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SPAWNING BED SEDIMENTATION STUDIES IN NORTHERN CALIFORNIA STREAMS[1]

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Changes in the size composition of spawning bed materials in six coastal streams were monitored for 3 years to determine the effects of logging on the habitat of silver salmon (*Oncorhynchus kisutch*) and trout (*Salmo gairdnerii gairdnerii* and *S. clarkii clarkii*). Four test streams were sampled before, during and after logging. Two streams in unlogged watersheds and the undisturbed upstream section of one test stream served as controls. A variety of stream types in second-growth and old-growth forests was selected for observation.

Spawning bed composition in the four test streams changed after logging, roughly in proportion to the amount of streambank disturbance. The heaviest sedimentation occurred when bulldozers operated in narrow stream channels having pebble bottoms. In a larger stream with a cobble and boulder bottom, bulldozer operations in the channel did not increase sedimentation greatly. Sustained logging and road construction kept sediment levels high in one stream for several years. Sedimentation was greatest during periods of road construction near streams and removal of debris from streams, confirming the need for special measures to minimize erosion during such operations. Control streams changed little in spawning bed composition during the 3 years.

INTRODUCTION

The condition of a streambed has important implications for salmon and trout production. These fish deposit their eggs and their young find food and shelter among the streambed grave's. Excessive sediment decreases productivity by smothering or crowding out the organisms living in the streambed (Cordone and Kelley, 1961). Incubating salmonid embryos and fry are particularly susceptible to sedimentation. Fine particles deposited in the streambed render redds less permeable (McNeal and Ahnell, 1964), impede fry emergence (Hall and Lantz, 1969), and may, by reducing oxygen levels in the riffles, cause high mortality and poor fry quality at emergence (Mason, 1969).

Logging has been recognized as a major cause of sediment in California streams (Calhoun, 1967) ; however, quantitative data on the accrual of fine sediments in spawning gravels are scarce, since most sedimentation work has concentrated on increases in suspended solids (U. S. Dept. Agriculture, 1965; Peters, 1967). Stream sedimentation in Alaska was temporary when reasonable habitat protection accompanied logging operations (Sheridan and McNeil, 1968). However, the results of work in other states are not generally applicable to California because of differences in climates, soils, forests andlogging techniques. Therefore, in 1966 the California Department of Fish and Game began monitoring the effects of logging on silver salmon *(Oncorhynchus*

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kisutch) and trout *(Salmo gairdnerii gairdnerii* and *S. clarkii clarkii)* habitat in the redwood *(Sequoia sempervirens)* and Douglas fir *(Pseudotsuga Menziesii)* forests of northwestern California. This report describes changes in spawning bed composition accompanying logging and associated road building.

LOCATION AND DESCRIPTIONS OF STUDY STREAMS AND LOGGING OPERATIONS

Seven stream sections on six small watersheds were chosen for study (Table 1). Four of the seven were logged using methods specific to their locales. The other three remained undisturbed and served as experimental controls. Soils in these drainages are predominately loamy and moderately erodable. Heavy winter rainfall and dry summers explain the large variations in streamflow. Air temperatures along the coast are cooled by dense, recurrent fogs.

Control Streams

The old growth redwood forest of Godwood Creek, Humboldt County, lies within Prairie Creek State Park. This stream drains into the Redwood Creek system. South Fork Yager Creek, Humboldt County, flows through private lands and is part of the Eel River system. Its drainage basin has no history of logging. The forest is old-growth Douglas fir and redwood. North Fork Caspar Creek, Mendocino County, lies within Jackson State Forest. Its redwood-Douglas fir forest was logged about 100 years ago. Caspar Creek enters the ocean south of Fort Bragg.

Test Streams

Bummer Lake Creek, Del Norte County, flows through private lands into the Smith River. One hundred and ten hectares (272 acres) of its old-growth forest were clear cut in alternate blocks on the southwest side of the stream in 1968. Redwood and Douglas fir logs were hauled by high lead away from the stream up to the road, and by bulldozer above the road. The average horizontal distance between the stream and the road was 120 m (400 ft) and there were no stream crossings. Fifty-eight thousand ms (25 million board feet) of timber were harvested. A bulldozer operated in the streambed to remove logs and other debris from the 1,524-m study section.

