PHYSICAL REARING HABITAT FOR ANADROMOUS SALMONIDS IN THE REDWOOD CREEK BASIN, HUMBOLDT COUNTY, CALIFORNIA

by

Randy A. Brown

A Thesis

Presented To

The Faculty of Humboldt State University

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

December, 1988

PHYSICAL REARING HABITAT FOR ANADROMOUS SALMONIDS

IN THE REDWOOD CREEK BASIN,

HUMBOLDT COUNTY, CALIFORNIA

by

Randy A. Brown

Approved by the Master's Thesis Committee

Richard L. Ridenhour, Chairman — 19 Sep 88 — Date

Terry D. Roelofs — 7 Nov. 1988 — Date

Terry Hofstra — 10/11/88 — Date

Director, Natural Resources Graduate Program — 11-29-88 — Date

88/FI-142/09/23

Natural Resources Graduate Program Number

Approved by the Dean of Graduate Studies

John C. Hennessy — 20 Dec. 1988 — Date

ABSTRACT

Surveys were conducted in the Redwood Creek basin, Humboldt County, California, from August through early October of 1980 and 1981 to determine the quantity of rearing habitat available for anadromous salmonids. Species distribution and relative abundance were also noted. In 1981 selected sample sites throughout the basin were electrofished to examine fish densities, species and age-class structure. In addition, physical habitat attributes in the sample sections were measured.

Surveys found steelhead (Salmo gairdneri) and coastal cutthroat trout (S. clarki), and coho salmon (Oncorhynchus kisutch) rearing in the watershed exclusive of the estuary. Steelhead were by far the prominent species in the mainstem of Redwood Creek and in tributaries upstream of Prairie Creek. Coho salmon and cutthroat trout were found almost exclusively in the Prairie Creek drainage. Steelhead also occurred in Prairie Creek but they were not nearly as abundant in sympatry with cutthroat and coho, as in allopatry. Allopatric steelhead populations were dominated in numbers and biomass by young-of-the-year, with some yearling and few older fish.

Approximately 175 km of mainstem and tributary habitat, divided 54 to 46 percent, respectively, were found accessible to anadromous salmonids. Salmonid distribution and abundance in tributaries were related to stream order

(Strahler 1957). First and second order tributaries were inaccessible because of high gradients and small size. Waterfalls and woody debris jams were the dominant barriers to migration in larger tributaries, blocking significant reaches in some streams, but not having much effect overall. Some third and fourth order, and all fifth through seventh order tributaries were accessible. Accessible mainstem reaches were fifth through seventh order. Ten of 47 accessible tributary streams contained 79 percent of the identified rearing habitat available in tributaries.

Extensive sedimentation in the mainstem and tributaries exacerbated the reduced quality of rearing habitat for juvenile salmonids during summer low-flow conditions. Pool depth and cover at all sample sites were rated low in quality. Sediment accumulations at tributary mouths limited emigration and trapped fish in drying streams.

Mean numerical abundance of salmonids increased in third through sixth order tributaries. Higher order stream sites, up to sixth order, generally also had higher total biomass densities. Total salmonid density was found to be significantly correlated with stream surface area but not to stream volume. Total salmonid biomass densities at sample sites were generally similar to densities found by other studies in northern California streams, although mean densities for allopatric steelhead were on the whole lower than mean densities for other streams.

ACKNOWLEDGEMENTS

Redwood National Park provided funding for this study as well as the use of vehicles and field equipment. Al Hatherill, Manager of the Humboldt State University wildlife stockroom was also very helpful in providing field equipment and putting up with numerous instances of student induced equipment malfunction. Simpson Timber Company, through the assistance of Juergen Momber, along with Barnum Timber Company and the Stover family, kindly provided access to Redwood Creek through their properties.

David Anderson was my constant companion in the field, braving the treacherous waters of Redwood Creek and even suffering a broken appendage. Without him this study would have been far less enjoyable, and I would be less a good friend. Jim Larson, Tim Salamunovich, Bob Deibel, and Jolene Jambor-Larson also cheerfully assisted in the collection of field data.

Rod Ledbetter tutored me in the use of microcomputers, and he and his wife Gail welcomed my constant presence in their home and provided unlimited use of their computer for word processing of early drafts. Tom Payne helped with the final printing of this thesis by providing the use of his computer facilities and technical expertise.

Dr. Richard L. Ridenhour served as my major professor throughout this study. I extend a special thanks to Rich for his guidance, patience, and unending support of this project.

Terry Hofstra and Dr. Terry Roelofs were also on my graduate committee. Both provided constructive reviews of my thesis draft, but more importantly, they were enthusiastic and supportive of my efforts. In addition, Terry Hofstra also acted as project liaison with Redwood National Park and served as my supervisor during my tenure there. I will always remember and appreciate his insight and constant humor. Each of my committee members were important contributors to my education at Humboldt State and my future in the profession.

There are many other students and professors of the Humboldt State fisheries program, and employees at Redwood National Park, that although not named individually here, made my stay in Humboldt County far more pleasant. They enhanced my education, and I will always consider them friends.

Finally, I thank my family. The love and support of my parents and sisters were always there when needed. I am especially indebted to my wife Sadie, and our sons Christian and Jordan. They suffered through the completion of this project, and I look forward to repaying my debt of support, patience, and lost time together.

Thank you all.

TABLE OF CONTENTS

TABLE OF CONTENTS (CONTINUED) Page

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES (CONTINUED)

LIST OF FIGURES (CONTINUED)

LIST OF FIGURES (CONTINUED)

INTRODUCTION

Historically, Redwood Creek was considered to have been a good producer of chinook (Oncorhynchus tschawytscha) and coho salmon (O. kisutch), and steelhead (Salmo gairdneri) and cutthroat trout (S. clarki) (State of California 1965; Fisk et al. 1966; FWS 1975; Hofstra 1983). Redwood Creek was particularly known for the exceptional number and size of its chinook salmon (Hofstra 1983). Although little actual data exist to quantify the magnitude of decline, it is generally accepted that anadromous salmonid populations in Redwood Creek are considerably smaller than at the turn of the century (State of California 1965; FWS 1975; Hofstra 1983).

The decline of anadromous salmonid populations in Redwood Creek has been attributed to extensive alteration of freshwater and estuarine habitats (FWS 1975; Hofstra 1983). A combination of multiple high discharge events, very erosive regolith, and extensive timber harvest have resulted in considerable streambed sedimentation which has filled pools, embedded substrates, widened stream channels, and raised summer water temperatures resulting in the degradation of physical rearing space through loss of habitat diversity (Fisk et al. 1966; Nolan and Janda 1979). The construction of flood control levees on the lower 5.3 kilometers of Redwood Creek has also greatly changed the estuary, an important rearing and acclimation area for smolting salmonids (Larson et al. 1981; Hofstra 1983; Ricks 1985). Of the six extreme flood events that have occurred since 1955, the 1964 flood is recognized as the event which contributed the most to current degraded conditions (Janda et al. 1975; Madej 1984). As recently as 1956 a California Department of Fish and Game field survey described Redwood Creek as an excellent spawning stream (FWS 1975). In contrast, a survey of the mainstem and a few major tributaries in 1966 described 64 of 84 stream miles as "severely damaged" (Fisk et al. 1966).

A major portion of the Redwood Creek basin is contained within the borders of Redwood National Park and Prairie Creek State Park. Restoration of aquatic habitats and associated fish communities was cited as a specific goal of the Redwood National Park Watershed Rehabilitation Plan (NPS 1981). The Plan also identified the need to determine the existing quality of aquatic habitats and formulate recommendations for restoring these habitats to historic levels of productivity and diversity.

Recent articles have emphasized that effective management of anadromous salmonid populations and their habitats will require resource professionals to become cognizant of ecologic interactions throughout the watershed (Keller and Tally 1979; Naiman and Sedell 1981; Platts 1984; Hall 1984). For instance, numerous studies have identified stream habitats which constitute a minor percentage of all habitats, or which are only usable on a seasonal basis, but which contribute disproportionately to the production of anadromous salmonids (Bustard and Narver 1975; Platts 1979; Sedell et al. 1982; Hartman and Brown 1987).

At the outset of this study existing information about the anadromous salmonid populations and habitats of the Redwood Creek watershed was scattered and incomplete (CDFG no date; Briggs 1953; Dewitt 1954; USDI 1960; State of California 1965; Fisk et al. 1966; Burns 1971; Janda et al. 1975; Iwatsubo et al. 1976; Reeves et al. 1976; Hawkins et al. 1983). This study was initiated to survey the quantity and quality of anadromous salmonid rearing habitats in the Redwood Creek watershed. The late-summer period of annual low stream discharge was targeted for the survey period since this is generally considered to be when juvenile anadromous salmonids in northern California streams are subjected to the greatest stress due to minimum habitat availability and maximum water temperatures (Burns 1971; Denton 1974). Specific goals of this study included:

(1) Identification of important rearing areas.
(2) Identification of factors limiting physical rearing habitat.
(3) Determination of salmonid species distribution.
(4) Comparison of juvenile salmonid densities at selected sites throughout the watershed and Northern California.

STUDY AREA

Redwood Creek drains an area of 730 km^2 (282 mi^2) in the northern California coast range, entering the ocean near the town of Orick in Humboldt County (Fig. 1). Basin relief is high (1600 m/ 5300 ft), average hillslope gradients are steep, ranging from 31 to 34 percent in the northern and southern basin respectively, and valley bottoms are narrow, seldom exceeding 60 m (200 ft) (Janda et al. 1975). Basin geology is dominated by rocks of the Franciscan assemblage which are highly susceptible to chemical decomposition and erosion. In contrast to the remainder of the watershed, the Prairie Creek drainage, largest tributary to Redwood Creek with an area of 104 km^2, exhibits gentler hillslope gradients and a regolith that is less susceptible to erosive processes. Redwood Creek enters the ocean as a seventh order stream, based on the convention of Strahler (1957). Because the basin is structurally controlled by the Grogan Fault the basin has an unusually elongate geometry with few major tributaries (Pitlick 1982). The trellis pattern of the drainage network upstream of Prairie Creek results in Redwood Creek achieving a relatively low stream order with respect to basin drainage area, and the unusual circumstance of Prairie Creek having a higher stream order (7th order) than Redwood Creek (6th order) at their confluence.

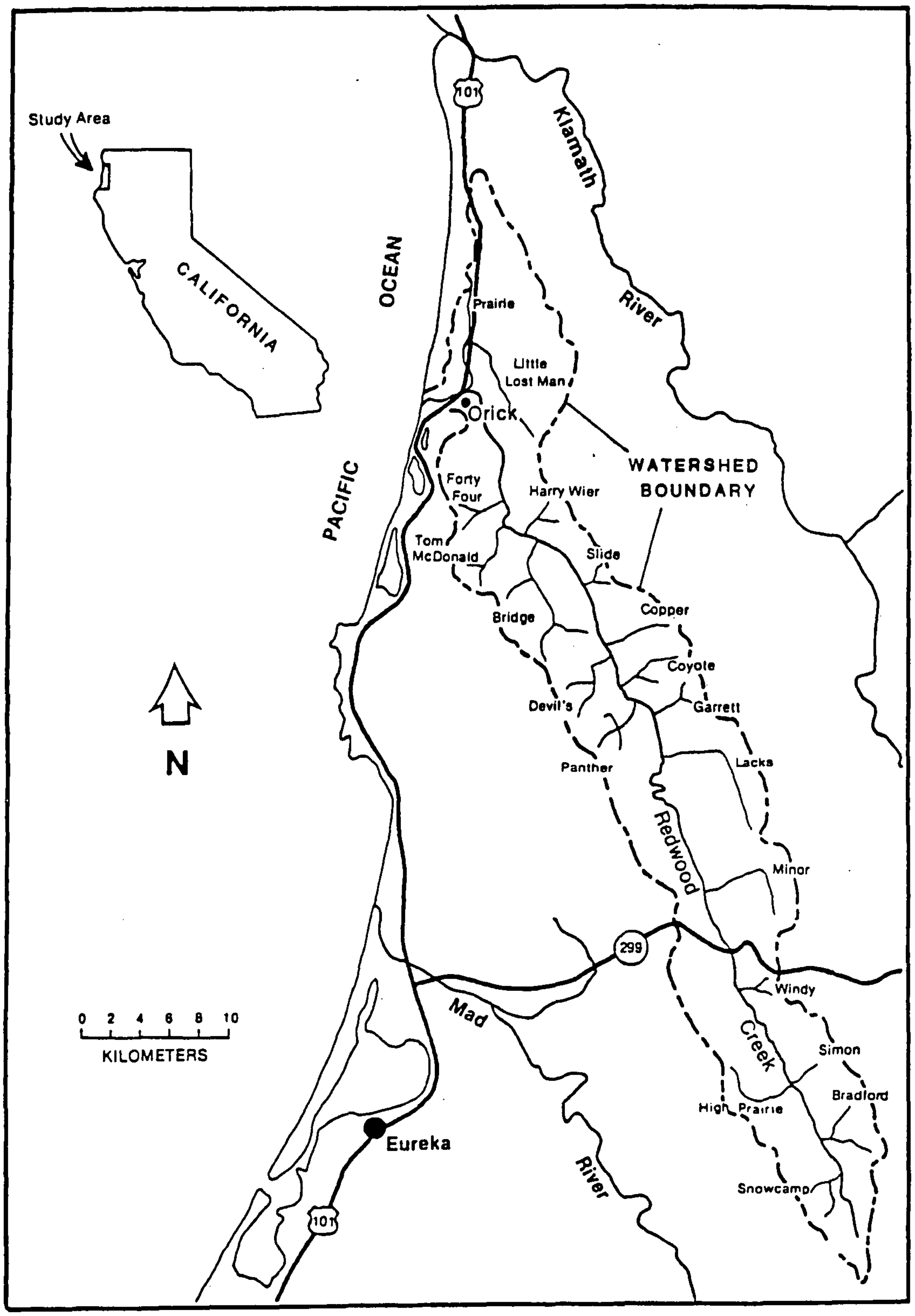


Figure 1. Redwood Creek Basin, Humboldt County, California.

Basinwide climate is greatly influenced by its proximity to the ocean with distinct regional differences evident between the northern/coastal one-third and the southern/inland two-thirds of the basin (Janda et al. 1975). The northern basin has mild winters and short, warm, dry summers with frequent fog. The southern basin has mild winters and hot, dry summers with infrequent fog. Air temperatures recorded near Orick ranged from 20.5°C to 34.6°C (69°F to 95°F) in July (mean maximum values) and from 0°C to 2.7°C (32°F to 37°F) in January (mean minimum values) (Janda et al. 1975). Inland, the drainage basin has somewhat higher summer and lower winter temperatures than along the coast.

Annual precipitation, mostly in the form of rain, averages 200 cm (80 in) basinwide with most occurring from November through April (Janda et al. 1975). Consequently, stream discharge varies considerably with seasonal differences in precipitation. Base flow discharge usually occurs from late-summer through early-fall. Streams with drainage areas of less than 2.6 km^2 (1 mi^2) are often intermittent or dry during the base flow period (Janda et al. 1975). Conversely, streams in the basin are subject to severe flooding in winter. Discharge records for Redwood Creek at Orick over the 31-year period spanning water-years 1954 through 1984, report an average discharge of 31 m^3/s (1,094 cfs) with mean daily low discharges less than 1 m^3/s (35 cfs) and mean daily flood discharges in excess of 255

m^3/s (9000 cfs) occurring in most years of record (USGS 1954-1984). Six flood events in excess of 1273 m^3/s (45,000 cfs) have occurred during this 31-year period.

Historically, 82 percent of the drainage basin was covered in dense coniferous forests (Best 1984). Climax vegetation in the northern basin was dominated by coast redwood (Sequoia sempervirens)/Douglas fir (Pseudotsuga menziesii) forests. The southern basin was dominated by a mixed Douglas-fir/hardwood forest community. Within the past 50 years, 81 percent of these forest lands have been harvested (Best 1984). The 18 percent of the watershed not in coniferous forest is divided equally between oak-woodlands and prairie grasslands.

Land use in the basin has been dominated by timber harvest activities. Some cattle grazing also occurs on private lands. As of 1978, with the last expansion of Redwood National Park, approximately 40 percent of the watershed, concentrated at the northern end, is state and national parklands established to protect virgin stands of coast redwood forest.

Geology, physiography, climate, and land use have combined in the basin to produce some of the most rapidly eroding, non-glaciated terrane in North America (Janda and Nolan 1979). For example, a mean annual suspended sediment discharge in excess of 3000 tons per square kilometer was recorded for Redwood Creek at Orick in 1975 (Janda and Nolan 1979). Suspended sediment discharge rates in the late 1960's and early 1970's were considered to be at least seven times greater than the natural erosion rate (Varnum and Ozaki 1986). Suspended sediment discharge has decreased significantly since 1978, apparently reflecting a reduction in hillslope erosion (Varnum and Ozaki 1986). A large decline in timber harvest activities as well as a decrease in major storms since 1975 may in part be responsible (Varnum and Ozaki 1986).

Fish fauna of the basin is typical of northern California coastal streams (Dewitt 1964; Moyle 1976). Salmonid species include coast cutthroat trout, winter and summer runs of steelhead/rainbow trout, coho salmon, and a fall run of chinook salmon. Both trout species exhibit resident as well as anadromous life histories within the watershed (Dewitt 1964; Moyle 1976; CDFG no date). Other freshwater species reported for the watershed, or observed during this study, include prickly sculpin (Cottus asper), coastrange sculpin (Cottus aleuticus), Humboldt sucker (Catastomus occidentalis humboldtianus), three-spine stickleback (Gasterosteus aculeatus), Pacific lamprey (Lampetra tridentata), and possibly, Pacific brook lamprey (Lampetra pacifica).

Prairie Creek Fish Hatchery, operated by Humboldt County, is located on Lost Man Creek near its confluence with Prairie Creek. During this study the hatchery operated fish traps on both Prairie and Lost Man Creeks to capture upstream migrating chinook and coho salmon and steelhead adults. The trap on Prairie Creek did not span the entire creek and was removed during periods of high flow. Therefore, anadromous salmonids had access to the Prairie Creek watershed upstream of the hatchery. The trap on Lost Man Creek spanned the entire stream but this too was removed during high flow events. Two dams constructed expressly for hatchery operations were located on Lost Man Creek. The upstream dam was a migrational barrier for adult salmonids depending on species and discharge. The downstream dam was not considered a barrier to migration.

METHODS

Most of the field work for this study was conducted in 1980 and 1981, although some information was gathered in subsequent years (see Appendixes A and B). Field data were collected, for the most part, during the period of minimum stream discharge from August through early October. Survey objectives were to identify, quantify, and describe the anadromous salmonid rearing streams in the Redwood Creek watershed. Surveys concentrated on the larger (third order and higher) tributary and headwater reaches of Redwood and Prairie Creeks since these areas were expected to be more important as rearing habitat. Based on the initial surveys, representative stream reaches were selected for further sampling to describe spatial microhabitat components and associated juvenile salmonid populations.

Stream Surveys

Salmonid Accessibility and Use

Tributaries were surveyed to locate barriers to anadromous salmonid spawning migration and thereby delineate habitat available for juvenile rearing. For each stream reach information was collected on migrational barrier type and location, fish species occurrence, relative abundance, and age-length data, and approximate stream discharge.

When possible, a backpack mounted direct-current electroshocker (Model no. BP-2, Coffelt Electronics Co., Inc., Englewood, Colorado) was used to detect the presence or absence of salmonids upstream of a suspected barrier. The electroshocker was heavy, unwieldy, and difficult to transport in steep terrain or on multi-day trips to remote locations and therefore was not always suitable for use. The electroshocker was also most effective in relatively shallow water less than approximately one meter in depth. When the electroshocker was not available or appropriate, dip nets and direct observation were used.

Resident trout species have been reported to occur in the reaches upstream of anadromous fish barriers in several of the basin's tributaries (CDFG no date). Early in the study I noted that suspected resident salmonids were secretive, less abundant, and apparently dominated by yearling and older fish. Known anadromous populations were dominated by young-of-the-year fish which were far more numerous and less wary than older fish. In the event that salmonids were found upstream of a suspected barrier these cues were considered when deciding whether the fish belonged to an anadromous or resident population.

Location of suspected migrational barriers was determined by identifying man-made or natural topographic features and relating these to 1:24,000 (7.5') U.S. Geological Survey (USGS) topographic maps of the watershed. Stream distances were measured with a map wheel. When an obvious landmark was not present, barrier location was estimated in the field by pacing the distance from the barrier to an identifiable location on the stream or by comparing the time required to hike an unknown length of stream with the travel time for a known stream length of similar terrain. These latter two methods were expected to be only rough approximations of the actual distance and no estimate of accuracy or precision was determined.

Although most of the reported migrational barriers and stream survey information were personally observed in the field, information from other sources (Reeves et al. 1976; Hofstra pers. comm.; CDFG no date; Warren pers. comm.) was also included to provide a more complete characterization of the watershed.

General abundance and distribution of salmonid species throughout the watershed were noted. The electroshocker, a small beach seine, a dipnet, and direct observation with mask and snorkel were used to capture or observe fish.

Salmonid relative abundance per meter of stream length was rated subjectively based on field observations. Since a quantitative measure was not applied, stream reaches were placed in broad ranges of abundance as follows:

none = 0 fish observed

one = single fish observed

few = less than 0.5 fish per linear meter of stream

some = 0.5-2.0 fish per meter

many = 2.0 or more fish per meter

Mean salmonid relative abundance was compared between stream orders. Abundance ranks were assigned whole values of zero through four, e.g. zero equals none and four equals many. Mean relative abundance for each stream order was determined by summing the abundance ranks for each stream in which fish were observed, over all species, and dividing by the number of streams.

Juvenile steelhead and cutthroat trout were sampled to determine age-length relationships and population age structure in the basin. For trout of varying size, fork length was measured to the nearest millimeter and scales were collected to determine age from the left dorsal surface beneath the dorsal fin. Scales were compressed between glass microscope slides and magnified with a microfiche reader in order to count annuli (Jearld 1983).

Stream Character

To gain a better understanding of flowing water habitats a variety of classification schemes have been developed (e.g. Huet 1959; Kuehne 1962; Pennak 1971). The approach which seems to have achieved the most widespread use among fishery scientists is the stream order classification system (Kuehne 1962; Harrel et al. 1967;

Whiteside and McNatt 1972; Lotrich 1973; Platts 1979; Barila et al. 1981). This method was originally developed by geomorphologists as a means of describing the physical characteristics of a given stream reach within a drainage network (Horton 1945; Strahler 1957).

This study used stream order as a means of comparing the existing condition of stream reaches throughout the Redwood Creek watershed. But the use of stream order is not without problems (Hughes and Omernik 1981). For instance, streams of a given order in an area of certain geology, topography, and climate are likely not comparable to a stream of the same order in a dramatically different area. Stream order has also not been applied consistently by researchers since there is no one accepted standard for setting a first order stream. In addition, variable map quality and scale may result in inconsistent order designation between adjoining maps for the same area. For these reasons and more, the use of stream order to compare streams in different regions has been considered inappropriate (Hughes and Omernik 1981). However, within a watershed or region in which geology, topography, and climate remain relatively constant, and order is designated in a consistent manner, then comparison of stream characteristics by order would appear to have application.

Stream order, watershed area, stream channel gradient, and stream location were determined or measured on 1:24,000 USGS topographic maps. Stream orders were determined following the convention of Strahler (1957). First-order streams were defined as the smallest crenulations identifiable on 1:24,000 topographic maps. Watershed areas were either those reported by Pitlick (1982) or were measured in an identical manner by tracing the outline of a watershed from the topographic maps onto mylar sheets and measuring with a polar planimeter. Stream channel gradient was defined for this study as the ratio of change in elevation to linear distance (meter per meter). To facilitate comparison between streams, tributary gradients were determined for stream sections, between one and two kilometers in length, located at or near their confluence with the mainstem of Redwood or Prairie Creeks. Tributary location is the distance measured along Redwood Creek from its mouth to the confluence of the tributary, in km. The general aspect of a tributary basin was also noted.

Discharge for most of the surveyed streams was estimated in their lower reaches using a timed-float method (Robins and Crawford 1954). The width, depth, and length of a flowing, uniform stream section were measured using a meter stick and calibrated rope. Water velocity was estimated by measuring the time required for a floating object, usually a small stick obtained on site, to pass through the stream section. Three float-timings were averaged to determine velocity.

Site-Specific Sampling

Twelve sites throughout the drainage basin were selected for quantitative sampling of stream microhabitat features and associated salmonid populations (Figs. 3-5). Sample site streams and identifying abbreviations are as follows:

Prairie Creek	= PRA	Lacks Creek	= LKS
Streelow Creek	= STR	Mill Creek	= MIL
Little Lost Man Creek	= LLM	Toss-up Creek	= TSP
Tom McDonald Creek	= TMC	Lake Prairie Creek	= LKP
Emerald Creek	= EMD	Minon Creek	= MIN
Panther Creek	= PTR	Redwood Creek	= RWD

At each site a sample section approximately 50 meters in length was selected in accordance with three criteria: (1) the section was downstream from any potential barrier to migration, (2) the section could be effectively electrofished, and (3) the section contained habitat features (e.g. riffles, pools, and cover types) representative of the stream in which it was located and still meet criteria 1 and 2. Sample section location in the smaller streams was measured directly with a meter tape from the downstream end of a section to the confluence of the stream with Redwood or Prairie Creeks. For these latter sites, section location was estimated and measured on the topographic maps.

To measure and quantify stream habitat, transects were placed at five meter (m) intervals along the length of

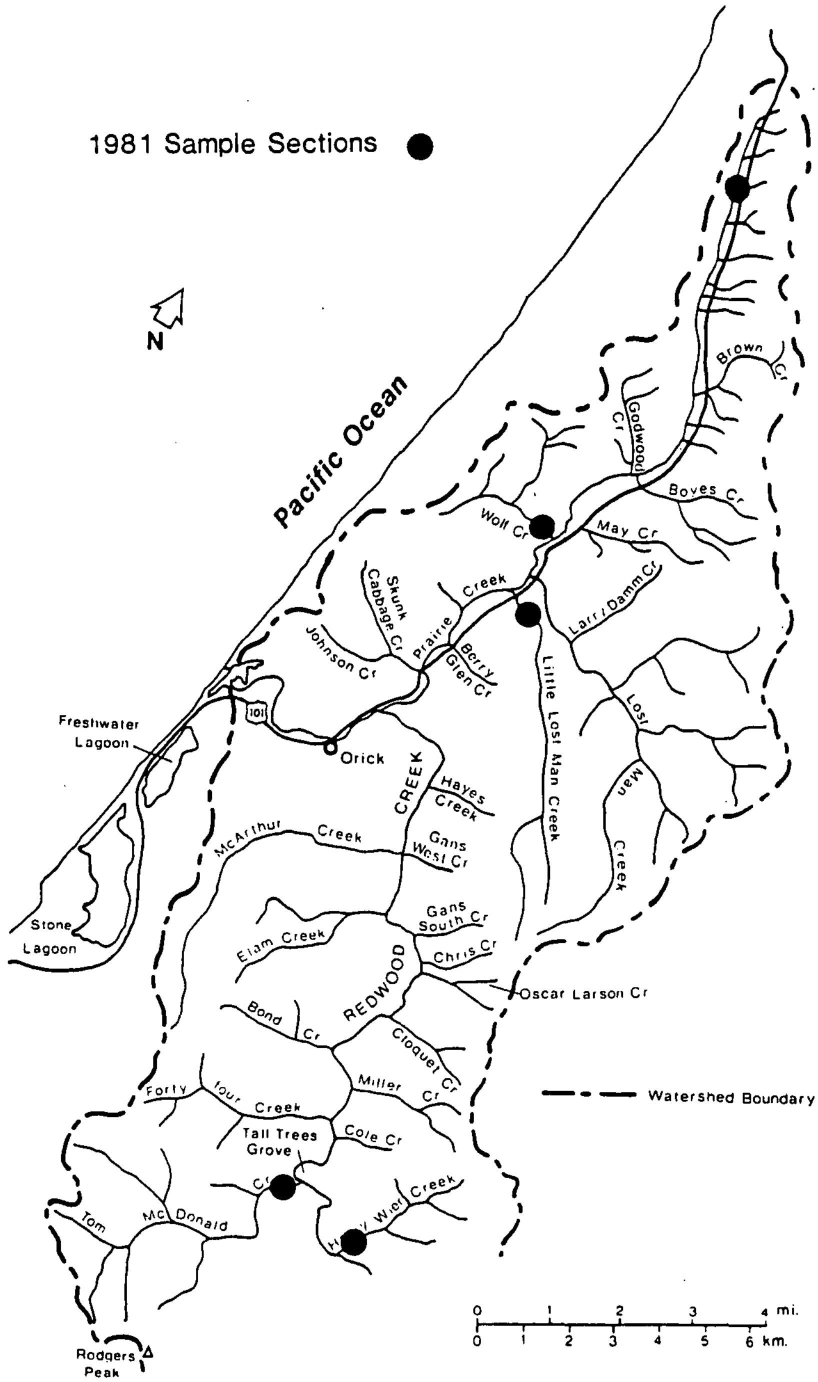


Figure 2. Tributaries and Sites Sampled in the Northern Third of the Redwood Creek Basin, Humboldt County, California, 1981.

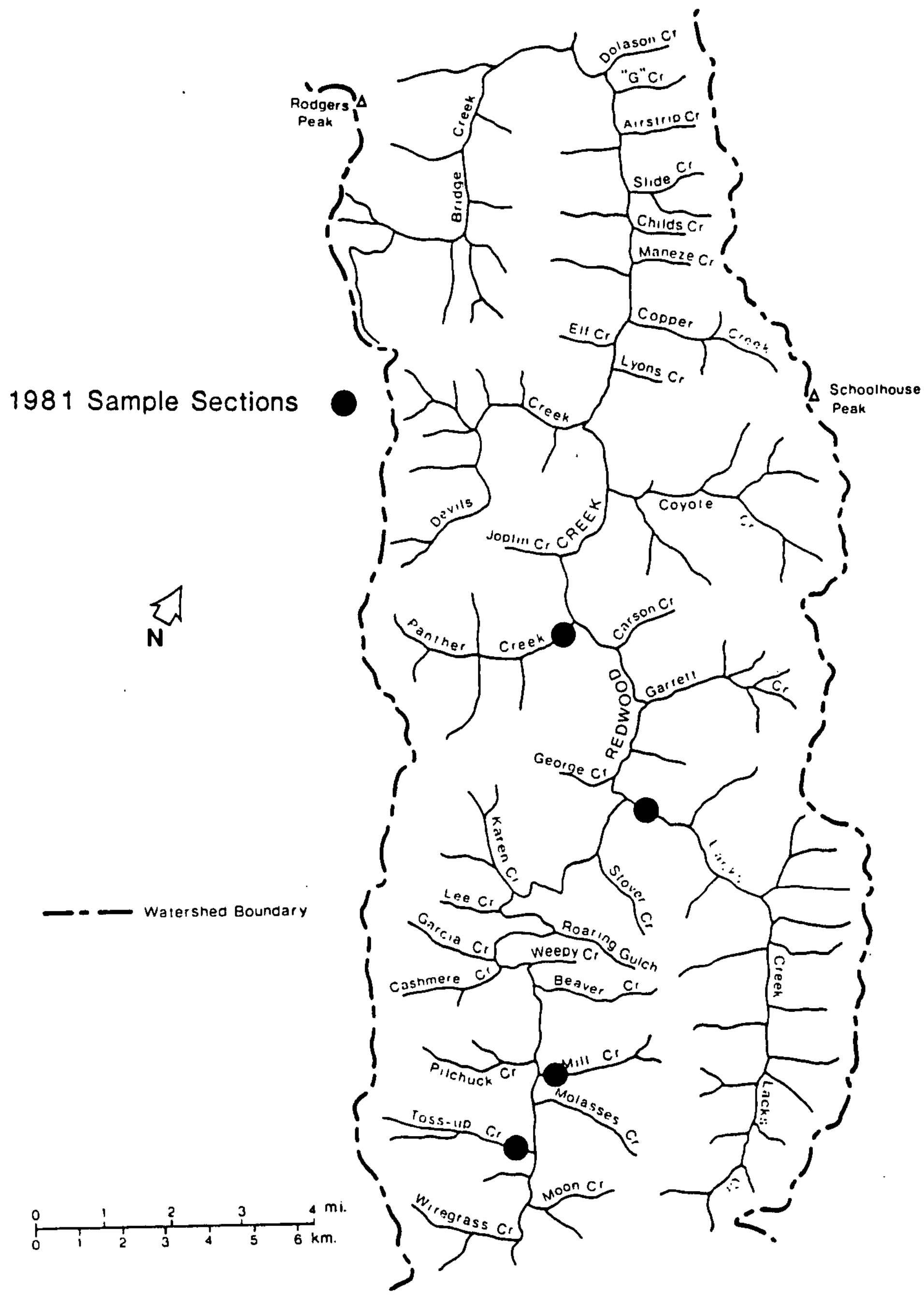


Figure 3. Tributaries and Sites Sampled in the Middle Third of the Redwood Creek Basin, Humboldt County, California, 1981.

