The Resources Agency of California
DEPARTMENT OF FISH AND GAME

WATER QUALITY OF SOME LOGGED AND UNLOGGED CALIFORNIA STREAMS[1]

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SUMMARY

Water quality was monitored in 1968 and 1969 in six coastal streams in northern California, four of which were subjected to logging and/or road building (Bummer Lake Creek, South Fork Yager Creek, Little North Fork Noyo River, and South Fork Caspar Creek), while the others remained undisturbed (Godwood Creek and North Fork Caspar Creek). The purposes of this study were to characterize the water quality of the streams, to determine if the logging and road construction drastically altered water quality, and to collect water quality data which could be tested for predicting stream carrying capacities for salmonids.

Conditions were generally suitable for salmonids during and after the logging. No abnormal concentrations of dissolved oxygen, alkalinity, hardness, dissolved solids, phosphate, chloride, sulfate, nitrate, tannin and lignin, or pH were detected. Carbon dioxide was low in most streams, except in South Fork Caspar Creek when it reached 8 ppm during decomposition of logging debris in the summer of 1968. Turbidity was highest in areas where bulldozers were working in the streams. Temperatures of most streams increased after the logging, but seldom exceeded 70 F because of the cool climate in the coastal fog belt. Alternating cut and uncut blocks on one stream, and retaining a buffer strip along another, kept temperatures low in two streams.

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INTRODUCTION

Water quality was measured periodically in six California streams in conjunction with evaluating the effects of logging on silver salmon (Oncorhynchus kisutch) and trout Salmo gairdnerii gairdiierii and S. clarkii clarkii) habitat. Four streams (Bummer Lake Creek, South Fork Yager Creek, Little North Fork Noyo River, and South Fort: Caspar Creek) were logged, while two streams (Godwood Creek and North Fork Caspar Creek) were undisturbed. The objectives of monitoring water quality were to characterize the streams, to determine if the logging drastically altered water quality, and to collect water quality data which could be tested for predicting stream carrying capacities for salmonids.

Northern California's coastal climate is characterized by heavy winter rainfall and dry summers. Mean annual precipitation ranges from 40 to 125 inches (Calif. Dept. Water Resources, 1964). Air temperatures are cooled by dense, recurrent fogs, and mean maximum temperature in July is about 70 F. Soils are predominately loam and moderately erodible (Storie and Weir, 1953). Watersheds studied were forested with redwood (Sequoia sempervirens) and Douglas fir (Pseudotsuga menziesii).

METHODS AND MATERIALS

Water samples were usually collected every three months for one year on each stream, commencing in May 1968. Prelogging water quality was not measured. Water samples were collected during daylight and analyzed with a Hach direct-reading, engineer's laboratory kit (Model DR-EL) and an Industrial Instruments conductivity meter (Model RA-2A). Concentrations of dissolved oxygen, carbon dioxide, total alkalinity, total hardness, total dissolved solids, total phosphate, chloride, sulfate, nitrate, tannin and ligin, pH, and turbidity were. measured. Samples analyzed away from the stream were packed in ice, kept dark (to retard biological activity), and analyzed within the time limits set forth by American Public Health Association (1965). Samples were warmed to 75 F and turbid waters filtered before analysis. Streamflow was measured with a Pygmy current meter, and in North and South Forks Caspar Creek, flows were continually recorded at permanent weirs.

Water temperatures were measured at the downstream end of the study sections in Godwood Creek, Little North Fork Noyo River, North Fork Caspar Creek, and South Fork Caspar Creek, and at selected locations in Bummer Lake Creek and South Fork Yager Creek to determine the differences between the logged and unlogged sections. Temperatures in both forks of Caspar Creek were measured in 1963 and 1964 (Kabel and German, 1967), and in 1967 and 1968 (John DeWitt and Roger Barnhart, Humboldt State College, pers. comm.). In the other streams, temperatures were measured in the summer at random intervals from 1966 to 1969, and usually included maximum temperatures for each year. Prelogging water temperature data for most streams are sparse because there was little time available between finding streams for study and the beginning of the logging.

