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Title: EFFECTS OF LOGGING ON THE SPAWNING BED ENVIRONMENT IN TWO OREGON COASTAL STREAMS

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James D. Hall

The effects of two patterns of logging on the intragravel environment were studied in three Oregon coastal streams between June 1968 and June 1969. The watershed of one stream (Needle Branch) had been clearcut, and that of a second stream (Deer Creek) cut in staggered settings in 1966. A third watershed (Flynn Creek) served as an unlogged control. The dissolved oxygen content, biochemical oxygen demand, and temperature of the intragravel water were determined, as well as the size composition and organic content of the gravel. Changes were evaluated in terms of their effects on the survival of salmonid eggs and alevins.

Water samples for analysis of dissolved oxygen and biochemical oxygen demand were removed from the streambed by means of standpipes. Intragravel water temperature was obtained with a thermister probe forced into the redds and with thermograph

probes buried at selected locations in the streambed. Gravel samples were removed from recent redds and from previously used spawning sites ("former redds") with a newly-developed sampler that incorporated dry ice and acetone to freeze an intact core of gravel around an iron pipe. Samples were cut into strata 8.3 cm in depth and analyzed for size composition by volumetric displacement and for organic content by weight loss upon ignition.

Dissolved oxygen in redds of Needle Branch averaged 7.15 mg/l, whereas that in Deer Creek averaged 8.91 mg/l during 1969. Oxygen levels in Needle Branch redds in 1969 were 37.4 percent lower than those reported in 1964. Oxygen in Deer Creek redds dropped 12.7 percent in the same period. Dissolved oxygen at permanent standpipe locations was significantly lower than that in redds and showed greater variability. Oxygen levels were positively correlated with streamflow and negatively correlated with temperature.

Organic content of the gravel ranged from 0.33 to 7.52 percent by weight; less than 3 percent of the organic material was larger than 6.35 mm. The quantity of organic material was directly related to the amount of fine sediment in the sample. Recent redds in Needle Branch contained significantly less organic debris than did former redds. However, the organic content of redds in Needle Branch did not differ statistically from that in Deer and Flynn Creeks. The biochemical oxygen demand of the intragravel water averaged 1.95 mg/l for the three streams; differences among streams were not statistically significant.

Stratification of fine sediment was evident in many redds, but a definite pattern of stratification could not be detected. Gravel size composition in Needle Branch did not differ statistically from that of the other streams. Recent redds in Needle Branch contained significantly less sediment than did former redds.

Intragravel water temperature lagged from 2 to 6 hours behind surface temperature in attaining the diurnal maximum. Water temperature decreased with depth in the gravel in Needle Branch and Deer Creek on clear days, but the intragravel water was almost isothermal in Flynn Creek. Fluctuation in intragravel water temperature occurred as early as March, and maxima as great as 19.7°C were recorded prior to complete emergence of coho salmon. Surface and intragravel temperatures reflected the amount of shade over the stream surface. Survival to emergence of coho salmon appeared to be little affected by the observed changes in the intragravel environment.

Effects of Logging on the Spawning Bed Environment in Two Oregon Coastal Streams

by

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EFFECTS OF LOGGING ON THE SPAWNING BED ENVIRONMENT IN TWO OREGON COASTAL STREAMS

INTRODUCTION

The streams of the Coast Range of Oregon are the habitat of the early life stages of salmon and trout that support important sport and commercial fisheries. These streams also drain watersheds containing valuable timber. The most beneficial use of both fishery and timber resources is a goal that will be reached only after the relation between logging activities and salmonid survival is clearly understood.

The research described in this paper is a part of the Alsea Watershed Study, an extensive 15-year study of the effects of logging on aquatic resources within the Coast Range of Oregon. Study of three small streams began in 1958, and was continued for seven years prior to logging. Data have been obtained on streamflow, temperature, and suspended sediment, as well as on fish populations and their food resources. In 1966 one stream was clearcut, another cut in staggered settings, and a third left as an unlogged control. Studies will continue until 1973 to evaluate the full impact of logging on aquatic resources.

The objectives of my study were to determine the changes which had occurred in the spawning bed environment as a result of logging, and to evaluate the importance of these changes to salmonid eggs and alevins developing within the gravel. The work was conducted from June 1968 to June 1969. Emphasis was placed on dissolved oxygen, organic debris, size composition of the gravel, and temperature. The design of the study allowed comparisons among streams subjected to different degrees of forest removal, as well as comparisons before and after logging on a given stream.