South Fork Yager Creek, Humboldt County, was divided into two equal sections. The test section extended from the mouth 560 m (1,835 ft) upstream to the lower end of the unlogged control section. Douglas fir and redwood were selectively cut to 305 m (1,000 ft) on each side of the test section in 1968. Great care was taken to protect the stream; riparian vegetation (including harvestable timber leaning toward the stream) was not cut and equipment did not enter the stream. Eighty percent of the timber volume was cut from the original 344 mg/hectare (60,000 board feet/acre). Roads were built away from the stream on low gradient slopes.

Little North Fork Noyo River, Mendocino County, flows through private lands into the Noyo River. Its redwood-Douglas fir forest, logged about 100 years ago, has been subjected to periodic road construction

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TABLE 1
Stream and Watershed Characteristics[1] Prior to Logging

	Bummer Lake Creek	Godwood Creek	S. Fork Yager Creek	Little N. Fork Noyo River	N. Fork Caspar Creek	S. Fork Caspar Creek
	Logged 1968	Old growth, unlogged	Logged 1968	Logged 1966-69	Second growth unlogged	Road construction 1967
Study section length	1,524	3,110	1,119	1,530	2,459	3,093
m (ft)	(5,000)	(10,196)	(3,670)	(5,016)	(8,061)	(10,142)
Drainage area, ha	1,400	467	2,514	989	508	425
(acres)	(3,456)	(1,152)	(6,208)	(2,432)	(1,255)	(1,050)
Avg canyon slope, percent	45	18	38	36	45	49
Avg stream slope, percent	5	1	4	3	2	3
Avg stream width, m[1]	4.9	3.1	5.2	1.5	1.8	1.8
(ft)	(16)	(10)	(17)	(5)	(6)	(6)
Soil series,[2]	Melbourne	Melbourne	Hugo	Hugo	Hugo	Hugo
Major streambed surface,[3]	cobble and boulder	pebble	cobble and boulder	pebble	pebble	pebble
Mean annual precipitation,[4]	203	152	102	127	127	127
cm (inches)	(80)	(60)	(40)	(50)	(50)	(50)
Annual streamflow range,[5]	0.014-1.4	0.023-0.37	0.008-0.93	0.002-0.40	0.001-0.23	0.002-0.25
m^3/sec (cfs)	(0.5-50)	(0.8-13)	(0.3-33)	(0.08-14)	(0.05-8)	(0.06-9)

1 Summer average minimum.
2 Storie and Weir (1953).
3 Wentworth's classification (Welch, 1948).
4 Durenberger (1960).
5 Range observed during water quality sampling in 1968-69 (Kopperdahl and Burns, 1970). Only two streams have streamflow gages and their recorded ranges exceed those observed during water quality sampling: N. Fork Caspar Creek usually reaches 13.0 m³/sec (46 cfs) in the winter and S. Fork Caspar Creek generally reaches 11.9 m³/sec (42 cfs) (Ziemer, Kojan, Thomas and Meller, 1966).

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and selective logging since 1964. Thirty percent of the timber volume has been removed from 542 hectares (1,338 acres) of watershed since 1966. A bulldozer worked in or near the 1,530-m study section during road construction and right-of-way logging in 1966 and 1969. Average road distance to the stream was about 23 m (75 ft). There was one bridge crossing at the upper end of the study section.