RESULTS

Bummer Lake Creek

Bummer Lake Creek, a tributary to Mill Creek and Smith River, is located on private land in Del Norte County (T15N, R1E, S4). It is about 7 miles south east of Crescent City, California, and 17.8 stream miles from the ocean. The main stream is 1.6 miles long and along with its two forks drains about 3,500 acres in a relatively steep canyon (side slope averages 45%). Mean stream gradient is 250 ft/mile. Headwater and mouth elevations are approximately 1,750 and 250 ft, respectively. The soils are in the Melbourne Series and are characterized by a moderate to strong acid reaction (Storie and Weir, 1953). Minimum air temperatures in January average about 35 F and maximum air temperatures in July average about 75 F (Durenberger, 1960). Air temperatures sometimes exceed 100 F. Precipitation ranges from about 90 to 110 inches a year, with most rain falling between October and May (Durenberger, 1960).

Alternate blocks of old growth redwood (totaling 272 acres) were clear cut on the southwest side of the stream in the spring and summer of 1968. Two blocks were cut adjacent to the stream within the study section and four additional blocks were cut along the South Fork upstream from the study area. The North Fork was undisturbed. Slash and debris were removed from the stream during the winter of 1968 (Burns, 1970).

Streamflow ranged from 0.86 to 50.10 cfs during the sampling and dissolved oxygen remained near saturation. Water temperatures in the summer remained cool after the logging, ranging from 44 to 66 F in 1969 (Table 1). From September 7 to 19, 1968 maximum temperatures for the South Fork and main stream were 6 and 12 F warmer, respectively than in the unlogged North Fork. Prior to the logging and during a similar period, in 1967, maximum temperatures were the same at these same three stations. On the hottest day in 1969, stream temperatures in the cut blocks were 8 F higher than those temperatures in the uncut section upstream. In the cut areas, stream temperatures increased 5.5 F/1,000 ft. The uncut block between the two cut blocks reduced stream temperatures 2.5 F/1,000 ft. resulting in water temperatures 4 F cooler upon leaving this shaded area. Except during periods of high flow, the water was clear. The highest turbidity observed was 25 J.T.U. Ranges for values of selected measurements were: oxygen 9.4 to 12.4 ppm. pH 6.7 to 8.0, carbon dioxide was not detectable, total alkalinity 15 to 40 ppm, chloride 5 to 6 ppm, sulfate from less than 2 to 5 ppm, tannin and lignin 0.2 to 0.4 ppm, total phosphate 0.19 to 0.50 ppm, total dissolved solids 38.3 to 74.0 ppm, total hardness 20 to 45 ppm (Table 2). Nitrate was not detectable.

Godwood Creek

Godwood Creek, Humboldt County (T1lN, R1E, S2), is located in public land (Prairie Creek State Park) approximately 5 miles north of Orick, California. The 1.9-mile-long stream flows into Prairie Creek about 10 stream miles from the ocean. This unlogged watershed is forested with old growth redwood and drains approximately 1,200 acres. The watershed is relatively flat with canyon side slope averaging 18% and stream gradient averaging 55 ft/mi. Headwater and mouth elevations are 250 ft and 150 ft, respectively. The soils are of the Melbourne Series. Minimum air temperatures in January average about 40 F and maximum air temperatures in July average about 60 F. Precipitation averages approximately 70 inches a year (Durenberger, 1960).

TABLE 1

Water Temperatures for Selected Intervals on
Four Northern California Streams, 1966-1969

Stream	Temperature recording station	Sampling interval	Logging phase	Minimum maximum temperatures
Bummer Lake Creek	Lower end of study section	Sept. 7-18, 1967	before	54-60 F
		May 2-Oct. 31, 1968	during and after	50-65 F
		May 2-Sept. 1, 1968	during	50-65 F
		Sept. 1-Oct. 31, 1968	after	50-62 F[1/]
		May 2-Sept. 17, 1969	after	44-66 F
		May 2-Sept. 7, 1969	after	44-66 F
		Sept. 7-19, 1969	after	55-66 F
Godwood Creek	Near mouth	July 15-Sept. 17, 1967	unlogged	52-58 F
		July 12-Nov. 20, 1969	unlogged	45-56 F[2/]
		July 15-Sept. 10, 1969	unlogged	52-54 F
So. Fork Yager Creek	Lower end of study section	Aug. 1-Sept. 17, 1967	before	55-70 F
		Aug. 4-Sept. 17, 1967	before	55-68 F
		June 3-Oct. 5, 1968	during and after	56-71 F
		Aug. 2-Sept. 17, 1968	during	56-70 F
		May 5-Oct. 1, 1969	after	54-70 F
		Aug. 4-Oct. 1, 1969	after	54-68 F
Little No. Fork Noyo River	Lower end of study section	Oct. 7-23, 1966	before	46-56 F
		May 5-Nov. 13, 1969	after	46-70 F
		Oct. 5-P'ov. 13 1969	after	47-55 F

[1/] After logging, but debris was still in the stream.

