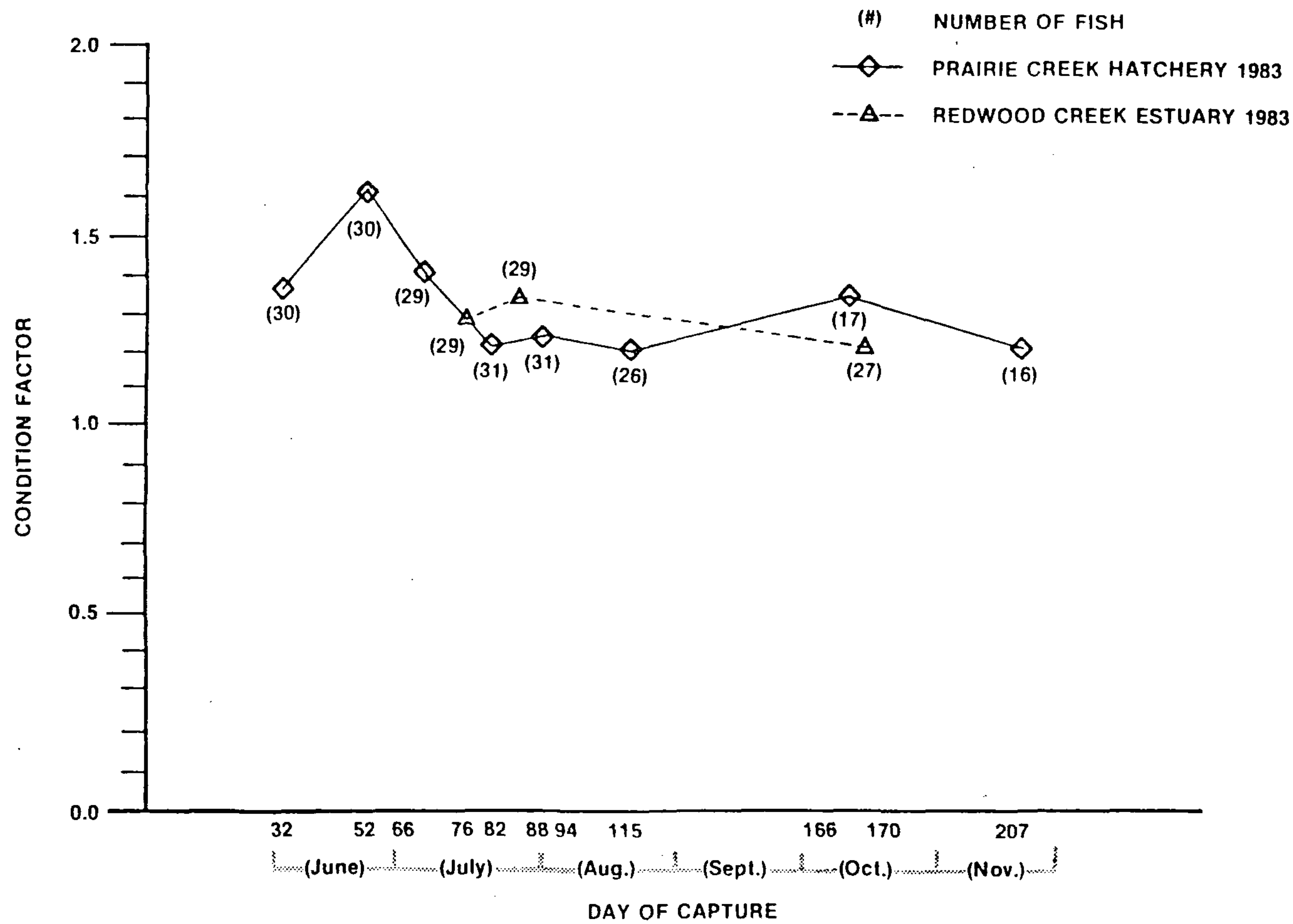


Figure 16. Mean Condition Factors of Juvenile Salmon from Prairie Creek Hatchery, and Redwood Creek Estuary (after downstream migration), 1983.

Scale Studies

Stream Samples

Relationships between number of riverine circuli and day of capture for migrant fish in Redwood Creek, 1981-1983, were described by:

$$Y^{0.008} = 1.011 + 0.0001(X)$$

where $R^2 = 0.750$, and n = 33 for 1981;

$$Y^{-0.366} = 0.601 + 0.002(X)$$

where $R^2 = 0.340$, and n = 47 for 1982; and

$$Y^{0.889} = 3.495 + 0.062(X)$$

where $R^2 = 0.695$, and n = 66 for 1983; and in all years $Y^{(A)}$ = number of riverine circuli, (A) = the appropriate exponent, and X = coded sample day.

Number of riverine circuli at sample date was calculated and each curved line was fitted through values obtained (Figure 17). A common power transformation could not be fitted to each year, and statistical comparisons among years were not possible. Mean number of riverine circuli for all fish captured in Redwood Creek, 1981 was 9.03, with a range from 4 to 15. In 1982 mean number of riverine circuli for all fish was 6.88, with a range from 3 to 14. In 1983 mean number of riverine circuli for all fish was 8.24, with a range from 4 to 16. Mean number of riverine circuli for all fish captured in Prairie Creek, 1983 was 7.06, with a range from 4 to 16. Mean number of riverine circuli for Redwood Creek seine site fish, 1983 was 8.6, with a range from 4 to

