Geomorphic Processes and Aquatic Habitat in the Redwood Creek Basin, Northwestern California

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Aquatic Biology of the Redwood Creek Basin, Redwood National Park, California

By ROBERT C. AVERETT *and* RICK T. IWATSUBO

GEOMORPHIC PROCESSES AND AQUATIC HABITAT IN THE REDWOOD CREEK BASIN, NORTHWESTERN CALIFORNIA

U.S. GEOLOGICAL SURVEY PROFESSIONAL PAPER 1454-R

CONTENTS

ILLUSTRATIONS

TABLES

AQUATIC BIOLOGY OF THE REDWOOD CREEK BASIN, REDWOOD NATIONAL PARK, CALIFORNIA

By ROBERT C. AVERETT and RICK T. IWATSUBO

ABSTRACT

A study of the aquatic biota in Redwood Creek drainage basin of Redwood National Park, California, was conducted between 1973 and 1975. The study included an assessment of coliform bacteria, benthic invertebrates, fish, periphyton, and phytoplankton.

Coliform bacteria numbers were low except in Prairie Creek where a fish hatchery, State park, lumber mill, and residential area are located.

Benthic invertebrate communities were diverse, and the number per unit area varied greatly among sampling sites. Numbers and types of benthic invertebrates were directly related to the type of bed material. Following major winter storms, the numbers of invertebrates decreased rapidly, but usually returned to prestorm levels by autumn. Using the functional group categories of Cummins, most of the benthic invertebrates were in the collector category, followed by the predator category.

Seven species of fish representing those typically found in northern California coastal streams were captured. The most common were steelhead trout *(Oncorlynchus mykiss).*

Periphyton and phytoplankton communities were diverse, variable in density, and dominated by diatoms. Periphyton rates of accrual on acrylic strips were low because of shading from the dense forest canopy. The phytoplankton community was dominated by detached periphytic algae. Variability of periphyton and phytoplankton could not be directly related to differences in land use history of the basin.

Two decades have passed since the Redwood Creek study began. Resampling selected sites could be useful to determine if there have been changes in the biota since logging has stopped and the watershed has been allowed to revegetate.

INTRODUCTION

Aquatic flora and fauna are an integral part of any stream system. Not only do they influence the quality of the water in a stream, but they, themselves, are influenced by the quality of the stream water. Aquatic organisms have therefore been used as indicators of stream quality (Hynes, 1960). In Redwood Creek, the aquatic flora and fauna are important elements of Redwood National Park. Historically, Redwood Creek and its estuary have supported a varied flora and fauna, some, such as anadromous salmonids, being of economic value. Realizing the value of this native aquatic flora and fauna, the National Park Service and the U.S. Geological Survey initiated a study in September 1973, in part to study aquatic plants and animals in the Redwood Creek drainage basin with particular emphasis on their types, abundance, and distribution. The study concluded in September 1975, and the results were reported by Averett and Iwatsubo (1975) and Iwatsubo and Averett (1981).

Redwood National Park was formed on October 2, 1968, when Congress passed Public Law 90-545. When the Redwood Park study began in September 1973, only about 10 percent of the Redwood Creek drainage basin was within Redwood National Park. Since 1973, the national parkland has been expanded by the addition of 48,000 acres in the Redwood Creek drainage basin, including all basins upstream to Copper Creek and Devils Creek (fig. 1). Moreover, a 14,569-hm^2 park protection zone includes Coyote, Panther, and Lacks Creeks to help ensure that land use practices will not have detrimental effects on downstream park areas. When this study began in 1973, much of the land upstream from the present Redwood National Park was privately owned. This land contained virgin redwood *(Sequoia sempervirens)* and was commercially clearcut and removed by tractor-yarding. This logging practice resulted in landslides, mass movement, fluvial erosion and deposition of sediment, increased water temperature, and changes in water-quality constituents. These problems were most noticeable in the 0.8-km-wide, 11.3-km-long Redwood Creek corridor in which this biological study effort was concentrated. In April 1975, 65 percent of the Redwood Creek drainage basin was cutover timberland.

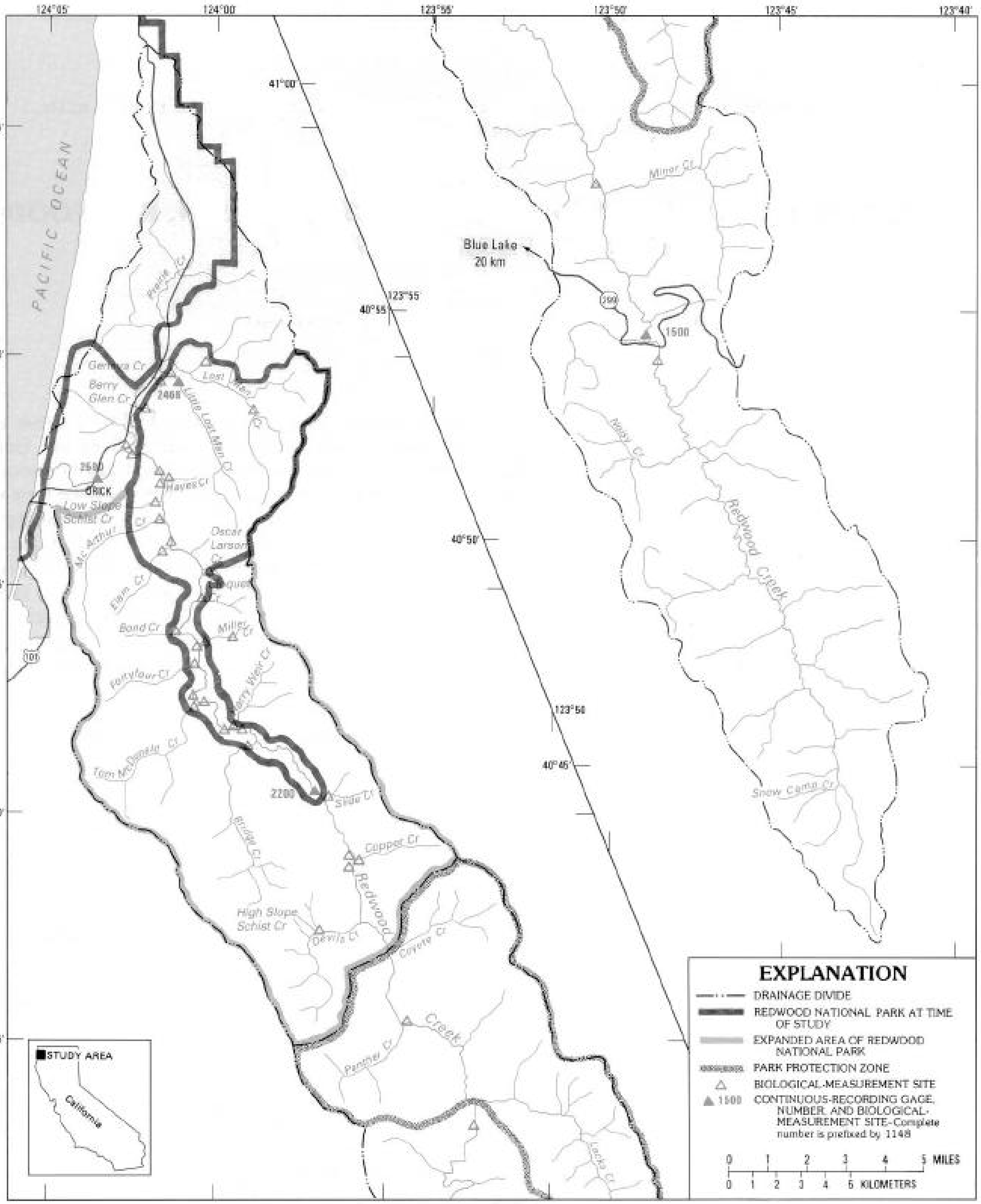

FIGURE 1.—Redwood Creek drainage basin showing main tributaries and sampling sites.

PURPOSE AND SCOPE

This paper summarizes the findings of the biological study as reported earlier by Averett and Iwatsubo (1975) and Iwatsubo and Averett (1981) and provides information that may be useful as the riparian vegetation in the Redwood Creek drainage basin matures, provides a medium for soil stabilization, and provides for more uniform flows in the main stem and tributary channels.

Bacteria, benthic invertebrates, fish, periphyton, and phytoplankton were the aquatic types included in the biological investigation. Most biological sampling was conducted during the receding flows of spring and during the low-flow periods of summer and early autumn in 1973, 1974, and 1975.

DESCRIPTION OF STUDY AREA

The Redwood Creek drainage basin covers 725 km^2 in the northern Coast Range of California. The basin has high relief, steep and unstable slopes, and narrow valleys and is elongated north-northwesterly. It is about 101 km long and 7.2 to 11.2 km wide. The overall drainage pattern is trellised, but some tributary drainage basins display a dendritic pattern. Altitude ranges from sea level at the mouth to 1,615 m at the upstream end. Relief is about 610 m in the north and greater than 900 m near the head of the basin. Average hillslope gradients range from 31 percent in the northern quarter to 34 percent in the southern quarter of the drainage basin. Flood plains along Redwood Creek are discontinuous and seldom exceed 60 m in width except for areas near Minor Creek, near the mouth of Lacks Creek, and near Orick (fig. 1).

Tributary channel gradients are steep, with average gradients ranging from 47 to 284 m/km. Streambed materials are extremely variable in size and range from large blocks of bedrock to fine sand and silt. However, pebbles and cobble gravel are the most prevalent materials. Small streamside slides and gullies are common. Numerous debris accumulations and large blocks of colluvium in the downstream end of many tributaries restricted the upstream migration of anadromous fish. Logging-related barriers to anadromous fish were uncommon, but in streams draining areas subject to recent timber harvest, coarse logging debris has accumulated on preexisting channel obstructions (Janda and others, 1975). Many tributaries are intermittent in their lower reaches during low-flow periods of summer and early autumn, restricting fish habitat to pooled areas. In the perennial streams, riffles and undercut banks provide additional habitat for fish.