[2/] Minimum-maximum thermometer was broken during 1968.

TABLE 2

Water Quality Properties Measured in Bummer Lake Creek, 1968-1969

Date	5/2/68 1/	8/5/68 1/	10/31/6 1/	1/31/69 2/	5/7/69 2/
Discharge (cfs)	2.83	0.86	7.80	50.10	8.57
Oxygen (ppm)	10.8	9.4	9.6	12.4	3/
Carbon dioxide (ppm)	4/	4/	4/	4/	4/
Total alkalinity (ppm)	20	30	40	15	25
Total hardness (ppm)	3/	35	45	20	3/
Total dissolved solids (ppm)	49.6	65.0	74.0	38.3	58.4
Total phosphate (ppm)	0.30	0.50	0.19	0.28	0.21
Chloride (ppm)	3/	5	5	6	3/
Sulfate (ppm)	4/	5	3	5	3/
Nitrate (ppm)	5/	5/	5/	5/	5/
Tannin- and Lignin-like compounds (ppm)	3/	0.2	0.3	0.4	3/
pH	8.0	7.7	7.4	6.7	7.3
Turbidity (J.T.U.)	6/	6/	10	25	6/
Temperature (^{o}F)	49	62	50	44	52

1/ Samples taken during logging

2/ Samples taken after logging

3/ Not tested

4/ Not detectable at a limit of 2 ppm

5/ Not detectable at a limit of 0.1 ppm

6/ Not detectable at a limit of 10 J.T.U.

Little streamflow fluctuation occurred in Godwood Creek. Flows ranged from 0.83 to 12.96 cfs during the sampling. Stream temperatures ranged from 45 to 58 F during the summer (Table 1). Turbidity remained low and did not exceed 10 J.T.U. during the sampling. Decomposing leaves covering the streambed in autumn imparted a yellow tint to the water and increased the concentration of tannin and lignin Ranges for values of selected measurements were: oxygen 8.8 to 12.0 ppm, pH 6.5 to 7.5, carbon dioxide was not detectable, total alkalinity 12 to 40 ppm, chloride 12 to 15 ppm, sulfate 2 to 3 ppm, tannin and lignin 0.2 to 1.2 ppm, total phosphate 0.20 to 0.80 ppm, total dissolved solids 44.0 to 103.0 ppm, and total hardness 10 to 50 ppm (Table 3). Nitrate was not detectable.

South Fork Yager Creek

South Fork Yager Creek, Humboldt County (T2N, R2E, S10), is part of the Van Duzen and Eel River system and is located in private land approximately 25 miles from the ocean. The 12.1-mile stream-drains from a 6,200-acre watershed. Canyon side slope averages 38%. Headwater and mouth elevations are at 3,200 and 550 ft, respectively. Mean stream gradient is 215 ft/mile. The soils are of the Hugo Series and are characterized by a moderate acid reaction (Storie and Weir, 1953). The watershed lies primarily outside the cooling influence of coastal fog and, consequently, maximum temperature in July averages about 80 F. Air temperatures sometimes exceed 100 F. Minimum air temperatures in January average around 35 F. Precipitation ranges from about 50 to 60 inches a year (Durenberger, 1966).

The old-growth forest was essentially in an unaltered state prior to this study and consisted of 30% redwood and 70% Douglas fir. The lower 1,835 ft of the stream was selectively logged in the summer of 1968 and the upper 1,835 ft of the stream was left undisturbed (Burns, 1970). Eighty percent of the harvestable timber volume was cut to 1,000 ft on each side of the stream. Care was taken to avoid disturbing the stream, riparian vegetation (including harvestable timber leaning toward the stream) was not cut and equipment did not enter the stream.