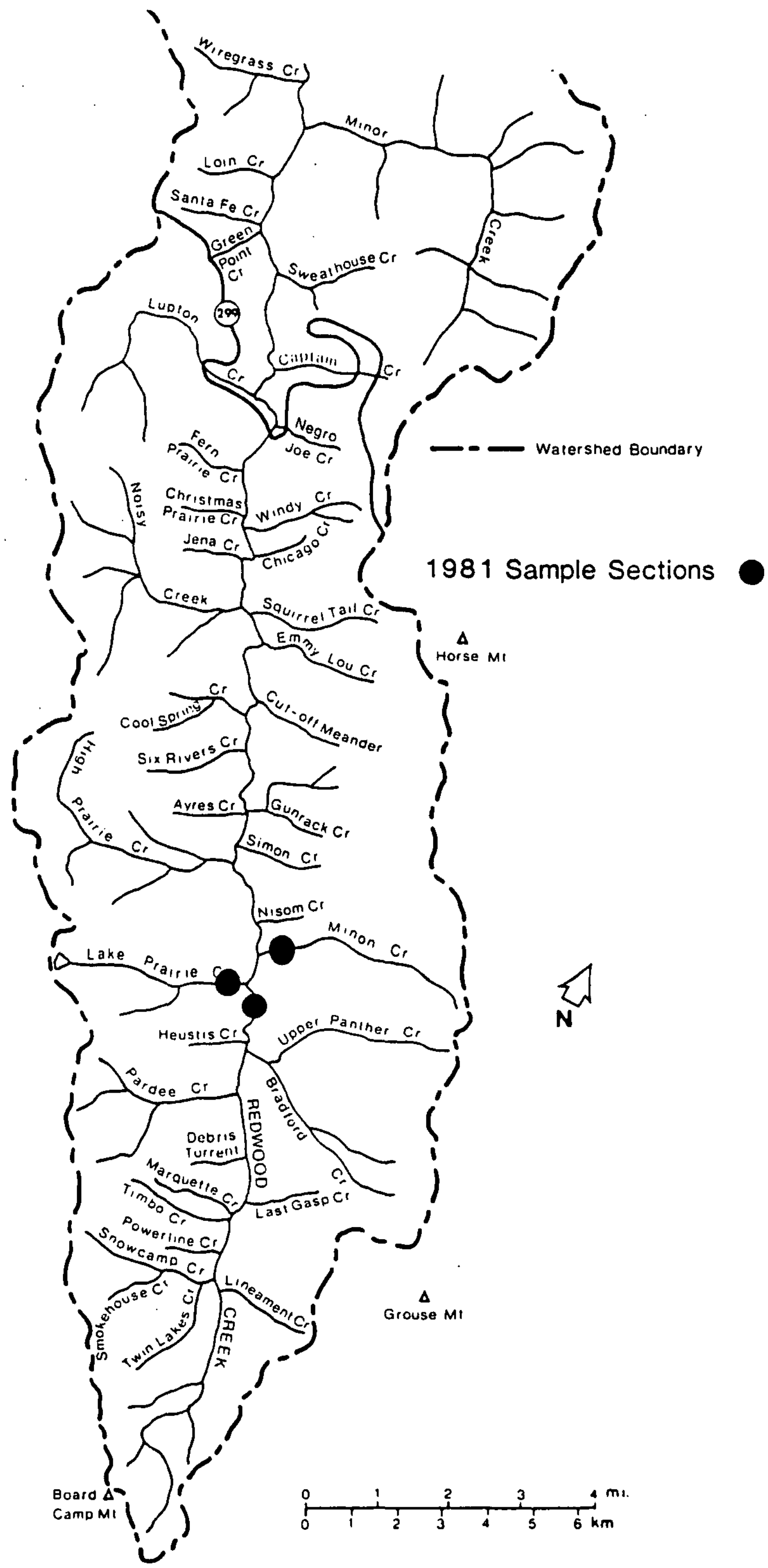


Figure 4. Tributaries and Sites Sampled in the Southern Third of the Redwood Creek Basin, Humboldt County, California, 1981.

the section and perpendicular to the thalweg. Wetted stream width was measured at each transect to the nearest fifteen centimeter (cm) interval. At 30 cm intervals along the transect, depth was measured to the nearest 0.5 cm and instream cover features were counted and described. Instream cover for juvenile salmonids was evaluated based upon criteria similar to those used by Nickelson et al. (1980).

Stream surface area and volume were calculated for each sample section. The distance between adjacent transects was multiplied by the mean width of those transects to obtain a subsection area. The sum of all subsection areas within a section constituted surface area. Section volume was the sum of the area of each subsection multiplied by the mean depth for that subsection. Mean depth of a subsection was the grand mean of the depths measured at the adjacent transects which delimited a subsection.

Frequency of occurrence of depth and cover within each section was tabulated by category. Depth categories included the intervals 0.5 to 15.0 cm, 15.5 to 30.0 cm, 30.5 to 45.0 cm, and 45.5 cm or greater. Cover attributes were placed in one of five categories; cutbanks, overhanging vegetation, woody debris, rock overhang, and surface turbulence (Table 1). Points along a transect with depths less than 0.5 cm, e.g. emergent sand bars or rocks, were not included in the tabulation.

Table 1. Criteria For Evaluating Instream Cover For Juvenile Anadromous Salmonids Following Nickelson et al. 1979.

Cover Types:

1) Undercut streambanks

2) Overhanging riparian vegetation

   - near water surface

3) Boulders or bedrock outcrops

   - submerged or emergent

4) Woody debris

   -logs, limbs, root wads

5) Surface turbulence

   - stream bottom is not visible but water velocity is not excessive, greater than approximately 2 feet per second

Cover Qualifiers:

- A depth of more than 5 cm must be associated with a cover feature.

- Cover feature must be within 15 cm of point of evaluation on transect.

- Cover refers to areas that would presumably be used as refuges from predation and for resting.

Stream discharge for each section was measured using the mid-section method (Buchanan and Somers 1969). Stream width and depth were measured with a meter tape and calibrated stream wading rod, respectively. Mean column water velocity was measured with a pygmy mechanical current meter (Model no. 625, Teledyne-Gurley, Troy, New York).

Stream channel gradient was calculated by dividing elevation change by the length of stream over which the elevation change was measured. The angle of the difference in elevation between two points was measured to the nearest 0.5 degree with a clinometer. A meter tape was used to measure distance between points. The actual change in elevation was calculated using standard trigonometric functions for a right triangle. Gradient was determined for each sample section, from upstream to downstream end, and for the reach extending from the downstream end of the section to the confluence of the stream, with the exception of reaches downstream from the Redwood and Prairie Creek sites.

Juvenile salmonid populations at each site were estimated using an equal-effort catch removal method (Youngs and Robson 1978). Block nets were placed at each end of a section to prevent emigration or immigration during sampling. A backpack DC battery-powered electroshocker was used to stun fish for capture. Fishing effort consisted of the time required to complete a sampling pass through a section. To maintain constant sampling effort, electroshocker voltage was not varied between passes and all passes were conducted in approximately the same elapsed time. Voltage settings ranged between 250 and 350 V depending on the site. Two or three passes were conducted in each section. A third pass was conducted if the second pass collected more than half the number of fish, of a given species, caught in the initial pass. Salmonid population estimates and confidence intervals were calculated using either the equations of Seber and LeCren (1967) or Moran-Zippin (Zippin 1958; Youngs and Robson 1978), depending on whether two or three sampling passes were conducted at the site.

Captured fish were kept in buckets until the end of a sampling pass. MS-222 (Tricaine Methanesulfonate) was used to anesthetize fish to facilitate handling. All captured fish were counted, and lengths and volumes were measured. Fork lengths were measured to the nearest millimeter (mm). Fish volumes were measured to the nearest 0.5 milliliter (ml) with a graduated cylinder. Volume was used as a facsimile for weight to avoid the problems associated with transportation and use of a balance at remote sample sites. The California Department of Fish and Game (CDFG) uses this method regularly and has developed weighting factors for transforming volume to weight for various species (Villa pers. comm.). For salmonids the Department assumes a one to one relationship between milliliters of volume and grams of weight.

To verify the CDFG assumption for volume and weight, steelhead trout were captured at accessible locations along lower Redwood and Prairie Creeks, and their respective weights and volumes were measured. The resulting regression equation, where $\hat{y}$ is the predicted weight of a fish, in grams, and x is the measured volume in milliliters was as follows:

$$\hat{y} = 1.03x,\ r^2 = 0.962,\ 82 \text{ d.f.}$$

The regression was forced through the origin since, presumably, a fish with no volume also has no weight. The regression verified the CDFG assumption for Redwood Creek, therefore I converted measured volume directly to weight, assuming a one to one relationship.

Biomass of salmonids at a site was calculated by multiplying the estimated number of fish by the mean weight of all fish captured. Biomass was calculated separately for age groups and species. The biomass density of salmonids at each site, in grams per meter squared, was calculated by dividing the calculated biomass by the measured surface area.

Pearson product-moment correlation coefficients and tests of significance were calculated using standard equations (Sokal and Rohlf 1981). A logarithmic transformation was performed on data for mean young-of-the-year (y-o-y) trout length and y-o-y trout sample site biomass density prior to calculating the correlation coefficient for those values.

RESULTS

Stream Surveys

Physical Description of Tributary Streams

One-hundred-three tributary streams in the Redwood Creek watershed were surveyed, including the major tributaries to Prairie Creek (Appendix A). Most effort was expended on larger tributaries, i.e. third order and higher, since these streams contained most of the tributary habitat accessible to anadromous salmonids.

Thirty streams of first and second order were surveyed (Fig. 5). These represented an uncounted, but presumably small percentage of all first and second order streams directly tributary to mainstem Redwood Creek based upon Horton's law of stream numbers which states that "...the numbers of stream segments of each order form an inverse geometric sequence with order number" (Strahler 1964). No first or second order tributaries to Prairie Creek were considered significant enough to survey. Forty-one, 79, and 100 percent of the third, fourth, and fifth order streams, respectively, in the watershed were surveyed. Only one sixth order tributary, Lost Man Creek in the Prairie Creek watershed, was identified and surveyed.

Prairie Creek downstream from its confluence with May Creek was ranked as a sixth order stream and became

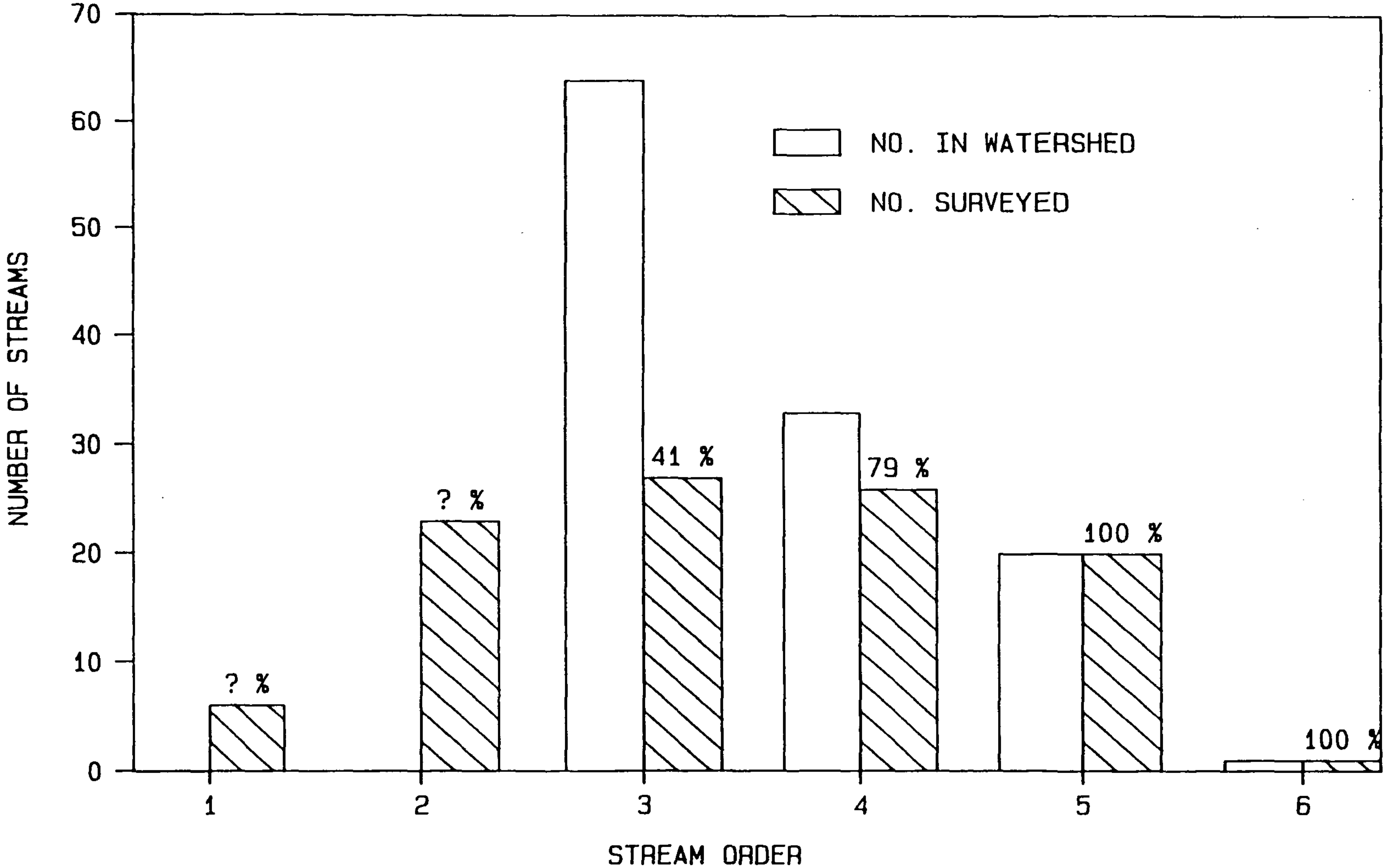


Figure 5. Number of Tributaries Surveyed, Segregated by Stream Order, Redwood Creek, Humboldt County, California, 1980-81.

seventh order at its confluence with Lost Man Creek. Redwood Creek became a sixth order stream at its confluence with Lacks Creek and did not achieve seventh order rank until its confluence with Prairie Creek. This illustrates one of the potential problems in classifying streams by order since Redwood Creek at its juncture with Prairie Creek was, in all other respects, the dominate stream course with a much greater drainage area, length, channel width, etc. The ranking of Redwood Creek as a lower stream order than Prairie Creek resulted from the trellis pattern of its drainage network, as opposed to the dendritic pattern of Prairie Creek (Kuehne 1962).

Despite the inconsistent relationship in stream order between Redwood and Prairie Creeks, the relation between physical characters and tributary stream order, on the whole, throughout the drainage basin was consistent with the relationships described by Strahler (1957) who noted that "...on the average, if a sufficiently large sample is treated, order number is directly proportional to size of the contributing watershed, to channel dimensions, and to stream discharge at that place in the system." For Redwood Creek tributaries I found that mean watershed area and mean summer base discharge increased, while mean channel gradient decreased, with increasing stream order (Figs. 6-8).

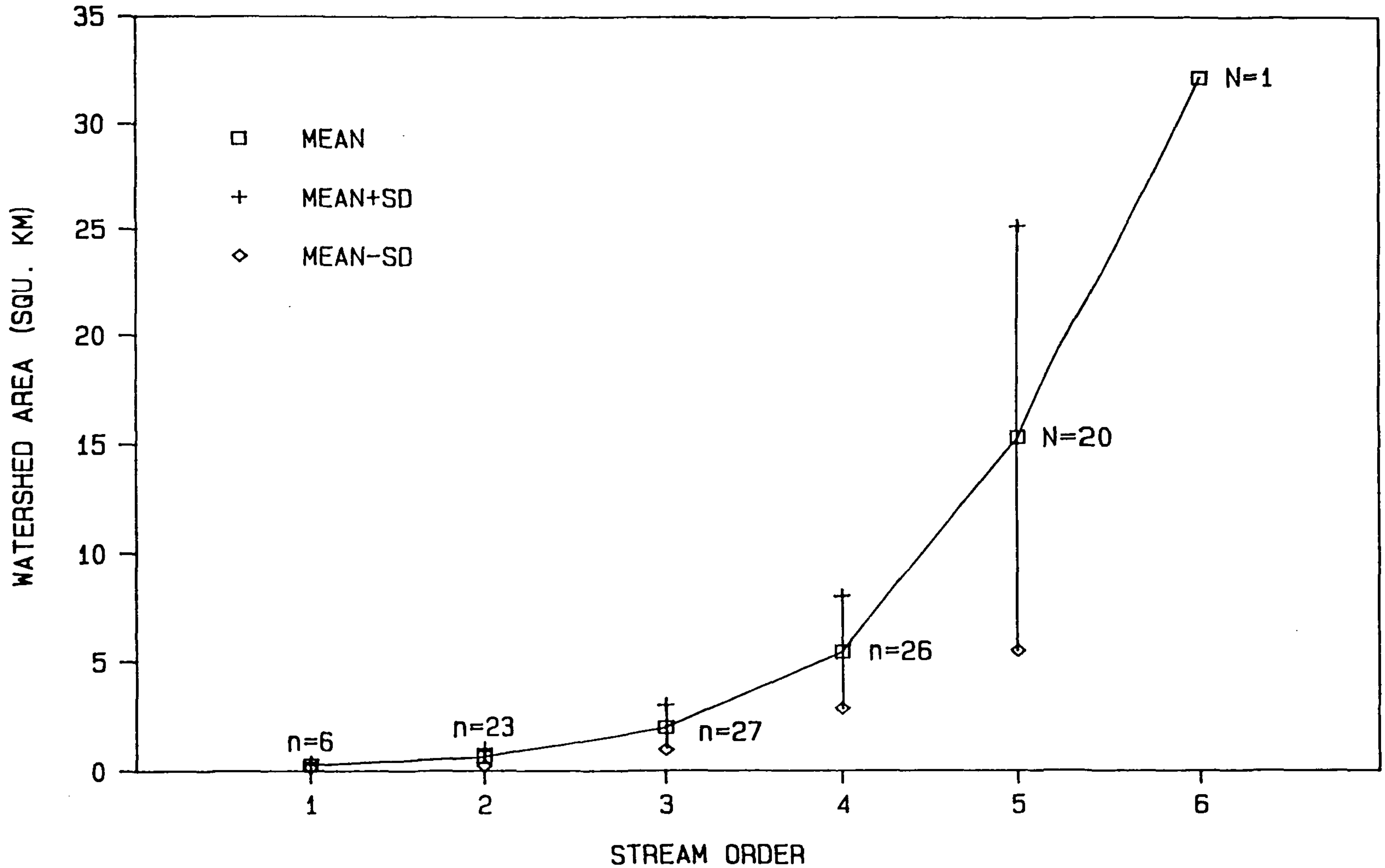


Figure 6. Means and Standard Deviations of Watershed Areas, for Surveyed Tributaries, Segregated by Stream Order, Redwood Creek, Humboldt County, California, 1980-81.

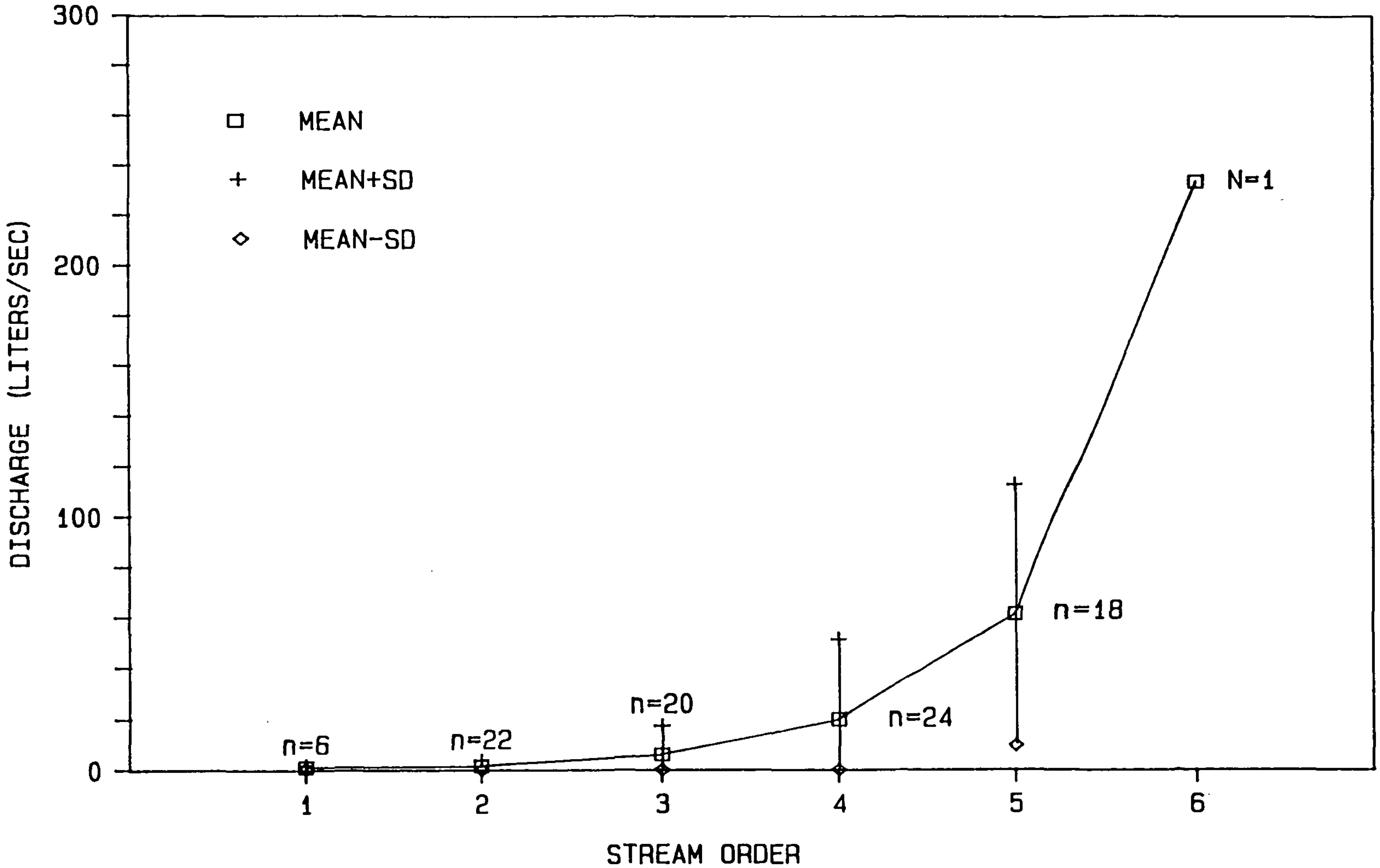


Figure 7. Mean and Standard Deviation of Late-Summer Discharge (August and September) for Surveyed Tributaries, Segregated by Stream Order, Redwood Creek, Humboldt County, California, 1980-81.

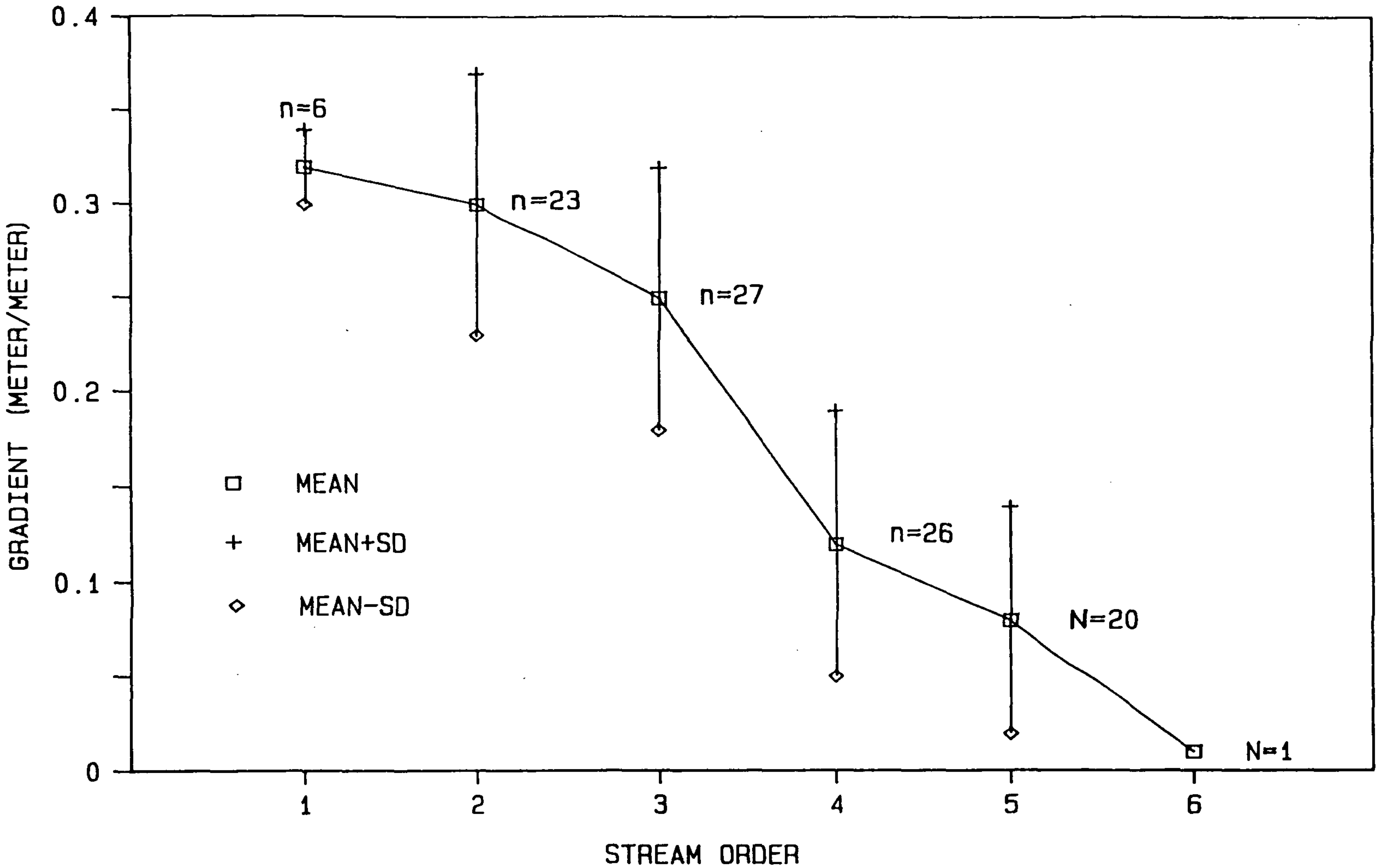


Figure 8. Mean and Standard Deviation of Stream Channel Gradient, for Surveyed Tributaries, Segregated by Stream Order, Redwood Creek, Humboldt County, California, 1980-81.

Barriers to Migration

One-hundred-ten barriers to migration were identified within the basin (Figs. 9-11). The number of barriers exceeds the number of tributaries surveyed because of barriers found on tributary branches. Barriers were categorized into four main types: woody debris jams, bedrock waterfalls, high gradient reaches, and drainage culverts underneath roadways.

Surveys did not identify barriers for all streams (Fig. 12). First through third order streams were often not extensively surveyed because of limited habitat quantity and quality. Surveys of fourth through sixth order streams were sometimes limited by time constraints. Only in a few instances, however, did a significant length of accessible habitat (greater than 0.1 km) in a stream remain unsurveyed.

Woody debris jams formed barriers in approximately 17 percent of the tributaries surveyed (Fig. 12). Eighty-five percent of woody debris jams were located on third order and larger tributaries (Fig. 13). Debris jams were usually associated with past logging activities since debris accumulations often contained sawn logs; were located adjacent to, or downstream from, logged slopes; and incorporated logging equipment, especially choker cables.