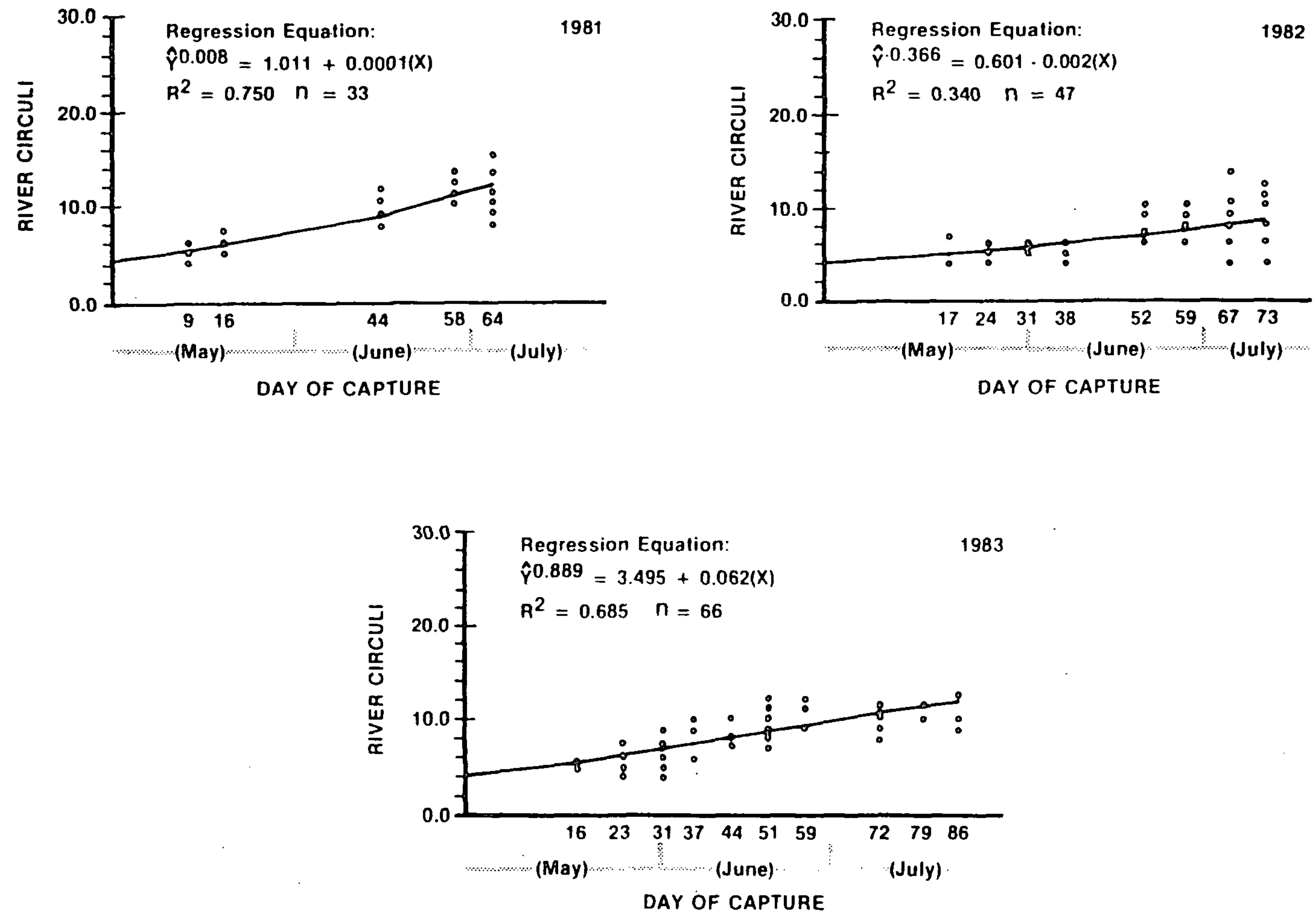


Figure 17. Relationship Between River Circuli and Day of Capture for Juvenile Salmon in Redwood Creek, 1981-1983.

13. In each year and at each site, number of riverine circuli on scales of captured fish increased throughout the season.

Mean platelet diameter of Prairie Creek fish was significantly larger than mean platelet diameter of Redwood Creek seine site fish (P=0.02). Mean platelet diameter of Prairie Creek fish was 17.84 mm with a range from 13.5 mm to 21.6 mm, whereas mean platelet diameter of Redwood Creek seine site fish was 17.09 mm with a range from 13.0 mm to 20.9 mm. Mean platelet diameter of fish captured in Redwood Creek, 1983 was 17.37 mm, with a range from 6.1 mm to 22.9 mm. Mean platelet diameter for pooled Prairie Creek and Redwood Creek seine site fish was 17.46 mm. The difference between pooled mean platelet diameter and mean platelet diameter for Redwood Creek fish was not significant. There were no significant differences in comparisons of mean circuli spacing and widths of the first and second bands of five circuli between Prairie Creek fish and Redwood Creek seine site fish (Table 3).

Estuary and Hatchery Samples

The relationship between total number of circuli and day of capture for estuary fish seined on 27 July (day 88) through 5 October 1983 (day 158), was described by:

$$\hat{Y}^{0.366} = 2.069 + 0.006(X)$$

where R^2=0.609, and n=89; and for hatchery fish sampled on 1 June (day 32) through 13 October 1983 (day 166).

Regression coefficients of the lines were not significantly different (F=0.0004, df=1 and 10, P>0.05). Elevation of the estuary

Table 3. Mean Platelet Diameter (mm), Mean Circuli Spacing (mm), and Mean Widths (mm) of the First and Second Bands of 5 Circuli at 114X Magnification for Prairie Creek and Redwood Creek Seine Site Juvenile Fall Chinook Salmon, 1983. ($\bar{X}$ = Mean; Stan. dev. = Standard deviation; and N = Number of fish).