Streamflow ranged from 0.26 to 33.36 cfs during the sampling. In February 1969, high runoff in Yager Creek blocked access to the South Fork, delaying water analysis until March 1. Using high water marks, we estimated that flows in the South Fork reached about 80 cfs during February. Stream temperatures were not significantly higher after the logging, ranging from about 54 to 71 F during the summer (Table 1). Longitudinal stream temperature profiles remained about the same after the logging. The stream warmed 1.6 F/1,000 ft in the unlogged section upstream, and 3.8 F/1,000 ft in the logged section, resulting in the lower section's water being about 7 F warmer than that of the upstream section on the hottest day in 1969. The stream was slightly alkaline. Turbidity increased during high flows. Tannin and lignin increased in autumn when deciduous hardwood leaves were degrading in the stream. Ranges for values measured at the mouth of South Fork Yager Creek were: oxygen 9.8 to 12.2 ppm, pH 7.4 to 7.9, carbon dioxide was not detectable, total alkalinity 23 to 80 ppm, chloride 4 to 17 ppm, sulfate 3 to 6 ppm, tannin and lignin 0.2 to 0.5 ppm, total phosphate 0.19 to 0.70 ppm, total dissolved solids 48.7 to 157.0 ppm, total hardness 32 to 95 ppm, and turbidity to 21 J.T.U. (Table 4). Nitrate was not detectable. Water quality in the unlogged section upstream was similar to that in the logged section (Table 5).

TABLE 3

Water Quality Properties Measured in
Godwood Creek, 1968-1969 1/

Date	5/1/68	8/5/68	10/30/68	1/31/69
Discharge (cfs)	1.64	0.83	2.26	12.96
Oxygen (ppm)	10.8	9.6	8.8	12.0
Carbon dioxide (ppm)	2/	3/	3/	3/
Total alkalinity (ppm)	30	40	38	12
Total hardness (ppm).	2/	50	40	10
Total dissolved solids (ppm)	85.2	103.0	86.8	44.0
Total phosphate (ppm)	0.50	0.80	0.30	0.20
Chloride (ppm)	2/	15	12	15
Sulfate (ppm)	2	3	2	2
Nitrate (ppm)	4/	4/	4/	4/
Tannin- and Lignin-like compounds (ppm)	2/	0.2	1.2	0.2
pH	7.2	7.5	7.5	6.5
Turbidity (J.T.U.)	5/	10	5/	5/
Temperature (^{o}F)	50	56	52	44

1/ Unlogged watershed

2/ Not tested

3/ Not detectable at a limit of 2 ppm

4/ Not detectable at a limit of 0.1 ppm

5/ Not detectable at a limit of 10 J.T.U.

TABLE 4

Water Quality Properties Measured in a Logged Section of South Fork Yager Creek, 1968-1969

Date	5/1/68 1/	8/4/68 1/	10/20/68 2/	3/12/69 2/	5/6/69 2/
Discharge (cfs)	3.08	0.26	0.96	33.36	15.78
oxygen (ppm)	10.4	9.8	10.4	12.2	11.0
Carbon dioxide (ppm)	4/	4/	4/	4/	4/
Total alkalinity (ppm)	50	80	80	23	45
Total hardness (ppm)	3/	95	81	32	3/
Total dissolved solids (ppm)	97.8	157.0	149.9	48.7	90.4
Total phosphate (ppm)	0.70	0.58	0.42	0.19	0.25
Chloride (ppm)	3/	17	9	4	3/
Sulfate (ppm)	3	4	6	4	3/
Nitrate (ppm)	5/	5/	5/	5/	3/
Tannin- and Lignin-like compounds (ppm)	3/	0.2	0.5 .	0.3	3/
pH	7.7	7.8	7.9	7.4	7.6
Turbidity (J.T.U.)	6/	6/	6/	21	10
Temperature (^{o}F)	52	62	52	42	56

1/ Samples taken during logging

2/ Samples taken after logging

3/ Not tested

4/ Not detectable at a limit of 2 ppm

5/ Not detectable at a limit of 0.1 ppm

6/ Not detectable at a limit of 10 J.T.U.

TABLE 5

Water Quality Properties Measured in an Unlogged Section of South Fork Yager Creek, 1968-1969

Date	8/4/68	10/20/68
Discharge (cfs)	1/	1/
Oxygen (ppm)	9.8	9.8
Carbon dioxide (ppm)	2/	2/
Total alkalinity (ppm)	75	80
Total hardness (ppm)	95	81
Total dissolved solids (ppm)	156	150
Total phosphate (ppm)	0.55	0.39
Chloride (ppm)	13	9
Sulfate (ppm)	1/	3
Nitrate (ppm)	3/	3/
Tannin- and Lignin-like compounds (ppm)	1/	0.3
pH	7.8	7.7
Turbidity (J.T.U.)	4/	4/
Temperature (°F)	59	50

1/ Not tested

2/ Not detectable at a limit of 2 ppm

3/ Not detectable at a limit of 0.1 ppm

4/ Not detectable at a limit of 10 J.T.U.