Waterfall barriers occurred in only 11 percent of the tributaries surveyed (Fig. 12), but all occurrences were in third order and larger tributaries (Fig. 13). It

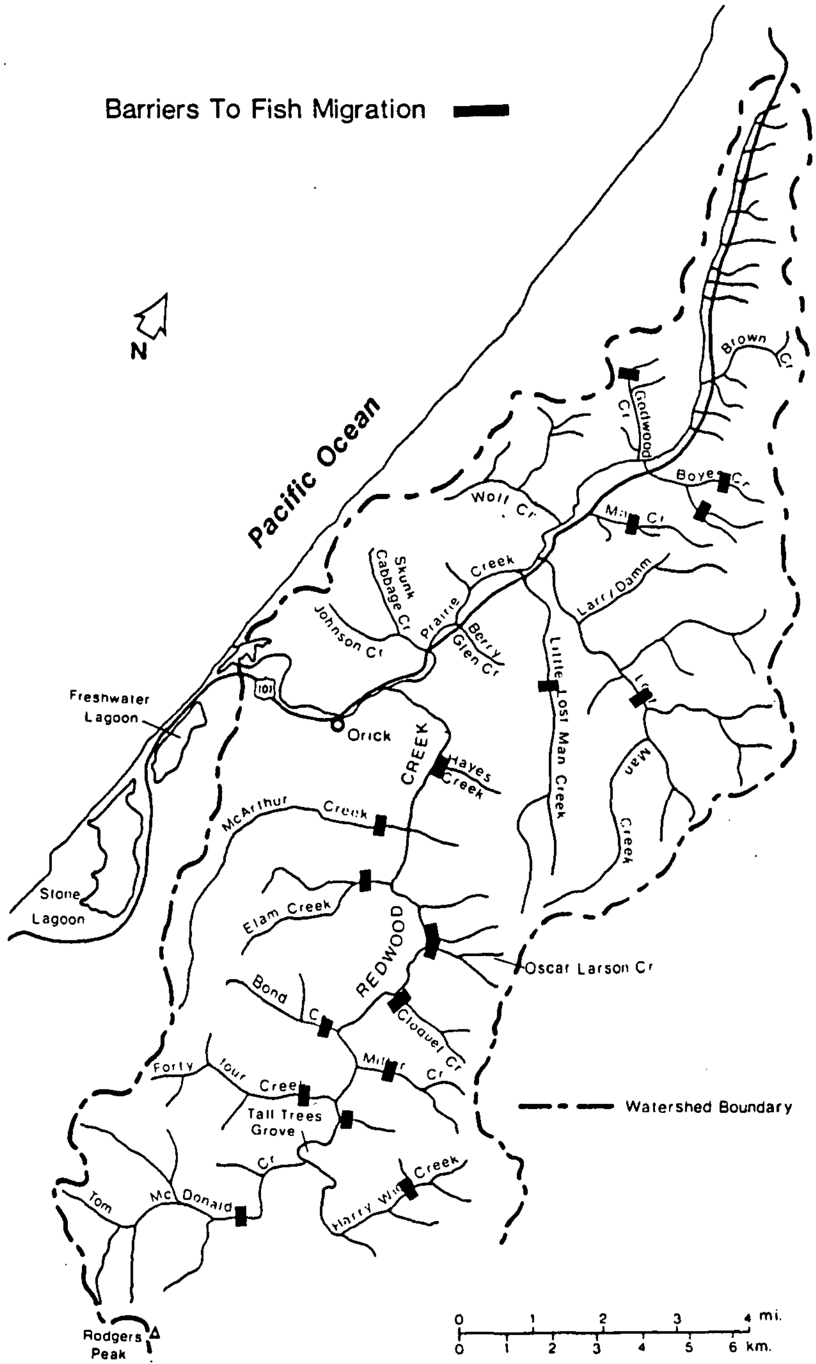


Figure 9. Location of Barriers to Adult Anadromous Salmonid Migration in the Northern Third of the Redwood Creek Basin, Humboldt County, California, 1980-81.

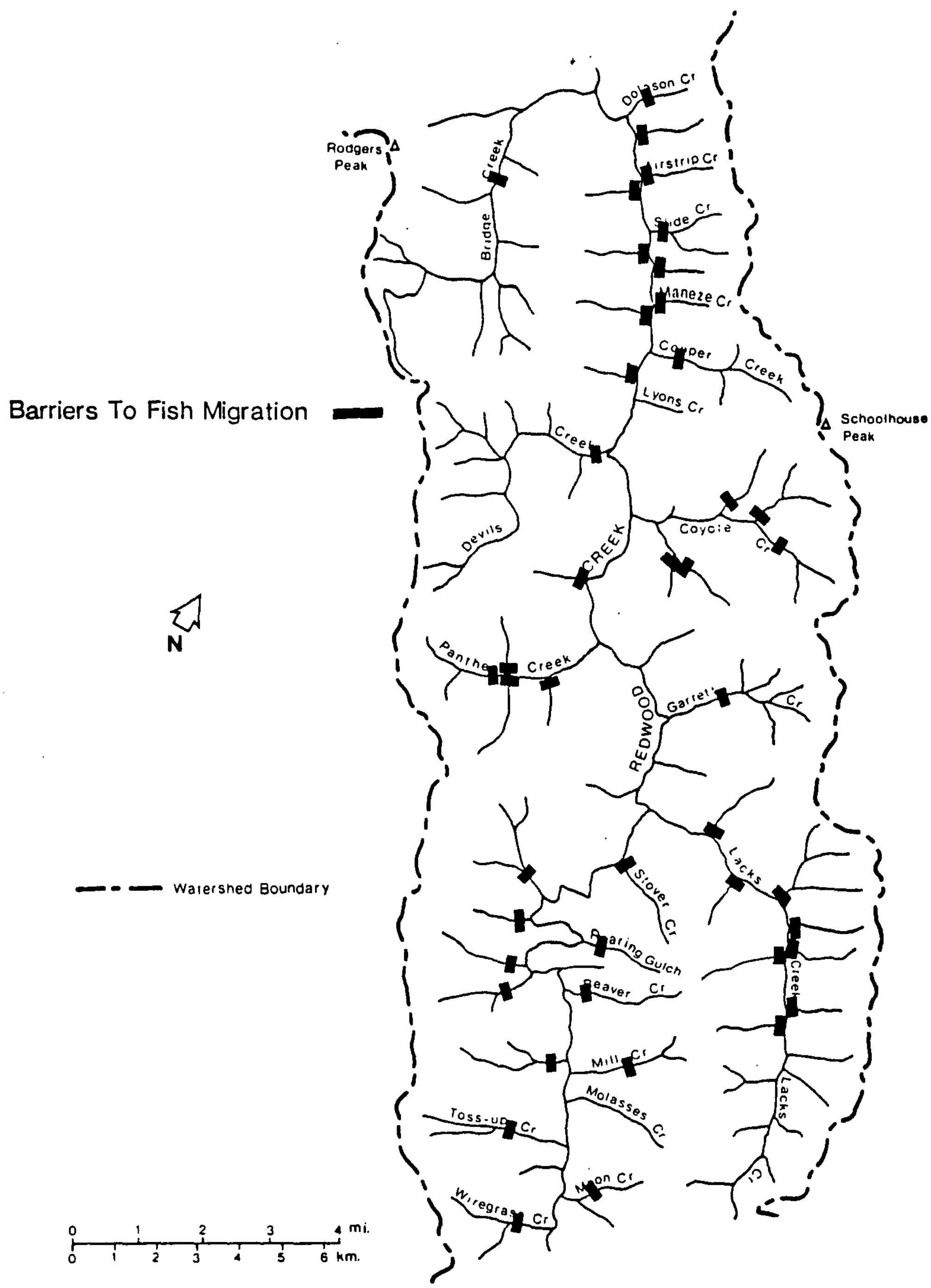


Figure 10. Location of Barriers to Adult Anadromous Salmonid Migration in the Middle Third of the Redwood Creek Basin, Humboldt County, California, 1980-81.

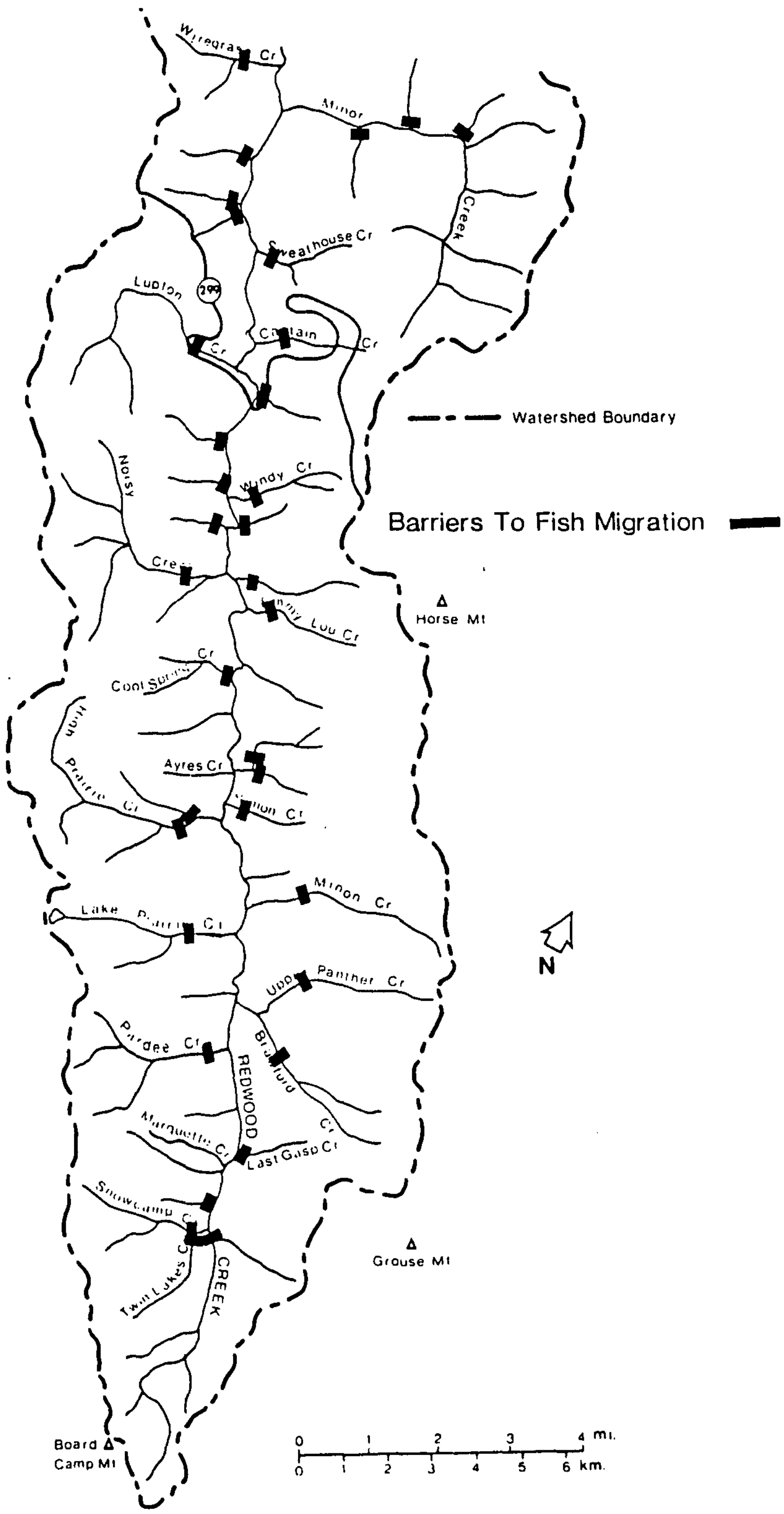


Figure 11. Location of Barriers to Adult Anadromous Salmonid Migration in the Southern Third of the Redwood Creek Basin, Humboldt County, California, 1980-81.

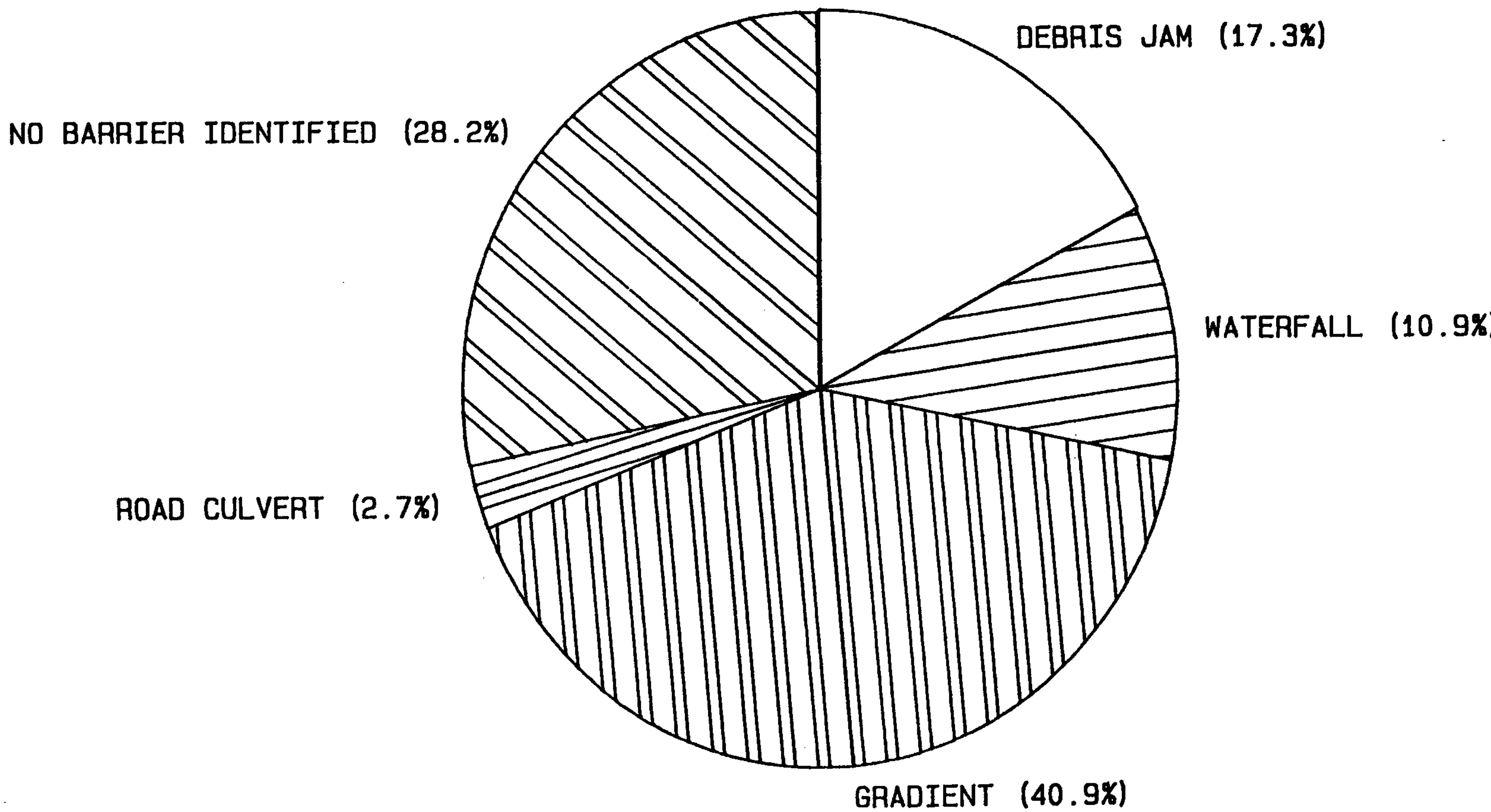


Figure 12. Percentage Occurrence of Barrier Types Found in Tributaries During Stream Surveys, Redwood Creek, Humboldt County, California, 1980-81.

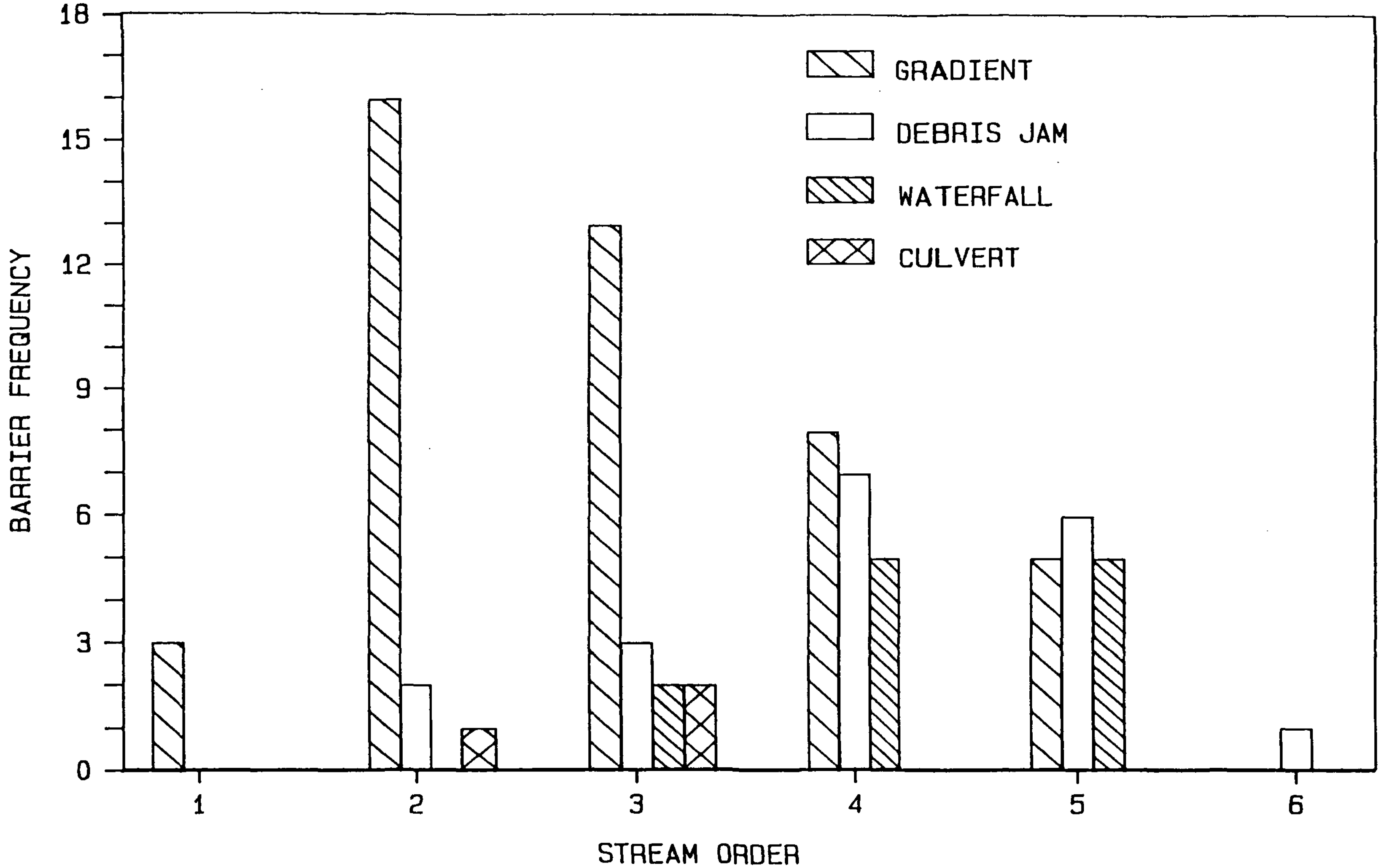


Figure 13. Frequency of Occurrence of Barrier Types in Tributaries, Segregated by Stream Order, Redwood Creek, Humboldt County, California, 1980-81.

is possible that some of the smaller waterfalls, e.g. May Creek in the Prairie Creek watershed, may be passable given the right flow conditions. Others, however, were quite formidable; e.g. Coyote, Garrett, and Devils Creeks, and were probably impassable at any flow. The Devils Creek waterfall occurs only 0.3 km upstream from the confluence with Redwood Creek and blocks most of the tributary from access to anadromous salmonids.

High gradient reaches were by far the most common barrier type, occurring in almost 41 percent of the tributaries surveyed (Fig. 12). Gradients were most important as barriers in smaller streams. Seventy-one percent of the streams in which gradient formed a barrier to migration were third order or smaller (Fig. 13).

Road culverts were barriers in three streams in the basin, accounting for approximately three percent of the tributaries surveyed (Fig. 12). Two of the culverts were located on county road crossings in Redwood Valley (bounded by Lacks and Minor Creeks), and one was associated with an old logging road within Redwood National Park. In each instance the culverts were located on third order or smaller tributaries and were not considered to be barring fish from significant lengths of upstream habitats (Fig. 13).

Two small dams constructed on Lost Man Creek in conjunction with Prairie Creek County Hatchery operations did not fit into the four main barrier categories. The first of these dams is located approximately 0.3 km upstream from the confluence with Prairie Creek, is 0.76 m in height (dam crest height above water surface elevation of pool below dam), and is not considered a major impediment to adult salmonid migration (Anderson pers. comm.). The second dam, located 0.9 km upstream of the first, is over 1.5 m in height, has a relatively long sloping face, and is apparently a major impediment to migration, especially for chinook and coho salmon. Surveys conducted during this study found steelhead and cutthroat trout juveniles but no salmon upstream of the second dam. Further, spawning and carcass surveys have found salmon extensively using the reach upstream of the first dam but not the second. The higher dam is no longer used by the hatchery and is scheduled for removal (Anderson pers. comm.).

A bedrock waterfall migrational barrier was reported for the Redwood Creek mainstem at a location just upstream of the confluence with Snowcamp Creek at river kilometer (RK) 96.0 (Janda et al. 1975). Surveys by this study between Snowcamp Creek and Pardee Creek, the latter entering the mainstem at RK 91.3, found several massive woody debris accumulations with extensive volumes of sediment stored behind them. It was quite possible that one or several of these debris jams acted as a barrier to migration, and they certainly would at low discharge. Although rainbow/steelhead trout were found upstream as far as Snowcamp Creek, it is unknown whether these were resident or anadromous fish. For the purpose of quantifying accessible mainstem habitat the barrier location identified by Janda et al. (1975) was used. It is likely, however, that at least in years of minimal discharge during adult migration, that these debris accumulations define the upstream limit of anadromous fish in the mainstem.

The accumulation of sediment in Redwood Creek at the mouths of tributaries was found in many instances to be a block to emigration of fry and juvenile fish during low flows. Where this occurred, surface flow from the tributary ceased when it entered the Redwood Creek channel, apparently as a result of sub-surface percolation through the sediment. This condition was far more common for lower order tributaries with 54, 46, and 5 percent of accessible third-, fourth-, and fifth-order tributaries, respectively, affected. This condition did not occur in the Prairie Creek drainage.

Accessibility of Tributaries by Anadromous Salmonids

None of the first and second order streams surveyed contained any significant amount of rearing habitat (Fig. 14). Some of the first and second order streams directly tributary to Redwood Creek had a short accessible reach near their confluence. None of these streams, however, was accessible for more than a tenth of a kilometer, the minimum distance identified. Further, many of these

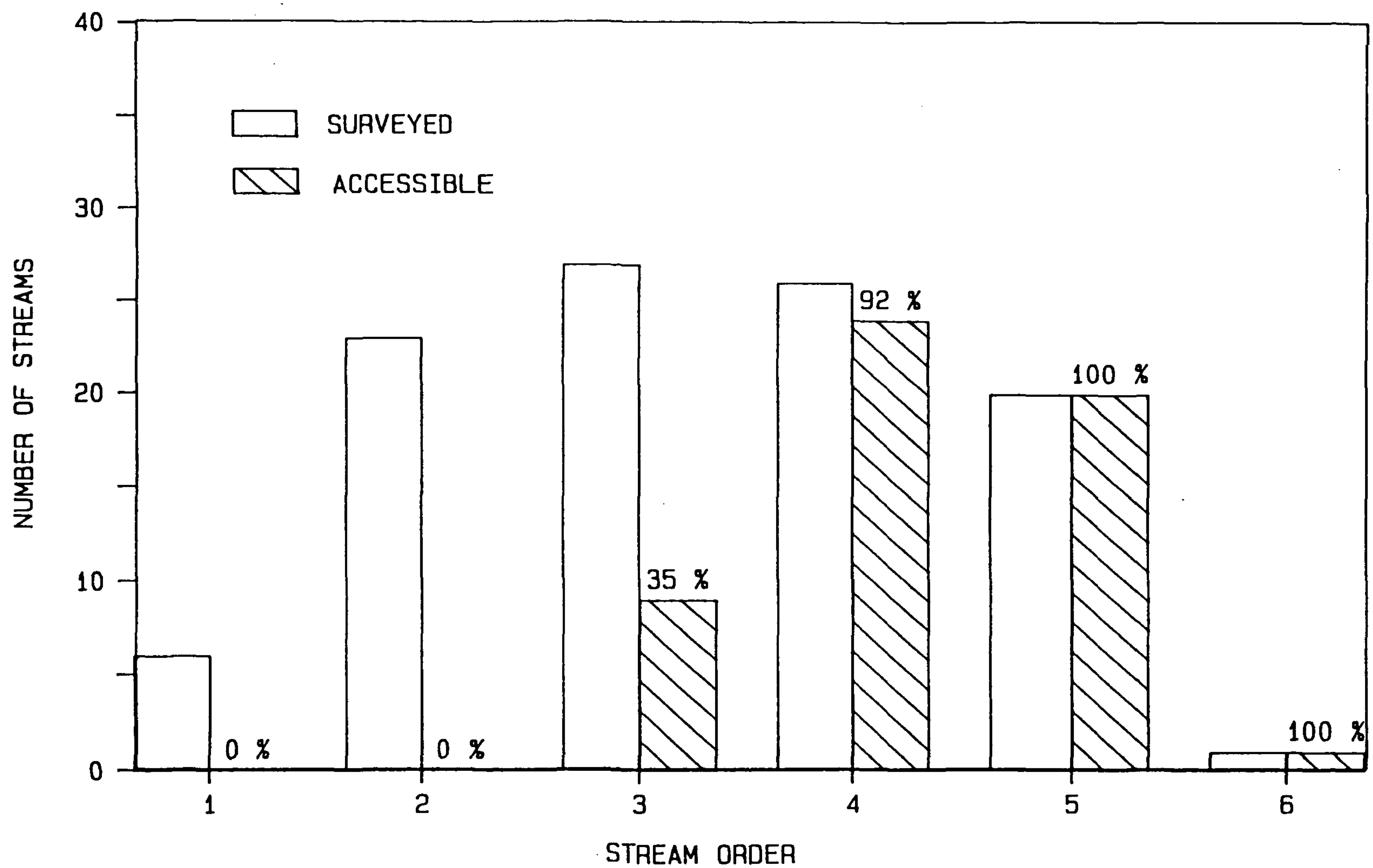


Figure 14. Number of Tributary Streams Which Were Accessible to Adult Anadromous Salmonids, Segregated by Stream Order, Redwood Creek, Humboldt County, California, 1980-81.

streams were dry or had very low flows. Even those with water had insufficient flow to reach all the way to Redwood Creek during the low flow period. Finally, none of these streams contained fish at the time they were surveyed. Overall, these streams contribute little, if any, to summer rearing habitat in the watershed.

All of the tributary rearing habitat identified in the watershed occurred in third order streams or greater. The transition between accessible and inaccessible tributaries occurred at the third order rank. Thirty-five percent of the third order streams surveyed were considered accessible (Fig. 14). In contrast, 92 percent of the fourth order streams surveyed had measurable access while all fifth and sixth order streams were accessible to some extent (Fig. 14).

The mean distance of accessible habitat increased with stream order (Fig. 15). Therefore, increases in access also coincided with increased watershed area (Fig. 16), and decreased stream gradient (Fig. 17). No stream with a watershed area less than 0.9 km^2 or a gradient higher than 0.37 m/m was identified with any accessible habitat greater than 0.1 km, the shortest distance recorded (Appendix A). Of those 10 tributaries with more than 1 km of accessible habitat, none had a watershed area less than 6.8 km^2 or a gradient higher than 0.11 m/m (Appendix A.) (Fig. 18).

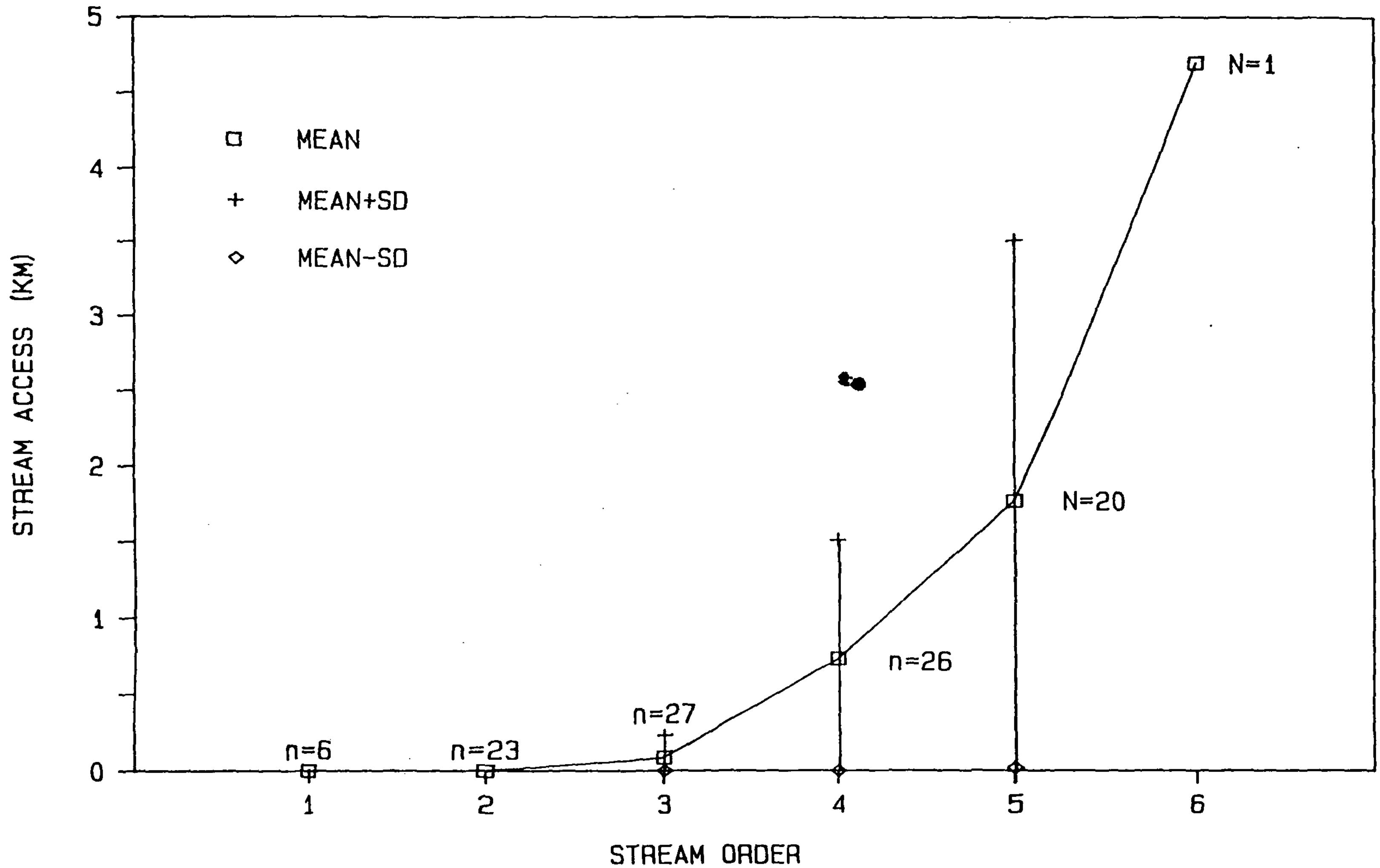


Figure 15. Mean and Standard Deviation of Length of Stream Accessible to Adult Anadromous Salmonids in Tributaries, Segregated by Stream Order, Redwood Creek, Humboldt County, California, 1980-81.