Redwood Creek enters the Pacific Ocean 2.7 km west of Orick, Calif. At its mouth, the estuary is restricted by channelization (fig. 2). A small tributary enters the estuary from the north. During low-flow periods of summer and early autumn, the mouth of Redwood Creek is closed by an emergent sandbar. Anadromous fish are usually able to enter the stream only after the autumn freshets open the sandbar. In some years fishermen open the mouth of Redwood Creek, and in other years ranchers do so to reduce backwater flooding of pastures.

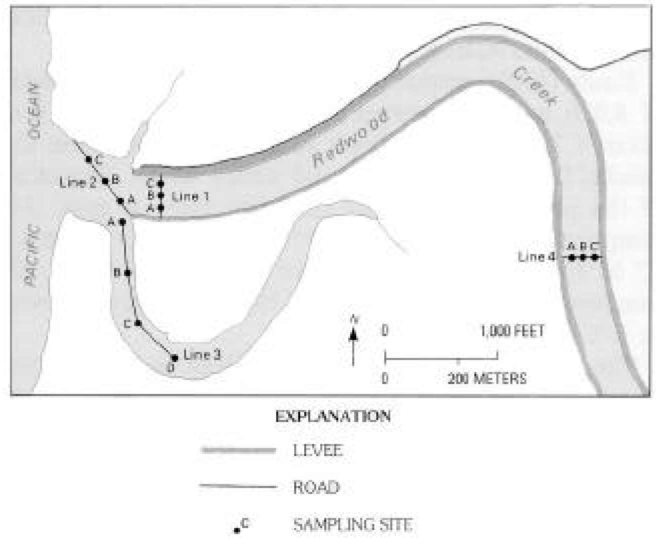

FIGURE 2.—Sampling stations on the Redwood Creek estuary.

The saltwater gradient of the Redwood Creek estuary has been described by Bradford and Iwatsubo (1978). Except during summer, the discharge of Redwood Creek is often sufficient to prevent saltwater from the Pacific Ocean from entering the estuary.

The dominant geologic unit of the Redwood Creek drainage basin is the Franciscan Complex (Strand, 1962, 1963), also considered as the Franciscan assemblage (Bailey and others, 1964). The eastern side of the Redwood Creek drainage basin, approximately upstream from Larry Damm Creek, is underlain by virtually unmetamorphosed Franciscan sedimentary rocks such as graywacke sandstone, mudstone, and conglomerate. The soil profile developed on this side of the drainage basin includes the Hugo, Kneeland, Melbourne, Mendocino, and Tyson soil series. On the west side of Redwood Creek, the drainage basin is underlain by mostly medium-gray, well-foliated quartz-mica schist, quartz-mica-feldspar schist, and quartz-graphite schist. These schists have weathered mostly to the Orick, Masterson, and Sites soil series (Iwatsubo and others, 1975). A transition zone exists between the unmetamorphosed sedimentary rocks of the east side of the drainage basin and the schists of the west side. Sheared rocks in this zone (Grogan, South Fork Mountain, and Bald Mountain faults and numerous small cross faults) are the parent material for the Atwell soil series, which is extremely unstable and susceptible to landslides.

Rantz (1969) estimated a basinwide precipitation total of 2,030 mm/yr. Average annual rainfall ranges from about 1,778 mm/yr at Orick to 2,540 or more near the head of the basin (Iwatsubo and others, 1975). Almost all of the precipitation in the drainage basin is rain. Air temperatures range from 15.6 °C in August to about 6.7 °C in January. In the southern part of the basin, air temperatures range from about 19.2 °C in July to about to 0 °C in January.

The highest flows in Redwood Creek occur between November and April, and lowest flows between August and October. Three continuous-recording streamflow gages are located on Redwood Creek. One is near Blue Lake (station 11481500), one at the South Park Boundary (station 11482200), and one at Orick (station 11482500). At the time of the study, Redwood Creek near Blue Lake, with 8 years of recorded data, had a maximum discharge of 346 m^3/s and a minimum of 0.08 m^3/s. Redwood Creek at South Park Boundary, with 5 years of recorded data, had maximum and minimum discharges of 935 and 0.13 m^3/s, respectively. Redwood Creek at Orick, with 24 years of recorded data, had maximum and minimum discharges of 1,430 and 0.26 m^3/s (U.S. Geological Survey, 1975).

Dissolved-solids concentrations in samples from Redwood Creek and tributaries ranged from 25 to 139 mg/L. Nitrogen and phosphorus concentrations were low but yet high enough to support modest algal production, especially in the main stem where insolation is high (Bradford and Iwatsubo, 1978).

SAMPLING STATIONS AND METHODS

SAMPLING STATIONS

Biological data were collected at 50 sampling sites in the Redwood Creek drainage basin. A brief description of the sampling stations and types of aquatic organisms collected was given in Iwatsubo and others (1976) and is repeated in brief form in table 1. Figure 1 shows the sampling sites along the Redwood Creek main stem, and figure 2 shows the sampling sites along the Redwood Creek estuary. The sampling sites were chosen on the basis of size of drainage area, location in reference to Redwood National Park, geology, and history of land use. The drainage basin of each sampling site had been categorized according to its history of land use or as a Redwood Creek main stem or estuary site; basin categories were (1) control (limited activities of man in the basin), (2) regenerating vegetation (after being logged), and (3) being logged in 1975.

METHODS

Biological assessments were made for fecal-coliform and fecal-streptococcal bacteria, benthic invertebrates, fish, periphyton and phytoplankton. Iwatsubo and Averett (1981) also reported on seston measurements. All techniques and methods used in the study conformed with those described by Slack and others (1973). Most of the aquatic organisms were collected during the receding-flow periods of spring and the low-flow periods of summer and early autumn. In winter, high streamflow limited biological sampling to the collection of bacteria. Water samples for bacterial determinations were collected in sterilized glass containers. The membrane-filter incubation method, using µm pore-size membrane filters, was used to determine the densities of bacterial colonies.

Benthic invertebrates were collected with a Surber sampler in the stream or with an Ekman dredge in the Redwood Creek estuary. Benthic invertebrates from the 1973 samples were separated from detritus in the field by using forceps. Invertebrates from 1974 and 1975 samples were separated from detritus in the laboratory by the flotation technique described by Anderson (1959). Identification and enumeration of benthic invertebrates were made by using the following taxonomic references: Ross (1944); Gaufin and Tarzwell (1952); Pennak (1953); Usinger (1956); Edmondson (1959); Jewett (1960); Edmunds and others (1963); Johannsen (1969); Borror and DeLong (1971); Mason (1973); and Smith and Carlton (1975).

Fish were collected by using a 15.2-m seine with a 6.4-mm mesh opening, or a backpack electrofishing unit. Tricaine methanesulfonate was used to anesthetize salmonids prior to identification and determination of length and weight.

Periphyton were collected on artificial substrates made of clear acrylic strips measuring 102 mm by 457 mm. Substrates were usually given 8 to 10 weeks for periphyton colonization before removal. Identification and biomass analysis were done in the laboratory.

Water samples for phytoplankton analysis were collected in 1-L polyethylene bottles and preserved with Lugol's solution. Phytoplankton were identified and enumerated by the inverted microscope method (Slack and others, 1973).

BACTERIA

Sampling for bacteria was limited to fecal-coliform and fecal-streptococcal types. These two types of bacteria are recognized as indicators of the sanitary quality of water and so were measured in this study. Fecal-coliform and fecal-streptococcal bacterial densities were low except in Prairie Creek, a lower tributary to Redwood Creek. A State park, fish hatchery, lumber mill, and residential area are located above this sampling site and doubtless contributed to the higher bacterial counts of 220 and 750 colonies per 100 milliliters (col/100 mL).

Excluding Prairie Creek, the other tributaries to Redwood Creek that were sampled for bacteria had colony counts ranging from <1 to 30 col/100 mL for fecal-coliform bacteria and from <1 to 190 col/100 mL for fecal-streptococcal bacteria. In the Redwood Creek main stem, densities of fecal-coliform and fecal-streptococcal bacteria ranged from <1 to 47 and 1 to 280 col/100 mL of water, with mean densities of 13 and 35 col/100 mL, respectively. Additional counts and detailed results are given in Iwatsubo and Averett (1981).

BENTHIC INVERTEBRATES

The benthic invertebrate community was diverse in the Redwood Creek drainage basin and consisted of 144 taxa from the main stem and tributaries and 30 taxa from the estuary. Insects composed 68.6 percent of the benthic invertebrates collected in the Redwood Creek drainage basin (table 2). Diptera was the dominant order, constituting 22.0 percent of the benthic invertebrates, and was followed by Ephemeroptera (17.7 percent), Coleoptera (13.2 percent), Trichoptera (11.3 percent), Plecoptera (4.3 percent), and Collembola, Hymenoptera, Lepidoptera, Neuroptera, and Odonata (<0.1 percent for each order).

Representatives of the Phyla Mollusca (snails and clams), Nematoda (roundworms), and Platyhelminthes (flatworms) also were collected. Of these three phyla, Nematoda were the most abundant (especially in the estuary) but represented only 0.7 percent of the total invertebrates collected.

Water mites, Acari, were the only members of the Class Arachnoidea collected in the basin. Crustaceans (Class Crustacea) occurred primarily in samples from the Redwood Creek estuary. The estuarian scud *Corophium* was the dominant crustacean and represented 98.4 percent of the class in the Redwood Creek estuary. Minor numbers of *Anisogammarus* and *Stygobromus* (freshwater scuds), *Exosphaeroma* (aquatic sow bug), and an unidentified group also were collected. A complete taxanomic list for all benthic invertebrates in the Redwood Creek drainage basin to the generic level is given in Iwatsubo and Averett (1981).