Little North Fork Noyo River

Little North Fork Noyo River, Mendocino County (T18N, R16W, S6), is located in private land approximately 10 miles east of Fort Bragg, California, and flows into the Noyo River about 10 stream miles from the ocean. The Little North Fork drains from a 2,400-acre watershed which has a canyon side slope averaging 36%. Headwater and mouth elevations are 960 and 75 ft, respectively. Average stream gradient is 190 ft/mile. Soil is of the Hugo Series. January minimum and July maximum, air temperatures average about 35 and 75 F, respectively, and precipitation. ranges from about 45 to 55 inches a year (Durenberger, 1960).

The redwood and Douglas fir forest was first logged about 100 years ago. Since 1966, 307 of the second-growth timber has been selectively cut from 1,338 acres on the upper watershed. The area studied was a 1-mile stream section which had a road built adjacent to it in the winter of 1966 and another road constructed on the other side of the stream in the summer of 1969. Selective logging also occurred along the stream in 1969. A bulldozer worked in the stream during the logging and stream cleanup.

Streamflow ranged from 0.26 to 14.20 cfs and water temperatures from 46 to 70 F (Table 1) during the sampling. In November 1969, turbidity reached 53 J.T.U. The stream remained slightly alkaline during the sampling. Ranges for values of selected measurements were: oxygen 9.6 to 12.4 ppm, pH 7.1 to 7.3., carbon dioxide was not detectable, total alkalinity 25 to 70 ppm, chloride 10 to 17 ppm, sulfate 2 to 13 ppm, tannin and lignin to 0.6 ppm, total phosphate 0.28 to 0.55 ppm, total dissolved solids 72.5 to 144.6 ppm, and total hardness 29 to 70 ppm (Table 6). Nitrate was not detectable.

North and South Forks Caspar Creek

North and South Forks Caspar Creek, Mendocino County (T17 and 18N, R17W), are located in public land (Jackson State Forest) approximately 5 miles south of Fort Bragg, California, and about 8 miles from the ocean. Each stream drains from a watershed of about 1,000 acres and canyon side slope averages 45% on the North Fork and 49% on the South Fork. Headwaters of the North and South Forks are at elevations of 720 and 560 ft, respectively. The mouths of both streams are at an elevation of about 80 ft. Average stream gradient is 111 ft/mile for the North Fork and 154 ft/mile for the South Fork. Soils are of the Hugo Series. Minimum air temperatures in January average about 35 F and maximum air temperatures in July average about 75 F. Annual precipitation ranges from about 40 to 50 inches (Thomas, 1966). Both watersheds are forested with second-growth redwood and Douglas fir (70-80 years old). North and South Forks Caspar Creek received more attention than the other streams since there was an inter-agency program (U. S. Forest Service, Calif. Div. of Forestry, Calif. Dept. of Water Resources, Humboldt State College, and Calif. Dept. of Fish and Game) to determine the effects of the road construction on streamflow, sedimentation, fish life, and fish habitat.

North Fork Caspar Creek

The study section of North Fork Caspar Creek was 1.5 miles long. The surrounding forest was not disturbed during this study. Streamflow ranged from 0.05 to 7.81 cfs during the water quality sampling (Table 7). Flows recorded at the weir ranged from 0.04 to 46.20 cfs for the same period (J. S. Krammes, U. S. Forest Service, pers. comm.). Water temperatures ranged from 38 to 66 F in 1963 and 1964 (Kabel and German, 1967). Waters were slightly alkaline, with pH remaining

TABLE 6

Water Quality Properties Measured in Little
North Fork Noyo River, 1968-1969 1/

Date	2/2/69	5/5/69	8/27/69	11/13/69
Discharge (cfs)	14.20	0.99	0.26	0.39
Oxygen (ppm)	12.4	11.0	9.6	11.4
Carbon dioxide (ppm)	2/	2/	2/	2/
Total alkalinity (ppm)	25	40	70	70
Total hardness (ppm)	29	43	7.0	63
Total dissolved solids (ppm)	72.5	114.0	116.0	144.6
Total phosphate (ppm)	0.35	0.28	0.28	0.55
Chloride (ppm)	10	17	15	12
Sulfate (ppm)	3	3	2	13
Nitrate (ppm)	3/	3/	3/	3/
Tannin- and Lignin-like compounds (ppm)	0.6	0.4	0.2	3/
pH	7.3	7.3	7.3	7.1
Turbidity (J.T.U.)	24	4/	4/	53
Temperature (^{o}F)	47	52	60	50

1/ Samples taken after logging

2/ Not detectable at a limit of 2 ppm

3/ Not detectable at a limit of 0.1 ppm

4/ Not detectable at a limit of 10 J.T.U.