Species	Sample site	$\bar{X}$ Platelet diameter (mm)			$\bar{X}$ Circuli spacing (mm)			$\bar{X}$ First band width (mm)[a]			$\bar{X}$ Second band width (mm)[a]		
		$\bar{X}$	dev.	n	$\bar{X}$	dev.	n	$\bar{X}$	dev.	n	$\bar{X}$	dev.	n
Fall Chinook	Prairie Creek	17.84	1.53	49	2.68	0.33	49	2.83	0.31	49	2.28	0.23	7
Fall Chinook	Redwood Creek Seine Site	17.09	1.72	49	2.60	0.29	49	2.85	0.38	49	2.24	0.31	16
Significant difference		Yes ($P = 0.02$)			No			No			No		

[a]Measurements of the first band of five circuli were made from the outside edge of the first circulus to the outer edge of the fifth circulus. Measurements of the second band of five circuli were made from the outside edge of the fifth circuls to the outer edge of the circulus.

regression line was significantly greater than the hatchery regression line ($t=158.3$, $df=191$, $P<0.001$).

As the season progressed, fewer fish in the estuary lacked apparent estuarine circuli. Six out of seven fish lacked estuarine circuli on 27 July (day 88), three out of 11 fish on 9 August (day 101), one out of 15 fish on 15 August (day 107), one out of four fish on 31 August (day 123), and zero out of 26 fish on 8 September, 29 September, and 5 October (days 131, 152, and 158) (Figure 18). It was assumed that migration had terminated for all practical purposes by 27 July 1983 (day 88).

The relationship between number of circuli classified as estuarine and coded day, for estuary fish seined on 27 July (day 88) through 5 October 1983 (day 158) was:

$$\hat{Y}^{0.441} = 1.091 + 0.011(X)$$

where $R^2=0.809$, and $n=78$, $\hat{Y}^{0.441}$ = number of estuarine circuli, and X=day of capture. A curved line was fitted to values calculated for each sample date (Figure 18).

There was not a significant linear regression in the relationship of number of riverine circuli on sample date for fish seined in the estuary in 1983 (Figure 19).

Fish captured in the estuary from 27 July (day 88) through 5 October 1983 (day 158) were stratified by day of capture and number of riverine ciculi to compare differences in riverine growth and estuarine growth. Seven comparisons of mean widths of riverine versus estuarine intercirculi spacing were made for fish stratified by number of riverine

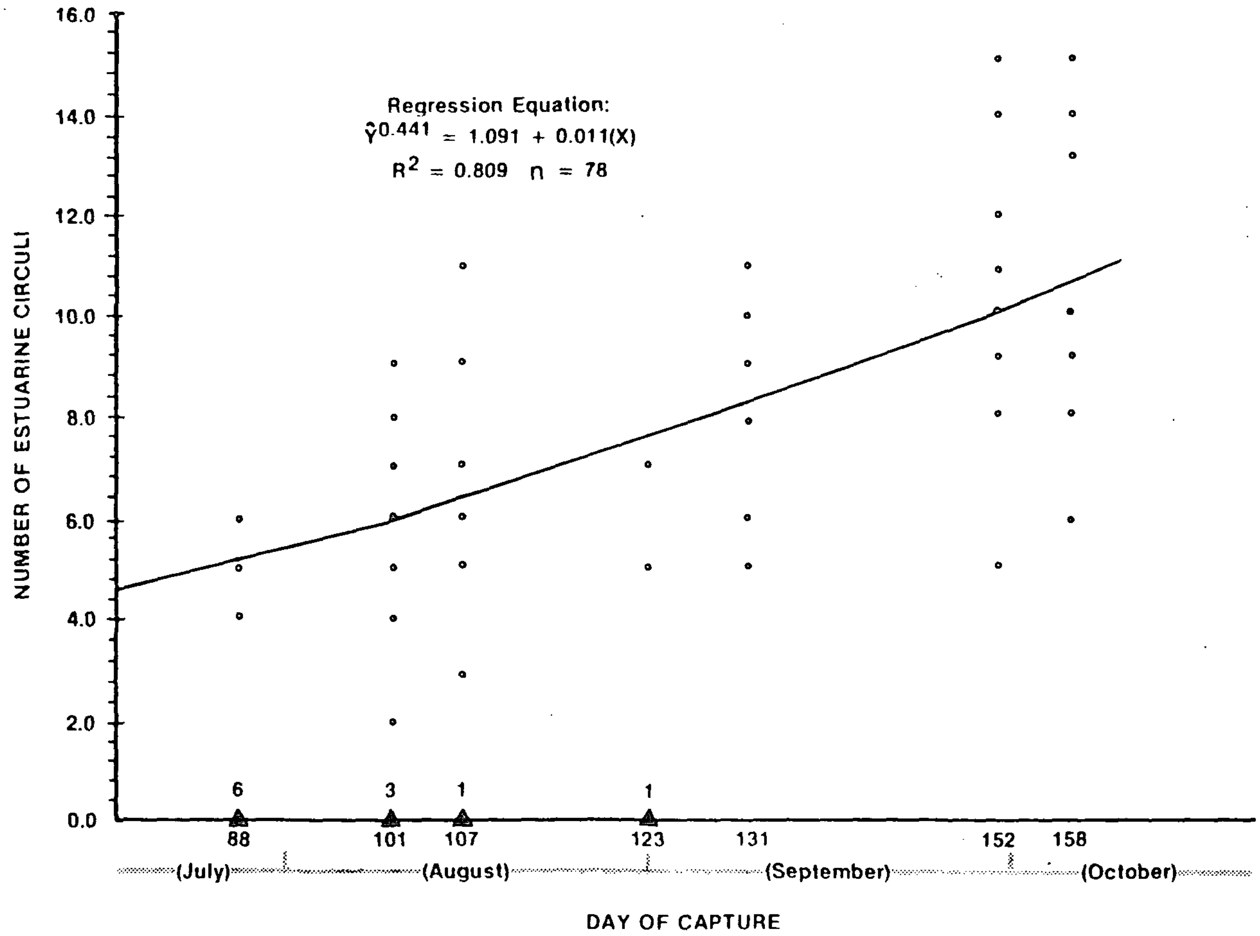


Figure 18. Relationship Between Number of Circuli Classified as Estuarine and Day of Capture for Juvenile Salmon in Redwood Creek Estuary 1983.