Several features of the intragravel environment have been studied intensively in recent years. Field studies by Wickett (1954) in Canada, Gangmark and Bakkala (1960) in California, Coble (1961) in Oregon, and McNeil (1966) in Alaska have shown that the survival of salmonid eggs and alevins is related to both the quality and exchange rate of the intragravel water. Other investigators have verified in laboratory experiments the importance of adequate velocity and dissolved oxygen concentration of intragravel water (Alderdice, Wickett, and Brett, 1958; Silver, Warren, and Doudoroff, 1963; Shumway, Warren, and Doudoroff, 1964). Sheridan (1962) and Vaux (1962) concluded that renewal of intragravel dissolved oxygen in an Alaskan stream was largely through exchange of surface water with intragravel water.

Fine sediments have been shown to act as an impediment to the free exchange of surface with intragravel water (McNeil and Ahnell, 1964; Cooper, 1965), and to physically entrap fry within the redd (Koski, 1966; Hall and Lantz, 1969).

Factors which indirectly influence the survival of embryos or fry, such as organic content of the gravel, or temperature of the intragravel water, have not been studied intensively. Several authors have stated that the decomposition of organic debris reduces dissolved oxygen levels, including Pollard (1955), McNeil (1966), and Hall and Lantz (1969). Quantitative studies of organic material in the gravel, however, have apparently been limited to two streams in Alaska (McNeil and Ahnell, 1964). McNeil (1966) concluded that temperature rarely exerts a directly lethal stress on pink and chum eggs or alevins in Alaskan streams. In another study, McNeil (1968) described the importance of high temperature in increasing the oxygen demand of organic debris.

The effects of logging on the intragravel environment have been studied in Oregon and Alaska. Hall and Lantz (1969) reported a 30 percent decrease in dissolved oxygen within the gravel following clearcut logging of a stream in the Alsea Watershed Study. Dissolved oxygen still had not returned to prelogging levels after two years. McNeil and Ahnell (1964) and Sheridan and McNeil (1968) reported an increase in fine sediment in the gravel of streams in Alaska during and after logging. They found, however, that the percentage of fine sediment had dropped to pre-logging levels within five years.

Temperature increases in the surface water following logging have been studied (Eschner and Larmoyeaux, 1963; Brown and Krygier, 1967). However, the influence of these temperature changes on the intragravel water has not been evaluated. Increases in suspended organic material have been reported following logging (McNeil and Ahnell, 1964), but changes in the organic content of the gravel remain to be demonstrated.

DESCRIPTION OF STUDY AREA

My work was conducted on three small streams in Lincoln County, about 11 km southeast of Toledo, Oregon. The streams are tributaries of Drift Creek, which flows about 40 km before emptying into Alsea Bay near Waldport, Oregon (Figure 1). Except for size, the streams are similar in physical and biotic characteristics. Coho salmon (Oncorhynchus kisutch) and cutthroat trout (Salmo clarki clarki) spawn in each of the streams, and in Deer Creek a small number of steelhead trout (Salmo gairdneri gairdneri) also spawn. Each stream has a resident population of the reticulate sculpin (Cottus perplexus).

There is great seasonal variation in streamflow. Major freshets occur from November to February when the salmon are spawning, but the streamflows drop to a low level during the summer (Table 1). Annual rainfall at the study area is about 250 cm, most of which occurs between October and May. Air temperatures range from -7 to 32°C, but the temperature regimes of the unlogged, heavily shaded streams are relatively stable (Table 2).

The watersheds consist of moderate to steep-sloped canyons typical of those in the Oregon Coast Range. Prior to logging they were forested primarily with Douglas-fir (Pseudotsuga menziesii), with varying percentages of red alder (Alnus rubra). The understory