TABLE 7

Water Quality Properties Measured in
North Fork Caspar Creek, 1968-1969 1/

Date	4/27/68	5/19/68	8/7/68	10/21/68	2/2/69
Discharge (cfs)	0.46	2/	0.05	0.06	7.81
Oxygen (ppm)	11.0	2/	9.4	9.6	12.0
Carbon dioxide (ppm)	3.0	2/	2	2	3/
Total alkalinity (ppm)	40	123	52	60	11
Total hardness (ppm)	2/	2/	65	70	30
Total dissolved solids (ppm)	112.0	2/	147.0	155.4	82.9
Total phosphate (ppm)	0.20	2/	0.30	0.50	0.35
Chloride (ppm)	2/	2/	17	19	15
Sulfate (ppm)	3	2/	12	9	6
Nitrate (ppm)	4/	4/	4/	4/	4/
Tannin- and Lignin-like compounds (ppm)	2/	0.2	4/	4/	0.6
pH	7.5	7.4	7.5	7.4	7.4
Turbidity (J.T.U.)	5/	5/	5/	5/	21
Temperature (^{o}F)	49	2/	55	48	47

1/ Unlogged watershed

2/ Not tested

3/ Not detectable at a limit of 2 ppm

4/ Not detectable at a limit of 0.1 ppm

5/ Not detectable at a limit of 10 J.T.U.

fairly stable throughout the year. Ranges for values of selected measurements were: oxygen 9.4 to 12.0 ppm, pH 7.4 to 7.5, carbon dioxide to 3 ppm, total alkalinity 11 to 123 ppm, chloride 15 to 19 ppm, sulfate 3 to 12 ppm, tannin and lignin to 0.6 ppm, total hardness 30 to 70 ppm, and turbidity to 21 J.T.U. (Table 7). Witrate was not detectable.

South Fork Caspar Creek

In 1967, 244,400 cubic yards of road materials were moved and 4.3 million board feet of timber harvested along 3.7 miles of road right-of-way. The road was built adjacent to the stream and there were four bridge crossings. Road materials were side-cast into a portion of the stream and one part of the stream was relocated during the road construction. A bulldozer operated through 41% of the 1.9-mile study section during the debris removal. Most of the fill slopes, secondary roads, and streambank were fertilized with urea and seeded with annual rye grass (*Elymus* sp.) at a rate of 50 lbs/surface acre (Burns, 1970).

Streamflow varied from 0.06 to 8.48 cfs during the sampling (Table 8). Flows recorded at the weir for the same period ranged from 0.06 to 67.25 cfs (J. S. Krammes, U. S. Forest Service, pers. comm.).

Prior to the road construction the amount of solar radiation received at some stations along the South Fork was less than 5% of the total available at that latitude. Even on clear days, about half of the stream received less than 10% of the available radiation due to the dense forest canopy. Absolute values ranged from 7.to 276 langleys/day (DeWitt, 1968). After the road construction, some stations along the South Fork received 140% more radiation than they had previously. The absolute average increased 98 langleys/day. Increased solar radiation increased stream temperatures. From February to mid-August 1964 stream temperatures at the lower end of the study section ranged from 38 to 57 F (Kabel and German, 1967). After the road construction, stream temperatures for the same period in 1968 ranged from 47 to 70 F (Roger Barnhart, Humboldt State College, pers. comm.). In some sections of the South Fork, water temperatures increased as much as 20 F during the road construction in 1967 (Dorn, 1969). The maximum observed stream temperature was 77.5 F at one station in 1967 (DeWitt, 1968).