The variations in the number of benthic invertebrates collected during the study reflected seasonal changes, but these variations were also greatly influenced by stream discharge and movement of the streambed. Data from the 1973 samples on benthic invertebrates should not be compared with the 1974 and 1975 data because the 1973 samples were sorted from sample detritus in the field, and the 1974 and 1975 samples were sorted in the laboratory. The field sorting resulted in a lower number of benthic invertebrates counted at each sampling site.

Along the Redwood Creek main stem, the number of benthic invertebrates collected during autumn 1973 ranged from 330 to 3,600 invertebrates per square meter (inverts/m^2) (table 3). The number of benthic invertebrates collected from Redwood Creek tributaries ranged from 90 to 4,400 inverts/m^2. Samples from Little Lost Man Creek ("control" land use class) had the largest number of benthic invertebrates (4,400 inverts/m^2), whereas the mouth of Miller Creek (logged drainage basin) had the smallest number (90 inverts/m^2).

On October 23, 1973, 157 mm of rain was recorded at the Orick-Prairie Creek precipitation station just north of Orick, Calif. (U.S. National Oceanic and Atmospheric Administration, 1973). Stream discharges at Redwood Creek near Blue Lake, at South Park Boundary, and at Orick peaked at 144, 305.8, and 459 m^3/s, respectively, on October 23, 1973 (U.S. Geological Survey, 1975). Because of increased water discharge, benthic invertebrate samples could not be collected from the Redwood Creek main-stem sites after the October 1973 storm; however, six tributaries—Harry Weir Creek, Tom McDonald Creek, Miller Creek at mouth, Miller Creek near Orick, Hayes Creek, Lost Man Creek, and Little Lost Man Creek—were resampled. The results indicated a marked decrease of benthic invertebrates in the samples collected after the storm (fig. 3).

Percentage decreases ranged from 20 at Hayes Creek to 93 at Little Lost Man Creek and averaged 62. Stream basins classified as "control" (Hayes Creek and Little Lost Man Creek) that were resampled after the October 23, 1973, storm had a mean decrease of 56 percent in the number of benthic invertebrates collected. Stream basins classified as "being logged" (Harry Weir Creek, Tom McDonald Creek, and Miller Creek at mouth) had a mean decrease of 60 percent. Lost Man Creek was the only stream basin classified as "regenerating vegetation" that was resampled following the storm, and it had an 81-percent decrease in the number of benthic invertebrates.

The variations in the number of benthic invertebrates collected from the Redwood Creek drainage basin in 1974 and 1975 were similar to the 1973 findings. Invertebrates in the spring samples represented individuals that were able to overwinter, as well as a few recently hatched individuals. In the autumn, when streamflows were lowest, samples of benthic invertebrates again were collected. The invertebrates collected in the autumn represented those organisms that had grown but had not emerged throughout the summer, as well as individuals

TABLE 1.—*Description of biological sampling sites, Redwood Creek drainage basin* [From Iwatsubo and others (1976). B=bacteria; BI=benthic invertebrates; F=fish; P_1=phytoplankton; P_2=periphyton; S=seston; —, not determined]

Sampling sites	Drainage area (km^2)	Stream order	Streambed composition[1]	Canopy (estimated, in %)[2]	Biological sampling	Basin classification[3]
Redwood Creek above Highway 299 bridge	171	5	Small cobbles, gravel, sand, and silt.	5	BI	Main stem
Redwood Creek near Blue Lake	175	5	....do....	30	B, BI, S	Do.
Redwood Creek at Redwood Valley Bridge, near Blue Lake	249	5	Cobbles, gravel, sand, and silt.	<1	B, BI, F,S	Do.
Redwood Creek at Lower End, Redwood valley	318.6	6	Small cobbles, mainly gravel, sand, and some silt.	5	BI	Do.
Redwood Creek above Panther Creek, near Orick	388.5	6	Cobbles, gravel, and sand.	10	B, BI, S	Do.
High Slope Schist Creek near Orick	1.37	2	Boulders, cobbles, some gravel, and sand.	98	BI, S	Control.
Redwood Creek above Copper Creek, near Orick	45.8	6	Cobbles, gravel, and sand.	<1	BI, F	Main stem.
Copper Creek near Orick	7.20	4	Cobbles, gravel, much sand, and silt.	<1	BI, F, S	Being logged in 1975.
Redwood Creek below Copper Creek, near Orick	466	6	Some boulders, mainly cobbles, gravel, and sand.	<1	BI	Main stem.
Slide Creek near Orick	3.00	3	Cobbles, gravel, sand, and silt.	95	BI	Being logged in 1975.
Redwood Creek at South Park Boundary, near Orick	479	6	Cobbles, some gravel, and sand.	5	B, BI, P_1, P_2, S	Main stem.
Bridge Creek near Orick	30.0	4	Cobbles, little gravel, sand, and silt.	3	BI, F, P_1, P_2, S	Being logged in 1975.
Redwood Creek above Harry Weir Creek, near Orick	523	6	Small cobbles, mainly gravel and sand, and some silt.	5	B, S	Main stem.
Harry Weir Creek near Orick	7.67	4	Cobbles, little gravel, sand, and silt.	95	B, BI, F, P_1, P_2, S	Being logged in 1975.
Redwood Creek below Harry Weir Creek, near Orick	531	6	Small cobbles, mainly gravel and sand, and some silt.	5	BI, F	Main stem.
Redwood Creek above Tom McDonald Creek, near Orick	534	6	Small cobbles, gravel, and sand.	5	BI	Main stem.
Tom McDonald Creek near Orick	17.8	4	Few boulders, cobbles, some gravel, sand, and silt.	50	BI, F, S	Being logged in 1975.
Redwood Creek below Tom McDonald Creek, near Orick	552	6	Cobbles and sand.	5	BI	Main stem.
Fortyfour Creek near Orick	8.00	3	—	—	S	Being logged in 1975.
Redwood Creek above Miller Creek, near Orick	565	6	Small cobbles and gravel, sand, and silt.	5	BI	Main stem.
Miller Creek near Orick	1.73	3	Small cobbles, gravel, sand, and silt.	70	B, BI, P_1, P_2, S	Being logged in 1975.
Miller Creek at mouth, near Orick	3.52	3	....do....	85	B, BI, F, P_1, P_2, S	Do.
Bond Creek near Orick	3.55	3	—	—	S	Do.
Cloquet Creek near Orick	2.95	2	Small cobbles, gravel, sand, and silt.	60	BI	Do.
Redwood Creek below Oscar Larson Creek, near Orick	583	6	Small cobbles, mainly gravel and sand, and silt.	5	BI	Main stem.
Elam Creek near Orick	6.45	3	Small cobbles, gravel, sand, heavily coated with oxidized material.	90	BI, S	Being logged in 1975.
Redwood Creek below Elam Creek, near Orick	593	6	Few cobbles, some gravel, mainly sand.	5	BI	Main stem.
McArthur Creek near Orick	9.66	3	—	—	S	Being logged in 1975.

TABLE 1.—*Description of biological sampling sites, Redwood Creek drainage basin* —Continued

[B=bacteria; BI=benthic invertebrates; F=fish; P_1 =phytoplankton; P_2=periphyton; S=seston; —, not determined]

Sampling sites	Drainage area (km^2)	Stream order	Streambed composition[1]	Canopy (estimated, in %)[2]	Biological sampling	Basin classification[3]
Low Slope Schist Creek near Orick	.49	2	—	—	S	Control.
Redwood Creek above Hayes Creek, near Orick	609	6	Large cobbles, gravel, and sand.	<1	BI, F, P_1	Main stem.
Hayes Creek near Orick	1.46	3	Cobbles, gravel, sand, and silt.	85	B, BI, P_1, P_2, S	Control.
Redwood Creek below Hayes Creek, near Orick	592	6	Cobbles, gravel, mainly sand.	<1	BI, F	Main stem.
Redwood Creek above Prairie Creek, near Orick	614	6	—	—	B	Do.
Prairie Creek near Orick	103	5	—	—	B	—
Lost Man Creek near Orick	10.3	4	Cobbles, little gravel, sand, and silt.	60	B, BI, P_1, P_2, S	Regenerating
Larry Damm Creek near Orick	4.84	3	—	—	S	Do.
Little Lost Man Creek at site 2, near Orick	8.96	4	Cobbles, gravel, sand, and some silt.	60	B, BI, P_1, P_2, S	Control.
Little Lost Man Creek near Orick	9.45	4	Cobbles, gravel, sand, and silt.	40	BI, F, S	Do.
Geneva Creek near Orick	.20	2	Small cobbles, gravel, and sand.	95	BI, S	Regenerating
Berry Glen Creek near Orick	1.03	2	—	—	S	Do.
Redwood Creek at Orick	720	6	—	<1	B, P_2, S	Main stem.
Redwood Creek estuary, site 1A, near Orick	730	6	Sand and silt.	<1	BI	estuary.
Redwood Creek estuary, site 1B, near Orick	730	6	....do....	<1	BI, P_2	Do.
Redwood Creek estuary, site 1C, near Orick	730	6	....do....	<1	BI	Do.
Redwood Creek estuary, site 2A, near Orick	730	6	....do....	<1	BI	Do.
Redwood Creek estuary, site 2B, near Orick	730	6	....do....	<1	BI, P_2	Do.
Redwood Creek estuary, site 2C, near Orick	730	6	....do....	<1	BI	Do.
Redwood Creek estuary, site 3A, near Orick	730	6	....do....	<1	BI	Do.
Redwood Creek estuary, site 3B, near Orick	730	6	....do....	<1	BI, P_2	Do.
Redwood Creek estuary, site 3C, near Orick	730	6	....do....	<1	BI	Do.