South Fork Caspar Creek, like the North Fork, is in Jackson State Forest and is managed by the California Division of Forestry. Its redwood-Douglas fir forest was also logged about 100 years ago. In 1967, 76,400 m^3 (100,000 cubic yards) of road materials were removed and 10,000 m^3 (4.3 million board feet) of timber harvested along 5.96 km (3.7 miles) of road right-of-way construction. The road was built adjacent to the stream, ranging from four bridge crossings to 76 m (250 ft) from the stream. Road materials were side-cast into the stream and one part of the stream was relocated during road construction. A bulldozer operated through 41 % of the 3,093-m study section during 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 56 kg/hectare (50 lbs /surface acre) (David Burns, Calif. Div. of Forestry, pers. comm.). This grass was well established before the first winter after road construction and again by the second winter. No logging trucks used the road during or after the first winter.

METHODS

The four test streams were sampled from 1966 through 1969, before, during and after logging, to measure changes in spawning bed composition which accompanied specific logging practices.Surveys were systematic so that the entire stream section was examined and most of the spawning beds sampled. The three control streams were sampled during the same general period. Usually 20 bottom samples were taken from each stream during each survey.

Surveys were made in the summer and fall when streamflow was stable and low enough to permit sampling. Samples were taken with a 15.24 cm (6-inch) diameter stainless steel cylinder similar to the one described by McNeil and Ahnell (1964), but with a plunger rather than a cap to retain suspended sediments. Each sample was taken to a depth of 15.24 cm in the center of the stream near the head of a riffle. This location was chosen as representative of the areas in which salmonoids spawn.

Tyler screens with openings of 26.67 mm (1.050 inch), 3.327 mm (0.131 inch), and 0.833 mm (0.0328 inch) were used to separate the samples into four size classes, three of which were retained by the screens, while the fourth passed through the 0.833mm screen. Volumes for those classes retained were measured by water displacement. The fraction passing the 0.833 mm screen was measured after settling in a graduated cylinder for 10 minutes.

These size classes were selected because past studies have defined their effects on embryo and fry survival. Generally, survival is lower as the volume of materials less than 25 mm diameter increases (Shelton, 1955; MacKinnon, 1960; Phillips, 1963). Specifically, materials from 1 to 3 mm impede fry emergence (Phillips, Campbell, Hug and Claire,

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1966; Lantz, 1967; Hall and Lantz, 1969; Phillips and Koski, 1969) ; and sediments smaller than 0.8 mm greatly reduce streambed permeability (McNeil and Ahnell, 1964; Koski, 1966), as do sediments smaller than 3.4 mm (Cooper, 1965).

The volume of each size class of materials was converted to a percentage of each streambed sample. These percentages were averaged to obtain the mean percentage of the total sample volume passing each sieve. Differences between streams were tested at the 5% significance level using Student's t-test (Burns, 1966).

CHANGES IN SPAWNING BED COMPOSITION OF UNLOGGED STREAMS

The size composition of the spawning bed materials remained fairly stable in Godwood and North Fork Caspar creeks during the 3 years of study (Tables 2 and 3). The amount of sediment smaller than 0.8 mm changed less than 1% in Godwood Creek. Materials smaller than 3.3 mm changed less than 8%, and those smaller than 26.7 min less than 10 /o. Similar differences were observed in the North Fork Caspar Creek, except in 1969 when the mean percentage of materials less than 0.8 mm diameter was 5.2 % greater than the average for the previous 2 years. This difference was not statistically significant, however. Heavier storms in the 1969 water year probably increased erosion in this relatively unstable watershed; in addition, there was a greater total precipitation in 1969 (148 cm) than in 1968 (105 cm). The deposition of sediments behind the North Fork Caspar Creek weir was 630% greater in 1969 than in 1968, indicating much greater streambed movement in 1969 (Jay S. Krammes, U. S. Forest Service, pers. comm.).

TABLE 2
Size Composition of Spawning Bed Materials in Godwood Creek, Humboldt County, California

Date	Mean percentage of total sample volume*			Number of samples
	Less than 0.8 mm	Less than 3.3 mm	Less than 26.7 mm	
July 1967	**17.3** (13.2-21.3)	**30.3** (24.5-36.2)	**70.2** (64.2-76.2)	20
July 1968	**17.8** (14.3-21.2)	**37.9** (33.1-42.7)	**79.6** (74.0-85.3)	20
July 1969	**17.7** (14.3-21.2)	**30.9** (26.2-35.6)	**73.5** (65.5-81.4)	20

*95% confidence intervals in parentheses.