During the right-of-way logging, dissolved oxygen dropped to 5 ppm in some isolated pools with decaying slash, while undisturbed stream sections had 10 ppm (Richard Brandon, Humboldt State College, pers. comm.). Turbidity was localized in areas where a bulldozer was working in the stream during bridge construction. Turbidity extended only a short distance downstream from the disturbance and the stream quickly cleared upon cessation of bulldozer activities (Hess, 1969). Unusual concentrations of carbon dioxide were detected in the late spring and summer months of 1968, with 8 ppm recorded in August. Ranges for values of selected measurements were: oxygen 8.6 to 12.0 ppm, pH 7.3 to 7.5, carbon dioxide to 8 ppm, total alkalinity 18 to 105 ppm, chloride 16 to 30 ppm, sulfate 5 to 10 ppm, tannin and lignin 0.2 to 0.8 ppm, total phosphate 0.31 to 0.60 ppm, total dissolved solids 88.4 to 194.5 ppm, total hardness 32 to 100 ppm, and turbidity to 33 J.T.U. (Table 8). Nitrate was not detectable.

TABLE 8

Water Quality Properties Measured in
South Fork Caspar Creek, 1968-1969 1/

Date	4/27/68 1/	5/19/68 2/	8/7/68 2/	10/21/68 2/	2/2/69 2/
Discharge (cfs)	0.28	3/	0.07	0.06	8.48
oxygen (ppm)	10.0	3/	8.6	10.2	12.0
Carbon dioxide (ppm)	3/	4.5	8.0	4.8	4/
Total alkalinity (ppm)	60	70	85	105	18
Total hardness (ppm)	3/	3/	80	100	32
Total dissolved solids (ppm)	156.0	157.0	194.5	150.0	88.4
Total phosphate (ppm)	0.40	3/	0.40	0.60	0.31
Chloride (ppm)	3/	3/	30	30	16
Sulfate (ppm)	7	5	5	7	10
Nitrate (ppm)	5/	5/	5/	5/	5/
Tannin- and Lignin-like compounds (ppm)	3/	0.2	0.4	0.6	0.8
pH	3/	3/	7.3	7.5	7.5
Turbidity (J.T.U.)	10	10	6/	6/	33
Temperature (°F)	58	56	57	50	46

1/ Samples taken before road construction

2/ Samples taken after road construction

3/ Not tested

4/ Not detectable at a limit of 2 ppm

5/ Not detectable at a limit of 0.1 ppm

6/ Not detectable at a limit of 10 J.T.U.

DISCUSSION AND CONCLUSIONS

Water quality generally remained suitable for salmonids after the logging. Water chemistry varied throughout the year but conditions in logged and unlogged streams were usually similar. We detected greater concentrations of total dissolved solids and total phosphate then Chapman (1965) did in three Oregon streams. Nitrate was not detected, but we were unable to detect nitrate below 0.1 ppm with our equipment. In the Oregon streams nitrate ranged from nearly zero to 1.7 ppm. Bulldozers operating directly in the stream during our study increased turbidity.(these increases were generally localized and short-lived) and streams in logged drainages were more turbid during periods of increased flow than undisturbed streams. Logging operations in other streams have been shown to increase sediment loads (Bevan, 1968; Hall and Lantz, 1969) and road construction is considered a major source of suspended sediment (Meehan, Farr, Bishop, and Patric, 1969). On January 14, 1968, during moderately, heavy rain fall, erosion and slippage of the road along South Fork Caspar Creek caused turbidities of 3,000 ppm and deposition of as much as 2 ft of sediment in the. stream (Hess, 1969). On the same day, turbidities in North Fork Caspar Creek were only 60 ppm. During periods of low flow after the logging, turbidity was usually not detectable in either disturbed or undisturbed streams. The concentration of carbon dioxide in most streams was usually less than 2 ppm. Even with the removal of logs and limbs after the road right of way logging in South Fork Caspar Creek, decomposition of the small logging slash remaining in the stream resulted in high carbon dioxide concentrations being detected in the spring and summer. of 1968 (maximum 8.0 ppm in August). Diurnal sampling may have demonstrated even higher concentrations. With cessation of photosynthesis and continuation of decomposition and respiration during darkness, a buildup of carbon dioxide could have occurred at night. Generally, dissolved oxygen remained near saturation. Levels as low as 5.0 ppm were observed in isolated pools containing decaying debris (Richard Brandon, Humboldt State College, pers, comm.) These concentrations are considerably higher than those recorded during clear cut logging in Needle Branch, a small stream in Oregon (Hall and Lantz, 1969). Dissolved oxygen levels as low, as 0.6 ppm made about one-third of the Needle Branch marginal for fish life. Conditions, however, improved after large debris was removed from the stream. If most of the debris had not been removed from the streams during our study, similar conditions may have occurred.