[1] Field observations not verified by laboratory analysis.
[2] Streambed exposure to direct sunlight at each station was influenced by deciduous riparian vegetation.
[3] The drainage basin of each sampling site is classified according to its history of land use or as a Redwood Creek main stem or estuary site. "Control" refers to areas of limited human activity and influence.

TABLE 2.—*Percentage taxonomic composition of benthic invertebrates collected from the Redwood Creek drainage basin*

[Taxonomic classification is by phylum, class, and order. The sum of the phylum percentages equaled 100 percent before rounding]

Taxonomic classification	Taxonomic composition, in percent		
	Main stem and tributaries	Estuary	Main stem, tributaries, and estuary
Annelida	1.2	0.6	1.0
Arthropoda	98.8	96.5	98.2
Arachnoidea	13.4	.4	10.1
Crustacea	.1	76.9	19.5
Insecta	85.3	19.2	68.6
Coleoptera	17.6	.2	13.2
Collembola	<.1	<.1	<.1
Diptera	23.1	18.9	22.0
Ephemeroptera	23.6	.1	17.7
Hymenoptera	<.1	.0	<.1
Lepidoptera	<.1	.0	<.1
Neuroptera	<.1	.0	<.1
Odenata	.1	.0	<.1
Plecoptera	5.7	.1	4.3
Trichoptera	15.1	.0	11.3
Mollusca	<.1	.0	<.1
Nematoda	<.1	2.9	.7
Platyhelminthes	<.1	<.1	<.1

from newly hatched eggs. At almost every sampling station, the autumn samples contained larger numbers of benthic invertebrates than did the spring samples.

Spatial variations in the number of benthic invertebrates collected from the Redwood Creek main stem (excluding the estuary) during spring 1974 and 1975 were low (table 3). There was little difference between the number of benthic invertebrates collected from the upstream and downstream reaches of Redwood Creek. In contrast, the autumn 1974 and 1975 samples showed wide variation in numbers of benthic invertebrates collected from the Redwood Creek main stem, ranging from 8,300 to 50,000 inverts/m^2.

In March 1975, a major storm in the study area resulted in flood discharges and attendant degradation and aggradation of the streambeds in the Redwood Creek drainage basin. The peak discharge for Redwood Creek at Orick of 1,422 m^3/s almost equaled the record flood peak discharge of 1,430 m^3/s on December 22, 1964. The number of benthic invertebrates collected in the samples during spring 1975 was low but somewhat similar to the number in the spring 1974 samples when the peak winter discharge reached 702 m^3/s. The benthic

TABLE 3.—*Number of benthic invertebrates per square meter in samples from the Redwood Creek drainage basin* [—, not sampled]

Station name	1973 Autumn	1973 After Oct. 23 storm	1974 Spring	1974 Autumn	1975 Spring	1975 Autumn
Redwood Creek above Highway 299	1,400	—	310	50,000	—	—
Redwood Creek near Blue Lake	1,900	—	250	22,000	590	33,000
Redwood Creek at Redwood Valley Bridge, near Blue Lake	3,200	—	280	34,000	—	—
Redwood Creek at lower end, Redwood Valley	830	—	190	15,000	—	—
Redwood Creek above Panther Creek, near Orick	3,600	—	370	35,000	—	—
High Slope Schist Creek near Orick	180	—	970	2,200	1,100	1,200
Redwood Creek above Copper Creek, near Orick	—	—	180	29,000	—	—
Copper Creek near Orick	1,800	—	1,500	38,000	1,200	51,000
Redwood Creek below Copper Creek	1,300	—	—	—	—	—
Slide Creek near Orick	610	—	1,400	7,700	—	—
Redwood Creek at South Park Boundary, near Orick	740	—	430	13,000	910	39,000
Bridge Creek near Orick	980	—	1,100	9,500	1,400	22
Harry Weir Creek near Orick	320	110	1,800	3,800	1,100	1,000
Redwood Creek below Harry Weir Creek, near Orick	450	—	430	17,000	—	—
Redwood Creek above Tom McDonald Creek, near Orick	—	—	420	15,000	560	19,000
Tom McDonald Creek near Orick	1,400	380	1,200	9,300	600	8,200
Redwood Creek below Tom McDonald Creek, near Orick	380	—	—	—	—	—
Redwood Creek above Miller Creek, near Orick	450	—	420	12,000	—	—
Miller Creek near Orick	—	200	4,400	5,500	6,000	13,000
Miller Creek at mouth, near Orick	90	52	580	2,300	1,200	4,500
Cloquet Creek near Orick	520	—	3,500	10,000	—	—
Redwood Creek below Oscar Larson Creek, near Orick	1,100	—	990	21,000	—	—
Elam Creek near Orick	440	—	1,000	1,300	—	—
Redwood Creek below Elam Creek, near Orick	330	—	670	15,000	1,100	8,400
Redwood Creek above Hayes Creek, near Orick	—	—	2,000	34,000	960	8,300
Hayes Creek near Orick	150	120	1,200	14,000	5,000	9,200
Redwood Creek below Hayes Creek, near Orick	720	—	—	—	—	—
Lost Man Creek near Orick	530	100	1,000	7,000	4,100	6,300
Little Lost Man Creek at site 2, near Orick	—	—	4,100	15,000	6,900	26,000
Little Lost Man Creek near Orick	4,400	290	4,200	—	—	—
Geneva Creek near Orick	—	—	1,800	—	—	—
Redwood Creek estuary, line 1A, near Orick[1]	—	—	2,800	—	—	—
Redwood Creek estuary, line 1B, near Orick[1]	—	—	2,300	79,000	—	—
Redwood Creek estuary, line 1C, near Orick[1]	—	—	1,700	—	—	—
Redwood Creek estuary, line 2A, near Orick[1]	—	—	15,000	—	—	—
Redwood Creek estuary, line 2B, near Orick[1]	—	—	1,900	68,000	—	—
Redwood Creek estuary, line 2C, near Orick[1]	—	—	1,100	—	—	—
Redwood Creek estuary, line 3A, near Orick[1]	—	—	11,000	—	—	—
Redwood Creek estuary, line 3B, near Orick[1]	—	—	2,900	45,000	—	—
Redwood Creek estuary, line 3C, near Orick[1]	—	—	26,000	—	—	—

[1] Estuary lines are shown in figure 2.

invertebrate density in Redwood Creek samples significantly increased in the autumn 1974 and 1975 samples. This increase is illustrated for eight sampling sites in figure 4. This dramatic increase in benthic invertebrates following major spring storms illustrates the ability of the benthic-invertebrate community to recolonize a stream. Benthic-invertebrate densities in the tributaries to Redwood Creek revealed a similar response in recolonization following the March 1975 flood. However, benthic-invertebrate densities in the tributary streams were more variable than in the Redwood Creek main stem.

Diversity indexes from the equation of Wilhm and Dorris (1968) and a similarity index derived by Sorenson (Odum, 1971) were calculated for use in a comparison of sampling stations (Iwatsubo and Averett, 1981). Diversity index values ranged from 1.00 to 4.09, with most between 2.50 and 3.50. There was no discernible pattern with the diversity index values, except that tributaries draining unlogged basins often had higher diversity index values than tributaries draining logged basins.

Most of the similarity index values were greater than 0.5 (the Sorenson index ranges from 0 to 1), and many were greater than 0.6. Similarity index values were not

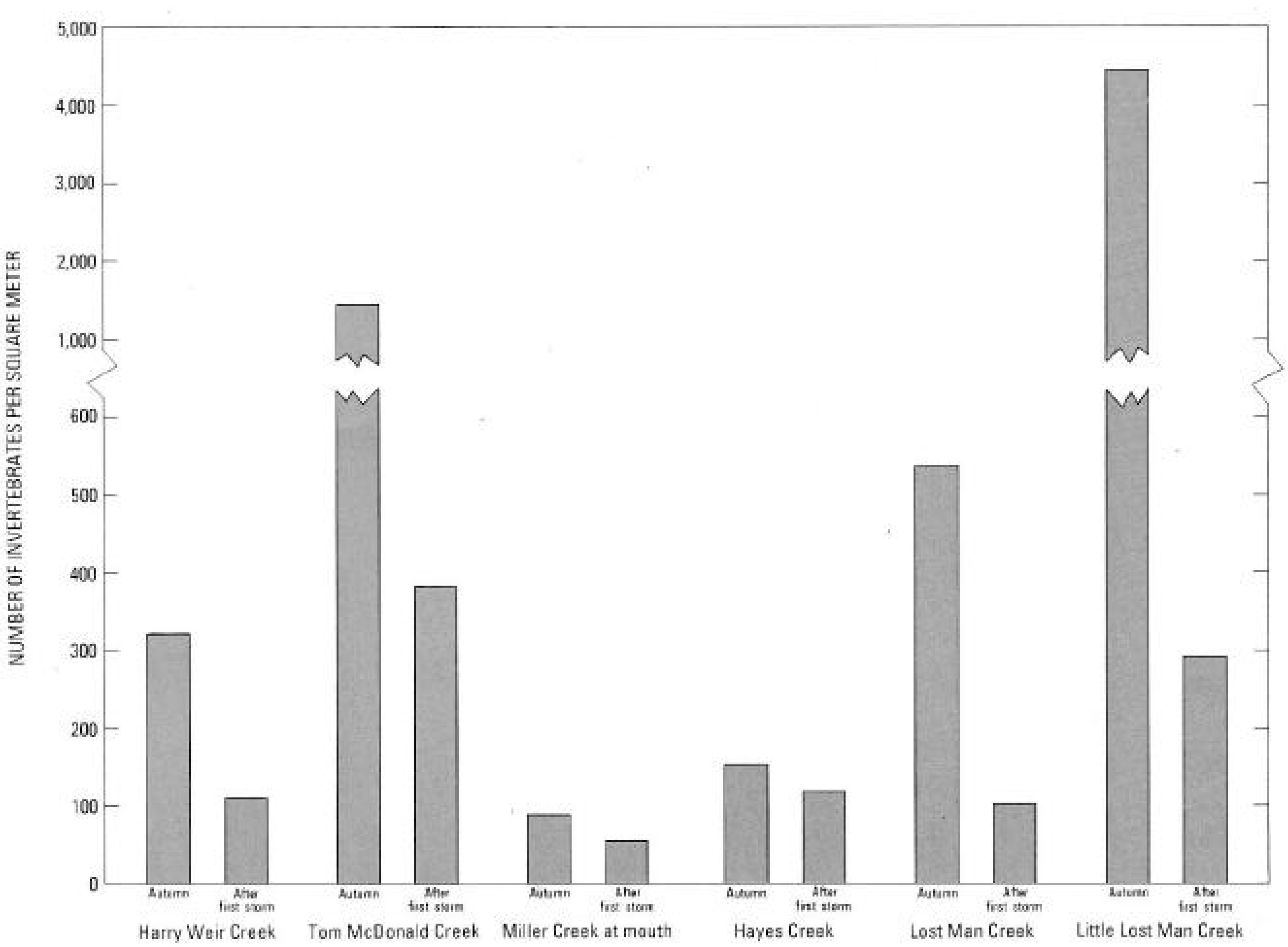

FIGURE 3.—Number of benthic invertebrates per square meter in six tributary streams to Redwood Creek in the autumn of 1973 and after the October 23, 1973, storm.