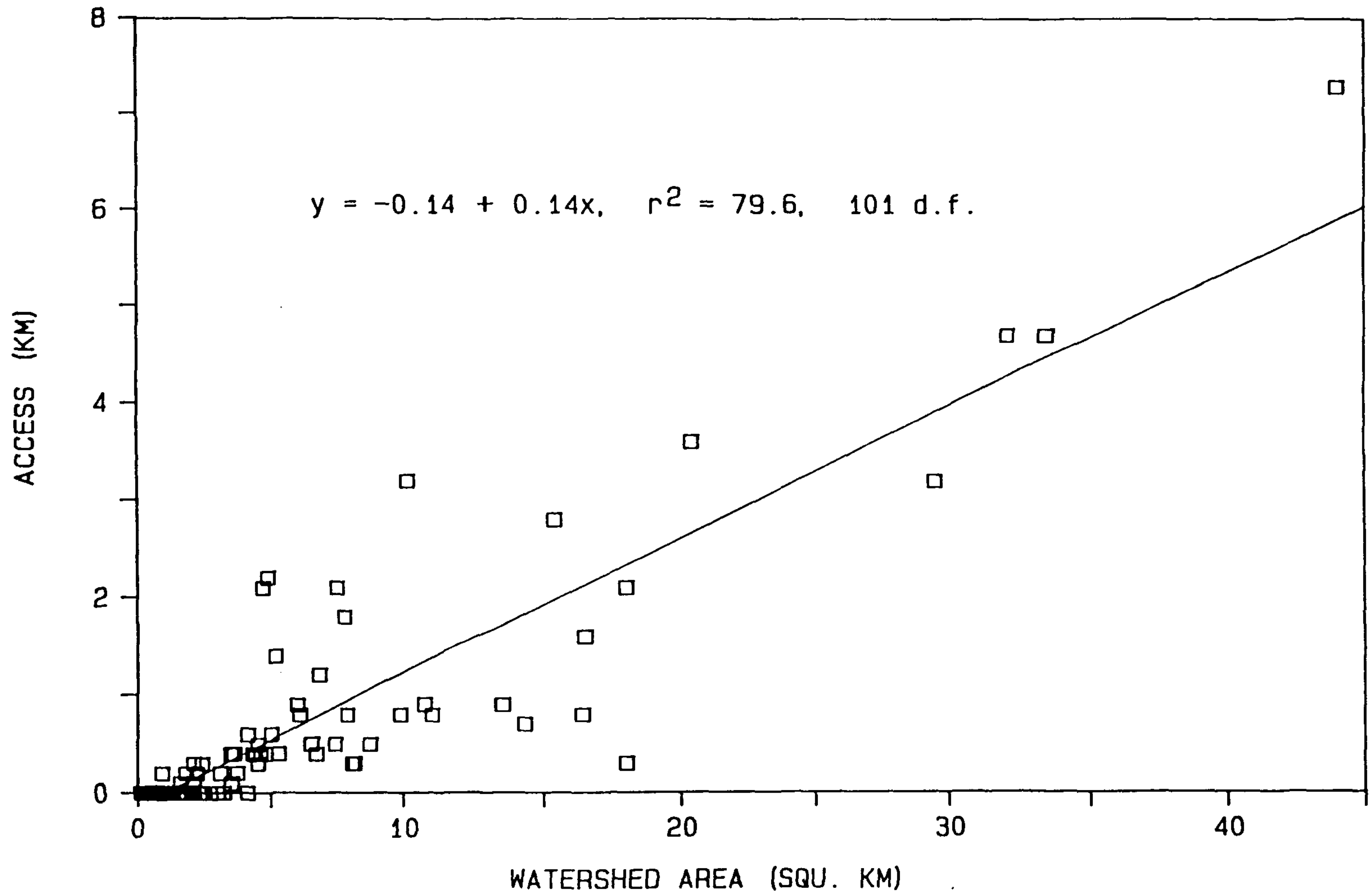


Figure 16. Adult Anadromous Salmonid Access in Tributaries in Relation to Watershed Area, Redwood Creek, Humboldt County, California, 1980-81.

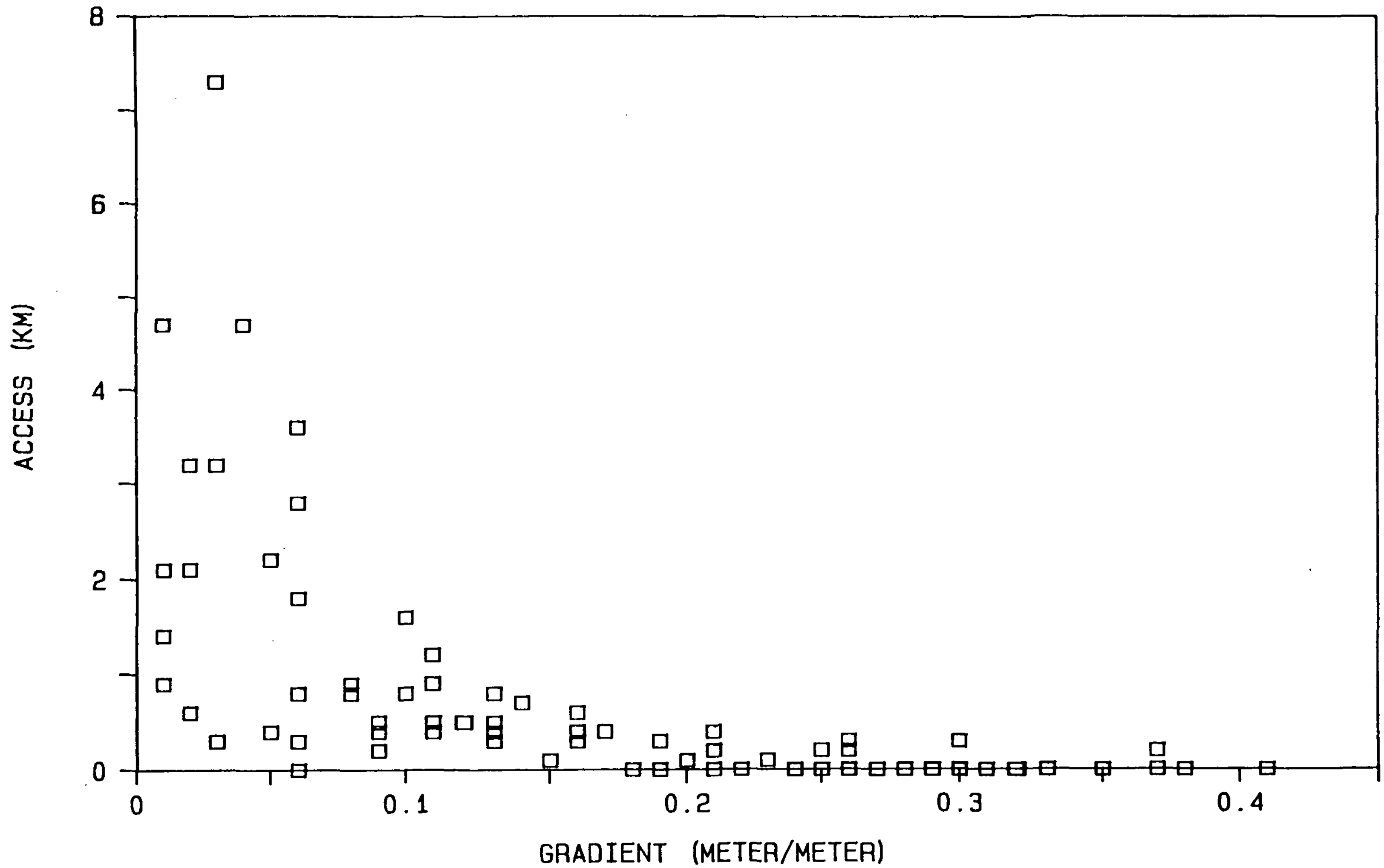


Figure 17. Adult Anadromous Salmonid Access in Tributaries in Relation to Stream Channel Gradient, Redwood Creek, Humboldt County, California, 1980-81.

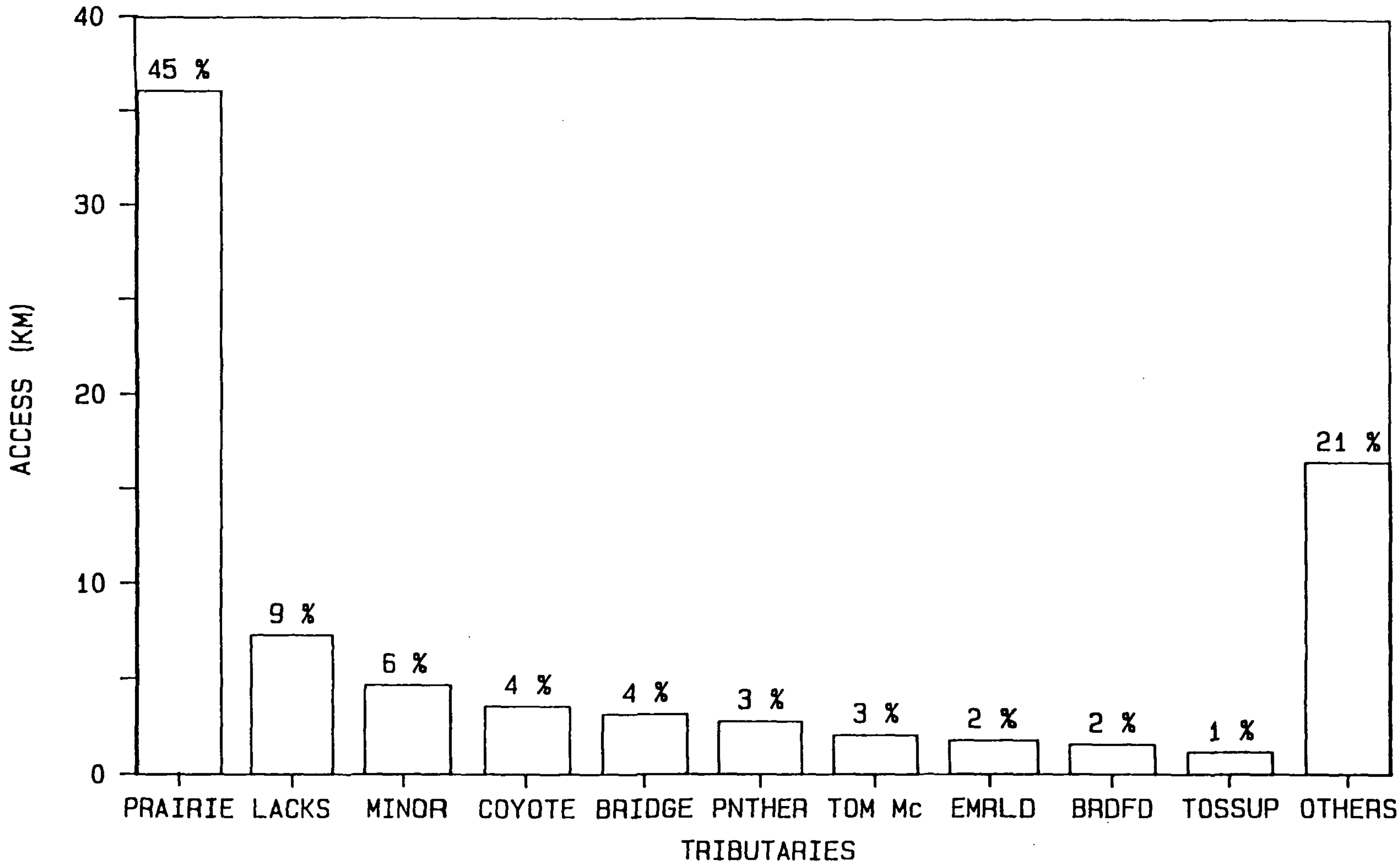


Figure 18. Distribution of Accessible Habitat Among Tributary Streams, Redwood Creek, Humboldt County, California, 1980-81.

Much of the accessible tributary rearing habitat in the watershed was concentrated in a minor percentage of tributaries. Of the 47 accessible tributaries surveyed, 10 (19 percent) contained 79 percent of the habitat (Table 2) (Fig. 18). Prairie Creek and its tributaries contributed the greatest share by far with 45 percent of accessible tributary habitat and 21 percent of all accessible habitat in the watershed.

Of all accessible rearing habitat in the watershed, the mainstem of Redwood Creek contained 54 percent, while tributary streams contributed the other 46 percent (Table 3). For comparison purposes, the mainstems of Redwood and Prairie Creeks were divided into their component order segments in Table 3 since mainstem habitats changed dramatically along their lengths. Sixth order reaches dominated all other stream ranks with 52 percent of all rearing habitat, most of which occurred in the mainstem of Redwood Creek (Table 3). If only tributaries were considered (including mainstem Prairie Creek), then fifth order streams were dominant, also with 52 percent of the total (Table 3).

Distribution and Abundance of Anadromous Salmonids

Steelhead trout were the most widespread and numerous species in the watershed. Of all tributaries in which salmonids were found, steelhead were absent from only a few Prairie Creek tributaries (Table 2). In contrast, anadromous cutthroat trout and coho salmon apparently were

Table 2. Hierarchy of Tributaries With Habitat Accessible to Anadromous Salmonids in the Redwood Creek Basin, Humboldt County, California, 1980-81.

Stream	Access (km)	Stream Order	Species/ Abundance
Prairie[a]	36.1+(18.9+)[b]	7	st/f,ct/s,co/s[c]
Lost Man	4.7+	6	st/f,ct/s
Little Lost Man	3.2	4	st/s,co/f
Brown	2.2	4	ct/?,co/?
Streelow	2.1+	5	st/f,ct/s,co/f
Godwood	2.1	4	st/s,ct/s
Boyes	1.4	4	st/?,ct/?
Skunk Cabbage	0.9+	4	ct/s
May	0.6	5	ct/f,co/f
Lacks	7.3+	5	st/m
Minor	4.7+	5	st/m
Coyote	3.6+	5	st/m,co/x
Bridge	3.2	5	st/m
Panther	2.8+	5	st/m
Tom McDonald	2.1	5	st/s,co/x
Emerald	1.8+	4	st/f,ct/f
Bradford/ Up.Panther	1.6	5	st/f
Toss-up	1.2+	5	st/m
Lupton	0.9	4	st/s
Garrett	0.9	5	st/s
Noisy	0.8	5	st/f
Minon	0.8+	5	st/s
McArthur	0.8	5	st/s,ct/f

Table 2. Hierarchy of Tributaries With Habitat Accessible to Anadromous Salmonids in the Redwood Creek Basin, Humboldt County, California, 1980-81. (continued)

Stream	Access (km)	Stream Order	Species/ Abundance
Karen	0.8+	5	st/s,co/x
Gunrack	0.8+	4	st/f,ct/f
High Prairie	0.7	5	st/s,ct/s
Sweathouse	0.6	4	st/f
Lake Prairie	0.5	4	st/s
Copper	0.5	4	st/s
Elam	0.5	5	st/f
Pilchuck	0.5	4	st/f,co/x
Emmy Lou	0.4	4	st/f
Captain	0.4	4	st/f
Wiregrass	0.4	4	st/f
Windy	0.4+	4	st/f
Molasses	0.4	3	st/s
Squirrel Tail	0.4+	3	st/f
Cashmere	0.4	4	st/f
Garcia	0.4	4	st/f
Mill	0.4	3	st/s
Devils	0.3	5	st/s
Snowcamp/ Smokehouse/ Twin Lakes	0.3	5	st/f
Forty-Four	0.3	5	st/s
Pardee	0.3	4	st/f
Simon	0.3	4	st/f

Table 2. Hierarchy of Tributaries With Habitat Accessible to Anadromous Salmonids in the Redwood Creek Basin, Humboldt County, California, 1980-81. (continued)

Stream	Access (km)	Stream Order	Species/ Abundance
Cut-off Meander	0.3+	3	st/f
Beaver	0.3	3	st/f
Bond	0.2	4	st/s
Slide	0.2+	4	st/f
Dolason	0.2+	4	st/f
Roaring Gulch	0.2	3	st/f
Jena	0.2+	3	st/f
Miller	0.1	4	st/s
Santa Fe	0.1	3	st/f
Xmas Prairie	0.1+	3	none

[a] Prairie Creek tributaries listed
[b] + = further access upstream, terminal barrier not found
[c] Species: st = steelhead trout, ct = cutthroat trout, co = coho salmon
Abundance: x = single fish, s = some, ? = unknown, f = few, m = many

Table 3. Accessible Stream Habitat for Anadromous Salmonids in the Redwood Creek Basin, Humboldt County, California, 1980-81.a,b,c

		Tributaries					
		Prairie Creek					
Order	Redwood Cr Mainstem	Mainstem	Tribs	Other	All Tribs (%)		Watershed Total (%)
3	0.0	0.7	0.0	2.4	3.1 (4)		3.1 (2)
4	0.0	5.7	9.8	9.3	24.8 (31)		25.2 (14)
5	5.7	5.5	2.7	32.7	40.9 (51)		46.6 (26)
6	85.2	2.0	4.7	0.0	6.7 (8)		91.9 (52)
7	5.1	5.0	0.0	0.0	5.0 (6)		10.1 (6)
Total (%)	96.0 (54)	18.9 (11)	17.2 (10)	44.4 (25)	80.5 (46)		176.5

a stream distance in kilometers
b most applicable to steelhead trout
c mainstems by component order, tributaries by ultimate order

limited in distribution. Outside of Prairie Creek and its tributaries, very few cutthroat or coho were found (Table 2). Because of their morphological similarities it is possible that some cutthroat fry may have been misidentified as steelhead progeny. However, the absence of only slightly larger, and easily identifiable, juvenile cutthroat suggests that their presence was probably not often overlooked.

Although chinook salmon occur in the watershed, as expected, none were found by any of the surveys. Fall-run chinook in California streams spend little time rearing in up-river areas (Moyle 1976) and studies by McKeon (1985) and Larson (1987) found that all naturally spawned juvenile chinook in the Redwood Creek watershed apparently migrate to the estuary well before the data collection period of this study.

Percentage salmonid species occurrence tended to increase with stream order (Fig. 19). Inaccessability probably played the greatest role in the use of lower order streams by salmonids, whereas habitat conditions gained greater influence in higher order streams.

Stream order had a greater influence on relative abundance since the largest tributaries tended to have the largest salmonid populations. The electroshocker, in shallow water (less than 1 meter), and mask and snorkel, in deeper water (greater than 60 cm) were found to be the most effective for determining abundance. In many instances

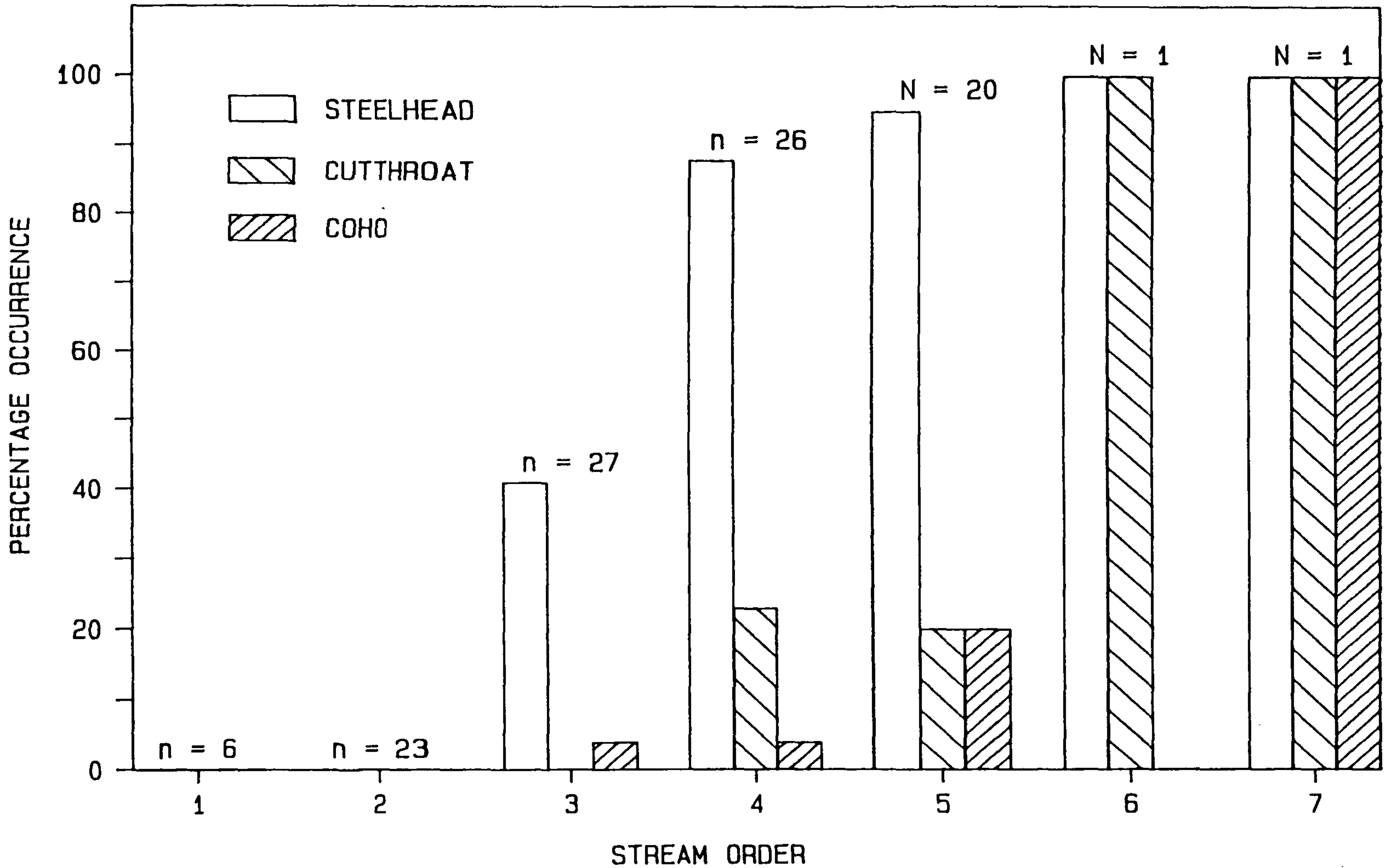


Figure 19. Occurrence of Anadromous Salmonid Species as a Percentage of Surveyed Tributary Streams, Segregated by Stream Order, Redwood Creek, Humboldt County, California, 1980-81.

observation of fish from the stream bank was sufficient to categorize abundance. Mean relative abundance values increased from zero for first and second order streams, to a value of 5.0 for Lost Man Creek, the lone sixth order tributary (Fig. 20). By definition, higher order streams tend to have larger channels and greater discharge than lower order streams (Strahler 1957). Therefore, this abundance measure does not recognize that streams which vary in order, with identical abundance ranks, may have different fish densities. In addition, abundance values were most representative of downstream reaches for tributaries with access exceeding 0.5 km. Tributaries with more accessible habitat had more variable fish densities with the greatest densities usually occurring in downstream reaches, where most spawning habitat occurred, and decreasing with distance upstream.

Study Sites

Site Characterization

Since all sample sites were the same length, differences in surface area and volume are reflective of channel cross-section and discharge at each site (Table 4, Appendix B). Mill Creek was the only third order site sampled and had the smallest wetted surface area and volume measured. Conversely, Redwood Creek the only sixth order site, had the greatest surface area measured, two and one-half times that of Mill Creek, and one of the greater

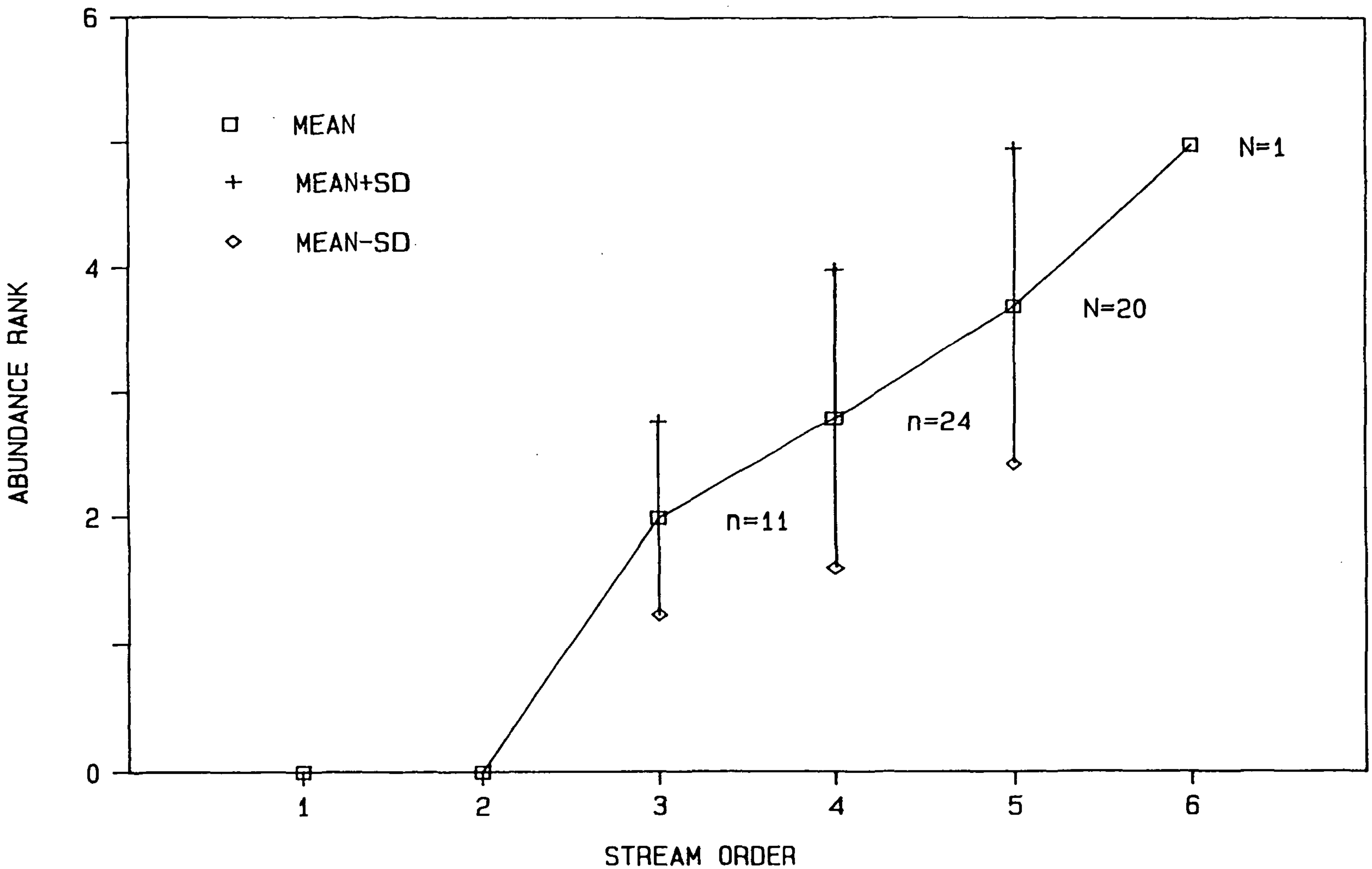


Figure 20. Mean and Standard Deviation of Rank Abundance of Anadromous Salmonid Juveniles in Tributaries, Segregated by Stream Order, Redwood Creek, Humboldt County, California, 1980-81.

Table 4. Selected Physical Stream Data From 12 Sites in the Redwood Creek Basin, Humboldt County, California, 1981.

Site	Order	Watershed Area[a]	Gradient site[b]	Gradient dnstrm	Flow[c]	Surface Area[d]	Volume[e]	Mean Depth[f]	Mean Width[g]
Prairie	4	8.5	0.02	----	37.9	216.6	31.1	14.2	3.8
Streelow	5	7.5	<0.01	0.01	66.6	194.6	37.5	17.7	4.0
Little Lost Man	4	10.2	0.04	0.02	5.1	204.4	14.6	7.7	3.9
Tom McDonald	5	18.0	0.01	0.01	47.3	185.2	34.4	18.4	3.5
Emerald	4	7.8	0.04	0.06	5.7	176.6	12.6	6.8	3.3
Panther	5	15.4	0.04	0.09	58.9	171.5	20.9	11.8	3.2
Lacks	5	44.0	0.04	0.03	15.6	243.7	31.6	12.4	4.7
Mill	3	3.5	0.06	0.06	9.1	104.2	5.8	5.5	2.0
Toss-up	5	6.8	0.04	0.04	8.2	130.7	11.9	8.1	2.5
Minon	5	11.1	0.05	0.08	2.8	116.8	8.6	7.1	2.3
Lake Prairie	4	8.8	0.07	0.11	46.4	248.1	21.8	9.5	4.1
Redwood	6	66.9	0.03	----	18.4	261.1	30.7	11.5	4.9

a upstream of site, square kilometers
b stream gradient within sample site and downstream to confluence, meter per meter
c near sample site, in liters per second
d square meters
e cubic meters
f centimeters
g meters

volumes, over five times that of Mill Creek. The Streelow Creek site had the greatest measured volume and discharge, as well as the lowest site gradient.

Percentage depth greater than 15 cm varied from only four percent at Mill Creek to 59 percent at Streelow Creek (Fig. 21). Only half of the sites had any depths greater than 45 cm, and even in these streams the amount of habitat this deep was limited. Tom McDonald Creek had the greatest amount with nine percent of its total over 45 cm depth.

Frequency of fish cover elements at each site ranged from a total of 7 (6 percent) at Lake Prairie Creek to 26 (22 percent) at Prairie Creek (Fig. 22). Cover associated with large rocks and boulders was by far the most common overall. Only at Prairie, Streelow, and Emerald Creeks were other individual cover types as, or more, common.