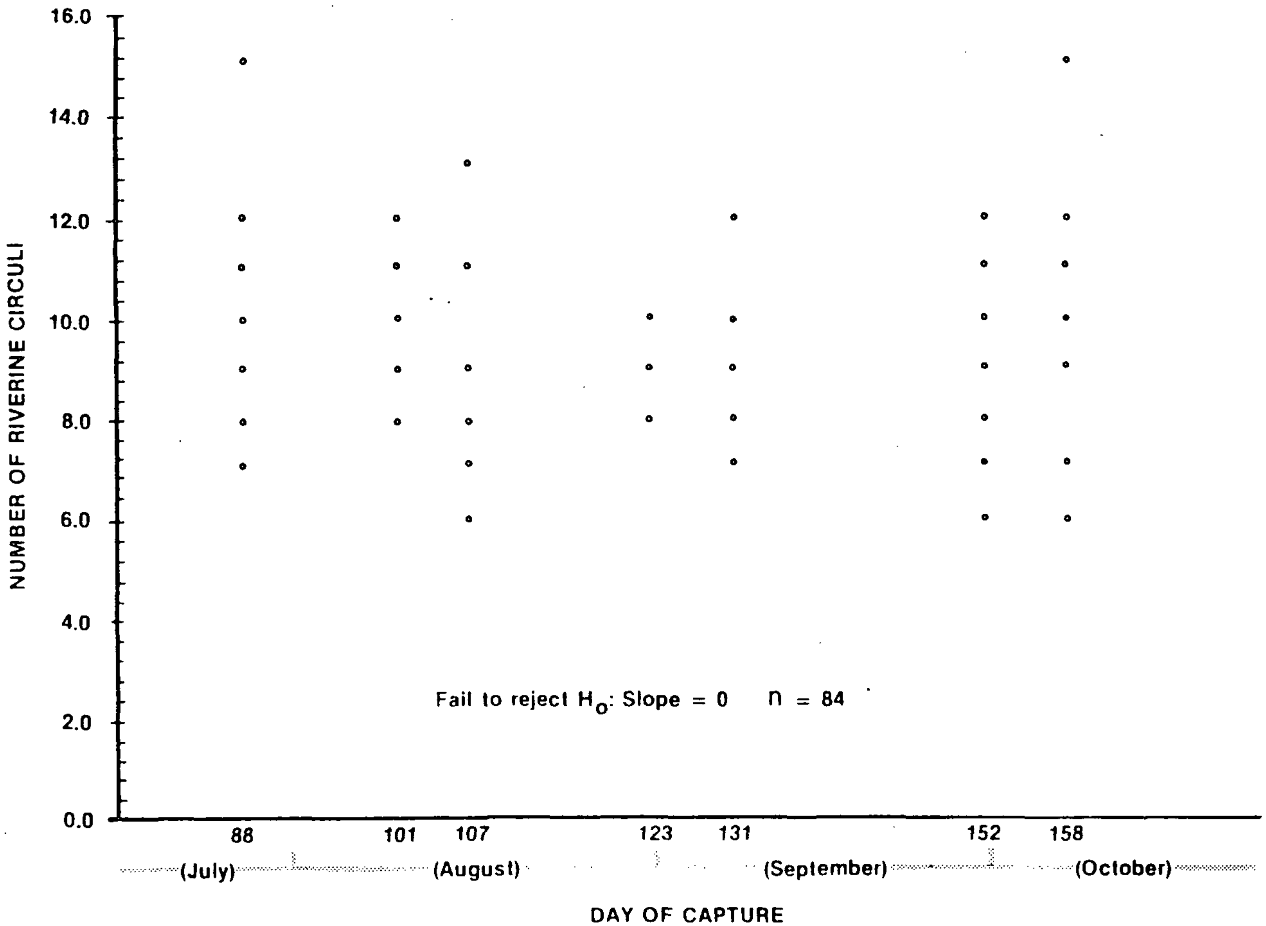


Figure 19. Number of Riverine Circuli on Day of Capture for Juvenile Salmon in Redwood Creek Estuary, 1983.

circuli. Comparisons involved fish with riverine scale circuli that ranged from six through 12. Six comparisons of mean widths of riverine versus estuarine intercirculi spacing were made for fish stratified by day of capture. Comparisons involved fish captured on 27 July, 9 August, 15 August, 8 September, 29 September, and 5 October 1983 (days 88, 101, 107, 131, 152, and 158). Mean spacing of riverine circuli was 2.44 mm and was significantly greater than mean spacing of estuarine circuli (2.24 mm) for fish with scales having eight riverine circuli ($P<0.05$) (Table 4). Mean spacing of riverine circuli was 2.35 mm and was significantly greater than mean spacing of estuarine circuli (2.10 mm) for fish caught on 9 August 1983 (day 101) (Table 5). There were no further significant differences in fish stratfied by riverine circuli or day of capture.