greatly altered following the October 1973 and March 1975 floods.

Cummins (1973) classified benthic invertebrates into four major functional groups based on feeding mechanisms: (1) shredders, which reduce coarse particulate organic matter (greater than 1 mm in diameter) such as leaves, twigs, bark, and flowers, into fine particulate organic matter (less than 1 mm in diameter); (2) collectors, which feed on this fine particulate organic matter; (3) grazers (scrapers), which feed on periphyton; and (4) predators, which feed on other animals in the stream. There are limitations to the functional group concept, mainly that some organisms occupy different functional groups at different life stages. Also, some organisms are difficult to place into a discrete functional group. Nevertheless, the functional group concept is useful in placing organisms into an "occupational" category and assessing the stream environment in terms of habitat stability for the benthic invertebrate community.

Iwatsubo and Averett (1981) listed nine functional group categories including the four listed above by Cummins (1973, 1974) and another five subcategories—micropredators, collector-grazers, collector-predators, collector-shredders, and grazer-shredders. Iwatsubo and Averett also presented a table showing the percentage of each type in the sample from each site. The predator and collector groups were by far the most numerous.

Table 4 is a compilation of the findings reported by Iwatsubo and Averett (1981). The representative sampling sites were from three control streams, two mainstem sites on Redwood Creek, one stream draining a regenerating forest, and three streams that were being logged in 1975 when the samples were collected.

The results indicate that the greatest percentage of organisms were in the collector category, followed by the predator category. Benthic organisms in the grazer category were third in percentage abundance, commonly less than 5 percent and never exceeding 30.8 percent.

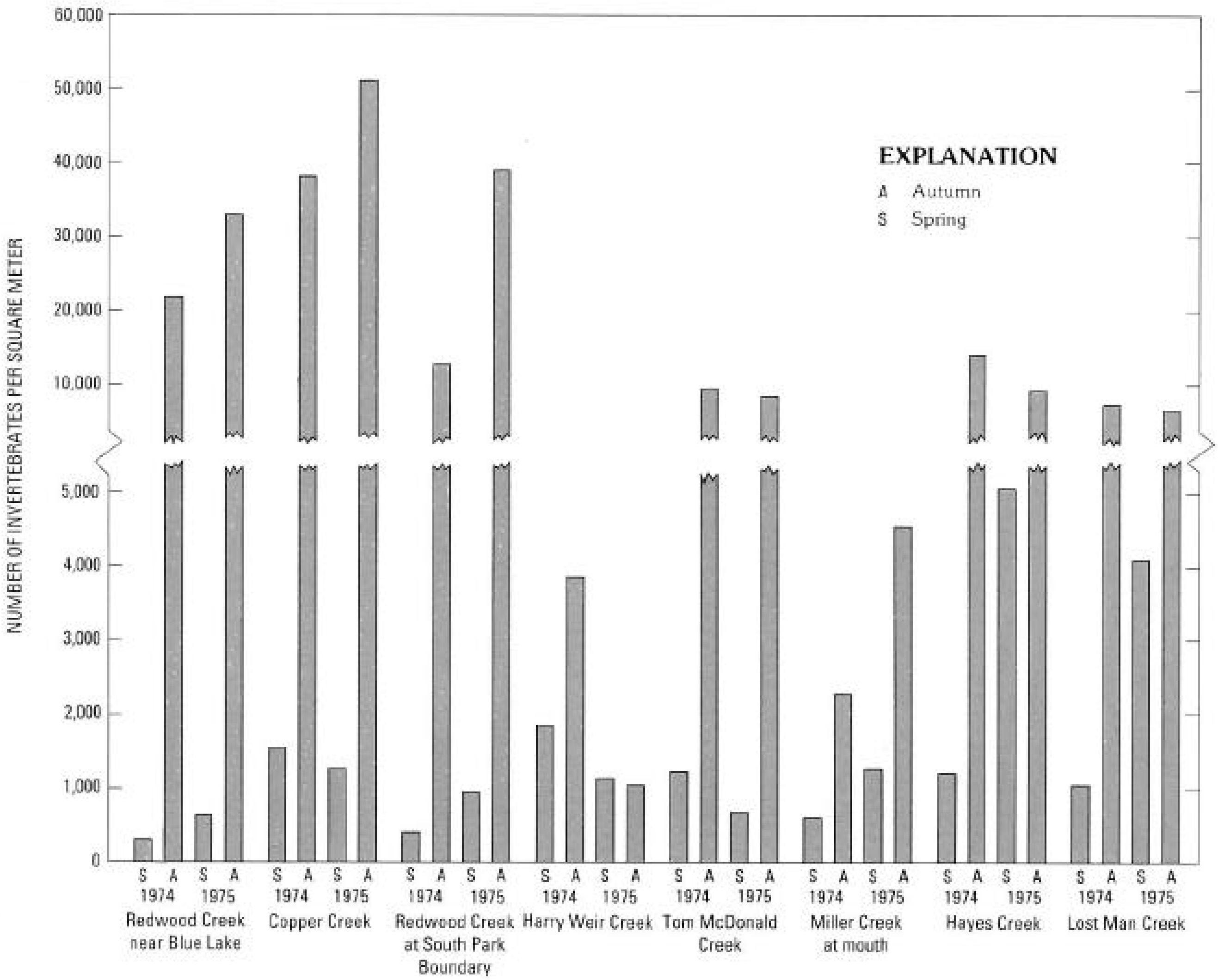

FIGURE 4.—Comparison of numbers of benthic invertebrates at eight sampling sites in the Redwood Creek drainage basin in the spring and autumn of 1974 and 1975.

The percentage of shredders in the samples was commonly less than 1.

The Redwood Creek drainage basin primarily contains coniferous trees. Thus, it is not surprising that collectors, those organisms that feed upon fine particulate organic matter, were the most abundant category in the samples. The dense canopy of the redwood forest reduces insolation and hence periphyton production, which limits the number of grazers in the samples. Predators were present in percentages ranging from 3.0 to 57.5. In only one instance was the predator percentage greater than 50 percent, an indication of community instability; however, these particular results could have been due to a sampling error. There were only small differences between percentage composition of the functional groups of benthic invertebrates collected from logged and unlogged tributary drainage basins.

FISH

The Pacific coastal streams, including Redwood Creek, have historically contained a varied and abundant fish fauna. Anadromous salmonids have received the greatest attention because of their size and their commercial and sport value. However, there are many resident fishes in the streams who do not seek saltwater for an ocean-growth period.

Of the 1,066 fish that were captured during the study, the species composition was steelhead trout, *Oncorlynchus mykiss* (69.6 percent); Humboldt sucker, *Catostomus humboldtianus* (10.6 percent); threespine stickle-

TABLE 4.—*Percentages of functional groups for benthic invertebrates from selected sampling stations in the Redwood Creek drainage basin*
[Modified from Iwatsubo and Averett (1981)]

Station name	Date	Basin classification[1]	Predator	Collector	Shredder	Grazer	Unknown	Individuals per square meter
High Slope Schist Creek near Orick	5-26-74	Control	39.1	60.4	0.5	0.0	0.0	970
	9-22-74		42.9	52.5	3.9	.0	.6	2,200
	5-30-75		43.4	53.3	3.4	.0	.0	1,100
	9-18-75		33.8	64.5	1.6	.1	.0	1,200
Hayes Creek near Orick	5-15-74	....do....	19.2	78.9	.9	.0	.0	1,200
	9-14-74		15.4	83.7	.3	.0	1.1	14,000
	5-29-75		19.3	80.1	.6	.0	.0	5,000
	9-20-75		19.2	80.8	.5	.2	.0	9,200
Little Lost Man Creek at site 2, near Orick.	5-10-74	....do....	17.6	81.4	.7	.3	.0	4,100
	9-14-74		27.9	66.8	3.0	.9	.0	15,000
	6-2-75		23.6	74.5	.4	1.6	.0	6,900
	9-20-75		16.8	78.0	1.1	3.3	.0	26,000
Redwood Creek near Blue Lake	5-8-74	Main stem	57.5	41.3	.0	.0	1.2	310
	9-18-74		12.6	86.5	.1	.8	.0	22,000
	5-27-75		33.3	66.2	.0	.5	.0	590
	9-14-75		10.4	88.8	.2	.7	.0	33,000
Redwood Creek above Hayes Creek, near Orick.	5-15-74	....do....	19.4	80.0	.3	.2	.2	2,000
	9-14-74		24.6	74.3	.1	1.0	.0	34,000
	5-28-75		30.9	61.5	.2	7.3	.0	960
	9-19-75		42.5	46.4	.1	11.0	.0	8,300
Lost Man Creek near Orick	5-10-74	Regenerating vegeta-	20.2	79.8	.0	.0	.0	530
	9-15-74	tion after logging.	24.6	70.3	1.0	3.0	1.1	7,000
	6-2-75		6.9	84.7	.0	8.4	.0	4,100
	9-17-75		18.3	50.4	.5	30.8	.0	6,300
Copper Creek near Orick	5-9-74	Being logged in 1975	12.9	86.7	.3	.0	.0	1,500
	9-19-74		18.0	80.3	.5	1.2	.0	38,000
	2-28-75		15.8	84.2	.0	.0	.0	1,200
	9-15-75		32.0	65.6	.4	2.0	.0	51,000
Harry Weir Creek near Orick	5-13-74	....do....	22.6	77.2	.2	.0	.0	1,800
	9-16-74		16.3	81.8	.0	1.0	.9	3,800
	6-1-75		23.0	77.0	.0	.0	.0	1,100
	9-16-75		25.1	73.0	.0	1.9	.0	1,000
Miller Creek near Orick	5-10-74	....do....	5.6	94.0	.4	.0	.0	4,400
	9-17-74		11.0	85.3	.3	2.6	.8	5,500
	5-31-75		3.5	95.3	.1	1.1	.0	6,000
	9-21-75		3.0	96.8	.0	.2	.0	13,000