Salmonid Populations

Scales from a limited sample of 68 trout (59 steelhead, 9 cutthroat) of selected sizes from throughout the basin were analyzed and three age classes were found (Fig. 23). Length-frequency of steelhead trout captured during site sampling also suggests that three age classes occur (Fig. 24). Fish less than 90 mm fork length (mm FL) were considered young-of-the-year (0+). Steelhead greater than 90 mm FL were deemed yearling or older (1+ and 2+). A great deal of overlap in size ranges occurred between age

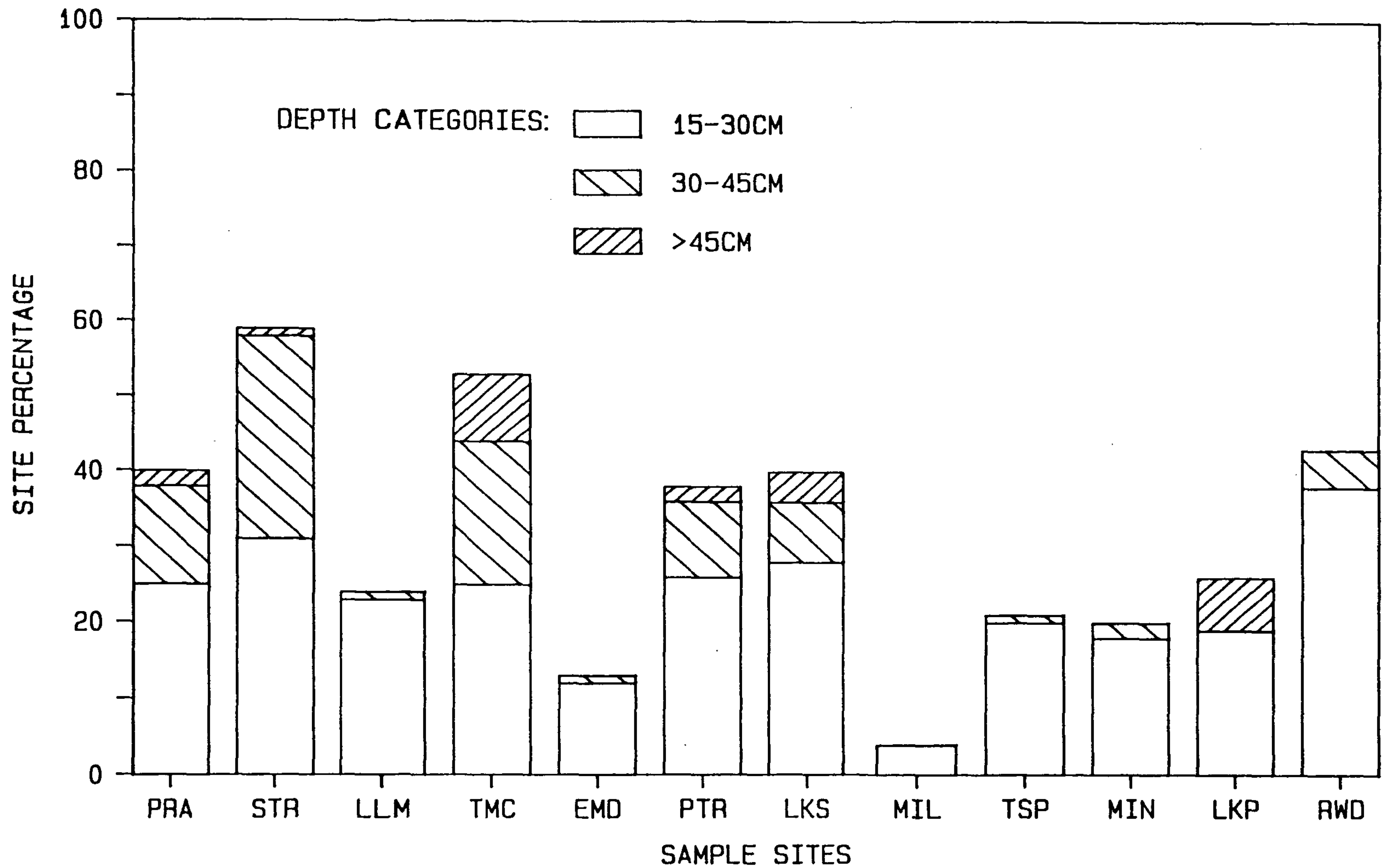


Figure 21. Percentage Depth Composition of Sample Sites, Redwood Creek, Humboldt County, California, 1981. See Methods Text for Site Identification.

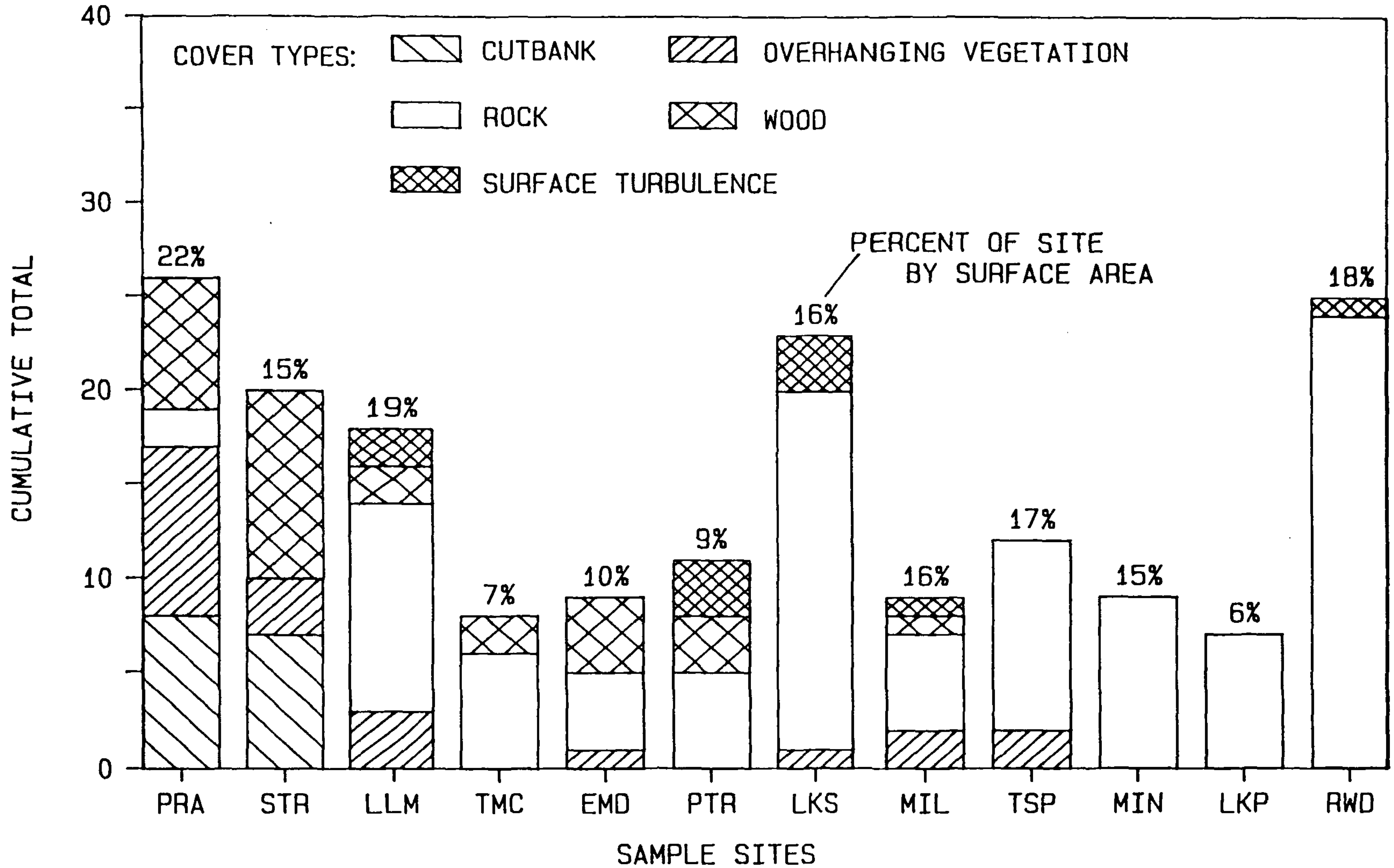


Figure 22. Cover Type Frequency at Sample Sites with Percentage of Cover by Surface Area Noted, Redwood Creek, Humboldt County, California, 1981. See Methods Text for Site Identification.

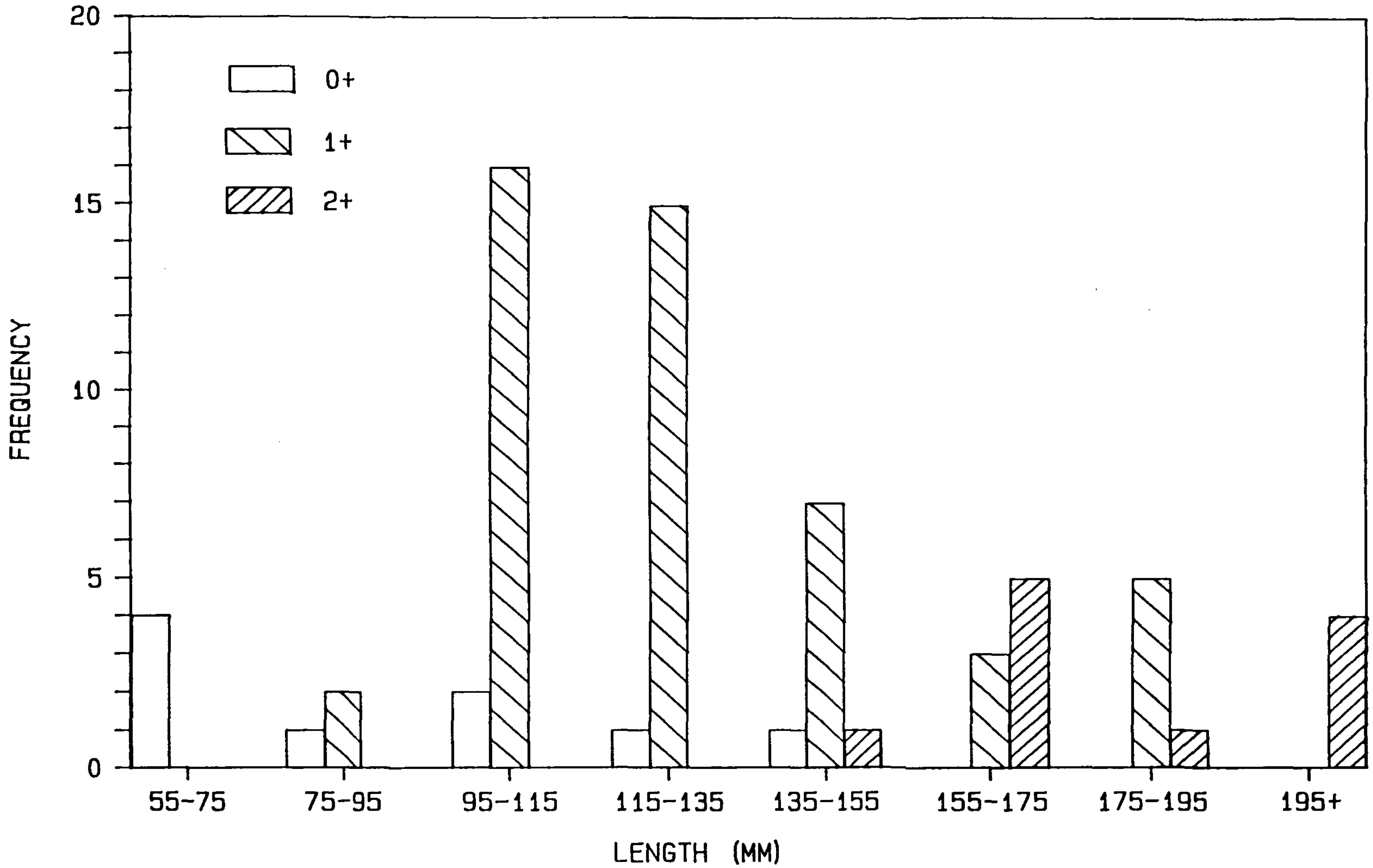


Figure 23. Age-Length Relationship of Steelhead and Cutthroat Trout Captured in Mainstem and Tributaries, Redwood Creek, Humboldt County, California, 1980-81.

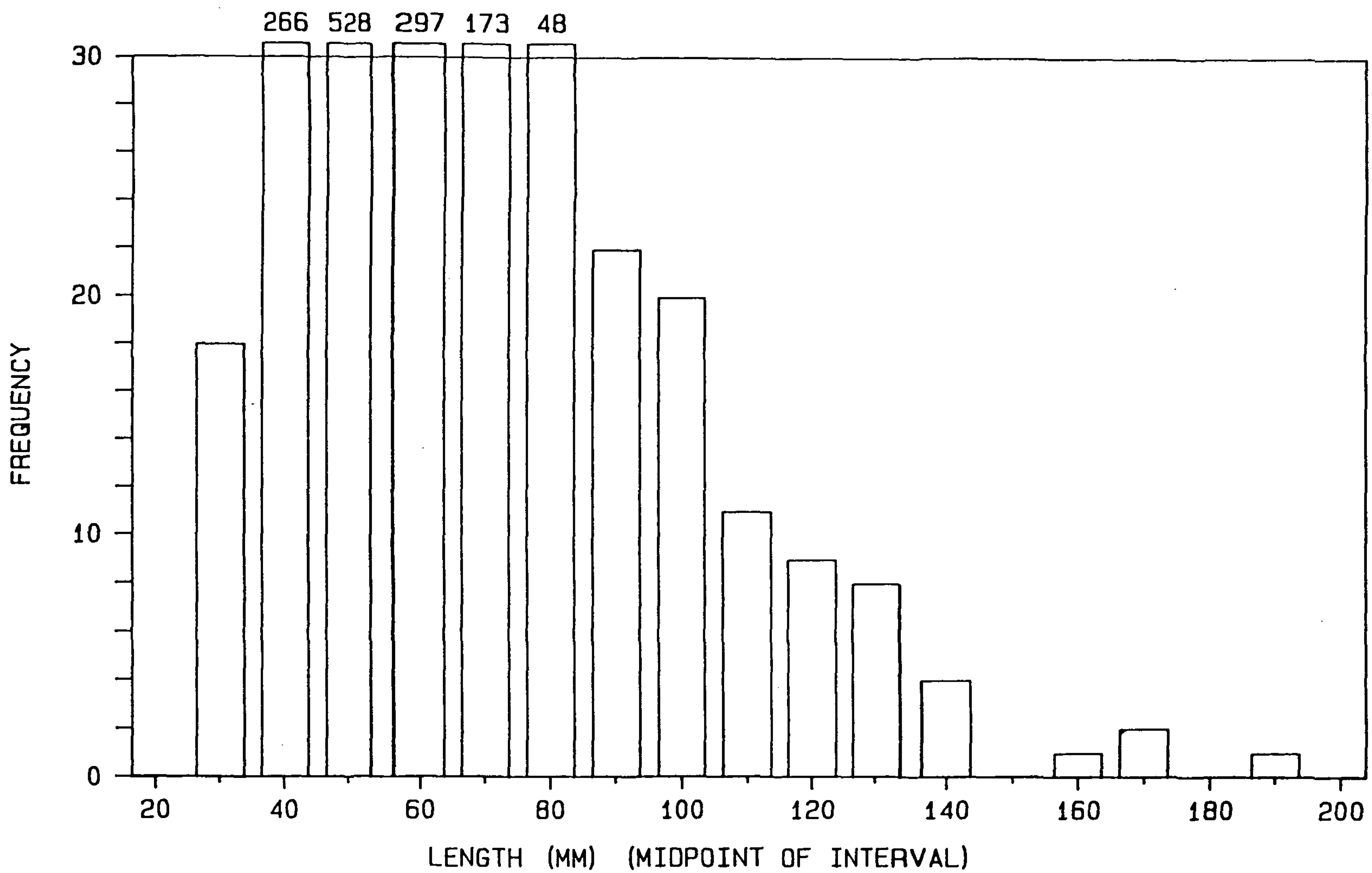


Figure 24. Length Frequency of Steelhead Trout Captured at Sample Sites, Redwood Creek, Humboldt County, California, 1981.

groups and the 90 mm cut-off length appeared to present the best compromise and also generally agreed with results from another study of Redwood Creek (Larson 1987) as well as information reported for juvenile steelhead trout in other northern California streams (Burns 1971,1972; Hamilton 1983). Although fish captured at the sample sites were not aged, those longer than 90 mm FL probably consisted almost entirely of fish in their second (1+) or third (2+) years of life. The relative contribution of older age classes to the population were not definable based on the sample site length-frequency data, therefore they were treated as a single group in comparisons. Neither this study or that by Larson (1987) found steelhead juveniles in Redwood Creek with more than 3 years of stream residence. Shapovalov and Taft (1954) in their study of Waddell Creek found that most steelhead trout emigrated prior to completing their third year of freshwater residence.

Cutthroat trout and coho salmon were not often captured. As a result, the age-size relationship and population age structure for these species are less certain. All captured coho juveniles were presumed to be young-of-the-year fish (Fig. 25). Coho salmon spend but one year rearing in freshwater prior to out migration in the southern part of their range (Shapovalov and Taft 1954, Moyle 1976). Anadromous coastal cutthroat trout adults migrate and spawn coincident with winter steelhead, and juvenile cutthroat in Oregon streams appear to grow at

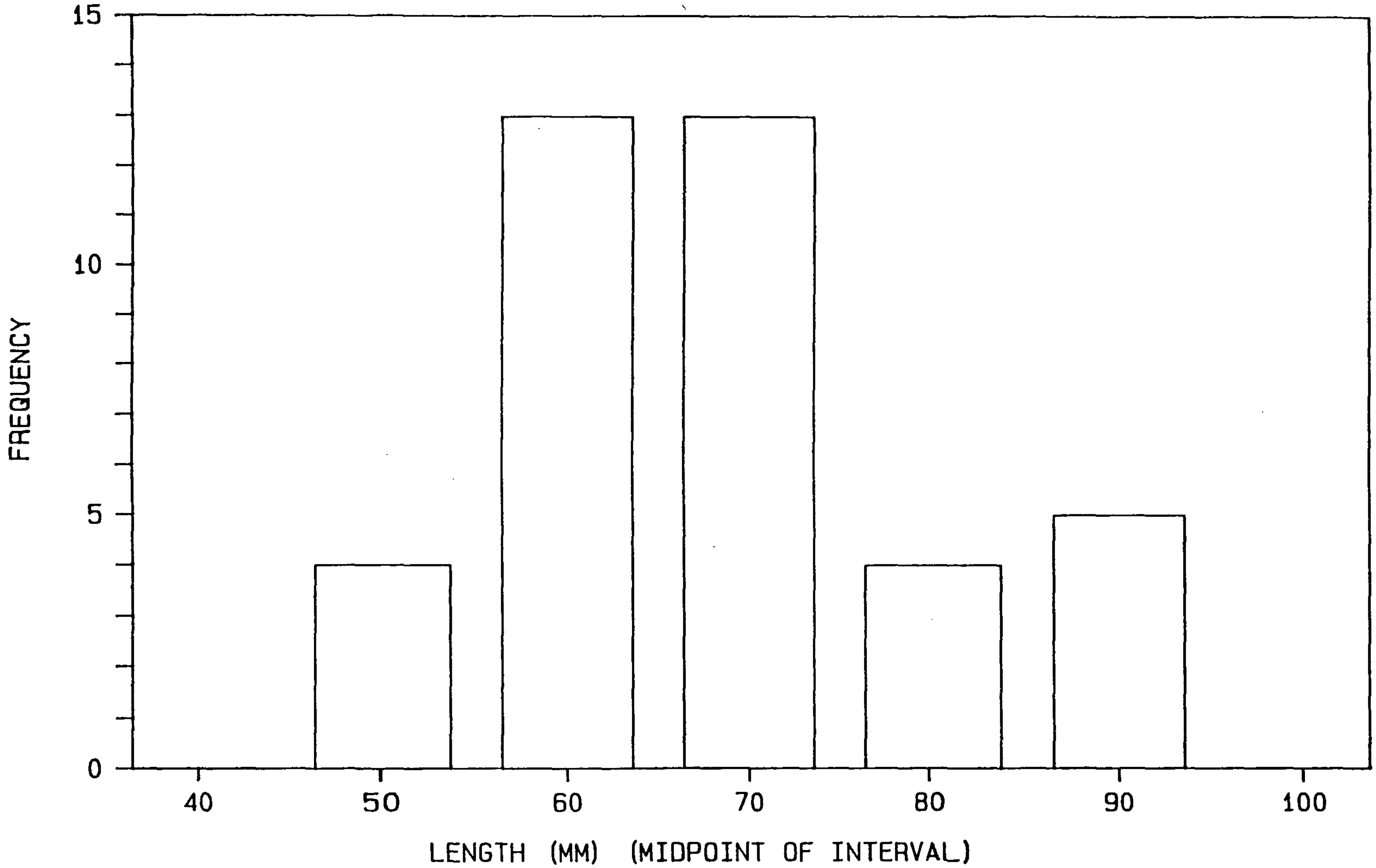


Figure 25. Length Frequency of Coho Salmon Captured at Sample Sites, Redwood Creek, Humboldt County, California, 1981.

approximately the same rate as steelhead found in Redwood Creek (Sumner 1962, Lowry 1965). I assumed that juvenile cutthroat in the basin grew at the same rate as juvenile steelhead in their first few years of life prior to downstream migration. Therefore, 90 mm FL was also used to separate 0+ from older cutthroat.

Trout less than approximately 70 mm FL proved impossible to distinguish by species in the field using morphological characters. Therefore, captured trout less than 90 mm FL in streams with known sympatric populations were combined in the young-of-the-year age class. Trout larger than 90 mm FL were easily identified to species by morphological characters. Based upon the lengths of the smallest sea-run cutthroat captured in other studies (Sumner 1962, Lowry 1965), I assumed that none of the cutthroat captured in this study had yet migrated to salt water (Fig. 26).

Steelhead trout occurred at all sample sites while cutthroat trout and coho salmon were only found at the Prairie and Streelow Creek sites (Table 5; Appendix C). At Prairie and Streelow Creeks, cutthroat (1+ and older) and coho dominated steelhead trout both in numbers and biomass. Steelhead populations for all sites were dominated by young-of-the-year fish. Only at Streelow Creek did yearling trout represent greater than 15 percent of the steelhead population by number. With the exception of Panther Creek, the biomass of young-of-the-year steelhead

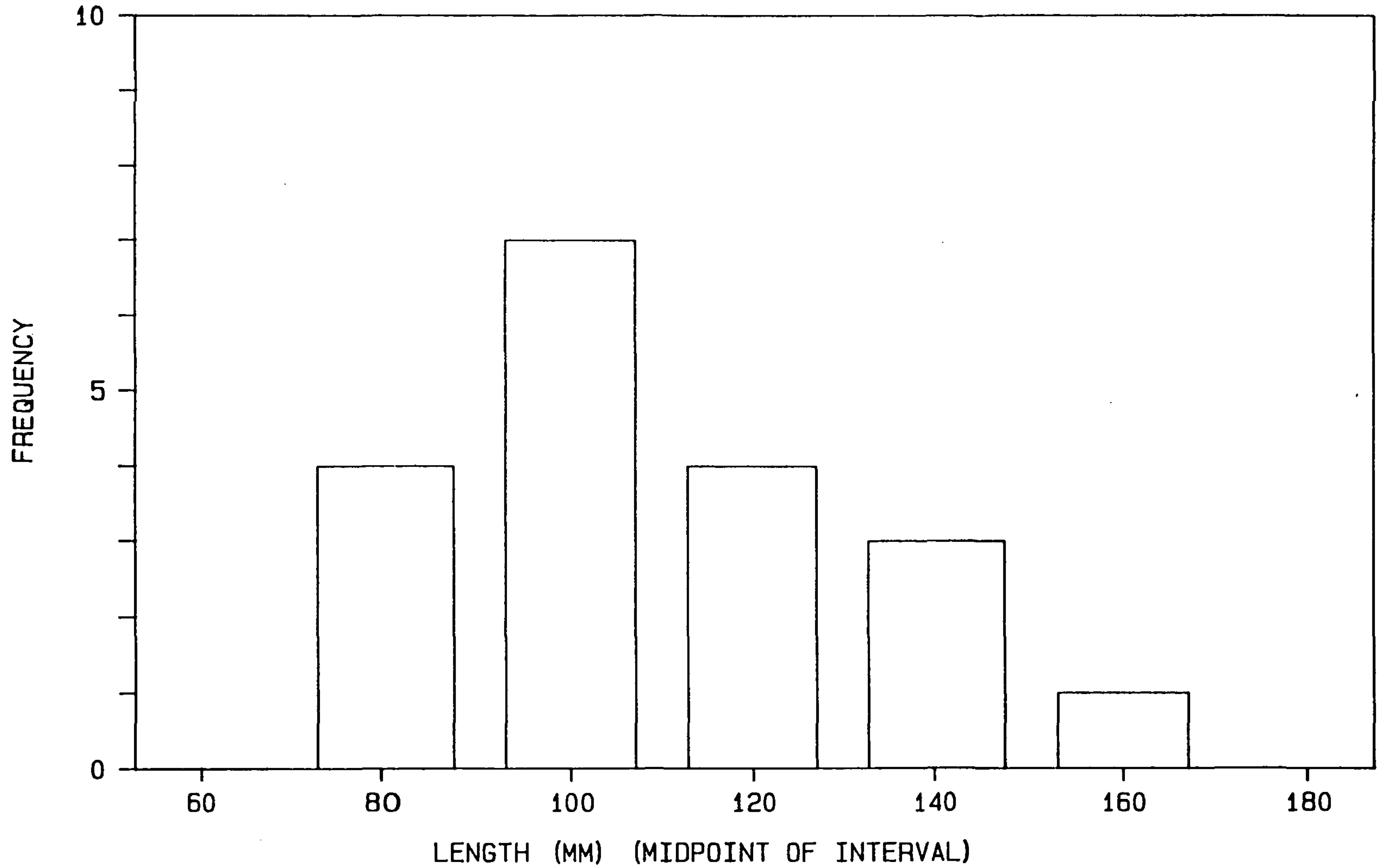


Figure 26. Length Frequency of Cutthroat Trout Captured at Sample Sites, Redwood Creek, Humboldt County, California, 1981.

Table 5. Estimates of Numbers and Biomass for Juvenile Anadromous Salmonid Populations at 12 Sites in the Redwood Creek Basin, Humboldt County, California, 1981.

Site	Species	Age	Numbers no.	Numbers CI	Numbers pct	Biomass total	Biomass pct
Prairie	st/ct[a]	0+[b]	28		37	67[c]	17
	st	1+	1		1	14	4
	ct	1+	8		11	155	39
	co	0+	38		51	160	40
Streelow	st/ct	0+	8		22	56	10
	st	1+	3		8	34	6
	ct	1+	15		42	385	68
	co	0+	10		28	88	16
Little	st	0+	74	± 5[d]	92	163	75
Lost Man	st	1+	6		8	55	25
Tom	st	0+	24		92	137	80
McDonald	st[e]	1+	2		8	35	20
Emerald	st	0+	21		88	86	64
	st	1+	3		12	49	36
Panther	st	0+	91	± 8	85	218	40
	st	1+	16		15	325	60
Lacks	st	0+	289	± 70	96	549	71
	st	1+	12		4	227	29
Mill	st	0+	91	± 15	97	191	84
	st	1+	3		3	35	16
Toss-up	st	0+	262	± 42	98	498	76
	st	1+	5		2	160	24
Minon	st	0+	98	± 10	96	137	69
	st	1+	4		4	60	31
Lake	st	0+	23		88	51	55
Prairie[e]	st	1+	3		12	41	45
Redwood	st	0+	633	± 52	97	1266	82
	st	1+	20		3	282	18

[a] st = steelhead; ct = cutthroat; co = coho
[b] 0+ = young of the year, 1+ = yearling and older
[c] total biomass = estimated number X mean weight (grams)
[d] Confidence Intervals: pop.<50 = no est.; pop. 50-200 = 90%CI; pop.>200 = 95%CI (see Zippin 1958)
[e] equipment failure, numbers and biomass are total captured

also exceeded that of yearling fish at all sites. Due to malfunction of the electroshocker at the Lake Prairie Creek site, capture effort was not consistently applied or equal between passes, therefore a population estimate was not calculated.

Biomass densities were calculated for all salmonids at each site (Fig. 27). Separate densities were also calculated for young-of-the-year and juvenile (1+/2+) trout, and coho salmon. Total densities were highest at Redwood Creek and lowest at Emerald Creek. Total density at Redwood Creek was over 7 times that at Emerald Creek, most of the difference was attributable to young-of-the-year densities. Juvenile trout densities were highest at Streelow Creek and lowest at Tom McDonald Creek. Of the two streams where coho were found Prairie Creek had a higher density than Streelow Creek. Note that juvenile trout density was much higher at Streelow Creek than Prairie Creek.

Pearson product moment correlation coefficients were calculated to examine the relationship between salmonid biomass density and measures of habitat area at all sample sites with the exception of Lake Prairie Creek. The calculated r value for the correlation between biomass density and stream surface area was significant at the 95 percent confidence level ($r = 0.602$, d.f. = 9, $p = 0.05$). The correlation coefficient for biomass density and stream volume was not significant ($r = 0.422$, d.f. = 9, $p = 0.05$).

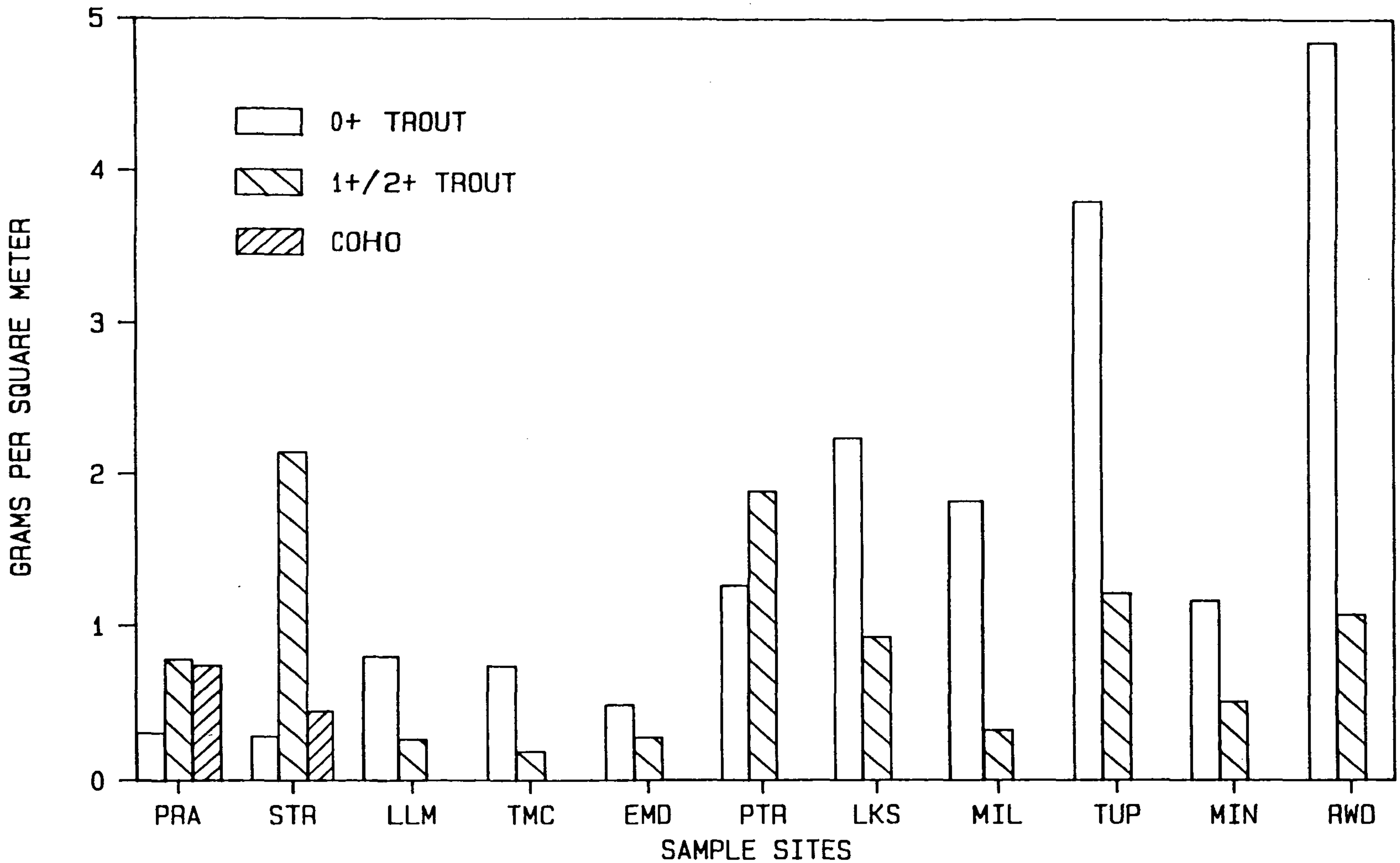


Figure 27. Biomass Density of Fry and Juvenile Anadromous Salmonids at Sample Sites, Redwood Creek, Humboldt County, California, 1981. See Methods Text for Site Identification.