Table 4. Mean Riverine and Mean Estuarine Circuli Spacing (mm) at 114X Magnification on Scales of Juvenile Fall Chinook Salmon Captured in Redwood Creek Estuary from 27 July (day 88) through 5 October (day 158), 1983. Fish were stratified according to number of riverine circuli. T-tests were used in comparisons of mean riverine and mean estuarine circuli spacing. ($\bar{X}$ = Mean)

		Riverine Circuli Spacing		Estuarine Circuli Spacing		
No. River circuli	Sample Size	$\bar{X}$ Circuli spacing (mm)	Standard deviation	$\bar{X}$ Circuli spacing (mm)	Standard deviation	Significant difference ($P = 0.05$)
6	3	2.40	0.346	2.40	0.265	No
7	7	2.42	0.281	2.25	0.472	No
8	19	2.44	0.259	2.24	0.269	Yes ($P = 0.02$)
9	15	2.48	0.262	2.30	0.245	No
10	16	2.38	0.266	2.27	0.330	No
11	11	2.26	0.238	2.32	0.294	No
12	5	2.24	0.270	2.48	0.249	No

Table 5. Mean Riverine and Mean Estuarine Circuli Spacing (mm) at 114X Magnification on Scales of Juvenile Fall Chinook Salmon Captured in Redwood Creek Estuary from 27 July (day 88) through 5 October (day 158), 1983. Fish were stratified according to day of capture, with 1 May = day one. T-tests were used in comparisons of mean riverine and mean estuarine circuli spacing. ($\bar{X}$ = Mean)

		Riverine Circuli Spacing		Estuarine Circuli Spacing		
Coded date	Sample Size	$\bar{X}$ Circuli spacing (mm)	Standard deviation	$\bar{X}$ Circuli spacing (mm)	Standard deviation	Significant difference (P = 0.05)
88	7	2.52	0.298	2.37	0.150	No
101	11	2.35	0.284	2.10	0.202	Yes (P = 0.03)
107	15	2.35	0.217	2.28	0.332	No
131	15	2.54	0.188	2.36	0.331	No
152	15	2.23	0.277	2.40	0.248	No
158	11	2.40	0.276	2.24	0.339	No

DISCUSSION

Trapping Efficiency

Trapping in Redwood Creek during high flows was limited as a means of estimating the number of downstream migrant salmon. Other factors also presented problems in quantitatively describing downstream migration of fish. Miller (1970) found that when assessing trap recapture percentages, two conditions biased percentages, and in this study a third related condition was evident: 1) the possibility of higher mortality in marked fish, 2) marked fish reintroduced above the weir may not have moved downstream again during the trapping period, and 3) inability to distinguish pre-capture or post-capture mortalities in marked fish. The recapture percentage of 26.8 percent for Prairie Creek was lower than expected when considering the weir extended the full width of the creek at all times. It appeared that many fish released upstream failed to again move downstream during the evening of release. In every year a few recapture mortalities were found in the weir. All marked fish were alive at the time of release, and it was assumed that recapture mortalities probably were unable to withstand the stress associated with mark and recapture. Mortalities were not included in recapture percentage calculations. Recapture percentage for Redwood Creek increased over the three year period, probably indicating increased efficiency in capturing fish due to improved gear, methods, and experience. Recapture percentages among years in Redwood Creek were not comparable as yearly differences in discharge and channel contour altered trapping effort.

Fish species captured were similar to the findings reported by Iwatsubo and Averett (1981). The percentage of species composition of fish captured was not an indication of relative abundance of fish within the watershed. Other species such as coho salmon were thought to migrate early in the year, prior to 1 May. Steelhead trout have a variable life history and may have migrated throughout the year. Other fish species may have migrated during the day. Throughout the study, trapping effort and techniques were directed toward the capture of juvenile chinook salmon.

Factors Affecting Migration

Miller (1970), Reimers (1973), and Mason (1975), presented evidence that peaks in number of outmigrant fry corresponded with the new moon phase, and occurred on evenings with low moonlight hours. Mason (1975) found a positive correlation between number of coho fry captured during the new moon phase. He also found a positive correlation between number of coho smolt and presmolt captured during the full moon phase. Miller (1970), and Reimers (1973) found that chinook fry migrated mostly at night. They suggested that movement during the night was a non-directed displacement due to lack of visual orientation rather than a directed or forced movement. Their speculations were that fry drifted with the currents during the night until light levels, whether moonlight or daylight, allowed visual orientation. During years of high fish capture, such as in Redwood

Creek in 1981, and in Prairie Creek in 1983, peaks in capture appeared to correspond with nights having minimal moonlight hours (Figures 7, 10). Similar trends were not as apparent in Redwood Creek in 1982 and in 1983. Peaks tended to occur closer to the full moon phase in these years (Figures 8, 9).

Though associations between peaks in migration and evenings with minimal moonlight hours were somewhat evident, concern can be raised regarding these associations. The presence of the weir may have affected migration of fish, and its effect may have varied with changes in discharge. The extent of nocturnal luminesence in lower Redwood Creek basin was affected by coastal climatic conditions, and cloud cover and coastal fog limited luminesence on many sampling evenings.

High flows, with low initial, yet progressively increasing temperatures in Redwood Creek in 1982 and 1983, probably supported in-river rearing, and temporally extended migration (Figures 8, 9). High temperatures and low discharge in Redwood Creek in 1981, probably resulted in a decrease in river rearing habitat, and the earlier initiation of downstream movement. This was supported by the large numbers of migrant fish captured, and the termination of migration at an earlier date in 1981 (Figure 7). Healey (1980) found trap catch of chinook fry to be positively correlated with river discharge but not with temperature. In all years in Redwood Creek, and in Prairie Creek in 1983, changes in temperature alone did not seem to affect migration patterns. Changes in river discharge may have had the effect of initiating or causing movement on occasion (Figures 7-10). Mason (1975) found that river discharge and water temperature were not related to peaks in juvenile coho migration. The range in water temperature in all years in Redwood Creek and Prairie Creek was not great. Temperature may have had the least affect on the migration of fish.