[1] The drainage basin of each sampling station is classified according to its history of land use or as a Redwood Creek main stem or estuary station. "Control" refers to areas of limited human activity and influence.

back, *Gasterosteus aculeatus* (10.3 percent); coastrange sculpin, *Cottus aleuticus* (5.8 percent); coho salmon, *Oncorhynchus kisutch* (3.4 percent); and chinook salmon, *Oncorhynchus tshawytscha* (0.3 percent). The Pacific lamprey, adult and ammocete, *Entosphenus tridentatus*, was observed also.

Fish species reported to inhabit the Redwood Creek drainage basin but that were not captured during the study include resident rainbow trout, *Salmo gairdneri;* coastal cutthroat trout, *S. clarki clarki;* and eulachon, *Thaleichthys pacificus* (DeWitt, 1964). The steelhead trout is an anadromous rainbow trout, whereas the rainbow trout is a permanent freshwater resident.

A summary of fish inventories including length and length-weight relations in the Redwood Creek drainage basin is given in table 5. The seasonal percentage composition of fish captured in the basin revealed that steelhead trout were most abundant in the summer of 1974 and 1975 and the autumn of 1975. Steelhead trout and coho salmon were equally abundant in the spring of 1974 (fig. 5).

The effect of the March 18, 1975, flood on the fisheries resource of the Redwood Creek drainage basin is not known; however, the absence of salmon fry in the 1975 samples could be attributed to the flood. The spawning of chinook and coho salmon is usually completed by February (California Department of Water Resources, 1965). Absence of salmon fry during the 1975 fish-inventory survey could indicate a high mortality of salmon embryos developing in the spawning gravel during the flood.

TABLE 5. —*Summary of fish inventories, Redwood Creek drainage basin* [—, not determined; *n*=number of measurements]

Sampling area	Date	Type of fish captured	Type composition (percent)	Fork length (cm)			Weight (g)		
				Range	mean	*n*	Range	mean	*n*
Redwood Creek near Redwood Valley Bridge	8-2-74	Steelhead trout	51	2.6-14.5	6.7	109	0.2-37.1	5.1	109
		Humboldt sucker	18	—	—	24	—	—	—
		Threespine stickleback	.7	—	—	1	—	—	—
	7-25-75	Humboldt sucker	59	—	—	19	—	—	—
		Steelhead trout	41	4.3-5.8	4.9	13	—	—	—
	9-26-75	Steelhead trout	100	7.2-16.1	10.3	50	4.2-56.1	17.2	50
		Humboldt sucker[1]	—	—	—	—	—	—	—
		Pacific lamprey-ammocete[1]	—	—	—	—	—	—	—
Redwood Creek near mouth of Copper Creek	7-24-75	Steelhead trout	100	2.8-5.6	4.4	11	—	—	—
		Humboldt sucker	74	—	—	14	—	—	—
		Steelhead trout	26	6.3-11.0	8.8	5	3.5-18.5	10.9	5
Copper Creek near mouth	7-24-75	Steelhead trout	100	2.5-9.4	3.8	42	_	—	—
	9-24-75	....do....	100	4.3-7.3	5.3	40	1.0-5.1	2.4	40
Bridge Creek near mouth	5-23-74	Coastrange sculpin	100	—	—	3	—	—	—
	7-17-75	Steelhead trout	100	2.5-13.5	6.0	16	—	—	—
	9-25-75	Steelhead trout	80	5.0-12.6	6.8	48	1.5-22.6	4.8	48
		Coastrange sculpin	18	—	—	11	—	—	—
		Humboldt sucker	1.7	—	—	1	—	—	—
Harry Weir Creek near mouth	5-23-74	Steelhead trout	75	3.9-11.3	8.1	3	< 1-18.0	—	3
		Coastrange sculpin	25	—	—	1	—	—	—
	7-16-75	Steelhead trout	100	3.0-4.8	3.9	16	—	—	—
	9-25-75	Steelhead trout	93	4.1-11.7	5.3	50	.5-21.4	2.2	50
		Coastrange sculpin	5.6	—	—	3	—	—	—
		Humboldt sucker	1.8	—	—	1	—	—	_
Redwood Creek below Harry Weir Creek	7-30-74	Steelhead trout	58	4.2-9.3	6.0	60	.5-9.1	2.3	60
		Threespine stickleback	26	—	—	27	—	—	—
		Humboldt sucker	15	—	—	15	—	—	—
		Coastrange sculpin	.9	—	—	1	—	—	—
Tom McDonald Creek near mouth	5-24-74	Coho salmon	78.9	3.2-4.9	3.9	15	—	<1	15
		Coastrange sculpin	15.8	—	—	3	—	—	—
		Threespine stickleback	5.3	—	—	1	—	—	—
	7-21-75	Steelhead trout	64.7	2.8-17.3	5.7	44	—	—	—
		Coastrange sculpin	27.9	—	—	19	—	—	—
		Threespine stickleback	7.4	—	—	5	—	—	—
	9-25-75	Steelhead trout	89.3	5.1-15.8	6.9	50	.7-14.2	5.26	50
		Coastrange sculpin	10.7	—	—	6	—	—	—
		Pacific lamprey-ammocete[1]	—	—	—	—	—	—	—
Miller Creek near mouth	7-24-74	Steelhead trout	66.7	4.7-9.5	7.1	2	< 1-8.0	—	2
		Coho salmon	33.3	—	3.9	1	—	<1	1
	7-22-75	Steelhead trout	70.0	4.1-11.2	7.6	7	—	—	—
		Coastrange sculpin	30.0	—	—	3	—	—	—
Redwood Creek near Hayes Creek	5-22-74	Coastrange sculpin	83.3	—	—	5	—	—	—
		Coho salmon	16.7	—	5.0	1	—	—	—
	5-29-74	Threespine stickleback	37.3	—	—	59	—	—	—
		Steelhead trout	29.1	4.9-14.6	8.2	46	.6-31.0	7.7	46
		Humboldt sucker	24.7	—	—	39	—	—	—
		Coho salmon	5.7	5.1-9.5	6.7	9	.9-10.5	3.5	9
		Chinook salmon	1.9	8.0-9.6	8.7	3	5.5-10.0	7.2	3
		Coastrange sculpin	1.3	—	—	2	—	—	—
Little Lost Man Creek near mouth	5-22-74	Steelhead trout	49.0	6.3-16.0	9.6	19	1.0-51.0	12.6	19
		Coho salmon	25.5	3.9-7.7	5.3	10	<1-4	—	10
		Threespine stickleback	25.5	—	—	10	—	—	—
	7-23-75	Steelhead trout	85.7	4.6-12.7	7.0	72	—	—	—
		Threespine stickleback[1]	8.3	—	—	7	—	—	—
		Coastrange sculpin	6.0	—	—	5	—	—	—
	9-24-75	Steelhead trout	100	6.0-23.6	8.6	39	1.4-147.3	11.7	39
		Threespine stickleback	—	—	—	—	—	—	—
		Pacific lamprey-ammocete[1]	—	—	—	—	—	—	—

[1] Observed only.