The correlation between size of young-of-the-year salmonids, represented by mean length, and salmonid density was also calculated. A significant negative correlation was found ($r = -0.630$, d.f. = 9, $p = 0.05$).

DISCUSSION

Species Distribution

As in past surveys of Redwood Creek, I found steelhead trout to be the most widely distributed and abundant salmonid rearing over the summer in the basin (CDFG no date; Iwatsubo et al. 1976) (Fig. 19) (Table 5). However, steelhead were noticeably less abundant, and in some instances absent, in reaches of Prairie Creek and its tributaries that were occupied by cutthroat trout, or cutthroat and coho salmon (Table 2). In contrast, cutthroat trout and coho salmon were uncommon outside of the Prairie Creek system (Table 2).

The distribution of steelhead and cutthroat trout in the Redwood Creek watershed was strikingly similar to that reported by Hartman and Gill (1968) for British Columbia streams. That study found cutthroat predominated in smaller watersheds or low gradient reaches which meandered through meadowlands. Steelhead, on the other hand, predominated in streams with larger watersheds (>120 km^2), mainstem reaches, and streams with steep gradients. In streams where both species occurred, they found that cutthroat were predominant in small tributaries and headwaters while steelhead occurred in the lower reaches and mainstem.

Although cutthroat have been found throughout the watershed (Dewitt 1954; CDFG no date; and this study), they were most abundant in Prairie Creek and its tributaries (Table 2), and apparently always have been (CDFG no date). Much of Prairie Creek and many of its tributaries have the small channels or low gradient slough-like reaches described above. Tributaries outside of the Prairie Creek basin were generally larger and steeper when compared by order, and they were dominated by steelhead. In addition, surveys conducted during this study along the mainstem of Redwood Creek, upstream from the confluence of Prairie Creek, found only steelhead trout.

The distribution of anadromous cutthroat in the basin, exclusive of Prairie Creek, was somewhat confused by the reported occurrence of resident cutthroat populations in the upstream reaches of tributaries. The effectiveness of some migrational barriers undoubtedly has changed from year to year and anadromous cutthroat progeny will apparently coexist with resident populations, therefore suspected resident cutthroat may in fact be the progeny of anadromous adults (Michael 1983). Resident rainbow trout were also reported to occur in the watershed, upstream of an anadromous fish migrational barrier in Devil's Creek (CDFG no date).

In contrast to the stream type and reach segregation displayed by cutthroat and steelhead trout, coho salmon often occur in the same stream reach with either of these trout species, although they do segregate by habitat type (Hartman 1965; Glova 1984). This study found few coho outside of the Prairie Creek stream system, although individuals were widely distributed in the lower half of the basin. Past Department of Fish and Game surveys (CDFG no date) have reported apparently significant coho populations in the larger tributaries upstream of Prairie Creek. For instance, a survey of Lacks Creek in July of 1953 found "many" steelhead, coho, and chinook juveniles. More recent surveys in 1966 and 1975 report only the occurrence of steelhead. A survey of Panther Creek in June of 1975 reported "numerous" coho and steelhead juveniles. Minor Creek was also a stream in which runs of "salmon" were found, but the species of salmon were not identified. The California Fish and Wildlife Plan (State of California 1965) implied that upstream tributaries greatly contributed to coho habitat in the basin.

Coho salmon have been considered far less abundant than chinook salmon and steelhead trout in the basin in recent decades (USDI 1960; State of California 1965), but they may have been far more numerous historically (Janda et al. 1975). Since the mid-1960's the escapement of wild and hatchery produced adult coho returning to Oregon coastal rivers and the lower Columbia River has declined (Scarnecchia and Wagner 1980, McGie 1981). Increased hatchery production of coho smolts in Oregon and Washington, beginning in the early 1960's led to subsequent increases in fishing pressure and harvest by ocean troll fisheries along the entire coast (Fry 1975; Scarnecchia and

Wagner 1980). Biologists have also suggested that reductions in coho abundance may be due to density-dependent mortality resulting from reductions in coastal upwelling combined with large releases of hatchery reared smolts (McGie 1981, Nickelson 1983).

Returns to Prairie Creek Fish Hatchery declined dramatically during the '70s and early '80s (Hofstra 1983), reflecting the coastwide downward trend in overall escapement (Scarnecchia and Wagner 1980; PFMC 1981; GAO 1983). In light of this information it appears likely that overall coho escapement to the basin, especially that of naturally spawned fish, was greatly reduced prior to this survey.

The condition of freshwater habitats certainly also plays an important role in the production of coho salmon (e.g., Reiser and Bjornn 1979, McMahon 1983, Johnson 1984). Janda et al. (1975) speculated that coho salmon may have been more negatively affected than other anadromous species by increased sediment loads in the Redwood Creek basin. They attribute the possible adverse impacts to; (1) the timing of coho spawning, resulting in a greater susceptibility of coho spawn to gravel-transporting floods, and, (2) channel aggradation, which resulted in the filling of pools that are preferred summer rearing habitats of coho. The straying of returning hatchery reared fish may, in part, have been responsible for the relatively stronger showing of coho in the Prairie Creek system. Generally, Prairie Creek has also not been subject to the extensive sedimentation that has occurred in the remainder of the basin (Janda et al. 1975).

Access

The quantity of accessible spawning and rearing habitat within the watershed likely varies by fish species because of physical abilities, run timing, and habitat requirements. For instance, adult steelhead trout have been reported to be faster swimmers and able to sustain higher swimming speeds over a longer period of time than other anadromous salmonids (Reiser and Bjornn 1979). A possible case in point was a woody debris jam that occurred on Bridge Creek, tributary to Redwood Creek within the National Park. Prior to intentional modification by the Park Service, this debris jam was known to be a barrier to upstream passage of chinook salmon but not steelhead trout. It was not known whether the differential access was because of the unique physical abilities of steelhead or the timing of the run occurring coincidently with increased streamflow which allowed steelhead to circumvent the barrier (Narver 1971).

Accessible habitat may also not be used because of species requirements with respect to substrate composition, water depth and velocity, and other associated factors (Briggs 1953; Reiser and Bjornn 1979). It appears the accessible habitat total identified in this study was most relevant for steelhead trout, based upon the distribution of juvenile fish. To accurately define the accessible habitat for different species in the watershed would be difficult because of poor visibility that often occurs during the high water periods when anadromous adults are migrating and spawning, limitations on access to remote locations during the spawning period, and underuse of suitable habitats by reduced populations.

Barriers to Migration

Elimination of access to historic habitats has been one of the major causes of reduced anadromous salmonid production in the Pacific Northwest (PFMC 1979). Dam construction has been by far the greatest cause of habitat loss in California rivers and streams, although northcoast waterways have been impacted by dams to a lesser extent than those of the Central Valley (PFMC 1979).

The Prairie Creek Hatchery dams on Lost Man Creek are the only permanent dams that are known to have been constructed within the Redwood Creek basin. Temporary gravel dams are constructed annually during the summer on the mainstem of Redwood Creek to impound water for recreational use. During this study most temporary dams were found within the reach between the confluence of Lacks Creek at RK 45.3 and the Lupton Creek confluence at RK 72.3. These dams may impede the migration of summer-run steelhead trout since none of the dams observed had any provisions for fish passage. Temporary dams are removed in the fall prior to the onset of the rainy season and as such miss the migration periods of most anadromous salmonids in the basin.

Timber harvest and road construction have been the two land use practices in northern California most likely to result in the creation of migrational barriers, and both have been particularly common in the Redwood Creek basin (Best 1984). The accumulation of slash and larger logging debris in streams can form impassable woody debris jams (Chamberlin 1982). Road construction, often associated with timber harvest, may cause migrational barriers when stream crossings have not been designed to allow fish passage (Yee and Roelofs 1980).

Most woody debris jams were located on third order and larger tributaries (Fig. 13). Woody debris tends to be randomly distributed in first and second order streams since they usually do not have the power to mobilize large organic material (Keller and Tally 1979; Pitlick 1981). Debris jams were often associated with past logging activities. Debris jams may be modified by major discharge events; however, jams which incorporate large redwood logs, can be very persistent stream features (Keller and Tally 1979).

The amount of potentially usable anadromous salmonid habitat that occurs above debris jams in the watershed was not quantified. Studies by Sedell et al. (1984) on Oregon streams found that, although access may be significantly affected on individual streams, on a watershed basis, debris jams limited fish access to but a minor percentage of usable habitat. Based on their loca tion in the tributaries surveyed, woody debris jams do not significantly limit access in the Redwood Creek watershed either, although some larger tributaries, such as Bridge Creek, do have reaches greater than 1 km in length that are blocked by apparently impassable woody debris jams.

Road culverts were uncommon barriers in the basin. Those that were found occurred on small streams and did not block access to significant stream reaches (Fig. 13). Stream gradient and bedrock waterfalls, migrational barriers of geologic rather than human origin, were more common than woody debris jams or road culverts. Excessive stream gradient and bedrock waterfalls together accounted for 71 percent of all barriers identified (Fig. 12).

Excessive gradients were most common in smaller order streams although most tributaries upstream of Prairie Creek have relatively steep gradients reflecting the steep inner gorge along Redwood Creek throughout much of the basin (Janda et al. 1975). Seventy-one percent of the streams in which gradient formed a barrier to migration were third order or smaller (Fig. 13). Stream gradient has long been recognized as an important factor in the distribution of fishes (Trautman 1942; Burton and Odum 1945; Huet 1959; Hocutt and Stauffer 1975), although previous studies concentrated on its effect upon stream habitat character rather than stream access. Overall, gradient was probably the single most important factor affecting anadromous salmonid access in the Redwood Creek basin.

Many studies have examined fish distribution with respect to stream order. Of those which used order designation criteria similar to this study (Kuehne 1962; Whiteside and McNatt 1972; Lotrich 1973; Platts 1979), all found fish species using first and second order streams. However, those studies reported mean stream gradients for first order streams that ranged from 0.5 to 10 percent, compared to the 30+ percent gradients measured for the lower sections of first and second order tributaries in the Redwood Creek basin.

All waterfall barriers occurred in third order and larger tributaries (Fig. 13). Most waterfalls occurred well upstream on tributaries, and as with most debris jams, on the whole did not block a major percentage of potentially usable habitat. The major exception was the waterfall on Devils Creek which blocked access and use of all but 0.3 km of that fifth-order stream.

<u>Quantification and Distribution of Habitat</u>

The California Fish and Wildlife Plan (State of California 1965) reported that the Redwood Creek basin contained 110 (177 km) and 112 (180 km) accessible stream miles for coho salmon and steelhead trout, respectively. Accessible habitat identified in this study totaled 176.5 km (Table 3). With the addition of remaining unsurveyed areas; third and fourth order tributaries and the upper reaches of larger tributaries such as Minor and Lacks Creeks, the total accessible habitat reported for this study is in close agreement with the State Plan. The Fish and Wildlife Plan (State of California 1965) did not identify the amount of habitat attributable to the mainstem or individual tributaries.

The total distance of accessible habitat was slightly greater in the mainstem (54 percent) than in tributary streams (46 percent) (Table 3). First and second order streams directly tributary to the mainstem or to accessible reaches of tributaries upstream of Prairie Creek were not accessible to any fish species because of their steep gradients. There may have been some second order tributaries in the Prairie Creek watershed that were accessible to juvenile salmonids, but if so they were few, and so small that they would be of little significance.

Platts (1979) examined fish distribution in first through fifth order Idaho streams. He found resident salmonids in first and second order streams but only third though fifth order streams provided spawning and rearing habitat for anadromous salmonids. In the Redwood Creek basin, only third order and larger tributaries were found to be accessible (Fig. 14), but 86 percent of the accessible tributary habitat was in fifth order and larger streams (Table 3). Nine of the 10 tributaries with the most accessible habitat were fifth order and higher (Fig.

18). All accessible mainstem habitat was also fifth order and higher (Table 3).

Late-Summer Rearing Space

Limits on space have been cited as one of the most important factors affecting salmonid densities in streams (Reiser and Bjornn 1979). The late-summer period of low stream flow has generally been considered to be when habitat availability is most constrained, and conditions most stressful, for salmonids rearing in California coastal streams (Burns 1971; Denton 1974). Increased flows during the summer low flow period have been related to increased survival of stream rearing salmonids (Havey and Davis 1970; Scarnecchia 1981). Rearing space in Redwood Creek tributaries was affected both by natural low flows and reduced habitat diversity caused by aggradation of sediment.

Low Stream Flows

Lower order streams tend to be intermittent or dry during low flow periods (Whiteside & McNatt 1972; Lotrich 1973; Tramer 1977; Platts 1979) and those in the Redwood Creek watershed were no exception (Janda et al. 1975). Surveyed first and second order streams had little or no flow, and even some third and fourth order tributaries had no measurable discharge (Fig. 7). Only in fifth and higher order tributaries did all streams have measurable discharge. During surveys in 1980, most of the Redwood

Creek mainstem upstream of Pardee Creek was also dry.

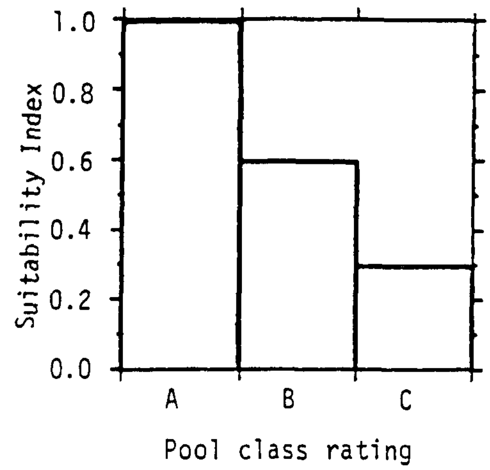
The detrimental effect of low streamflow on the quality and quantity of salmonid rearing habitat is widely recognized and most contemporary salmonid habitat rating indices incorporate measures of baseflow conditions and/or habitat quantity and quality in one form or another (e.g., Bovee 1978; Binns and Eiserman 1979; Nickelson et al. 1979). Habitat Suitability Index (HSI) Models developed by the U.S. Fish and Wildlife Service for rainbow (Raleigh et al. 1984) and cutthroat trout (Hickman and Raleigh 1982), and coho salmon (McMahon 1983) include several space variables as components. Rainbow and cutthroat trout HSI variables for the juvenile lifestage (1+ and older) included pool abundance and quality, abundance of cover for resting and predator avoidance, and baseflow volume (Figs. 28 and 29). The coho salmon HSI model for young-of-the-year included pool abundance and size, and abundance of instream cover (Fig. 30).

Both trout habitat indices for the juvenile life stage (ages 1+ and older) use pool class rating as a variable (Fig. 28). Based on depth and cover frequencies observed at each of the sample sites (Figs. 21 and 22), no site had a pool class suitability rating above 0.3 on a scale of 0 to 1. A rating of less than 0.4 indicates low habitat quality for a given variable and identifies it as a probable limiting factor (Hickman and Raleigh 1982; Raleigh et al. 1984). Proportion of pools of sufficient size (Fig.

V_{15} Pool class rating during the late growing season low flow period. The rating is based on the % of the area that contains pools of the three classes described below:

A) ≥ 30% of the area is comprised of 1st-class pools.
B) ≥ 10% but < 30% of the area is 1st-class pools or ≥ 50% is 2nd-class pools.
C) < 10% of the area is 1st-class pools and < 50% is 2nd-class pools.

(See pool class descriptions below)



- First-class pool: Large and deep. Pool depth and size are sufficient to provide a low velocity resting area for several adult trout. More than 30% of the pool bottom is obscured due to depth, surface turbulence, or the presence of structures, such as logs, debris piles, boulders, or overhanging banks and vegetation. Or, the greatest pool depth is ≥ 1.5 m in streams ≤ 5 m wide or ≥ 2 m deep in streams > 5 m wide.

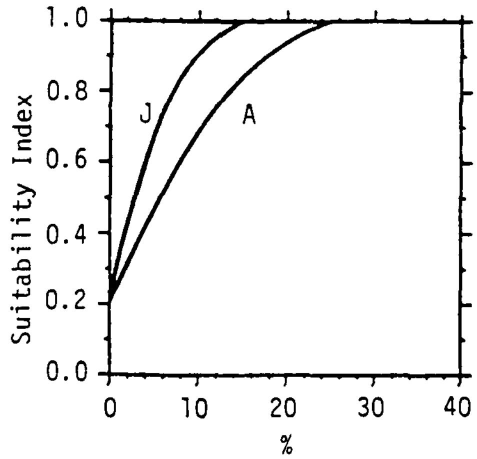
- Second-class pool: Moderate size and depth. Pool depth and size are sufficient to provide a low velocity resting area for a few adult trout. From 5 to 30% of the bottom is obscured due to surface turbulence, depth, or the presence of structures. Typical second-class pools are large eddies behind boulders and low velocity, moderately deep areas beneath overhanging banks and vegetation.

- Third-class pool: Small or shallow or both. Pool depth and size are sufficient to provide a low velocity resting area for one to a very few adult trout. Cover, if present, is in the form of shade, surface turbulence, or very limited structures. Typical third-class pools are wide, shallow pool areas of streams or small eddies behind boulders. The entire bottom area of the pool is visible.

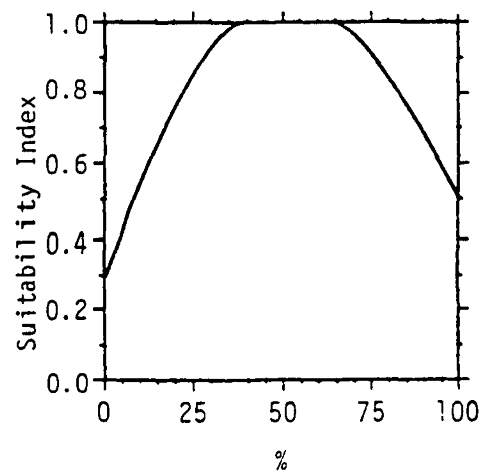
Figure 28. Pool Class Rating Variable From Rainbow and Cutthroat Trout Habitat Suitability Index Models (Hickman and Raleigh 1982; Raleigh et al. 1984).

V_6 Percent instream cover during the late growing season low water period at depths ≥ 15 cm and velocities < 15 cm/sec.

J = juveniles
A = adults



V_{10} Percent pools during the late growing season low water period.



V_{14} Average annual base flow regime during the late summer or winter low flow period as a percentage of the average annual daily flow.

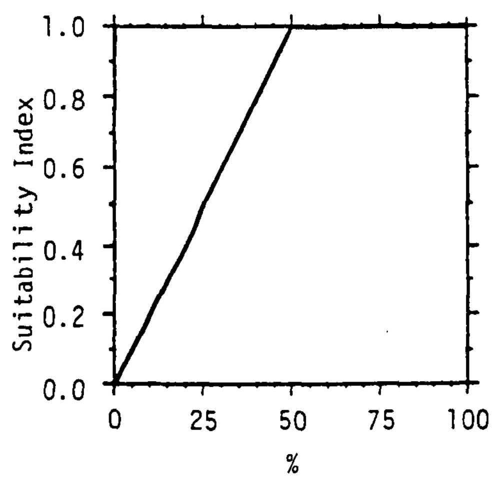
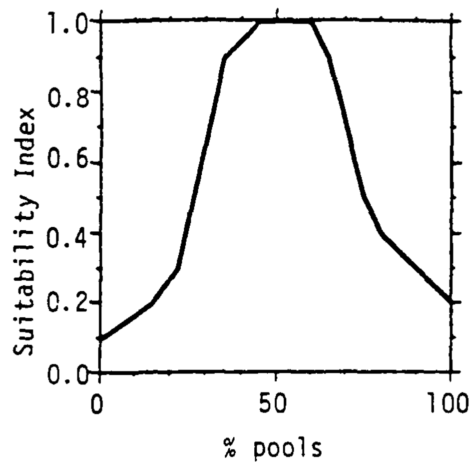
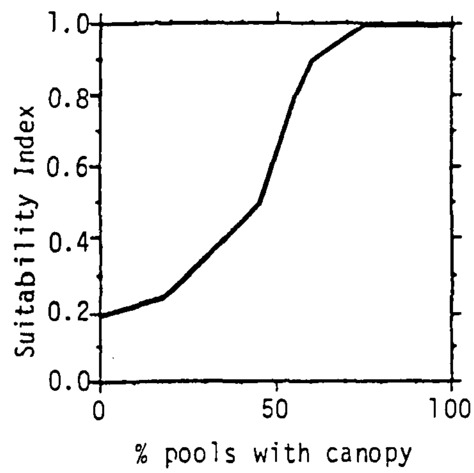


Figure 29. Percentage of Instream Cover, Percent Low-flow Pools, and Average Annual Base Flow Variables From Rainbow and Cutthroat Trout Habitat Suitability Index Models (Hickman and Raleigh 1982; Raleigh et al. 1984).

V_{10} Percent pools during summer low flow period.



V_{11} Proportion of pools during summer low flow period that are 10 to 80 m^3 or 50 to 250 m^2 in size and have sufficient riparian canopy to provide shade.



V_{12} Percent instream and bank cover present during summer low flow period.

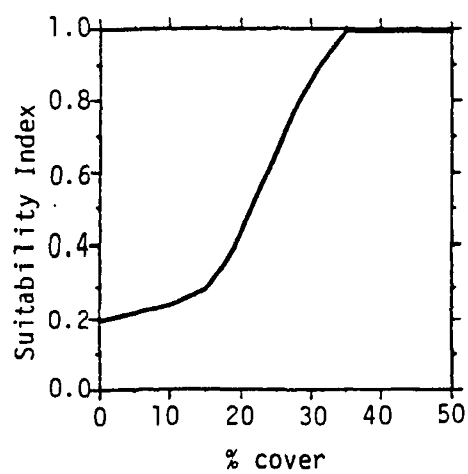


Figure 30. Percentage Low-flow Pools, Proportion of Pools with Sufficient Size and Canopy, and Percent Cover Variables From the Coho Salmon Habitat Suitability Index Model (McMahon 1983).

30) and total percentage of pool area during the low flow period (Figs. 29 and 30) also would have received low suitability ratings at all sample sites.

Percentage instream cover present at the sample sites based upon the criteria of Nickelson et al. (1979) would have been rated at generally high suitability levels for trout at most sites (Fig. 29). However, Nickelson et al. (1979) consider a minimum depth of 5 cm associated with a cover feature to be sufficient, while the trout HSI models consider 15 cm to be the minimum depth necessary. Cover for coho salmon would have been rated at low suitability levels regardless of the depth criteria (Fig. 30).

Of interest and potential relevance to the Redwood Creek basin, is the role that extensive timber harvest may have had in the reduction of low flow period discharge. Timber harvest has typically been found to cause increased runoff in logged areas due to decreased evapotranspiration and interception of precipitation (Chamberlin 1982). However, a study in Oregon found that clear-cut logging in a small watershed resulted in significantly decreased discharge during the low flow period (Harr 1980). The cause of the decrease has been tentatively attributed to a reduction in fog or cloud interception, i.e. "fog drip", by the forest canopy. A study conducted in the Eel River basin (Azevedo and Morgan 1974), which reported fog drip measurements up to 42.5 cm (16.7 in.) under an 18-meter

Douglas-fir tree suggests that fog drip may be a significant contributor to stream flow in some Redwood Creek tributaries during the late-summer and early-fall. It is hard to imagine that the removal of many acres of 200 to 300-foot tall trees has not had some effect upon fog drip interception, especially in those sub-basins nearest the coast.

Stream Sedimentation

The tremendous volume of sediment that was deposited in the main channel of Redwood Creek as a result of the 1964 flood event has not appreciably decreased, although it has been redistributed further downstream (Madej 1984). Total recovery from this aggradational event is likely to require more than one-hundred years (Madej 1984). Extensive sedimentation also persists in the tributaries of the watershed (Pitlick 1982).

For the most part, the majority of sediment stored in tributaries occurs in their lower (downstream most) half (Pitlick 1982), coincidently where most accessible anadromous salmonid habitat occurs (Figs. 9-11). Past reports have documented the effects that extensive sedimentation has had upon anadromous salmonid habitats (Dewitt 1964; Fisk et al. 1966; Janda et al 1975; Nolan and Janda 1979), including channel widening, change in substrate composition, and filling of pools. This study also found that sedimentation continues to degrade physical habitat for rearing salmonids.

Sedimentation exacerbates habitat reduction during naturally occurring low-flow conditions. Quality and quantity of pool habitat was obviously limited at many sites, especially those outside of the Prairie Creek watershed (Figs. 21-22, and 28-30). Unstable stream banks do not provide cutbank or overhanging vegetation cover and sediment accumulations bury woody debris (Fig. 22). All are considered to be quality rearing habitat features, and all were limited in streams outside of the Prairie Creek drainage.

Sediment aggradation at the mouths of tributaries that blocked fish emigration during low flows may have been detrimental to fry and juvenile survival (Appendix A). Fish that remained in these streams risked increased mortality from predation as flows decreased, and certain death in the event that streamflow became intermittent or ceased (Tramer 1977). Steelhead/rainbow trout fry are apparently able to reduce territory size in response to crowding (Hartman 1965, Rimmer 1985), unlike coho salmon (Chapman 1962). Therefore, trout may be more likely to remain in streams as flows decrease and perhaps become trapped. Resulting high fish densities may also be reflected in lower growth rates (Rimmer 1985). Data from this study showed a significant negative correlation between size (mean length) of young-of-the-year (age 0+) trout and their density. However, dates of emergence at the sites were not known and may have greatly influenced the relationship between fish size and density since streams with larger fry may have simply had earlier spawners.

Salmonid Populations

Stream surveys and site sampling found that mean total numerical and total biomass densities of salmonids in tributaries and upper mainstem reaches generally increased with stream order (Figs. 20 and 27). Unfortunately, inadequate sampling did not allow for comparisons of tributaries with all mainstem reaches.

Platts (1979) found increased densities of total fish numbers with increases in order, and Lotrich (1973) found increases in both total numbers and biomass densities of fish with increasing stream order. The former study was conducted on the South Fork of Idaho's Salmon River, where chinook salmon and rainbow trout were the most abundant species, whereas the latter study occurred on the Clemons Fork, a warmwater stream in eastern Kentucky.

Platts (1979) also found that fourth and fifth order reaches together contributed 75 percent of the fish standing stock in the study area. Although a total percentage can not be determined using the data gathered for this study, based upon length of tributary reach per order (Table 3) and mean relative abundance of salmonids per order (Fig. 20) it appears that fifth order reaches make the greatest contribution to the number of salmonids in tributary streams with at least 51 percent of the total. Fourth and sixth order reaches make smaller but likely significant contributions to total numbers, while third order reaches support the least number of fish overall.

The contributions of lower Prairie Creek and most of the Redwood Creek mainstem to fish production in the basin were not evaluated by this study. Dewitt (1954) sampled a 779-ft section of lower Prairie Creek and found only 0.71 salmonids per linear meter. Based upon limited observations by this author and others (Keller and Hofstra 1983) much of the mainstem of Redwood Creek has spotty distributions of salmonids during the summer low flow period and the population estimates for the upper mainstem sample site are probably only representative of a limited area.

Burns (1971) in a study of northern California streams, found total salmonid density to be significantly correlated with measures of stream surface area and volume. For sample sites in the basin I also found a significant correlation between surface area and total salmonid densities, but that did not hold for stream volume (see Results). Although the correlation coefficient calculated for salmonid density and stream surface area may have been significant, it was barely so, and not nearly as strong as the relationship found by Burns (1971).

Several explanations may account for the weakness or lack of correlation. For instance, stream sites may have been greatly underseeded, and therefore not at carrying capacity. As a result of his studies, Burns (1971) rejected the hypothesis that most northern California streams reach carrying capacity during the summer low flow period. Another explanation may be that neither surface area, nor volume, adequately describe habitat availability when habitat quality has been degraded. Two streams could have similar wetted surface areas but much different values for cover, depth, and other regulating factors. Gorman and Karr (1978) also noted that as stream flows are reduced, fish are forced into habitats that they would not otherwise select. In addition, steelhead populations, and perhaps cutthroat as well, may not respond to changing habitat conditions in the same manner as coho salmon (Hartman 1965), which are apparently more sensitive to fish densities and habitat change (Chapman 1962).

Biomass densities of allopatric populations of steelhead trout (Fig. 31) and sympatric populations of steelhead, cutthroat, and coho salmon (Fig. 32) estimated by this study were compared with allopatric and sympatric population densities from other studies around northern California (Table 6). A visual comparison of the means and standard errors for biomass densities suggests that Redwood Creek anadromous salmonid populations are probably not too different from those in other northern California streams. Although, it is interesting to note that in light of the

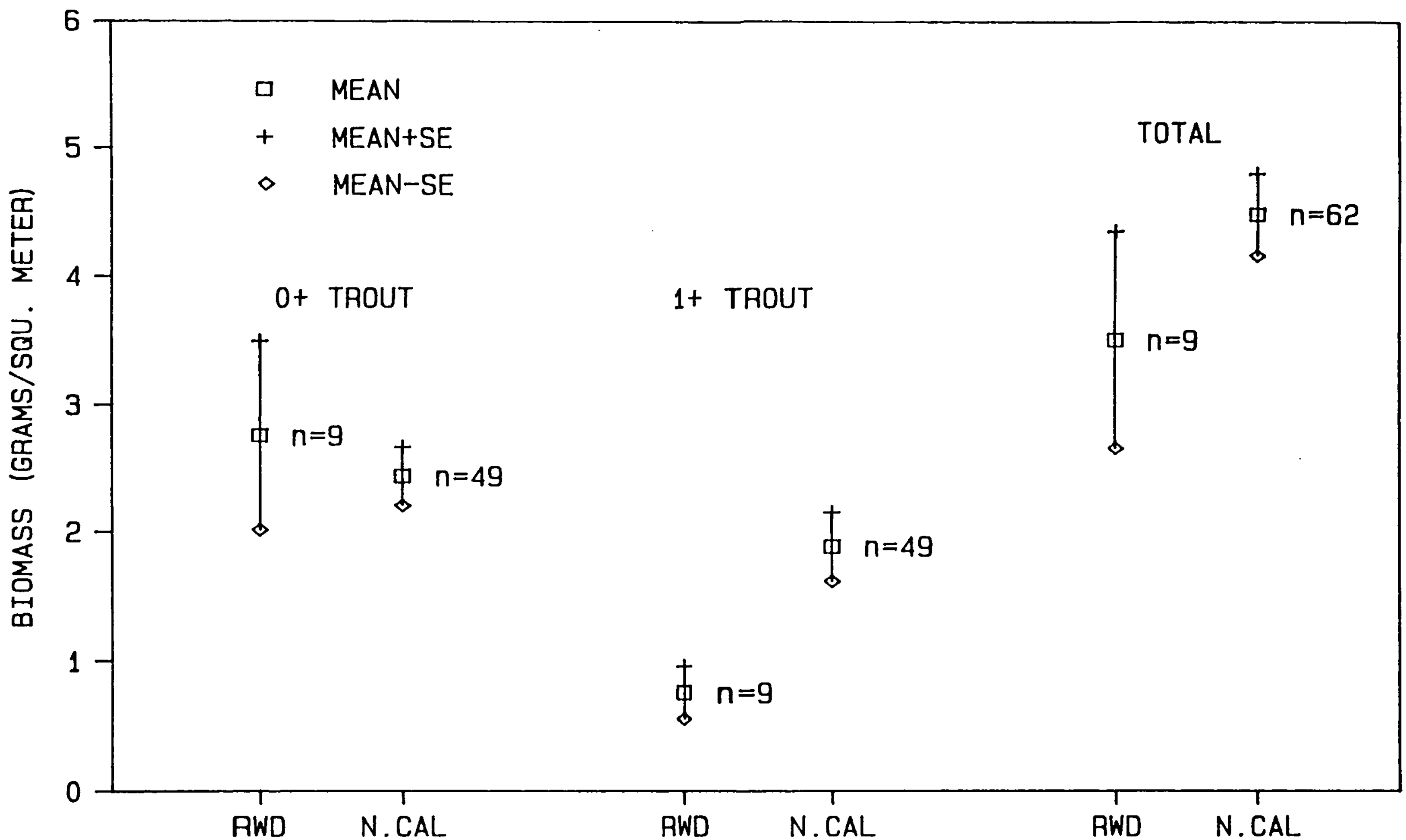


Figure 31. Biomass Densities for Allopatric Populations of Fry and Juvenile Steelhead Trout at Redwood Creek Sample Sites (RWD) Compared with Other Streams in Northern California (N.CAL).