Logging had the greatest effect on stream temperature. Generally, maximum temperatures were below 60 F in the unlogged streams, while after the logging, temperatures approached 70 F. Heating in streams is due to an increase in direct solar radiation (Brown, 1969) and, consequently, removal of riparian vegetation can produce significant increases in stream temperature (Brown and Krygier, 1967; Levno and Rothacher, 1967). Temperature increases in the South Fork Caspar Creek after the logging were significantly correlated with canopy removal (Dorn, 1969). In South Fork Caspar Creek, radiation increased about 140% after the logging (DeWitt, 1968) and temperature increases of nearly 20 F were recorded at several stations (Dorn, 1969). Similar temperature increases occurred in Needle Branch; after clear cut logging and slash removal, maximum temperature increased from 61 to 86 F (Hall and Lantz, 1969). In several streams in Alaska temperature increases of only 9 F occurred after the logging (Meehan et al, 1969). The degree of canopy removal is an important factor in controlling stream temperatures. Fifty-five percent of the watershed of a small stream in Oregon was clear cut before increases in stream temperature were statistically significant (Levno and Rothacher, 1967). In our California study, maximum temperatures increased 6 F in Bummer Lake Creek after block cutting, increased 17 F in the South Fork Caspar Creek after road right of way clearing, and did not change in South Fork Yager Creek after selective logging with retention of a buffer strip. Shaded areas (uncut blocks and buffer strips) mitigate temperature increases (Brown, 1969). In Bummer Lake Creek, temperatures increased 5.5 F/1,000 ft as the stream flowed through clear cut sections and decreased 2.5 F/1,000 ft while flowing through an uncut section. An even greater reduction in temperature occurred in a small stream in North Carolina; stream temperature dropped 12 F as the stream meandered through 400 ft of shade (Green, 1950). The effects of canopy removal are most dramatic on clear, sunny days (Meehan, 1968). If canopy removal is extensive along a stream (or on several small tributaries in one drainage) located outside the cooling influence of coastal fog, the resulting high temperatures would probably be deleterious to salmonid survival. Logging in our California study, however, was limited to short stream sections (usually less than ½ mile). The steepness of the canyon wall may also affect water temperature. If the canopy of a stream in relatively flat terrain is removed, the stream would receive more solar radiation than a stream with steep canyon walls.

The combination of a cool coastal climate and the smallness of the areas logged, kept stream temperatures low enough for salmonid survival. Temperatures above 77 F for extended periods are usually lethal to salmonids (Brett, 1952; Leitritz, 1959). Lower temperatures, however, may have secondary effects. Sustained temperatures near 70 F may seriously impair growth by increasing metabolism and maintenance requirements. Growth in young sockeye salmon (Oncorhynchus nerka) is poor at temperatures above 69.8 F (Brett, 1958). During our study high temperatures were not sustained and probably did not retard growth. Differences in growth sometimes occurred but appeared to be related to factors other than temperature (Burns, 1971). High temperatures increase pathogenic activity and decrease oxygen solubility. Egg quality and incubation may also be affected by temperature. If female rainbow trout are held at temperatures exceeding 56 F within 6 months before spawning, they usually produce eggs of poor quality (Leitritz, 1959). Loss of insulation (canopy removal) can cause lower stream temperatures during the winter (Green, 1950), resulting longer incubation periods. Delay of fry emergence could increase losses to predation and decrease growth during the first year of life. Warmer temperatures in the spring, however, could be beneficial. Incubation period could decrease and growth increase. Algal production could increase also, ultimately providing more food for fish. Salmonid biomass varied during our study, but increases as well as decreases occurred (Burns, 1971).

The water quality of coastal streams. is continually changing and cursory analyses such as these can only generally characterize nutrient levels and physical chemical parameters. Water quality factors measured during this study (total dissolved solids, total alkalinity and total phosphate), did provide a useful method for predicting stream carrying capacities for salmonids (Burns, 1971). Logging did not greatly affect most parameters measured during our study. Generally, conditions were similar in logged and unlogged streams and were suitable for salmonids. Changes due to logging activities usually could not be detected, except in those instances where gross changes occurred due to sever stream disturbance.

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