In Redwood Creek and Prairie Creek it was assumed that peaks and troughs in number of migrant fish occurred during non-sampling days, and may have reflected patterns quite different from actual data obtained. Sampling once per week provided information concerning seasonal, diurnal, and temporal movements of chinook salmon and other fish species. Weekly sampling intervals may not have been sufficient to clearly see relationships between environmental factors and peaks in movement of juvenile fish.

Factor analyses may have been limited by the number of observations. Adjusted weir capture for Redwood Creek in 1981 was positively correlated with an increase in discharge (Table 2, Figure 7). Actual weir capture for Prairie Creek in 1983 was positively correlated with an increase in discharge (Table 2, Figure 10). The number of observations which was limited to one each week may have explained why correlations between number of chinook captured, and environmental variables considered, were weak for Redwood Creek in 1981, and not evident in analyses for Redwood Creek in 1982 and 1983 (Table 2, Figures 8, 9).

An increase in fish movement during and following increases in flow may have suggested that fish became disoriented and were moved downstream, or may have suggested that fish were entrained in the flow and forced downstream. Turbidity may have increased during periods of high flow and may have prevented visual orientation resulting in fish movement downstream. Relocation or displacement caused by high flows may have resulted in agonistic behavior among relocated fish and emigration may have occurred. This agonistic behavior in fish may have been ongoing throughout the time of downstream movement as was suggested in the comparison of fork lengths of seined and trapped fish in Redwood Creek in 1983 (Figure 9).

In 1983 a larger mean fork length for fish seined in Redwood Creek than in fish captured in the weir may have been attributed to density related factors, territoriality, and resultant aggressive behavior (Figure 12). Large fish were perhaps causing late, small arrivals to emigrate downstream. This was in agreement with Reimer's (1973) findings in his studies of chinook salmon in Sixes River, Oregon. Mean fork length of seined fish was not greater than mean fork length of migrating fish in Redwood Creek in 1983 until late in the season, near 14 June 1983 (day 45) (Figure 12). Chapman (1962) found territoriality and aggressive behavior to be a factor in the downstream movement of coho fry. Edmundson et al. (1968) found that the density of populations of steelhead and chinook salmon may have had an effect on movement of fishes. Studies of chinook in aquaria indicated that excessive fish densities became adjusted by emigration. Juvenile chinook do exhibit an in-river permanence in station. Edmundson et al. (1968) indicated that

> as growth occurs and stimuli such as water depth and velocity, temperature, food supply, or social relationships no longer release holding behavior, the fish move to another area and that new area provides the stimuli releasing motor patterns that, in turn, cause fixation to a station or limited area.

In all years, captured fish were usually enumerated after the weir had been in place for approximately three hours. The weir was not in place at exactly the same time throughout each season. It was checked more frequently in the early evening during each season. Often, few or no fish were captured during the few hours immediately following sunset. Relationships between cumulative percentage of chinook captured and percentage of evening hours fished (Figure 5, 6) represented the time that fish began to migrate in Redwood Creek and Prairie Creek. The relationships did not clearly represent the time when fish ceased to migrate. Frequent checking of the weir and enumeration of captured fish during hours prior to sunrise would have provided more precise information concerning cessation of fish movement. In all years and in each creek, fish did not begin to move until 1.0 h to 1.5 h after sunset. This observation offered support to Miller's (1970) and Reimers' (1973) speculation that fish movement at night was a non-directed displacement due to lack of visual orientation.

Size and Condition

Mean fork lengths of fish captured in the early weeks of sampling in Redwood Creek in 1981 were smaller than mean fork lengths of fish captured in the early weeks in 1982, and 1983 (Figure 11, 12). This difference in fork lengths may have suggested that migration occurred earlier than in ensuing years. It may also have suggested that there was a large population of fish in the 1981 brood. A decrease in habitat due to low flow may have resulted in competition for space. Displaced fish may have emigrated early at a small size. Low flow may have limited habitat and food resources, with competition for food resources limiting growth. Fish captured in 1982, at the time of increased migration from 28 June (day 59) through 12 July 1983 (day 73), exhibited a broad range in fork length. This range in fork length, may have suggested that watershed conditions caused fish of all sizes to move downstream (Figure 8, 11). Mean fork length of fish captured late in season in Redwood Creek in 1983 was greater than mean fork length of fish captured at a similar time of year in Redwood Creek in 1981 and 1982. Difference in mean fork length may have indicated extended river rearing. High flow and low water temperature may have provided suitable habitat (Figure 11, 12).

The range in fork length of Prairie Creek fish was well represented through 9 June 1983 (day 40) in Redwood Creek trap captures (Figure 12). In comparison to Redwood Creek, large numbers of migrating fish were captured in Prairie Creek at the start of sampling. It was assumed that migration of fish began early in Prairie Creek, and may have occurred prior to the start of sampling in either creek. Mean condition of Prairie Creek and Redwood Creek fish fluctuated throughout the season. Similarities in fluctuations of mean condition factors for Prairie Creek fish and Redwood Creek fish in 1983 suggested that fluctuations may have been real and not the result of sampling error (Figure 13).