The unlogged portion of South Fork Yager Creek also showed a large, but not statistically significant increase in the volumes of sediment less than 0.8 mm and less than 3.3 mm (Table 4). For materials smaller than 0.8 mm the increase was 5.70/0 and for materials less than 3.3 mm the increase was 16.3%. In 1969 there was a significant increase (19.8% greater than in 1967) in the volume of materials smaller

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TABLE 3

Size Composition of Spawning Bed Materials in North Fork Caspar Creek, Mendocino County, California

Date	Mean percentage of total sample Less than 0.8 mm	Less than 3.3 mm	Less than 26.7 mm	Number of samples
June 1967	18.4 (16.0-20.7)	32.0 (28.8-35.1)	72.0 (67.4-76.6)	20
Oct. 1967	17.5 (14.4-20.6)	33.5 (28.5-38.6)	79.5 (75.5-83.4)	20
June 1968	18.2 (14.5-21.9)	34.6 (30.4-38.8)	78.0 (73.7-82.3)	20
Oct. 1968	18.0 (15.6-20.4)	35.5 (32.4-38.7)	75.7 (72.8-78.6)	20
Aug. 1969	23.2 (20.1-26.2)	40.5 (35.5-45.5)	80.4 (73.6-87.2)	20

' 95% confidence intervals in parentheses.

than 26.7 mm. A portion of a tree jam and rock barrier immediately upstream from the control section collapsed during the 1968-69 winter. Deposition of sediments which had accumulated behind this barrier accounted for the increase.

TABLE 4

Size Composition of Spawning Bed Materials in the Unlogged Control Section of South Fork Yager Creek, Humboldt County, California

Date	Mean percentage of total sample volume* Less than 0.8 mm	Less than 3.3 mm	Less than 26.7 mm	Number of samples
August 1967	16.4 (13.2-19.6)	36.1 (28.5-43.7)	75.4 (65.1-85.8)	10
August 1968	17.3 (13.7-20.9)	44.7 (36.2-53.3)	86.2 (77.2-95.1)	10
August 1969	22.1 (18.1-26.0)	52.4 (40.4-64.4)	95.2 (91.0-99.5)	10

' 95% confidence intervals in parentheses.

CHANGES IN SPAWNING BED COMPOSITION IN TEST STREAMS

Sediment of all size classes increased slightly after logging in Bummer Lake Creek, although differences were not statistically Significant (Table 5). They were also within the range of natural change

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observed in the control streams. Such a small increase was unexpected, since bulldozers had operated extensively in the clear cut areas and in the stream channel during debris removal. The boulders and cobbles composing the streambed and the wide stream channel (Figure 1) apparently kept the bulldozer from gouging the stream banks.

The logged section of South Fork Yager Creek exhibited streambed composition changes like those in the upstream control section (Table 6). The only statistically significant change was an increase in the class of sediments smaller than 26.7 mm, which occurred in both the test and the control sections. Release of sediments following collapse of the upstream barrier mentioned earlier adequately explains this change. I did not expect sedimentation to increase after logging in South Fork Yager Creek, since neither the stream channel nor the watershed was appreciably disturbed by bulldozer operations, which were conducted with unusual care.

Following construction of an all weather road in the winter of 1966 67, the percentage of sediments smaller than 0.8 mm increased significantly in the Little North Fork Noyo River (Table 7). By 1968 these sediments had increased 11%. In 1969, after a second road was constructed on the other side of the stream, sediments smaller than 0.8 mm increased to 13.3% over the predisturbance level. Much sediment entered the stream in 1968 through road slippage. In 1969, however, most sediment resulted from bulldozer operations in the lower stream (Figure 2). Small materials composing the narrow streambed and bank were deeply gouged by the bulldozer, leaving a heavily silted stream bed with a channel consisting of bulldozer tracks.