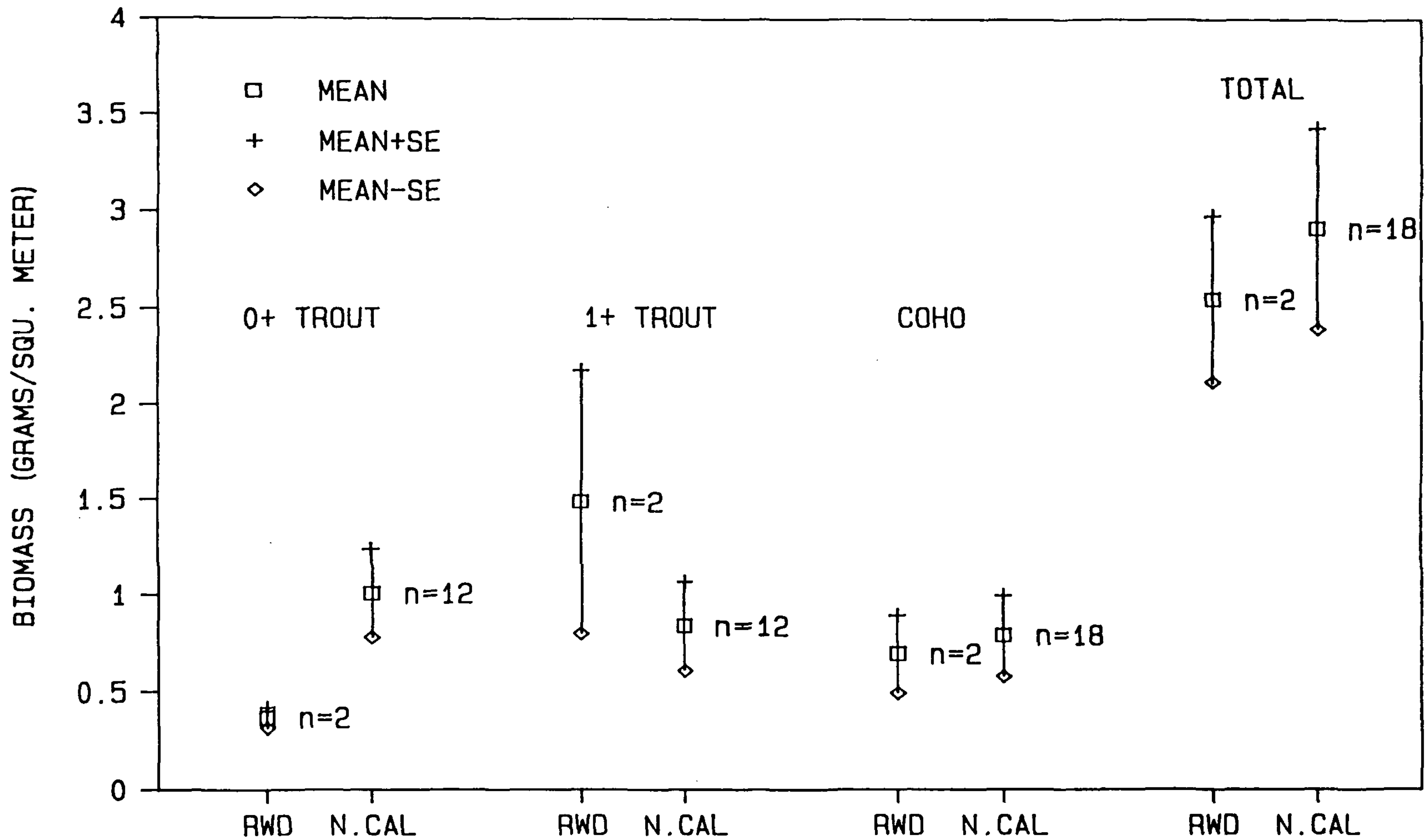


Figure 32. Biomass Densities for Sympatric Populations of Fry and Juvenile Steelhead and Cutthroat Trout, and Coho Salmon at Redwood Creek Sample Sites (RWD) Compared with Other Streams in Northern California (N.CAL).

Table 6. Studies Conducted in Northern California Streams Reporting Standing Stock of Sympatric and Allopatric Steelhead Trout and Coho Salmon Populations.

Author(s)	Stream/Location	Month	Range of Standing Stock[a]			
			0+ trout	1+ trout	coho	total
Burns 1971	Godwood Cr.,[b] Humboldt Co.	July	0.12-0.14	0.37-0.43	0.34-1.1	0.84-1.67
	N.Fk. Caspar Cr., Mendocino Co.	Oct.	0.70-1.03	0.43-0.58	0.15-0.81	1.61-1.94
	S.Fk. Yager Cr., Humboldt Co.	Aug.	1.02-1.84	1.83-2.38		2.94-4.22
	N.Fk. James Cr., Mendocino Co.	Oct.				6.5[c]
Burns 1972	Little N.FK. Noyo R., Mendocino Co.	Oct.			0.72-2.07	0.93-2.41[c]
	Bummer Lake[b] Cr., Del Norte Co.	Sept.	1.33-2.88	1.84-2.54	0.09-0.49	3.66-4.93
	S.Fk. Caspar Cr., Mendocino Co.	Oct.	0.49-1.71	0.21-0.52	0.55-0.81	1.49-3.04
	S.Fk. Yager Cr., Humboldt Co.	Aug.	1.34-2.26	0.41-1.35		1.75-3.61
Cross 1975	Singley Cr., Humboldt Co.	Sept.				7.6-12.4[c]

Table 6. Studies Conducted in Northern California Streams Reporting Standing Stock of Sympatric and Allopatric Steelhead Trout and Coho Salmon Populations. (continued)

Author(s)	Stream/Location	Month	Range of Standing Stock: 0+ trout	1+ trout	coho	total
Harper 1980	Jacoby Cr., Humboldt Co.	Aug., Oct.			0.1-3.8	4.6-9.3 [c]
Hamilton 1983	Nooning Cr., Humboldt Co.	Aug., Sept.	2.67-6.7	0.0-3.75		3.07-8.14
Barnhart et al. 1983 [d]	Browns Cr., Trinity Co.	Sept.	0.17-3.14	1.99-6.78		2.72-7.77
Brock 1986 [d]	Red Cap Cr., Humboldt Co.	Sept.	2.22-4.03	1.28-2.15		4.37-5.31
Pennington 1986	Manzanita Cr., Trinity Co.	Sept., Oct.	0.64-1.05	0.54-2.18		1.2-2.89
Hassler et al. 1986 [d]	Canyon Cr., Trinity Co.	Sept.	0.87-2.46	0.0-4.59		0.3-10.2 [c]

a grams per meter squared
b cutthroat trout also present
c trout biomass not separated by age class; Hassler et al. separated some but not all samples
d studies evaluated effects of stream habitat improvement projects; only pre-treatment or control section data used

degraded conditions in the basin, and considering the HSI models (Hickman and Raleigh 1982; McMahon 1983; Raleigh et al. 1984), the mean allopatric steelhead density of 1+ and older fish for Redwood Creek sites appeared noticeably smaller than the mean for other northern California streams (Fig. 31). In contrast, juvenile trout populations in sympatry had higher mean biomass densities at Redwood Creek sites than in other northern California streams (Fig. 32). However, the two sites where sympatric trout and coho populations were measured were two of the better sites, with respect to physical habitat quality, that were sampled.

A more rigorous statistical analysis to detect any differences between salmonid densities in Redwood Creek versus other streams seemed unwarranted and inappropriate because of; (1) the small sample sizes collected for Redwood Creek, (2) varying data collection methods between studies, (3) widely separated sampling periods between studies, and (4) the variation in population estimates at each site that was not reflected in density values. High variability, both spatially and temporally, in stream salmonid populations is well recognized and often confounds the detection of less than catastrophic population changes in a reasonable study period (Burns 1971; Pella and Myren 1974; Lichatowich and Cramer 1979; Hall and Knight 1981).

Management Recommendations

This study provides information that can be used to guide future management decisions and rehabilitation efforts at the National and State Parks and other properties throughout the watershed. Perhaps the greatest utility of this study is to document baseline conditions against which the success of the rehabilitation efforts for anadromous fish populations can be judged.

The Prairie Creek drainage is already recognized as a unique feature of the Redwood Creek basin because of its topography, regolith, and extensive undisturbed old-growth redwood forests. Stream surveys revealed the importance of the Prairie Creek drainage to coastal cutthroat trout and coho salmon populations in the watershed. Future management actions should seek to minimize disturbances in this drainage basin to protect these salmonid populations. The undisturbed reaches of Prairie Creek reaches should also be looked to as a model for future instream rehabilitation measures in other Redwood Creek tributaries. Prairie Creek contains habitat features such as cutbanks, overhanging vegetation, and woody debris that were likely common and important features in other tributary streams prior to extensive logging and stream sedimentation.

Although summer rearing habitat appears to be the obvious limiting factor to salmonid populations, the often neglected role of winter habitat in many Redwood Creek tributaries may also be of concern, especially for steelhead trout in the upper drainage basin. Steelhead trout have been shown to seek out deep pools with cover elements during periods of low temperature (Bustard and Narver 1975). Unstable streams with a paucity of such habitats may prove to be more detrimental to fish survival in winter than summer. Future fisheries investigations in the watershed upstream of the estuary should look more closely at the relative contribution of selected mainstem reaches to summer rearing habitat and over-winter survival by steelhead trout. In addition, as part of the watershed rehabilitation program being conducted by the National Park Service, monitoring studies should be following changes in habitat as well as fish populations.

If anything, this study should confirm that ongoing rehabilitation efforts in Redwood National Park aimed at stabilizing hillslopes and reducing sediment input to streams are probably the best use of monies for rehabilitating fish habitats upstream of the estuary. It does not appear that there are any fish migration barriers worth the effort or expense at this time to remove or modify in the basin. The key would seem to be to improve existing habitats in downstream areas before introducing fish to upstream areas of equal condition and questionable need.

Any instream rehabilitation work that is performed specifically for anadromous salmonids should concentrate on the larger fifth and higher order streams identified.

These streams should provide the greatest opportunity for success with greater seeding by adults and more potential habitat, i.e. larger stream size, higher low flows, and greater accessibility.

REFERENCES CITED

Azevedo, J. and D.L. Morgan. 1974. Fog precipitation in coastal California forests. Ecology 55:1135-1141.

Barila, T.Y., R.D. Williams, and J.R. Stauffer, Jr. 1981. The influence of stream order and selected stream bed parameters on fish diversity in Raystown Branch, Susquehanna River Drainage, Pennsylvania. Journal of Applied Ecology 18:125-131.

Barnhart, R. A., D. Bremm, and R. H. Deibel. 1983. Fish habitat development project, Browns Creek, Trinity County, California. California Cooperative Fishery Research Unit, Humboldt State University, Arcata, California. 141 pp.

Best, D.W. 1984. Land use of the Redwood Creek basin. Redwood National Park, Research and Development, Technical Report No. 9., Arcata, California. 24 pp.+ maps.

Binns, N.A. and F.M. Eiserman. 1979. Quantification of fluvial trout habitat in Wyoming. Transactions of the American Fisheries Society 108(3):215-228.

Bovee, K.D. 1978. Probability of use criteria for the family salmonidae. Instream Flow Information Paper: No. 4. U.S. Fish and Wildlife Service. FWS/OBS-78/07. 80 pp.

Briggs, J.C. 1954. The behavior and reproduction of salmonid fishes in a small coastal stream. State of California, Department of Fish and Game, Marine Fisheries Branch, Fish Bulletin No. 94, Sacramento, California. 62 pp.

Brock, W.A. 1986. Enhancement of rearing habitat for juvenile steelhead trout (Salmo gairdneri) by boulder placement in a tributary to the Klamath River. M.S. Thesis, Humboldt State University, Arcata, California. 49 pp.

Buchanan, T.J. and W.P. Somers. 1969. Discharge measurements at gaging stations. U.S. Geological Survey, Techniques of Water-Resources Investigations, Book 3, Washington, D.C.

Burns, J.W. 1971. The carrying capacity for juvenile salmonids in some northern California streams. California Fish and Game 57(1):44-57.

Burns, J.W. 1972. Some effects of logging and associated road construction on northern California streams. Transactions of the American Fisheries Society 101(1): 1-17.

Burton, G.W. and E.P. Odum. 1945. The distribution of stream fish in the vicinity of Mountain Lake, Virginia. Ecology 26(2):182-194.

Bustard, D.R. and D.W. Narver. 1975. Aspects of the winter ecology of juvenile coho salmon (Oncorhynchus kisutch) and steelhead trout (Salmo gairdneri). Journal of the Fisheries Research Board of Canada 32:667-680.

CDFG (California Department of Fish and Game). No Date. Stream surveys of Redwood Creek and tributaries. On file, Region 1 Office, Eureka, California

Chamberlin, T.W. 1982. Timber Harvest. Number 3 in series: Influence of Forest and Rangeland Management on Anadromous Fish Habitat in Western North America, W.R. Meehan, technical editor. U.S.D.A. Forest Service, General Technical Report, PNW-136. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon. 30 pp.

Chapman, D.W. 1962. Aggressive behavior in juvenile coho salmon as a cause of emigration. Journal of the Fisheries Research Board of Canada 19(6):1047-1080.

Cross, P.D. 1975. Early life history of steelhead trout (Salmo gairdneri) in a small coastal stream. M.S. Thesis, Humboldt State University, Arcata, California. 44 pp.

Denton, D.N. 1974. Water management for fishery enhancement on north coastal streams. State of California, The Resources Agency, Department of Water Resources, Northern District, Sacramento, California. 34 pp.

Dewitt, J.W., Jr. 1954. A survey of the coast cutthroat trout, Salmo clarki clarki Richardson, in California. California Fish and Game 40:329-335.

Dewitt, J.W., Jr. 1964. The fish and fish habitats of the coast redwood region in Mendocino, Humboldt, and Del Norte counties in California. Final Report for Coast Redwood Study Project, USDI, National Park Service. NPS-WASO-11-64-(4). Western Regional Office, San Francisco, California. 31pp.

Fisk, L., E. Gerstung, R. Hansen, and J. Thomas. 1966. Stream damage surveys-1966. Inland Fisheries Administrative Report No. 66-10. The Resources Agency of California, Department of Fish and Game, Sacramento, California. 14 pp.

Fry, D.H., Jr. 1975. Information on California salmon fisheries and stocks. Pages 15-23 in Bulletin Number 36 of the International North Pacific Fisheries Commission. Vancouver, Canada.

FWS (Fish and Wildlife Service, U.S. Department of the Interior). 1975. Unpublished internal memorandum summarizing existing information relating to past and present fishery resources of Redwood Creek, California. To Associate Director-Environment and Research from Acting Chief, Division of Ecological Services. On File, FWS Sacramento Field Office, Sacramento, California. 4 pp.

GAO (U.S. General Accounting Office). 1983. The Oregon production index: A sound fishery management tool that can be improved. Report to the Honorable Les AuCoin, U.S. House of Representatives. GAO/RCED-83-185. Washington, D.C. 34 pp.

Glova, G.J. 1984. Management implications of the distribution and diet of sympatric populations of juvenile coho salmon and coastal cutthroat trout in small streams in British Columbia, Canada. Progressive Fish Culturist 46:269-277.

Gorman, O.T. and J.R. Karr. 1978. Habitat structure and stream fish communities. Ecology 59(3):507-515.

Hall, J.D. 1984. Evaluating fish response to artificial stream structures: problems and progress. Pages 214-221 in Proceedings of the Pacific Northwest Stream Habitat Management Workshop. Held October 10-12, 1984, Humboldt State University, Arcata, California.

Hall, J.D. and N.J. Knight. 1981. Natural variation in abundance of salmonid populations in streams and its implications for design of impact studies. U.S. Environmental Protection Agency, Corvallis, Oregon. EPA-600/S3-81-021. 85 pp.

Hamilton, J.B. 1983. Performance of rock deflectors for rearing habitat improvement on a tributary of the Mattole River, northern California. M.S. Thesis, Humboldt State University, Arcata, California. 85 pp.

Harr, R.D. 1980. Streamflow after patch logging in small drainage within the Bull Run municipal watershed, Oregon. U.S.D.A. Forest Service, Research Paper, PNW-268. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon. 16 pp.

Harrel, R.C., B.J. Davis, and T.C. Dorris. 1967. Stream order and species diversity of fishes in an intermittent Oklahoma stream. The American Midland Naturalist 78(2):428-436.

Hartman, G.F. 1965. The role of behavior in the ecology and interaction of underyearling coho salmon (Oncorhynchus kisutch) and steelhead trout (Salmo gairdneri). Journal of the Fisheries Research Board of Canada 22(4):1035-1079.

Hartman, G.F. and C.A. Gill. 1968. Distributions of juvenile steelhead and cutthroat trout (Salmo gairdneri and S. clarki clarki) within streams in southwestern British Columbia. Journal of the Fisheries Research Board of Canada 25(1):33-48.

Hartman, G.F. and T.G. Brown. 1987. Use of small, temporary, floodplain tributaries by juvenile salmonids in a west coast rain-forest drainage basin, Carnation Creek, British Colombia. Canadian Journal of Fisheries and Aquatic Sciences 44:262-270.

Harper, W.G. 1980. Age, growth, and migration of coho salmon and steelhead trout in Jacoby Creek, California. M.S. Thesis, Humboldt State University, Arcata, California. 53 pp.

Hassler, T.J., W.L. Somer, and G.R. Stern. 1986. Impacts of suction dredge mining on anadromous fish, invertebrates and habitat in Canyon Creek, California. California Cooperative Fishery Research Unit, U.S. Fish and Wildlife Service, Humboldt State University, Arcata, California. 135 pp.

Havey, K.A. and R.M. Davis. 1970. Factors influencing standing crops and survival of juvenile salmon at Barrows Stream, Maine. Transactions of the American Fisheries Society. 99(2):297-311.

Hawkins, C.P., M.L. Murphy, N.H. Anderson, and M.A. Wilzbach. 1983. Density of fish and salamanders in relation to riparian canopy and physical habitat in streams of the northwestern United States. Canadian Journal of Fisheries and Aquatic Sciences 40(8): 1173-1185.

Hickman, T. and R.F. Raleigh. 1982. Habitat suitability index models: cutthroat trout. U.S. Department of the Interior, Fish and Wildlife Service. FWS/OBS-82/10.5. 38 pp.

Hocutt, C.H. and J.R. Stauffer. 1975. Influence of gradient on the distribution of fishes in Conowingo Creek, Maryland and Pennsylvania. Chesapeake Science 16(1):143-147.

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

Horton, R.E. 1945. Erosional development of streams and their drainage basins: hydrophysical approach to quantitative morphology. Bulletin of the Geological Society of America. 56:275-370

Huet, M. 1959. Profiles and biology of western European streams as related to fish management. Transactions of the American Fisheries Society 88(3):155-163.

Hughes, R.M. and J.M. Omernik. 1981. Use and misuse of the terms watershed and stream order. Pages 320-326 in Proceedings of The Warmwater Streams Symposium, L.A. Krumholz, Editor. Sponsored by Southern Division, American Fisheries Society. Allen Press, Inc., Lawrence, Kansas.

Iwatsubo, R.T., K.M. Nolan, D.R. Harden, and G.D. Glysson. 1976. Redwood National Park Studies, Data Release Number 2, Redwood Creek, Humboldt County, and Mill Creek, Del Norte County, California, April 11, 1974-September 30, 1975. U.S. Geological Survey, Open-File Report 76-678. Menlo Park, California. 247 pp.

Janda, R.J. and K.M. Nolan. 1979. Stream sediment discharge in northwestern California. Pages IV-1 to IV-27 in Guidebook For A Field Trip To Observe Natural And Management-Related Erosion In Franciscan Terrane Of Northern California. The Cordilleran Section of the Geological Society of America, San Jose, California.

Janda, R.J., K. Nolan, D.R. Harden, and S.M. Colman. 1975. Watershed conditions in the drainage basin of Redwood Creek, Humboldt County, California, as of 1973. U.S. Geological Survey, Open-File Report 75-568. Menlo Park, California. 267 pp.

Jearld, A., Jr. 1983. Age determination. Pages 301-324 in Fisheries Techniques, L.A. Nielson and D.L. Johnson, editors. American Fisheries Society, Bethesda, Maryland. 468 pp.

Johnson, S.L. 1984. Freshwater environmental problems and coho production in Oregon. Information Report No. 84-11. Oregon Department of Fish and Wildlife. Portland, Oregon. 31 pp.

Keller, E.A. and T. Tally. 1979. Effects of large organic debris on channel form and fluvial processes in the coastal redwood environment. Pages 169-197 in Adjustments of the Fluvial System, proceedings of the tenth annual geomorphology symposium, SUNY, Binghamton, New York. D.D. Rhodes and G.P. Williams, editors. Kendall/Hunt Pub. Co., Dubuque, Iowa.

Keller, E.A. and T.D. Hofstra. 1983. Summer "cold pools" in Redwood Creek near Orick, California and their importance as habitat for anadromous salmonids. Pages 221-224 in Proceedings of the First Biennial Conference of Research in California's National Parks. C. van Riper III, L.D. Whittig, and M.L. Murphy, editors. University of California, Davis.

Kuehne, R.A. 1962. A classification of streams, illustrated by fish distribution in an eastern Kentucky creek. Ecology 43(4):608-614.

Larson, J.P. 1987. Utilization of the Redwood Creek estuary, Humboldt County, California by juvenile salmonids. M.S. Thesis, Humboldt State University, Arcata, California. 79 pp.

Larson, J.P., C.L. Ricks, and T.J. Salamunovich. 1981. Alternatives for restoration of estuarine habitat at the mouth of Redwood Creek, Humboldt County, California. Pages 236-245 in Watershed Rehabilitation in Redwood National Park and Other Pacific Coastal Areas, R.N. Coats, editor. Proceedings of a symposium held at Humboldt State University, August 24-28, 1981 by the Center for Natural Resource Studies, John Muir Institute, Inc., Berkeley, California.

Lichatowich, J. and S. Cramer. 1979. Parameter selection and sample sizes in studies of anadromous salmonids. Oregon Department of Fish and Wildlife, Portland, Oregon. 25 pp.

Lotrich, V.A. 1973. Growth, production, and community composition of fishes inhabiting a first-, second-, and third-order stream of eastern Kentucky. Ecological Monographs 43(3):377-397.

Lowry, G.R. 1965. Movement of cutthroat trout, *Salmo clarki clarki* (Richardson) in three Oregon coastal streams. Transactions of the American Fisheries Society 94:334-338.

Madej, M. A. 1984. Recent changes in channel-stored sediment. Redwood Creek, California. Redwood National Park, Technical Report No. 11. Arcata, California. 54 pp.

McGie, A.M. 1981. Trends in the escapement and production of fall chinook and coho salmon in Oregon. Information Report No. 81-7. Oregon Department of Fish and Wildlife. Portland, Oregon. 44 pp.

McKeon, J.F. 1985. Downstream migration, growth, and condition of juvenile fall chinook salmon in Redwood Creek, Humboldt County, California. M.S. Thesis, Humboldt State University, Arcata, California. 90 pp.

McMahon, T.E. 1983. Habitat suitability index models: coho salmon. U.S. Department of the Interior, Fish and Wildlife Service. FWS/OBS-82/10.49. 29 pp.

Michael, J.H., Jr. 1983. Contribution of cutthroat trout in headwater streams to the sea-run population. California Fish and Game 69(2):68-76.

Moyle, P.B. 1976. Inland Fishes of California. University of California Press. Berkeley, California. 405 pp.

Naiman, R.J. and J.R. Sedell. 1981. Stream ecosystem research in a watershed perspective. Proceedings, International Association of Theoretical and Applied Limnology 21:804-811.

Narver, D.W. 1971. Effects of logging debris on fish production. Pages 100-111 in Proceedings of a Symposium-Forest Land Uses and Stream Environment, J. Morris, editor. Oregon State University, Corvallis, Oregon.

Nickelson, T.E. 1983. The influence of ocean conditions on abundance of coho salmon (Oncorhynchus kisutch) in the Oregon Production Area. Information Report No. 83-6. Oregon Department of Fish and Wildlife. 23 pp.

Nickelson, T.E., W.M. Beidler, and M.J. Willis. 1979. Streamflow requirements of salmonids. Oregon Department of Fish and Wildlife, Federal Aid Project AFS-62-8, Final Report. Portland, Oregon. 30 pp.

Nolan, K.M. and R.J. Janda. 1979. Recent history of the main channel of Redwood Creek. Pages X-1 to X-16 in Guidebook For A Field Trip To Observe Natural And Management-Related Erosion In Franciscan Terrane Of Northern California. The Cordilleran Section of the Geological Society of America, San Jose, California.

NPS (National Park Service, U.S. Department of the Interior). 1981. Watershed rehabilitation plan, Redwood National Park. Denver Service Center, Denver, Colorado. 65 pp.

Pella, J.J. and R.T. Myren. 1974. Caveats concerning evaluation of effects of logging on salmon production in southeastern Alaska from biological information. Northwest Science 48(2):132-144.

Pennak, R.W. 1971. Toward a classification of lotic habitats. Hydrobiologia 38(2):321-334.

Pennington, H.M. 1986. Emigration and mortality of juvenile steelhead in a nursery stream. M.S. Thesis, Humboldt State University, Arcata, California. 55 pp.

PFMC (Pacific Fishery Management Council). 1979. Freshwater habitat, salmon produced, and escapements for natural spawning along the Pacific coast of the United States. Portland, Oregon. 67 pp.

PFMC (Pacific Fishery Management Council). 1981. Proposed plan for managing the 1981 salmon fisheries off the coast of California, Oregon and Washington. Portland, Oregon. 163 pp. + appendixes.

Pitlick, J. 1981. Organic debris in tributary stream channels of the Redwood Creek basin. Pages 177-190 in Watershed Rehabilitation in Redwood National Park and Other Pacific Coastal Areas, R.N. Coats, editor. Proceedings of a symposium held at Humboldt State University, August 24-28, 1981 by the Center for Natural Resource Studies, John Muir Institute, Inc., Berkeley, California.

Pitlick, J. 1982. Sediment routing in tributaries of the Redwood Creek basin: northwestern California. Redwood National Park, Technical Report No. 8, Arcata, California. 67 pp.

Platts, W.S. 1979. Relationships among stream order, fish populations, and aquatic geomorphology in an Idaho river drainage. Fisheries 4(2):5-9.

Platts, W.S. 1984. Welcoming address. Pages 1-2 in Proceedings of the Pacific Northwest Stream Habitat Management Workshop. Held October 10-12, 1984, Humboldt State University, Arcata, California.

Raleigh, R.F., T. Hickman, R.C. Solomon, and P.C. Nelson. 1984. Habitat suitability information: rainbow trout. U.S. Department of the Interior, Fish and Wildlife Service. FWS/OBS-82/10.60. 64 pp.

Reeves, G., T. Roelofs, and J. West, editors. 1976. Aquatic ecosystem analysis of two logged and two unlogged watersheds in Redwood National Park and Prairie Creek Redwoods State Park. Fisheries 130 Class Project Report, Humboldt State University, Arcata, California. 49 pp.

Reiser, D.W. and T.C. Bjornn. 1979. Habitat requirements of anadromous salmonids. Number 1 in series: Influence of Forest and Rangeland Management on Anadromous Fish Habitat in Western North America, W.R. Meehan, technical editor. U.S.D.A. Forest Service, General Technical Report, PNW-96. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon. 54 pp.

Ricks, C.L. 1985. Flood history and sedimentation at the mouth of Redwood Creek, Humboldt County, California. Redwood National Park Technical Report Number 15. U.S. Department of the Interior, National Park Service, Redwood National Park, Arcata, California. 154 pp.

Rimmer, D.M. 1985. Effects of reduced discharge on production and distribution of age-0 rainbow trout in seminatural channels. Transactions of the American Fisheries Society 114:388-396.

Robins, C.R. and R.W. Crawford. 1954. A short accurate method for estimating the volume of stream flow. Journal of Wildlife Management 18:366-369.

Scarnecchia, D.L. 1981. Effects of streamflow and upwelling on yield of wild coho salmon (Oncorhynchus kisutch) in Oregon. Canadian Journal of Fisheries and Aquatic Sciences 38:471-475.

Scarnecchia, D.L. and H.H. Wagner. 1980. Contribution of wild and hatchery-reared coho salmon, Oncorhynchus kisutch, to the Oregon ocean sport fishery. Fishery Bulletin 77(3):617-623.

Seber, G.A.F. and E.D. LeCren. 1967. Estimating population parameters from catches large relative to the population. Journal of Animal Ecology 36(3):631-643.

Sedell, J.R., P.A. Bisson, J.A. June, and R.W. Speaker. 1982. Ecology and habitat requirements of fish populations in South Fork Hoh River, Olympic National Park. Pages 35-42 in Ecological Research in National Parks of the Pacific Northwest compiled from Proceedings of the Second Conference on Scientific Research in the National Parks, San Francisco, California.

Sedell, J.R., F.J. Swanson, and S.V. Gregory. 1984. Evaluating fish response to woody debris. Pages 222-245 in Proceedings of the Pacific Northwest Stream Habitat Management Workshop. Held October 10-12, 1984, Humboldt State University, Arcata, California.

Shapovalov, L. and A.C. Taft. 1954. The life histories of the steelhead rainbow trout (Salmo gairdneri gairdneri) and silver salmon (Oncorhynchus kisutch) with special reference to Waddell Creek, California, and recommendations regarding their management. State of California, Department of Fish and Game, Fish Bulletin No. 98, Sacramento, California. 375 pp.

Sokal, R.R. and F.J. Rohlf. 1981. Biometry. Second Edition. W.H. Freeman and Co., San Francisco. 859 pp.

State of California. 1965. California Fish and Wildlife Plan, Volume III, Supporting Data, Part B-Inventory Salmon-Steelhead and Marine Resources, pages 323-679. The Resources Agency of California, Sacramento, California.