The effects of the March 18, 1975, flood on the steelhead trout population are somewhat different than the effects of that flood on the chinook and coho salmon populations. The total number of steelhead trout captured during the 1975 fish-inventory survey increased by 48 percent. The steelhead trout fry captured during the

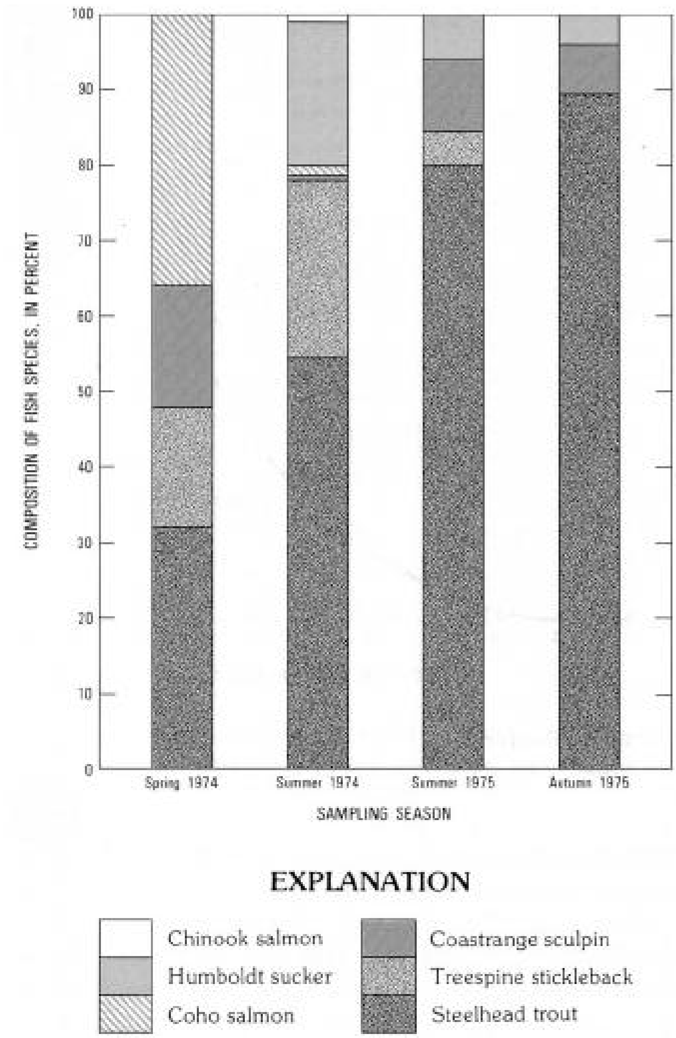

FIGURE 5.—Seasonal variations in percentage composition of fish species sampled in the Redwood Creek drainage basin.

July 1975 survey were probably the result of the spawning activity that occurred after the March 18, 1975, flood. This assumption was based on field observations of recent yolk-sac absorption of the steelhead trout fry and the notation that a large majority of the fry were captured within the depression of their redd. Survival of steelhead trout, chinook, and coho salmon fry from spawning activity prior to the March 18, 1975, flood is not known.

It is often useful to calculate a length-weight relation of fish and compare the findings to those for fish from other areas. The length-weight relations for steelhead trout were made by using the following equation (Lagler, 1969):

$$W=aL^b$$

Where:

W = weight in grams
L = length in centimeters
a = constant, and
b = slope of the regression line.

A least-squares regression was derived from the logarithmic transformation of the above equation. The values of a and b were determined empirically from the actual fork length and the weights of the salmonids captured. The slope of the regression line, b, can be used to indicate the extent of growth occurring in the salmonid fish captured; that is, the steeper the slope of the regression line, the more weight the fish is gaining per unit growth in length. Generally, when the slope of the regression is greater than 3, the fish are stout, and when the slope of the regression is less than 3, the fish are slim.

During the summer 1974, three areas along Redwood Creek main stem were sampled for fish. The slopes of the length-weight regression for the steelhead trout captured during this survey ranged from 3.06 to 3.61 with a mean slope of 3.38. During the autumn 1975 fish-inventory survey, both the Redwood Creek main stem and tributaries were surveyed. The slopes of the length-weight regression for steelhead trout captured from two Redwood Creek main-stem sites were 3.00 and 3.29 with a mean slope of 3.15; the slopes of the length-weight regression for steelhead trout captured from selected tributaries ranged from 2.71 to 3.18 with a mean slope of 2.90.

The length-weight relation, $W=0.017287L^{2.768}$, for the steelhead trout captured from the Redwood Creek drainage basin during the study was compared to the length-weight relation, $W=0.006237L^{3.063}$, for steelhead trout populations from small coastal California streams, as described by Calhoun (1966). Graphs of the compared length-weight relations are shown in figure 6. These equations indicate that the steelhead trout captured from the Redwood Creek drainage basin were substantially slimmer than the steelhead trout population representative of small California coastal streams.

PERIPHYTON

Periphyton is the assemblage of organisms that attach to or live on underwater substrates and includes algae, bacteria, fungi, protozoans, rotifers, and other small organisms. Insolation, streambed stability, sedimentation, plant nutrients, and water temperature have an effect on the abundance and diversity of the periphyton community.

The taxonomic classification and enumeration of periphyton collected from selected areas in the Redwood Creek drainage basin have been reported in Iwatsubo and others (1976). The composition of periphyton in the Redwood Creek drainage basin consisted of 50 taxa. Diatoms (Bacillariophyceae) were the most common group in each sample, and *Epithemia sorex, Achnanthes lanceolata*, and *Diatoma vulgare* occurred in the largest numbers. The percentage of green algae (Chlorophyta) was low for each periphyton sample with the exception of Bridge Creek in the spring of 1974 and Little Lost Man Creek at site 2 in the spring of 1975. *Chlamydomonas* sp., *Spirogyra* sp., and *Ulothrix* sp., were the most numerous green algae sampled from the Redwood Creek drainage basin.

Biomass of periphyton was determined for each sample collected during the study to obtain estimated daily rates of periphyton accrual, and organic and inorganic-material deposition (table 6). These rates were computed by simply dividing the weights of organic and inorganic materials deposited on the sampler by the number of days allowed for colonization. The results indicated that periphyton accrual was low in the Redwood Creek drainage area.

In the spring and summer 1974, the deposition of inorganic and organic material on the periphyton samplers was greater at the lower Miller Creek station than at the upper Miller Creek station (table 6). Excessive amounts of fine sediment were deposited on the periphyton sampler at the Miller Creek at mouth station. The input of sediment into Miller Creek probably was caused by the construction of a bridge located upstream and between the two sampling sites. The increases in organic material during these two sampling periods were not related to periphyton production but to the organic material that adhered to the sediment deposited on the substrates and to the inputs of fine organic debris directly into the stream during bridge construction. The increases that occurred during spring and autumn 1974 sampling as a result of bridge construction were, however, temporary, as no increases in deposition of organic or inorganic material on the periphyton samplers occurred between these two sites during spring 1975 sampling. The rate of accrual of periphyton increased from spring to summer 1974 for samples at Bridge Creek, Redwood Creek above Hayes Creek, and Lost Man Creek sites. Periphyton samplers installed at Little Lost Man Creek at site 2 were vandalized during spring 1974. During the 1975 sampling, the deposition of inorganic material on the periphyton samplers was greater in Bridge Creek and Harry Weir Creek than in the other streams sampled. Prior to the retrieval of the periphyton sampler installed at Bridge Creek, an input of sediment into the stream was caused by activities related to the removal of logging debris upstream from the sampling site. The cause of the increased deposition of inorganic material on the periphyton sampler installed at Harry

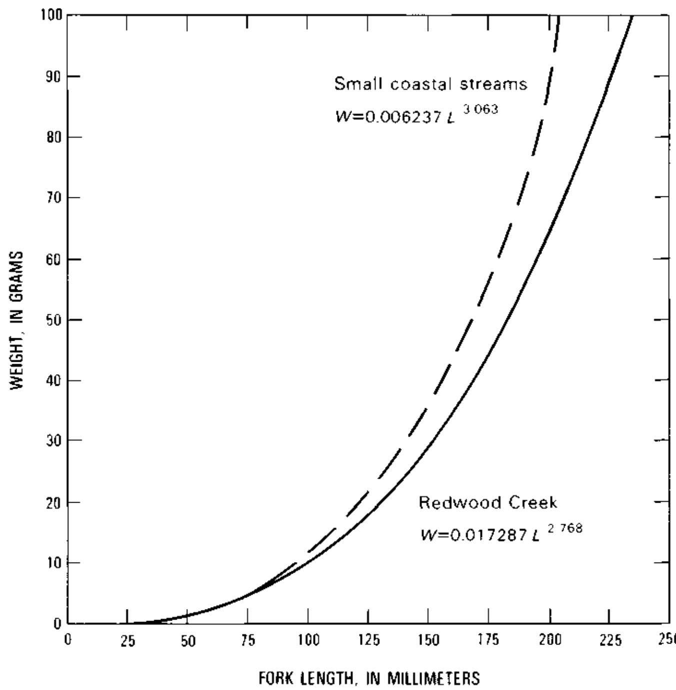

FIGURE 6.—Comparison of length-weight relations for steelhead trout. The length-weight relation for small coastal California streams is from Calhoun (1966).

Weir Creek may have been the construction of a road approach to an existing bridge.

The spring 1975 periphyton samplers installed at Redwood Creek at South Park Boundary and above Hayes Creek sites were lost. Periphyton was resampled at these two sites during summer 1975, and rates of accrual were similar to the rates of summer 1974 (table 6).

Diversity index was calculated for each periphyton sample collected during the study by using the equation of Wilhm and Dorris (1968). The periphyton samples have a wide variation in diversity-index values, which range from 0.00 to 2.76. Diversity indexes of periphyton samples collected within the Redwood Creek drainage basin ranged from 0.98 to 2.34 for main-stem sites and from 0.00 to 2.76 for tributary sites. Hayes Creek, a control basin, had the 0.00 diversity index, whereas Bridge Creek, a basin being logged in 1975, had the 2.76 diversity index.