The volume of sediments smaller than 0.8 mm in South Fork Caspar Creek increased 13.6% immediately after road construction (Table 8). The next summer it returned to the predisturbance level. Twenty-two months later, however, the small sediments were 8.8 % higher than the predisturbance level. The initial increase in 1967 followed extensive use of a bulldozer to clear the stream of logging debris. The narrow streambed composed of small materials was particularly susceptible to degradation (Figure 3). Erosion was minimized the first winter by establishing annual rye grass on the stream banks, fill-slopes and skid trails (Figure 4). Without additional erosion, accumulated sediments were scoured from the riffles. The increase in 1969 was probably caused by streambank erosion and two winters of erosion on side casts and slides. Erosion from only a fraction of a logged area can pollute an entire stream (Lull and Reinhart, 1965). The winter storms of the 1968 water year were mild (total annual precipitation: 98 cm) compared with the heavier storms and greater total precipitation (142 cm) for the 1969 water year. Heavier rainfall could have accounted for in creased erosion. Moreover, there was less rye grass to hold the soil in place in disturbed areas than there had been the first winter. Bed load movement within the stream was also greater in 1969 than in 1968. There was a 73% increase in the amount of sediment deposited behind the South Fork weir in 1969 (Jay S. Krammes, U. S. Forest Service, pers. comm.). Road slides were common in both winters and repair was necessary each spring. Road slides also play an unpredictable but important role in sedimentation (Fredrickson, 1965).

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TABLE 5

Size Composition of Spawning Bed Materials in Bummer Lake Creek, Humboldt County, California

Date	Condition	Mean percentage of total sample volume* Less than 0.8 mm	Less than 3.3 mm	Less than 26.7 mm	Number of samples
Sept. 1967	Unlogged	10.2 (8.1-12.2)	28.0 (24.5-31.6)	73.0 (66.5-79.5)	21
Sept. 1968	Two months after logging	11.7 (9.6-13.8)	30.7 (26.8-34.7)	76.8 (70.4-83.2)	21
Sept. 1969	Fourteen months after logging and 11 months after stream cleanup	13.3 (11.1-15.5)	31.3 (27.4-35.3)	82.5 (78.5-86.5)	

* 95% confidence intervals in parentheses.

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TABLE 6

Size Composition of Spawning Bed Materials in the Test Section of South Fork Yager Creek, Humboldt County, California

Condition		Mean percentage of total sample volume*			er es
		Less than 0.8 mm	Less than 3.3 mm	Less than 26.7 mm	
August 1967	Unlogged	16.4 (12.7-20.1)	40.1 (34.2-45.9)	76.0 67.5-84.5)	10
August 1968	Immediately after logging	16.5 (11.8-21.2)	39.9 (29.6-50.3)	78.9 (65.6-92.2)	10
August 1969	Twelve months after logging	23.6 16.9-30.3)	54.8 (44.3-65.4)	95.2 (90.9-99.5)	10

* 95% confidence intervals in parentheses.

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FIGURE 1-Bummer Lake Creek, Del Norte County, before logging 1967. Boulder and rubble sized materials made up the streambed. *Photograph by Michael Moore.*

TABLE 7

Size Composition of Spawning Bed Materials in Little North Fork Noyo River, Mendocino County, California

Date	Condition	Mean percentage of total sample volume*			Number of samples
		Less than 0.8 mm	Less than 3.3 mm	Less than 26.7 mm	
Oct. 1966	Second growth forest, pre-road construction	20.0 (17.7-22.2)*	NR†	84.7 (80.5-88.8)	27
Oct. 1968	Twenty-four months after initial road construction and 12 months after gully logging	31.0 (23.6-38.3)	42.1 (33.3-50.8)	81.3 (73.6-89 0	8
Sept. 1969	Immediately after second road construction	33.3 (25.1-41.5)	44.4 (36.6-52.2)	86.2 (81.0-91.3)	16

95% confidence intervals in parentheses.
† NR = The † 3.3 mm sieve was not used in 1966.