Similarities in condition between hatchery and estuary fish from 15 July (day 76) through 23 November 1983 (day 207) may have supported the fact that this condition represented condition of fish after or during the process of parr-smolt transformation (Figure 16). Meehan and Siniff (1962) found that condition factors of coho and chinook salmon increased significantly throughout the downstream migration in the Taku

River, Alaska. Fessler and Wagner (1969) reported a general decrease from December through July in mean coefficient of condition (condition factor) for hatchery reared and native migrant steelhead. They suggested that the decrease was related to the process of smoltification.

Scale Characteristics and Analyses

Mean platelet diameter was significantly larger in Prairie Creek fish than in Redwood Creek fish (Table 3). There were no differences in mean circuli spacing, and in widths of the first and second bands of five circuli. Bilton (1970) and Marshall (1953) addressed the ecological aspect of adaptive fitness, and found positive correlations between sizes of female parent, and the size of larvae on hatching, egg, and fry. Bilton (1975) postualted that in sockeye salmon there was a potential for growth correlated with egg size that was reflected in the size of the scale nucleus (platelet) and number of circuli that form subsequently. Prairie Creek fish appeared to migrate early, and appeared to enter the estuary and perhaps the ocean at a young age. The ecological significance may have been that large eggs produce large larvae, with smaller relative food requirements, faster swimming speed, and an edge in intraspecific and interspecific competition for food (Marshall 1953; Healey and Heard 1984). Prairie Creek was a relatively pristine creek that had been less adversely impacted by land use (Briggs 1953). Spawning habitat in Prairie Creek may still have supported a race of chinook salmon that was larger in size when returning to spawn than existed in the rest of Redwood Creek. This race may have been once characteristic of the entire Redwood Creek basin.

The inability to establish a common transformation among the three regression equations describing the relationship of riverine circuli on day of capture in Redwood Creek precluded comparisons among years. This may have been due to changes in riverine growth rates, or temporal variability among years in migration of fish (Figure 17). Neave (1936, 1940) and Bilton (1975) have indicated that when growth of a fish changes, circuli may or may not form immediately, and if formed, circuli spacing may vary. In this study it was assummed that heavy, wider spaced scale circuli represented faster growth in a fish, and fine, closely spaced circuli represented slower growth (Clutter and Whitsel 1956; Reimers 1973). Regressions of riverine circuli on day of capture for salmon in Redwood Creek, 1981-1983, provided a base to compare scale characteristics of outmigrant juveniles from the same brood year (Figure 17).

Fish captured in the estuary on 27 July 1983 (day 88) with no estuarine circuli could have been described as recently recruited to the estuarine population (Figure 18). Fish captured on 9 August (day 101), 15 August (day 107), and 31 August (day 123) with no estuarine circuli suggested that late arrivals entered the estuary, but probably at a decreasing rate.

Growth Rate and Life History

Number of riverine circuli on coded day for estuary fish in 1983 (Figure 17) suggested that some fish that arrived throughout the migration (fewer riverine circuli/smaller fish; more riverine circuli/ larger fish), remained in the estuary from 26 July (day 88) through 5 October (day 158). The composite size range of fish in the estuary from 26 July (day 88) through 5 October (day 158) seemed to remain constant. This supported the fact that after 27 July (day 88) fish of all lengths may have been equally affected by emigration and mortality. The regression equation for fork length on day of capture may have represented an unbiased estimate of growth rate for fish during their residence in the estuary (Figure 14).

Growth rate and rate of scale circuli formation for hatchery and estuary fish were not significantly different (Figure 14, 15). The fact that the elevations of the lines were significantly different was difficult to interpret biologically. The curved lines describing growth rate and scale circuli formation in estuarine fish were fitted for fish captured from 27 June (day 58) through 5 October 1983 (day 158). Differences in elevation reflected the relationship apparent among samples throughout the sampling time period and were not construed to represent processes that occurred in the estuary at a time prior to 27 July (day 88).

When calculating hatchery and estuary growth rates, fish sampled on 23 November (day 207), and 17 October 1983 (day 170) were excluded (Figure 14, 15). In each case a linear model that described growth was not possible when using these data. Rise in mean fork length for estuary fish on 17 October (day 170) may have indicated accelerated growth (Figure 14). For hatchery fish, decrease in mean fork length on 23 November (day 207) may have reflected a sampling artifact, or may have been indicative of density dependent factors (Figure 15). A factor that may have biased growth rate of hatchery fish was mortality of either a greater number of larger fish, or greater number of smaller fish. There was no evidence that indicated this occurred. Growth rate for estuary fish in 1983 was less affected by recruitment than by emigration and mortality (Figure 9, 10).

Reimers (1973) described five major life history types of juvenile fall chinook salmon in the Sixes River, Oregon:

1. Emergent fry moved directly downstream and into the ocean within a few weeks;
2. Juveniles reared in the main river or remained in tributaries until early summer, then emigrated into the estuary for a short period of rearing and entered the ocean before the improved growth in late summer;
3. Juveniles reared in the main river or tributaries until early summer, then emigrated into the estuary for extended rearing during the period of improved growth in late summer and entered the ocean in autumn;
4. Juveniles remained in the tributary streams (or rarely in the main river) until autumn rains, then emigrated to the ocean;
5. Juveniles remained in the tributary streams (or rarely in the main river) through the summer, reared until the following spring, and entered the ocean as yearlings. Through scale analyses Reimers' (1973) determined that for the Sixes River, Oregon, fish with the type three life history were the most abundant group of returning spawners.

Juvenile rearing habitat in the mainstem and tributaries of Redwood Creek was limited in summer and early fall due to low flow, high temperature, and lack of cover (Keller and Hofstra 1983). It was likely that type one fish were present in Redwood Creek and particularly in Prairie Creek. In all years, emigrants captured in Redwood Creek prior to mid-June, were thought to have entered the estuary at a time when it was not stablized.