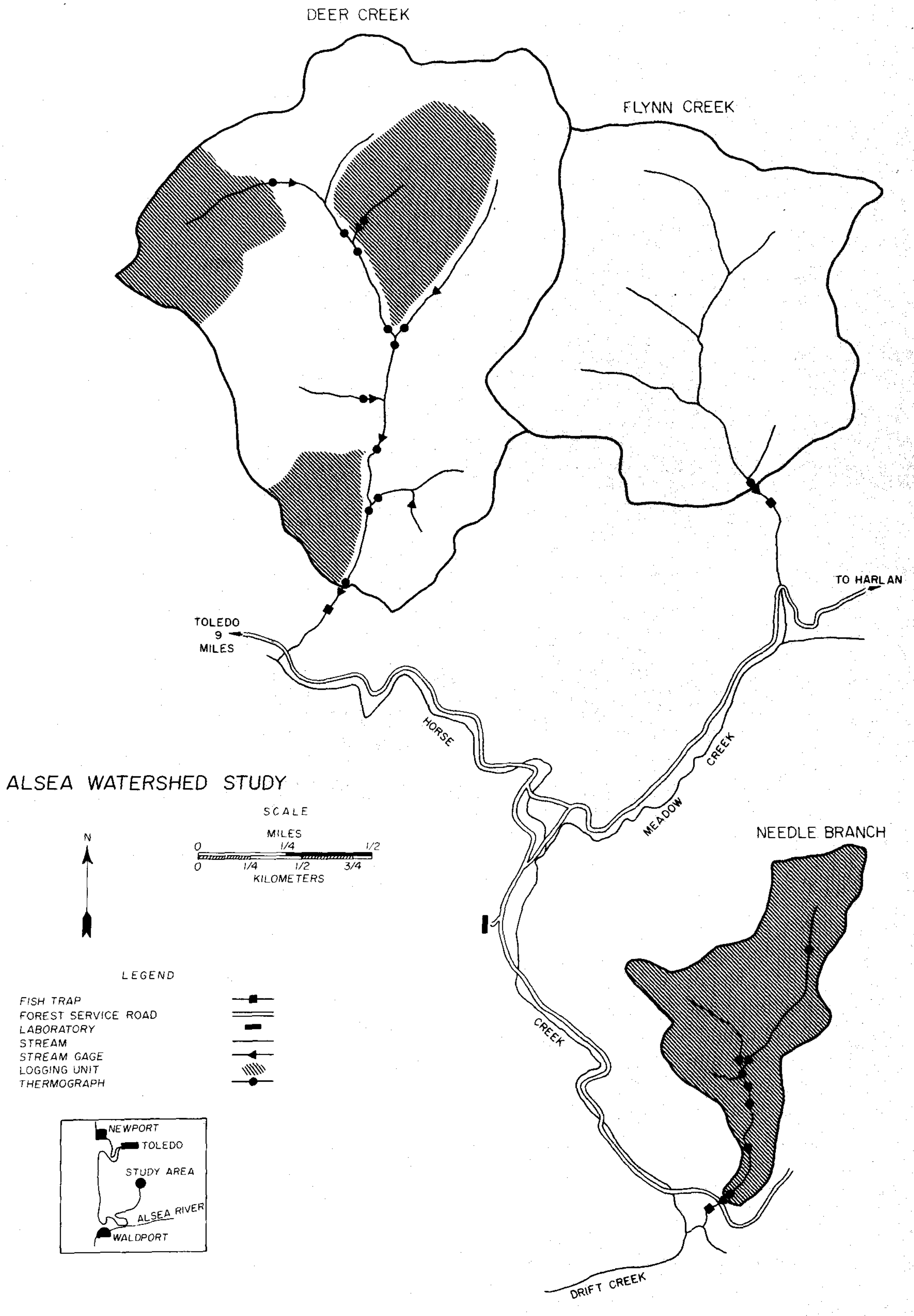


Figure 1. Map of the study streams.

Table 1. Summary of the streamflow regimes (liters per second) in the study streams before logging, 1959 through 1965. (Data from U. S. Geological Survey).

Stream	Daily Mean	Range of Annual Means	Mean Minimum Summer Flow	Peak Winter Flow
Deer Creek	183	157-219	8.5	5688
Flynn Creek	126	118-206	4.5	3877
Needle Branch	42	35-48	0.6	1415

Table 2. Summary of temperature regimes (°C) in the study streams before logging, 1959 through 1965. (Data from U. S. Geological Survey).

Stream	Annual Mean	Range of Monthly Means	Minimum Temperature	Maximum Temperature	Diurnal Temperature Range
Deer Creek	9.6	6.7-12.8	1.1	16.1	0.5-2.2
Flynn Creek	9.7	7.2-12.8	2.2	16.6	0.5-2.2
Needle Branch	9.7	6.1-12.8	1.6	16.1	0.5-1.5

consisted largely of salmonberry (*Rubus spectabilis*), vine maple (*Acer circinatum*), and salal (*Gaultheria shallon*) (Corliss and Dyrness, 1965).

The gravel in the streambed consists of micaceous sandstones intermixed with mudstones and siltstones. It originated from marine sedimentary deposits during the Middle Eocene epoch (Vokes, Norbisrath, and Snavely, 1949).

ACCOUNT OF LOGGING

Access roads were built into the Needle Branch and Deer Creek watersheds in 1965, and logging occurred in 1966. High-lead yarding was used on both streams.