Similarity indexes were calculated for selected periphyton samples on the basis of the Sorenson equation as given by Odum (1971). These indexes varied from sampling site to sampling site during the study and ranged from 0.12 to 0.80. There were no apparent similarities in periphyton communities that could be related directly to upstream land use activities. The variability in similarity indexes of periphyton primarily reflects the relatively small number of taxa present in each sample when

TABLE 6.—*Rates of accrual of periphyton at selected stations on Redwood Creek and tributaries*
[—, not determined; (g/m²)/d, grams per square meter per day]

Station name	Date sampler installed	Date sampler removed	Colonization period, in days	Weight of periphyton, in $(g/m^2)/d$		
				Dry	Inorganic	Organic
Redwood Creek at South Park Boundary, near Orick	5-9-74	7-16-74	68	0.13	0.09	0.04
	7-16-74	9-13-74	59	.05	.02	.03
	Spring 1975	(1)	—	—		
	7-30-75	9-5-75	37	.08	.05	.03
Bridge Creek near Orick	5-13-74	7-15-74	63	.02	.01	.01
	7-15-74	9-16-74	63	.43	.29	.14
	6-7-75	7-31-75	54	.59	.54	.05
Harry Weir Creek near Orick	5-13-74	7-15-74	63	.10	.07	.03
	7-15-74	9-16-74	63	.12	.09	.03
	6-1-75	7-31-75	60	.20	.18	.02
Miller Creek near Orick	5-10-74	7-16-74	67	.03	.02	.01
	7-16-74	9-17-74	63	.04	.03	.01
	5-31-75	7-28-75	58	.02	.02	.00
Miller Creek at mouth, near Orick	5-14-74	7-16-74	63	1.19	1.12	.07
	7-16-74	9-17-74	63	.92	.85	.07
	5-31-75	7-28-75	58	.03	.02	.01
Redwood Creek above Hayes Creek, near Orick	5-15-74	7-15-74	61	.11	.10	.01
	7-15-74	9-14-74	61	1.59	1.15	.44
	Spring 1975	(1)	—	—	—	—
	8-1-75	9-5-75	35	2.66	2.11	.55
Hayes Creek near Orick	5-15-74	7-15-74	61	.06	.06	.00
	7-15-74	9-14-74	61	.01	.01	.00
Lost Man Creek near Orick	5-10-74	7-15-74	66	.05	.03	.02
	7-15-74	9-15-74	62	.12	.08	.04
	6-2-75	7-27-75	55	.05	.03	.02
Little Lost Man Creek at site 2, near Orick	Spring 1975	(1)	—	—	—	—
	7-15-74	9-14-74	61	.46	.35	.11
	6-2-75	7-27-75	55	.01	.06	.04

[1] Samplers missing.

compared to the total number of taxa occurring in the periphyton community sample.

PHYTOPLANKTON

The taxonomic classification and enumeration of the phytoplankton (unattached algae) collected from selected areas in the Redwood Creek drainage basin have been reported in Iwatsubo and others (1976) and Iwatsubo and Averett (1981). Sixty phytoplankton taxa were identified from water samples collected from the Redwood Creek drainage basin upstream from the estuary, and 22 phytoplankton taxa were identified from samples collected from the Redwood Creek estuary.

Diatoms usually were the dominant phytoplankton group collected during the study; however, unknown flagellates and green algae were dominant at times. In the Redwood Creek drainage basin, exclusive of the estuary, unknown flagellates, *Gomphonema angustatum, Achnanthes lanceolata,* and *Coconeis placentula,* were the most numerous of the phytoplankton taxa collected. In Redwood Creek estuary, *Chlamydomonas* sp., unknown flagellates, *Cryptomonas* sp., and *Selenastrum minutum* were the most numerous phytoplankton.

The taxa *G. angustatum, A. lanceolata,* and *C. placentula* are not truly planktonic but are epiphytic (Smith, 1950). Analysis of the life histories of the remaining phytoplankton taxa (except the dominant taxa from Redwood Creek estuary) suggests that the majority of the phytoplankton were actually periphytic algae that had become dislodged from their substrate and were passively drifting downstream when sampled. In the Redwood Creek estuary, however, the dominant phytoplankton *Chlamydomonas* sp., *Cryptomonas* sp., and *Selenastrum minutum* are truly planktonic. The dominance of these truly planktonic forms in the Redwood Creek estuary can be related to an emergent sandbar that usually closes the mouth of Redwood Creek to the Pacific Ocean during low-flow periods. When this closing occurs, the Redwood Creek estuary becomes a ponded environment that favors production of planktonic phytoplankton.

Diversity-index calculations of phytoplankton ranged from 0.06 to 3.86. At the main-stem sites, diversity indexes ranged from 2.06 to 3.86, and they ranged from 1.37 to 3.18 at the tributary sites. In the estuary, the diversity indexes ranged from 1.03 to 2.43. Upstream from the estuary, diversity indexes of the phytoplankton samples were larger in the streams that received more insolation. Along the Redwood Creek main stem, a downstream increase in diversity indexes of phytoplankton occurred.

Phytoplankton samples collected at the estuary sites had smaller diversity indexes than did the samples collected at the upstream sites. The phytoplankton community in the estuary was primarily dominated by large numbers of *Chlamydomonas* sp. and *Cryptomonas* sp. Both of these genera have been related to organically enriched waters (Palmer, 1969). In addition, the presence of *Cryptomonas* in large numbers has been used to indicate the completion of organic-matter decomposition in the stream (Brinley, 1942).

Similarity index values were calculated for selected phytoplankton samples and ranged from 0.18 to 0.95. Comparisons between phytoplankton samples collected at Bridge Creek and the other areas sampled during summer 1975 showed low similarity indexes, ranging from 0.20 to 0.34. The phytoplankton community of Bridge Creek was dominated by green algae, whereas diatoms dominated the phytoplankton communities of the other sampling areas. Timber-harvest activities in the Bridge Creek basin were extensive, and removal of the streamside canopy resulted in increased insolation and green algal production. The types of green algae dominating the Bridge Creek phytoplankton community were actually dislodged filamentous periphyton such as *Ulothrix* sp., *Spirogyra* sp., and *Zygnema* sp.

Similarity indexes for phytoplankton collected from the Redwood Creek estuary were slightly variable between sampling sites. This variability probably was related to differences in salinity. The lowest similarity index occurred during midsummer 1974 when salinity values were highest in the estuary. At that time, the mouth of Redwood Creek was open to the ocean, and saltwater entered directly into the estuary during high-tide periods. In late summer 1974, the mouth of Redwood Creek was closed to the ocean by an emergent sandbar. Saltwater entered the estuary, but the volume was minimal because the inflow of seawater was subsurface and through the sandbar during high-tide periods. Salinity of the estuary was lower, and the similarity indexes were higher than those for the midsummer samples.

DISCUSSION AND CONCLUSIONS

Aquatic organisms have frequently been used to assess water quality (Hynes, 1960, 1964, and 1970). Coliform bacteria are indicators of direct fecal contamination by man and other animals. Periphyton and phytoplankton are short-term indicators of enrichment, and benthic invertebrates and fish are long-term integrators of changes in the aquatic environment.

In this study of the Redwood Creek drainage basin, an attempt was made to relate the biota to land use practices. Because few data were available, the design of the study was limited and thus resulted in some incomplete conclusions. Nevertheless, some definite conclusions are apparent from the data and deserve further comment.

Data on coliform bacteria indicated that fecal contamination was low. This finding was expected in an area having a low human population. There were, however, indications of fecal contamination at the Prairie Creek site.

The benthic invertebrates received the greatest emphasis in this study because of their importance as long-term integrators of water quality and because they are relatively easy to sample. In the Redwood Creek drainage basin, the size of streambed material and its stability were the major factors related to the distribution and abundance of benthic organisms.

There were striking differences between the number of benthic invertebrates collected before and after major storms. Many of these differences doubtless were related to streambed movement resulting from stream discharges. Most benthic organisms either cling to or hide beneath the larger streambed material. When this material is moved as a result of high discharges, these organisms are usually killed or moved downstream. Prolonged high discharges, which often occur after a major storm, result in the death of many benthic invertebrates.

Most benthic invertebrates are insect larvae, pupae, and nymphae (85.3 percent in the Redwood Creek main stem and tributaries). These organisms usually reach maturity in the spring and summer, emerge as sexually active winged adults, and lay their eggs over the water. The eggs usually hatch the same spring or in early summer. It was demonstrated in this study that reestablishment of benthic invertebrate populations in a stream can take place within one summer. Thus, while numbers of benthic invertebrates were low in the spring after the winter storms, they became high in the autumn after egg laying and when the streambed was stable. Recolonization of a stream with benthic invertebrates is thus rapid, and in streams having flow characteristics like those of Redwood Creek (winter floodflows ranging from 4,500 to 7,300 times greater than summer low flows), summer recolonization by surviving overwinter benthic organisms may be an evolutionary pattern. During the study period there were no samples collected in the spring following a low-flow winter. It would be instructive to have a sampling period following such a winter to determine if the spring counts of benthic invertebrates were in the same order of magnitude as the autumn counts.

On the basis of trophic-level categories defined by Cummins (1973, 1974) for insects, most of the aquatic insects in Redwood Creek drainage basin were in the collector category, followed by the predator category. Cummins developed his technique for Eastern streams, and there may be regional differences. Iwatsubo and Averett (1981) presented a list of species, and their functional group categories is based on Cummins' (1973) listing. The functional group concept is still new, however. As more is learned, some species on this list may be shifted to different categories. It was difficult at first to understand why more grazers and shredders were not found in the samples. Vannote and others (1980), however, indicated a predominance of collectors and predators in the middle lower reaches of streams. Our sample sites in the Redwood Creek drainage basin were located at the mouths of tributaries and in the Redwood Creek main stem. It is possible that grazers and shredders are found in the upper sections of the tributaries. The only conclusion that can be considered at this time is that much of the organic material that enters Redwood Creek is in the form of fine particulate organic matter.

While fish collections were made in Redwood Creek drainage basin, the goal of this study was primarily to determine species composition. No attempt was made to determine population numbers. It was surprising not to find cutthroat trout or resident rainbow trout. While the latter are sometimes difficult to distinguish from steelhead, the cutthroat trout are easy to identify. The lower (slimmer) condition of steelhead trout from Redwood Creek as compared to other coastal streams may be due to the low number of benthic organisms following the first major storms of winter. This supposition is certainly subject to experimental verification. Moreover, the results of Calhoun (1966) were from smaller coastal streams that may not have been subjected to extensive winter flooding. A more extensive fish study is needed before more definitive results can be forthcoming.

The findings on the periphyton and phytoplankton are inconclusive and probably are best suited for use in comparative future studies.

Studies of the Redwood Creek estuary did not reveal any unexpected findings. The data collected from the estuary could be useful, however, for future studies and comparisons.

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