Strahler, A.N. 1957. Quantitative analysis of watershed geomorphology. Transactions of the American Geophysical Union 38:913-920.

Strahler, A.N. 1964. Quantitative geomorphology of drainage basins and channel networks. Pages 4-39 to 4-76 in Handbook of Applied Hydrology, V.T. Chow, editor. McGraw-Hill, New York.

Sumner, F.H. 1962. Migration and growth of the coastal cutthroat trout in Tillamook County, Oregon. Transactions of the American Fisheries Society 91: 77-83.

Tramer, E.J. 1977. Catastrophic mortality of stream fishes trapped in shrinking pools. American Midland Naturalist 97(2):469-478.

Trautman, M.B. 1942. Fish distribution and abundance correlated with stream gradients as a consideration in stocking programs. Transactions of the North American Wildlife Conference 7:211-224.

USDI (U.S. Department of the Interior). 1960. Natural resources of northwestern California. A preliminary survey of fish and wildlife resources. Report appendix. 104 pp.

USGS (Geological Survey, U.S. Department of the Interior) 1954-1984. Annual records of mean daily discharge for stream gage on Redwood Creek located at Orick, California for Water Years 1954 through 1984. Water Resources Data for California.

Varnum, N. and V. Ozaki. 1986. Recent channel adjustments in Redwood Creek, California. Redwood National Park Technical Report Number 18. U.S. Department of the Interior, National Park Service, Redwood National Park, Arcata, California. 74 pp.

Whiteside, B.G. and R.M. McNatt. 1972. Fish species diversity in relation to stream order and physicochemical conditions in the Plum Creek drainage basin. American Midland Naturalist 88(1):90-101.

Yee, C.S. and T.D. Roelofs. 1980. Planning forest roads to protect salmonid habitat. Number 4 in series: Influence of Forest and Rangeland Management on Anadromous Fish Habitat in Western North America, W.R. Meehan, technical editor. U.S.D.A. Forest Service, General Technical Report, PNW-109. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon. 26 pp.

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

Zippin, C. 1958. The removal method of population estimation. Journal of Wildlife Management 22:82-90.

PERSONAL COMMUNICATIONS

Anderson, D.G. 1988. Aquatic Biologist, Redwood National Park, Arcata, California, 95521.

Hofstra, T.D. 1981. Fish and Wildlife Ecologist, Redwood National Park, Arcata, California, 95521.

Villa, N. 1981. Fishery Biologist, California Department of Fish and Game, Red Bluff, California, 96080

Warren, C. 1985. Aquatic Biologist, Redwood National Park, Arcata, California, 95521.

Appendix A. Selected Measurements and Field Observations of Tributaries in the Redwood Creek Basin, Humboldt County, California, 1980-81

STREAM[a]	Prairie	Skunk Cabbage	Little Lost Man	Lost Man	Streelow/ (Wolf)	May/(Mae)
DATE[b]	10/3-6/81	10/84	10/12/80, 9/24-27/81	10/11-12/80	9/28-30/81	NS
LOCATION[c]	E 5.1	W 6.2	E 9.8	E 10.1	W 11.7	E 12.1
ORDER[d]	7	4	4	6	5	5
AREA[e]	104.0	6.0	10.2	32.2	7.5	5.0
GRADIENT[f]	0.01 (18.9)	<0.01 (1.6)	0.03 (1.4)	0.01 (1.9)	0.01 (2.0)	0.02 (1.6)
DISCHARGE[g]	38 (1981)	noest	5 (1981)	234	67 (1981)	51 (1983)
ACCESS[h]	MS/7-5.0, 6-2.0, 5-5.5, 4-5.7, 3-0.7/VI 18.9 km	0.9/+	3.2/I	MS/6-4.3/I NF1/4-0.4/+ NF2/4-NS	MS/5-1.3 NF/4-0.4/I WF/4-0.4/+	0.6/III
SPECIES[i]	MS/4-st/f, ct/s, co/s	ct/s	st/s, co/f	MS-st/s, ct/f NF1-st/f, ct/s NF2-?	MS-st/f, ct/s, co/f NF-ct/s WF-ct/s	ct/f, co/f
COMMENTS[j]	L(1,2,4), M(1),N	O	M(1,2),N,O	B,L(2), M(1,2),O	L(1,2,4), M(4),N,O,K	L(2,3,4), O,M(1,5)

Appendix A. Selected Measurements and Field Observations of Tributaries in the Redwood Creek Basin, Humboldt County, California, 1980-81 (continued).

STREAM	Godwood	Boyes	Brown	HT	Hayes	McArthur
DATE	10/9/80	NS	NS	8/19/80	8/19/80	8/4/80
LOCATION	W 14.8	E 14.9	E 17.6	E 6.6	E 7.3	W 8.9
ORDER	4	4	4	3	3	5
AREA	4.7	5.2	4.9	1.0	1.5	9.9
GRADIENT	0.01 (2.1)	0.01 (1.2)	0.05 (1.4)	0.29 (1.0)	0.22 (1.1)	0.08 (1.8)
DISCHARGE	55	noest	20	int	dry	170
ACCESS	2.1/VI	MS/4-1.1 NF/3-0.2/III SF/3-0.1/I	MS/4-0.6 NF/3-1.6/I SF/3-NS	MIN/IV	MIN/IV	0.8/IV
SPECIES	st/s, ct/s	MS-st/? ct/? NF-? SF-?	MS-ct/s co/f, NF-ct/s co/f SF-?	st/f, co/x	none	st/s, ct/f
COMMENTS	O	L(4),O, M(1)	M(1,5),O, L(2)	D(0.8), I(e)	A	B,K,L(1), M(3)

Appendix A. Selected Measurements and Field Observations of Tributaries in the Redwood Creek Basin, Humboldt County, California, 1980-81 (continued).

STREAM	Elam	Gans South	Chris	Oscar Larson	LC	Cloquet
DATE	8/4/80	9/21/80	9/21/80	9/21/80	9/21/80	9/21/80
LOCATION	W 10.4	E 11.3	E 12.1	E 12.4	W 12.8	E 13.6
ORDER	5	2	2	4	2	3
AREA	6.5	1.2	1.2	1.8	0.3	3.0
GRADIENT	0.09 (1.2)	0.29 (1.2)	0.24 (1.1)	0.24 (1.4)	0.25 (1.1)	0.18 (1.2)
DISCHARGE	76	int	4	7	low	2
ACCESS	0.5/I	NA/IV	MIN/VI	MIN/VI	MIN/V	MIN/VI
SPECIES	st/f	none	none	none	none	none
COMMENTS	L(1)	A,C	A,C	A,C	A	A,C

Appendix A. Selected Measurements and Field Observations of Tributaries in the Redwood Creek Basin, Humboldt County, California, 1980-81 (continued).

STREAM	Bond	Miller	Forty-Four	Cole	Tom McDonald	Emerald/ (Harry Weir)
DATE	8/8/80	8/9/80	8/9/80	8/9/80	8/6/80, 9/11-13/81	9/6,20/80, 9/21-23/81
LOCATION	W 15.1	E 16.1	W 17.1	E 17.6	W 19.6	E 22.2
ORDER	4	4	5	3	5	4
AREA	3.7	3.5	8.1	0.8	18.0	7.8
GRADIENT	0.09 (1.7)	0.15 (1.4)	0.03 (1.1)	0.27 (1.2)	0.02 (1.4)	0.06 (1.3)
DISCHARGE	37	7	67	2	187(1980), 47 (1981)	7(1980), 6(1981)
ACCESS	0.2/IV	0.1/IV	0.3/III	MIN/VI	2.1/I	1.8/+
SPECIES	st/s	st/s	st/s	none	st/s, co/x	st/f, ct/f
COMMENTS	B,H,I(o)	B,C,I(e)	B,J(e), L(1)	A,C	B,H,J(o), K,L(1,2),N	C,H,N

Appendix A. Selected Measurements and Field Observations of Tributaries in the Redwood Creek Basin, Humboldt County, California, 1980-81 (continued).

STREAM	Bridge	GH 17	Dolason	G	GH 15.3	Airstrip
DATE	8/83	8/30/80	8/30/80	8/29/80	8/29/80	8/29/80
LOCATION	W 23.4	W 24.0	E 24.7	E 25.0	W 25.7	E 26.3
ORDER	5	3	4	3	1	2
AREA	29.5	1.2	2.2	2.0	0.2	1.1
GRADIENT	0.02 (2.2)	0.28 (1.3)	0.26 (1.2)	0.29 (1.1)	0.33 (1.2)	0.25 (1.2)
DISCHARGE	noest	noest	int	dry	low	low
ACCESS	3.2/I	NA/IV	0.2/+	MIN/IV	MIN/VI	MIN/IV
SPECIES	st/m	none	st/f	none	none	none
COMMENTS	B,J(o),K, L(1,2), M(2)	A	C,D(0.1),	A	A	A

Appendix A. Selected Measurements and Field Observations of Tributaries in the Redwood Creek Basin, Humboldt County, California, 1980-81 (continued).

STREAM	GH 15.1	GH 15	GH 14	GH 13	Slide	GH 11
DATE	8/29/80	8/29/80	8/29/80	8/29/80	8/29/80	8/29/80
LOCATION	W 26.6	W 27.1	W 27.2	W 27.5	E 27.7	W 27.8
ORDER	2	2	2	1	4	2
AREA	0.9	0.4	0.3	0.1	3.1	0.6
GRADIENT	0.32 (1.3)	0.35 (1.2)	0.32 (1.3)	0.31 (1.1)	0.25 (1.2)	0.30 (1.4)
DISCHARGE	low	low	low	low	2	int/2
ACCESS	MIN/IV	MIN/IV	MIN/IV	MIN/VI	0.2/+	MIN/IV
SPECIES	none	none	none	none	st/f	none
COMMENTS	A	A	A	A	C,D(0.03),	A,C

Appendix A. Selected Measurements and Field Observations of Tributaries in the Redwood Creek Basin, Humboldt County, California, 1980-81 (continued).

STREAM	GH 10	GH 8	Childs	GH 7.2	GH 7.1	GH 7
DATE	8/29/80	8/29/80	8/29/80	8/29/80	8/29/80	8/29/80
LOCATION	W 28.1	W 28.2	E 28.5	W 28.9	W 29.1	W 29.3
ORDER	1	1	2	2	2	2
AREA	0.3	0.2	0.7	0.4	0.5	0.6
GRADIENT	0.32 (1.3)	0.32 (1.3)	0.32 (1.3)	0.30 (1.4)	0.32 (1.3)	0.28 (1.4)
DISCHARGE	low	1	dry	low	low	9
ACCESS	NA/IV	MIN/IV	MIN/VI	NA/IV	NA/IV	MIN/IV
SPECIES	none	none	none	none	none	none
COMMENTS	A	A	A	A	A	A

Appendix A. Selected Measurements and Field Observations of Tributaries in the Redwood Creek Basin, Humboldt County, California, 1980-81 (continued).

STREAM	Maneze	GH 5	GH 4	Copper	GH 3	Elf
DATE	8/28/80	8/28/80	8/28/80	9/20/80	8/28/80	8/28/80
LOCATION	E 29.4	W 29.8	W 30.3	E 30.8	W 31.2	W 31.4
ORDER	3	1	2	4	2	2
AREA	0.8	0.4	0.5	7.4	0.6	2.0
GRADIENT	0.30 (1.3)	0.30 (1.3)	0.30 (1.3)	0.12 (1.2)	0.33 (1.2)	0.26 (1.5)
DISCHARGE	low	2	int	10	4	5
ACCESS	NA/I	MIN/IV	MIN/VI	0.5/IV	NA/IV	MIN/II
SPECIES	none	none	none	st/s	none	none
COMMENTS	A	A	A	B,C, D(0.05), I(e)	C	A

Appendix A. Selected Measurements and Field Observations of Tributaries in the Redwood Creek Basin, Humboldt County, California, 1980-81 (continued).

STREAM	Lyon	Devils	Coyote	Joplin	NP 1	Panther
DATE	8/28/80	8/23/80	9/3/80, 8/13/81	8/27/80	8/27/80	8/26/80, 8/14,29-30/81
LOCATION	E 32.3	W 33.5	E 35.3	W 37.5	W 37.7	W 39.1
ORDER	3	5	5	3	2	5
AREA	0.6	18.0	20.4	1.8	0.6	15.4
GRADIENT	0.37 (1.4)	0.06 (1.9)	0.06 (1.7)	0.30 (1.2)	0.30 (1.2)	0.06 (1.3)
DISCHARGE	dry	80	42	noest	noest	42(1980), 59(1981)
ACCESS	MIN/VI	0.3/III	MS/5-3.1/III SF/3-0.4/II NF/4-0.1/+	MIN/IV	MIN/IV	MS/5-2.4, 4-0.4/+
SPECIES	none	st/s	MS-st/m SF-st/s, co/x NF-st/f	none	none	MS/5-st/m, 4-st/f
COMMENTS	A	B,H,K, M(1)	B,I(e)	A	A	H,N

Appendix A. Selected Measurements and Field Observations of Tributaries in the Redwood Creek Basin, Humboldt County, California, 1980-81 (continued).

STREAM	Garrett	Lacks	Stover	Karen	Lee	Roaring Gulch
DATE	9/4/80	9/18-19/80, 9/2-4/81	8/21/80	8/21/80	8/21/80	8/21/80
LOCATION	E 41.9	E 44.9	E 46.4	W 49.4	W 50.0	E 51.4
ORDER	5	5	3	5	3	3
AREA	10.8	44.0	2.3	7.9	1.3	1.8
GRADIENT	0.11 (1.5)	0.03 (1.9)	0.21 (1.5)	0.06 (1.3)	0.27 (1.6)	0.37 (1.2)
DISCHARGE	14	46(1980), 16(1981)	low	34	14	1
ACCESS	0.9/III	7.3/+	NA/V	MS/5-0.6 NF/4-0.1/+ SF/4-0.1/+	MIN/III	0.2/III
SPECIES	st/s	st/m	none	MS-st/s, co/x NF-none SF-st/x	none	st/f
COMMENTS	B,H	B,H,L(2),N	A	B,H	A	C,H,I(e)

Appendix A. Selected Measurements and Field Observations of Tributaries in the Redwood Creek Basin, Humboldt County, California, 1980-81 (continued).

STREAM	Garcia	Cashmere	Beaver	Pilchuck	Mill	Molasses
DATE	8/15/80	8/12,15/80	8/12/80	8/16/80	8/5/80, 9/9-10/81	8/16/80
LOCATION	W 53.3	W 53.5	E 54.9	W 57.0	E 57.3	E 58.0
ORDER	4	4	3	4	3	3
AREA	3.5	3.6	2.1	4.5	3.5	4.4
GRADIENT	0.16 (1.1)	0.16 (1.1)	0.16 (1.1)	0.13 (1.3)	0.13 (1.3)	0.11 (1.6)
DISCHARGE	141	39	1	7	17(1980), 9 (1981)	11
ACCESS	0.4/I	0.4/III	0.3/V	0.5/III	0.4/I	0.4/II
SPECIES	st/f	st/f	st/f	st/f, co/x	st/s	st/s
COMMENTS	B,H	I(o)	B,C,H,I(o)	B,C	N	H,I(o)

Appendix A. Selected Measurements and Field Observations of Tributaries in the Redwood Creek Basin, Humboldt County, California, 1980-81 (continued).

STREAM	Toss-up	Wiregrass	Minor	Loin	Santa Fe	Sweathouse
DATE	8/5/80, 9/4-6/81	8/5/80	8/13-14/80	8/15/81	8/15/81	9/24/80
LOCATION	W 59.2	W 61.6	E 62.6	W 64.1	W 65.3	E 66.4
ORDER	5	4	5	3	3	4
AREA	6.8	4.8	33.6	2.4	2.1	4.1
GRADIENT	0.11 (1.3)	0.17 (1.6)	0.04 (2.0)	0.24 (1.5)	0.20 (1.2)	0.16 (1.5)
DISCHARGE	35(1980), 8 (1981)	7	85	noest	noest	<1
ACCESS	1.2/+	0.4/III	4.7/+	MIN/VI	0.1/IV	0.6/IV
SPECIES	st/m	st/f	st/m	st/x	st,f	st,f
COMMENTS	C,H,N	H,I(o)	B,H	C,	I(e)	C,D(0.1), H

Appendix A. Selected Measurements and Field Observations of Tributaries in the Redwood Creek Basin, Humboldt County, California, 1980-81 (continued).

STREAM	Captain	Lupton	Fern Prairie	TO	Christmas Prairie	Windy
DATE	9/24/80	8/22/80	8/22/80	9/10/80	9/10/80	9/10/80
LOCATION	E 69.0	W 70.0	W 72.2	E 72.9	W 73.5	E 74.1
ORDER	4	4	3	2	3	4
AREA	5.3	13.5	2.0	0.2	1.6	4.6
GRADIENT	0.09 (1.1)	0.08 (1.2)	0.24 (1.3)	0.38 (0.7)	0.23 (1.4)	0.05 (1.4)
DISCHARGE	1	37	noest	int	1	int
ACCESS	0.4/IV	0.9/III	MIN/IV	MIN/IV	0.1/VI	0.4/+
SPECIES	st/f	st/s	none	none	none	st/x
COMMENTS	C,D(0.3), H	B,H	A	A,C	C,D(0.1),	C,H

Appendix A. Selected Measurements and Field Observations of Tributaries in the Redwood Creek Basin, Humboldt County, California, 1980-81 (continued).

STREAM	Jena	T4	T5	T6	Noisy	Squirrel Tail
DATE	9/10/80	9/10/80	9/10/80	9/10/80	9/9/80	9/9/80
LOCATION	W 74.7	E 75.4	W 75.4	E 75.9	W 76.9	E 77.2
ORDER	3	2	2	2	5	3
AREA	0.9	0.5	0.4	0.3	16.4	4.3
GRADIENT	0.21 (1.4)	0.06 (1.1)	0.24 (1.1)	0.30 (0.9)	0.13 (1.3)	0.11 (1.5)
DISCHARGE	noest	dry	dry	dry	99	int
ACCESS	0.2/IV	MIN/IV	MIN/IV	MIN/I	0.8/IV	0.4/+
SPECIES	st/x	none	none	none	st/f	st/f
COMMENTS	C,D(0.1), H	A	A	A	B,H	C,D(0.2), H

Appendix A. Selected Measurements and Field Observations of Tributaries in the Redwood Creek Basin, Humboldt County, California, 1980-81 (continued).

STREAM	Emmy Lou	TA	Cut-off Meander	Cool Spring	Six Rivers	TZ
DATE	9/9/80	9/11/80	9/11/80	9/11/80	9/11/80	9/12/80
LOCATION	E 77.9	W 78.6	E 79.8	W 80.3	W 81.3	E 81.5
ORDER	4	1	3	3	3	2
AREA	6.7	0.4	2.4	3.0	3.2	0.3
GRADIENT	0.21 (1.3)	0.35 (0.7)	0.30 (1.3)	0.26 (1.5)	0.26 (1.4)	0.41 (0.9)
DISCHARGE	int	dry	int	37	35	dry
ACCESS	0.4/I	MIN/VI	0.3/+	NA/IV	MIN/IV	MIN/IV
SPECIES	st/f	none	st/x	none	st/f	none
COMMENTS	I(o)	A	C	I(e)	I(e)	A

Appendix A. Selected Measurements and Field Observations of Tributaries in the Redwood Creek Basin, Humboldt County, California, 1980-81 (continued).

STREAM	Gunrack	Ayres	Simon	High Prairie	Minon	Lake Prairie	Bradford, Upper-Panther
DATE	9/12/80	9/12/80	9/12/80	8/19/81	8/26/81, 9/15-16/81	8/21/81, 8/24-26/81	8/20/81
LOCATION	E 83.4	W 83.4	E 84.6	W 84.9	E 87.3	W 88.0	E 90.3
ORDER	4	3	4	5	5	4	5
AREA	6.1	0.9	4.5	14.3	11.1	8.8	16.5
GRADIENT	0.08 (1.2)	0.31 (1.5)	0.13 (1.5)	0.14 (1.4)	0.10 (1.8)	0.11 (1.6)	0.10 (1.2)
DISCHARGE	int	dry	1	noest	3 (1981)	46 (1981)	MS-5,SF-9, NF-1
ACCESS	MS/4-0.5 EF/3-MIN/IV NF/4-0.3/+	NA/IV	0.3/II	0.7/II	0.8/+	0.5/II	MS/5-0.8 SF/5-0.5/ IV NF/4-0.3/ IV
SPECIES	MS-st/f, ct/f NF-st/x	none	st/f	st/s, ct/s	st/s	st/s	MS-st/f SF-st/f NF-st/f
COMMENTS	C,H	A	C, D(0.03), I(e)	B,H	L(2),N	B,J(e),N	B,H

Appendix A. Selected Measurements and Field Observations of Tributaries in the Redwood Creek Basin, Humboldt County, California, 1980-81 (continued).

STREAM	Pardee	Debris Torrent	Last Gasp	Marquette	Timbo	Powerline	Snowcamp, Smokehouse, Twin Lakes
DATE	9/30/80	9/30/80	9/26/80	9/26/80	9/26/80	9/26/80	9/25/80
LOCATION	W 91.3	W 92.3	E 93.8	W 94.2	W 94.4	W 95.3	W 96.0
ORDER	4	2	4	3	2	3	5
AREA	8.1	0.5	4.1	2.1	1.0	1.7	8.2
GRADIENT	0.19 (1.3)	0.33 (1.4)	0.19 (1.4)	0.33 (1.2)	0.35 (1.1)	0.26 (1.3)	0.26 (1.7)
DISCHARGE	45	dry	low	low	low	dry	int/1
ACCESS	0.3/IV	MIN/IV	MIN/IV	MIN/IV	MIN/IV	MIN/IV	0.3/IV
SPECIES	st/f	none	none	none	none	none	st/f
COMMENTS	B,F,J(o)	A	A	A	A	A	I(e)

Appendix A. Footnotes.

---

[a] STREAM: Stream name or identification.

[b] DATE: Date(s) of survey, sampling. NS indicates that no survey was conducted by the author on that stream and reported information is from other sources. See comments below.

[c] LOCATION: Stream location, identified by side of basin, East or West, and distance of stream confluence from mouth of mainstem Redwood Creek, in kilometers.

[d] ORDER: Stream order (Strahler 1957). First order streams are the smallest identifiable crenulations on 1:24000 USGS topographic maps.

[e] AREA: Drainage area, in square kilometers.

[f] GRADIENT: Stream channel gradient, meter per meter, near confluence with mainstem Redwood Creek. Value in parentheses is distance of stream over which change in altitude was measured, in kilometers.

[g] DISCHARGE: Estimated stream discharge, in liters per second; 28.32 liters equals 1 cubic foot.

noest = discharge not estimated
low = flow continuous but too low to estimate (probably less than one liter per second)
int = intermittent flow (isolated pools and runs)
dry = no flow

[h] ACCESS: Approximate length of stream, in kilometers, per stream segment, that is accessible to anadromous salmonids and the type of barrier(s) limiting migration to adult fish.

Format: segment/order-access/barrier

NA = stream not accessible to anadromous salmonids
MIN = minimal access; less than 100 meters
+ = unknown length of accessible habitat upstream of area surveyed
NS = not surveyed

Stream segments: MS = mainstem, NF = North fork, SF = South Fork, etc.

Barrier Types:
- I = woody debris jam
- II = bedrock/boulder waterfall
- III = gradient
- IV = road culvert
- V = stream size very small
- VI = terminal barrier not identified

[i] SPECIES: Anadromous salmonid species found and their approximate abundance per meter of stream length.

Format: segment/order-species/abundance

Species:
- none = no salmonids found
- st = steelhead trout
- ct = cutthroat trout
- co = coho salmon
- ? = unknown

Abundance:
- x = single specimen found
- f = few (less than .5 fish per meter)
- s = some (from .5 to 2 fish per meter)
- m = many (more than 2 fish per meter)
- ? = unknown

Appendix A. Footnotes (continued).

[j] COMMENTS: Selected observations and notes regarding surveyed tributaries.

A = Survey restricted to stream reach near confluence with Redwood Creek,little or no apparent rearing potential.
B = Potential barrier(s) downstream of terminal barrier.(e.g. at different flow regimes)
C = Stream did not connect with Redwood Creek during periods of low discharge due to sediment aggradation.
D = Stream intermittent or dry in lower reach, continuous stream flow resumes (x) kilometers upstream from confluence with Redwood Creek.
H = Density of salmonids decreased with distance upstream.
I = No salmonids found upstream of terminal barrier.
  Method: (o) = observation.
  (e) = electrofishing.
J = Salmonids found upstream of terminal barrier; suspected to be resident population.
  Method: (o) = observation
  (e) = electrofishing
K = Reported resident salmonid population upstream of terminal barrier.
L = Non-salmonid fishes found in tributary:
  (1) = sculpins (<u>Cottus spp.</u>)
  (2) = Pacific lamprey (ammocoetes)
  (3) = Pacific brook lamprey
  (4) = three-spine stickleback
M = Additional source(s) of information:
  (1)-CDFG stream surveys
  (2)-Hofstra pers. comm.
  (3)-Pitlick 1982
  (4)-Reeves et al. 1976
  (5)-Warren pers. comm.
N = Discharge and species abundance values supplemented with 1981 sample site data.
O = Prairie Creek Tributary.
P = Reported migrational barrier upstream of area surveyed.

Appendix B. Physical Stream Characteristics at 12 Sites in the Redwood Creek Basin, Humboldt County, California, Sampled in 1981.

Stream	Date	Site [a]	Order	Watershed Area [b]	Gradient [c] site	Gradient [c] dnstrm	Flow [d]	Surface Area [e]
Prairie	10/3-6/81	15.2	4	8.5	0.02	----	37.9	216.6
Streelow	9/28-30/81	0.3	5	7.5	<0.01	<0.01	66.6	194.6
Little Lost Man	9/24-27/81	0.8	4	10.2	0.03	0.02	5.1	204.4
Tom McDonald	9/11-13/81	0.3	5	18.0	0.01	<0.01	47.3	185.2
Emerald	9/21-23/81	0.3	4	7.8	0.03	0.05	5.7	176.6
Panther	8/29-30/81	0.1	5	15.4	0.03	0.07	58.9	171.5
Lacks	9/2-4/81	0.8	5	44.0	0.03	0.02	15.6	243.7
Mill	9/9-10/81	0.2	3	3.5	0.05	0.05	9.1	104.2
Toss-up	9/4-6/81	0.2	5	6.8	0.03	0.03	8.2	130.7
Minon	9/15-16/81	0.1	5	11.1	0.04	0.05	2.8	116.8
Lake Prairie	8/24-26/81	0.1	4	8.8	0.05	0.09	46.4	248.1
Redwood	9/17-18/81	88.1	6	66.9	0.02	----	18.4	261.1

a distance from stream confluence in kilometers
b upstream of sample site, in square kilometers
c meter per meter
d liters per second
e square meters

Appendix B. Physical Stream Characteristics at 12 Sites in the Redwood Creek Basin, Humboldt County, California, Sampled in 1981 (continued).

Stream	Width		Volume	Depth Frequency				n	Cover Frequency				
	mean[f]	range	Volume[g]	0-15	15-30[h]	30-45	>45	n[i]	cb[j]	ov	ro	wd	tb
Prairie	3.84	2.85-5.05	31.1	71	29	16	2	118	8	9	2	7	0
Streelow	4.05	2.70-6.20	37.5	53	41	35	1	130	7	3	0	10	0
Little Lost Man	3.90	2.10-5.05	14.6	74	22	1	0	97	0	3	11	2	2
Tom McDonald	3.50	2.10-5.35	34.4	50	27	20	9	106	0	0	6	2	0
Emerald	3.32	1.35-5.20	12.6	77	11	1	0	89	0	1	4	4	0
Panther	3.16	1.10-4.65	20.9	75	31	12	2	120	0	0	5	3	3
Lacks	4.69	2.20-6.15	31.6	87	40	12	5	144	0	1	19	0	3
Mill	2.03	1.00-2.60	5.8	54	2	0	0	56	0	2	5	1	1
Toss-up	2.47	1.30-3.20	11.9	55	14	1	0	70	0	2	10	0	0
Minon	2.26	1.10-3.25	8.6	48	11	1	0	60	0	0	9	0	0
Lake Prairie	4.11	2.30-6.10	21.8	80	21	0	7	108	0	0	7	0	0
Redwood	4.95	3.25-6.05	30.7	78	52	6	0	136	0	0	24	0	1

f meters
g cubic meters
h watered points only, in centimeters
i number of watered points per site
j watered points only, cb = cutbank, ov = overhanging vegetation, ro = rock overhang, wd = woody debris, tb = water surface turbulence

Appendix C. Length and Weight Data for Juvenile Anadromous Salmonids Captured at 12 Sample Sites in the Redwood Creek Basin, Humboldt County, California, 1981.

				Length			Weight	
Stream	Sp.	Age	n	mean	SD	range	mean	SD
Prairie	st/ct[a]	0+[b]	24[c]	58.2[d]	11.4	43-86	2.4[e]	1.6
	st	1+	1	110.0	----	-------	14.5	----
	ct	1+	8	116.6	21.5	95-155	19.4	11.6
	co	0+	32	65.9	8.9	53-86	4.2	1.6
Streelow	st/ct	0+	7	81.3	4.8	73-89	7.0	1.2
	st	1+	3	98.0	8.5	90-107	11.5	2.8
	ct	1+	7	125.4	19.5	103-150	25.7	10.8
	co	0+	7	83.7	7.3	72-93	8.8	1.9
Little	st	0+	71	52.4	9.4	34-71	2.2	1.2
Lost Man	st	1+	6	93.3	2.9	90-98	9.2	0.5
Tom	st	0+	19	76.5	7.6	64-89	5.7	1.5
McDonald	st	1+	2	111.0	22.6	95-127	17.8	8.8
Emerald	st	0+	20	67.3	6.5	52-76	4.1	1.1
	st	1+	3	111.0	20.1	97-134	16.3	8.4
Panther	st	0+	85	56.0	12.8	30-84	2.4	1.5
	st	1+	15	118.2	24.6	91-185	20.3	13.8
Lacks	st	0+	205	52.0	9.9	30-84	1.9	1.2
	st	1+	10	116.6	21.8	94-164	18.9	12.8
Mill	st	0+	79	53.2	12.6	31-78	2.1	1.4
	st	1+	3	101.0	3.5	97-103	11.8	0.6
Toss-up	st	0+	209	53.1	10.1	33-88	1.9	1.2
	st	1+	5	139.4	27.2	113-169	32.0	16.3
Minon	st	0+	90	46.9	8.6	31-67	1.4	0.8
	st	1+	4	110.0	17.4	95-127	15.0	7.0
Lake	st	0+	23	53.8	11.3	39-87	2.2	1.7
Prairie	st	1+	3	111.0	18.5	93-130	13.8	9.8
Redwood	st	0+	529	53.1	9.8	34-87	2.0	1.2
	st	1+	15	105.1	13.1	92-127	14.1	6.0

[a] st = steelhead; ct = cutthroat; co =coho
[b] 0+ = young of the year; 1+ = yearling and older
[c] total number captured and measured
[d] fork length, in millimeters
[e] in grams, converted from milliliters (see Methods)