On 31 August 1983 (day 123), high flow (20 cms) caused by unusual precipitation, was recorded in Redwood Creek (U. S. Geological Survey 1983, Figure 9). The estuarine population of chinook salmon decreased following this unusual weather event, with many of the fish possibly entrained in the flow and forced into the sea (Redwood National Park 1984a). Fish may also have volitionally migrated seaward. Fish that left the estuary at this time may have been characteristic of Reimers' type two fish. Fish captured in the estuary after 31 August (day 123) may have been characteristic of type three fish. This was based on the assumption that a decrease in the estuarine population provided optimal spatial and food resources with improved growth. It was questionable whether type four or type five fish were represented in Redwood Creek and Prairie Creek. A few fish may have found adequate habitat and reared in the tributaries until autumn. Yearling chinook were never captured in the estuary.

In the comparison of estuarine and riverine spacing of circuli for estuarine fish, the spacing of estuarine circuli may not have been maximized due to a time lag. Number and width of circuli spaces on estuarine fish may not yet have been sufficient to overcome the large mean attributed to the first five to 10 widely spaced riverine circuli. Reimers' (1973) qualitatively compared riverine and estuarine growth rates of juvenile salmon in Sixes River, Oregon using mean circuli spacing. He found growth rate of fish during their residence in the estuary to be improved. Bilton (1975) found that circuli spacing was positively correlated with growth. He did not refute the possibility of a time lag between a change in diet and a subsequent record of change on the scale. A progressive increase in mean circuli spacing of estuarine fish, with an increase in number of riverine circuli may have reflected a change in productivity in the estuary (Table 4). Fish that arrived in the estuary at a large size (more riverine circuli), may have been better able to utilize the available food source and grow faster (Marshall 1953). Initially, food in the estuary may have been lacking or limiting for early arrivals (fewer riverine circuli) resulting in a slow growth rate (Larson et al. 1981, 1983). Physiological changes in fish with entrance into seawater could have explained differences in riverine and estuarine growth rates. Hoar (1976) reported that, for Salmo and Oncorhynchus, as young fish increased in size, salinity resistance increased, and for a given age, larger fish were more resistant to changes in salinity. Fish that arrived in the estuary at a large size may have been less effected physiologically, better able to utilize the food resource, and may have grown fast. Comparisons of mean riverine and estuarine circuli spacing for fish in the estuary stratified by date and number of riverine circuli, indicated that estuarine circuli spacing was never significantly greater than riverine circuli spacing (Table 4, 5). In the summer and fall of 1983, chinook salmon appeared to remain in the estuary for a period of extended growth, and not accelerated growth.

CONCLUSIONS AND RECOMMENDATIONS

Knowledge of growth and condition, migration patterns, and scale characteristics of juvenile salmon served as a necessary starting point in describing life history patterns of adult salmon that returned to spawn in Redwood Creek basin. Reimers (1978) purported that lack of understanding about fall chinook salmon in estuaries may have been a weak link in current management decisions, limiting our ability to pursue progressive management in the future. This study provided data addressing the temporal pattern of downstream movement of juvenile salmon. It also provided information concerning size and condition of salmon at the time of migration into the estuary near the mouth of Redwood Creek.

Year to year variations in discharge and water temperature may have affected the extent and quality of riverine rearing habitat in Redwood Creek. In low water years, with high water temperatures in early May, downstream movement may have occurred over a shorter period of time. The migration may have been extended in years when flows were high and water temperatures cool during the first part of May.

In years of low flow such as in Redwood Creek in 1981, chinook salmon may enter the estuarine environment in large numbers and perhaps at a small size. At such times, the need for a stable and suitable estuarine environment is critical. The variations in size, in configuration, and in quality of the estuarine environment when the stream has similar low flow conditions as in 1981, may be important factors for brood survival. Irrespective of riverine conditions, year to year and seasonal variations in the estuarine environment may have affected the growth and survival of salmon using this habitat. Scale analyses suggested that in 1983 chinook salmon remained in the estuary for a period of extended growth and not accelerated growth. Regressions of riverine circuli on day of capture for migrating salmon in Redwood Creek, 1981-1983, provided a base to assess the importance of riverine rearing. In the future, scale characteristics of returning adult spawners can be compared with scale characteristics of outmigrant juveniles from the same brood year. Regressions of fork length on day of capture, total number of scale circuli on day of capture, and number of estuarine scale circuli on day of capture for fish captured in the estuary in 1983, provided information that will help assess the importance of estuarine residence on growth and survival of this species.

Reimers and Downey (1982) suggested that for chinook salmon there was a minimum size threshold for survival at the time of ocean entry (approximately 120 mm fork length). Salmon this size were present in Redwood Creek estuary only late in September and October of 1983. Mean size of salmon at time of entrance into the estuary in 1983 was approximately 90 mm. In 1982 and 1981, mean fork length was 66 mm and 74 mm respectively. Mean fork length of Prairie Creek hatchery salmon at time of release in November, 1983 was 138 mm, which was greater than the mean fork length (120 mm) of the terminal population of estuary fish in October, 1983. If size at time of ocean entry was a critical factor

Service 1984b), continued sampling of downstream migrant salmonids should occur to monitor changes in size, condition, and time of entrance of fish into the estuary. Monitoring could be accomplished through periodic sampling in Redwood Creek and Prairie Creek during late evening and early morning hours from April through July.

A final priority should be to assess the impacts of Prairie Creek hatchery on the fishery. The aspect of juvenile survival to maturity, and the economic benefit to the fishery should be considered. Inherent in such an assessment would be the ability to clearly differentiate hatchery stock from wild stock. A consistent and reliable means of identifying hatchery fish should be implemented and maintained.