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FIGURE 2-Little North Fork Noyo River, Mendocino County, immediately after logging debris removal, 1969. The stream's course was formed by bulldozer tracks. *Photograph by the author.*

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TABLE 8

Size Composition of Spawning Bed Materials in South Fork Caspar Creek, Mendocino County, California

Condition		Mean percentage of total sample volume* Less than 0.8 mm	Less than 3.3 mm	Less than 26.7 mm	
June 1967	Second growth forest, pre-road construction	20.6 (17.8-23.4)	36.4 (32.3-40.6)	73.3 (68.6-77.9)	20
Oct. 1967	Immediately after road construction	34.2 (25.6-42.8)	47.8 (38.6-57.1)	77.8 (71.5-84.2)	20
June 1968	Eight months after completion	17.9 (10.9-24.9)	37.2 (29.6-44.9)	84.4 (79.4-89.5)	19
Oct. 1968	Twelve months after completion	19.0 (14.8-23.2)	37.1 (31.8-42.5)	74.8 (68.2-81.4)	20
Aug. 1969	Twenty-two months after completion	28.5 (24.6-32.3)	44.2 (39.8-48.5)	75.0 (69.8-80.2)	20
Sept. 1969	Twenty-three months after completion	27.1 (23.7-30.5)	40.8 (35.7-45.8)	75.7 (71.0-80.5)	19

* 95% confidence intervals in parentheses.

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.. Fork Caspar Creek, Mendocino County, immediately after road constructio in 967 bulldozer operated extensively in the stream channel and materials fro mar lding slid into the stream. *Photograph by Paul Hubbell*

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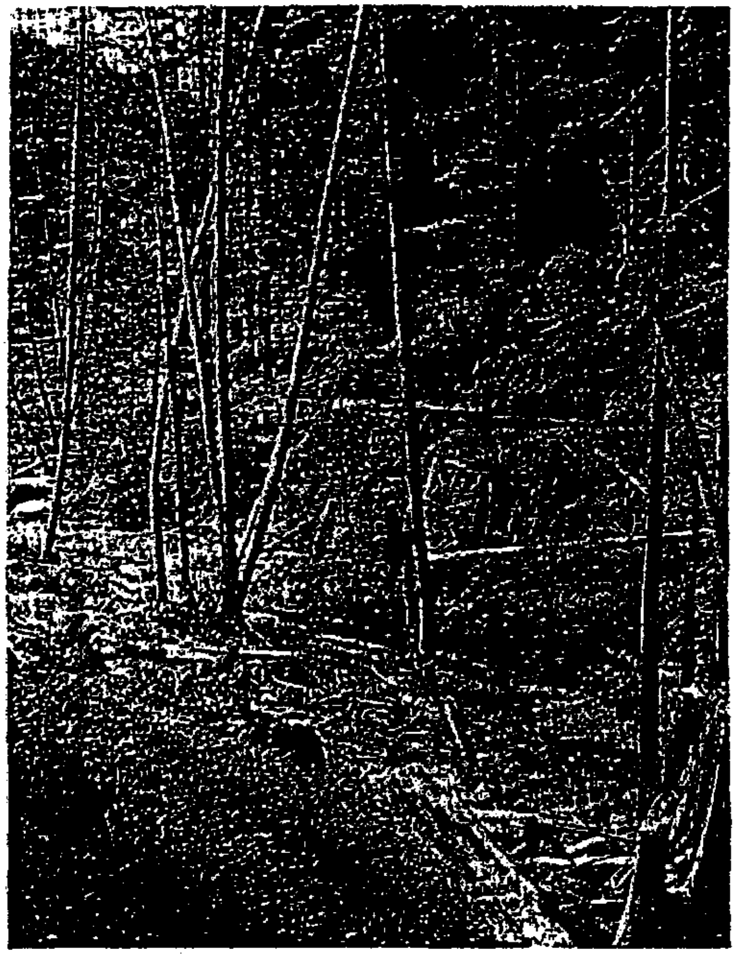