The Needle Branch watershed (70 hectares) was entirely clear-cut, the operation extending from March to September. Cable yarding of logs across the stream channel to uphill landings resulted in sediment deposition on the spawning gravel, but most of the fry had emerged before yarding had begun. Considerable amounts of organic debris remained in the stream channel, creating ponds in which dissolved oxygen levels dropped to a low of 0.6 mg/l in June of 1966. Intragravel dissolved oxygen had dropped to an average of 1.3 mg/l by June 30. The maximum surface temperature was 24°C in August, 8°C higher than the pre-logging maximum. The stream channel was cleared of large debris in September, and slash burning occurred in October of 1966. Surface water temperatures as great as 28°C occurred when the slash burning was in progress. Fall freshets removed much of the debris and sediment from the surface of the spawning gravel, and dissolved oxygen in the surface water returned to near-saturation values characteristic of pre-logging conditions. Intragravel dissolved oxygen, however, remained about 3 mg/l below the average of the values recorded prior to logging (Hall and Lantz, 1969).

In the Deer Creek watershed cutting began in May, and yarding was completed by December 1966. Three areas, totaling about 25 percent of the 305-hectare watershed, were removed in staggered settings. A strip of vegetation, consisting largely of red alder, was left along the stream channel. No changes were observed in the stream environment immediately after logging. Because few trees had been felled into the stream, clearance of debris from Deer Creek was unnecessary. Slash burning of the three clearcut areas occurred at different times. One was burned in 1967, another in 1968, and the third in 1969.

The Flynn Creek watershed (200 hectares) was left unlogged to serve as a control throughout the study.

METHODS

Dissolved Oxygen

Intragravel water in coho salmon redds was sampled from standpipes installed approximately four weeks after spawning was complete. The pipes were constructed of 85-cm lengths of 1.25-cm diameter PVC plastic pipe. The lower 8 cm of each pipe was perforated with 20 4.7-mm holes, as described by McNeil (1962). A single standpipe was placed in the selected redds, except for two redds in each stream in which five pipes were installed. The four additional pipes were spaced around the center standpipe in a circle 60 cm in diameter. Nine redds in Needle Branch and 11 in Deer Creek were chosen for sampling.

In addition to the redd standpipes, Mark VI standpipes (Terhune, 1958) permanently installed in the streambed were used to obtain water samples. Nine of these permanent standpipes were sampled in Needle Branch and Deer Creek. Samples of 60 ml were removed from each standpipe three times weekly from January 15 to May 2, 1969, by oral suction. A modification of the semi-micro Winkler technique (Harper, 1953) was used to determine the dissolved oxygen content. A 25 ml aliquant from the original sample was titrated with 0.025N phenylarsine oxide (PAO), using an automatic burette graduated to 0.01 ml. Samples were taken from one stream in the morning of a sampling day, whereas those of the other stream were obtained during the afternoon. To compensate for possible temperature effects on intragravel dissolved oxygen, the order of sampling was alternated throughout the study period.

Gravel Sampling

Gravel samples were removed from coho salmon redds with a special frozen core device to be described below. Samples were collected during July and August of 1968 following completion of emergence in all streams. The procedure was to sample two points per redd approximately a meter apart along the long axis of the redd. Oregon Game Commission personnel had previously collected samples from the same redds with the sampler described by McNeil and Ahnell (1964). My samples were spaced between the points already sampled to allow a comparison of the two sampling methods. I also obtained gravel samples from areas used as redds during previous years. Such previously used locations are termed "former redds".

Frozen Core Sampler

The sampler used in this study was built from a design of Mr. Peter Ryan, Canada Department of Fisheries, Vancouver, British Columbia, who supplied a sketch and explained the principle of its operation. Ryan has recently developed several improvements in the design, and now has detailed drawings available. My sampler consists of two tin cans of different sizes, a larger "shell", and a smaller "basket". The shell measures 19 cm high by 16 cm in diameter, and the basket 8 cm high by 12 cm in diameter. The upper third of the basket is perforated with 4.7 mm holes; a 1.25-cm diameter copper tube extends through its base. Blockage of the tube by dry ice fragments or other debris is prevented by a disc of 6.4-mm wire mesh in the bottom of the basket. A 4.15-cm diameter iron pipe passes through the base of the shell; the lower end of the pipe is formed into a driving point (Figure 2).

To accommodate differences in the depth of the surface water, samplers of two lengths were built. For work in shallow water the iron pipe was 52 cm and the copper tube 48 cm long; for work in deep water the iron pipe was 80 cm and the copper tube 75 cm long.