FIGURE 4-Annual rye grass was well established on the stream banks, fill-slopes and skid trails of South Fork Caspar Creek, Mendocino County, by the first winter after logging. *Photograph by Paul Hubbell.*

DISCUSSION AND CONCLUSIONS

Changes in spawning bed composition need not be gross to affect fry survival. For example, in Deer Creek, Alsea drainage, Oregon, an increase in materials smaller than 0.8 mm of only 5% (from 20 to 25%) caused a 19% decrease in the survival to emergence of silver salmon fry (Hall and Lantz, 1969). Since I did not measure survival to emergence or spawning bed composition during incubation, it was not pos-

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sible to relate the observed changes in sediment composition to fry survival for California streams. The relationships are probably similar to those found in Oregon. I did measure, however, summer standing crops of juvenile salmonids in the streams. This will be the subject of a later report (Burns, in preparation).

Sampling during the low flow periods of late spring and summer may not have reflected conditions during incubation. For example, a layer of silt could have been deposited on the spawning bed, cutting off intragravel flow and dissolved oxygen delivery, and then washed out, leaving no evidence of its former presence. Even when turbulence prevents deposition of fine materials on the streambed surface, deposition may still occur within the gravels (Cooper, 1965). Because of seasonal variations in Alaskan streams, investigators there used summer samples for long-term comparisons (Sheridan and McNeil, 1968). I assumed that this sampling period would - also be adequate for my long-term comparisons. Furthermore, it is very difficult to sample during high water and the probability of destroying redds during intensive sampling is quite high.

All streams increased somewhat in fine sediments during the 3-year study, although logged streams increased the most. Unlogged Alaskan streams have fluctuated about 7% in the 0.8 mm class (Sheridan, Hoffman and Olson, 1965). Unlogged California streams have fluctuated even less. For example, Godwood and North Fork Caspar creeks changed less than 1% in this size class in 3 years, while the control section of South Fork Yager Creek changed 5.7%. The greatest increase observed in the logged streams was 13.6% (South Fork Caspar Creek). However, none of the four logged streams received extensive watershed disturbance. Except for the Little North Fork Noyo River, the logging operation was limited to one season. Furthermore, the disturbances were restricted to a small fraction of the total watershed. Heavy sedimentation might have been the rule rather than the exception if these watersheds had been heavily cut or subjected to sustained logging over a longer period. These results, however, provide a base for future comparisons, after these same watersheds are logged more extensively.

My studies suggest that different streams may be affected differently by bulldozer activities. Narrow ones (Little North Fork Noyo River and South Fork Caspar Creek) with small gravel or pebble bottoms were adversely affected by bulldozer operations in the stream. The largest stream (Bummer Lake Creek), with a cobble and boulder bottom was not as easily gouged and eroded.

Road location is another important consideration in streambed sedimentation. Roads on low gradient slopes or located more than 30 m (100 ft) from the stream generally did not contribute to spawning bed sedimentation. Turbid runoff from these roads usually sank into the forest floor before reaching the stream. Roads located close to a stream usually feed sediment directly into the channel and streambed (Lull arid Reinhart, 1965).

Spawning bed recovery may be rapid or may take several years. The riffles in streams with relatively stable flows generally accumulate sediments more readily than those with very high peak flows. Fine sediments are readily flushed out by freshets once the source of erosion

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is removed (McNeil and Ahnell, 1964; Shapley and Bishop, 1965; Saunders and Smith, 1965) ; however, continuing disturbances, such as occurred in building another road along the Little North Fork Noyo River, prolonged sedimentation. Ideally, logging operations in a watershed should be completed as soon as possible (Lull and Reinhart, 1965) . Anderson and Richards (1961) found that once logging was completed in a small Sierra Nevada watershed, suspended solids markedly decreased from those concentrations observed during logging. Most of the sedimentation I observed occurred during road construction and removal of debris from the streams, suggesting that special attention should be paid to erosion control during such operations.

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