To collect a sample, a wooden block is first placed on the upper end of the iron pipe. By pounding on the block with a hammer, the pipe is driven 30 cm into the streambed. The basket is next placed inside the shell, and acetone poured into the device until the shell is approximately one-third filled and the basket nearly filled. By adding dry ice to the basket, the temperature of the acetone is lowered to about -79°C. The cold, dense acetone sinks into the copper tube and becomes warmed through contact with the relatively warm lower end of the iron pipe. The warmer, lighter acetone then moves upward

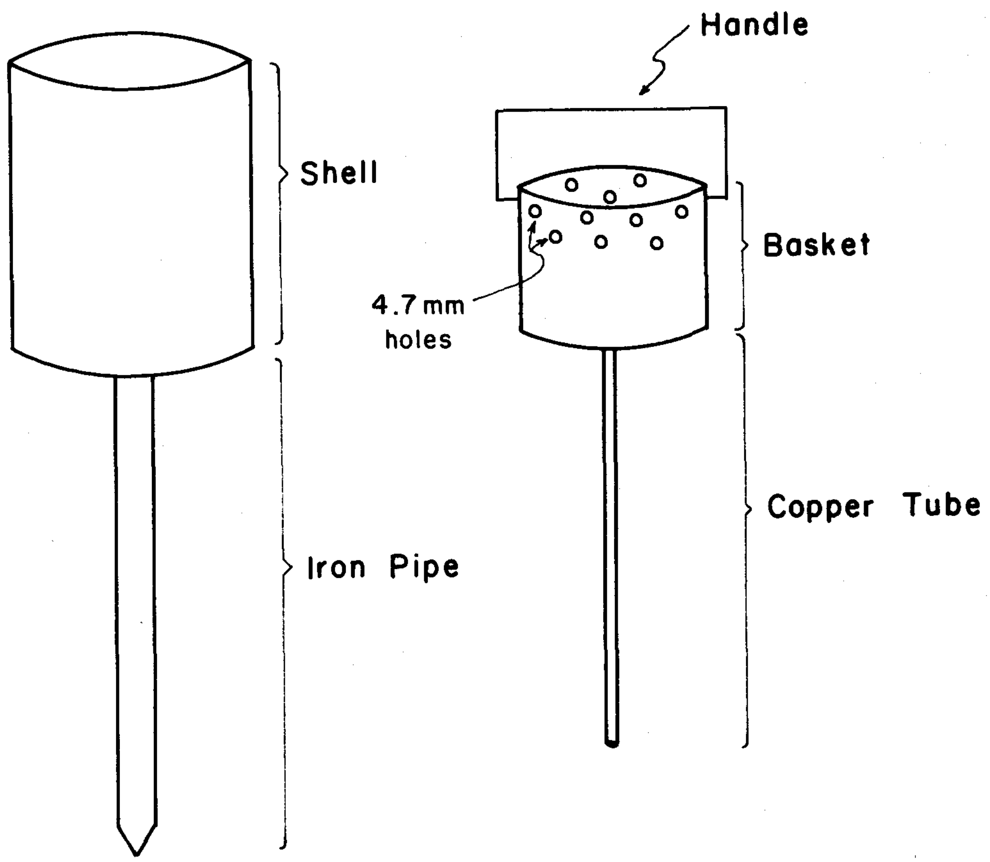


Figure 2. Components of the frozen core sampler.

in the outer pipe and is cooled again by contact with the dry ice in the basket. The resulting circulation of cold acetone within the device lowers the temperature sufficiently to freeze the water and gravel surrounding the pipe (Figure 3).

It was possible to freeze a core 18 to 25 cm in diameter by 35 cm deep in 1-1/2 to 2 hours, during which time 12 to 14 kg of dry ice were used to maintain the freezing temperature. Two samplers were operated simultaneously in a redd.

Removal of the sample from the streambed was facilitated by insertion of a steel hook into two holes at the upper end of the iron pipe. With a combination of upward pressure on the hook and leverage with a shovel, the sample was rapidly extracted from the streambed. While still attached to the sampler, the cores were packed in dry ice and transported to the laboratory. Here, hot water was poured down the iron pipe to release the frozen core of gravel from the sampler.

To evaluate the vertical distribution of sediment, each core was split into four strata while still frozen. A guillotine-like "core splitter" was used (Figure 4). After placing the core between the blades of the splitter, a sharp blow on the upper blade resulted in a relatively even slice. This method was selected in preference to sawing, which provided a somewhat straighter cut but caused the gravel to break into fine particles along the cut edge. Each of the

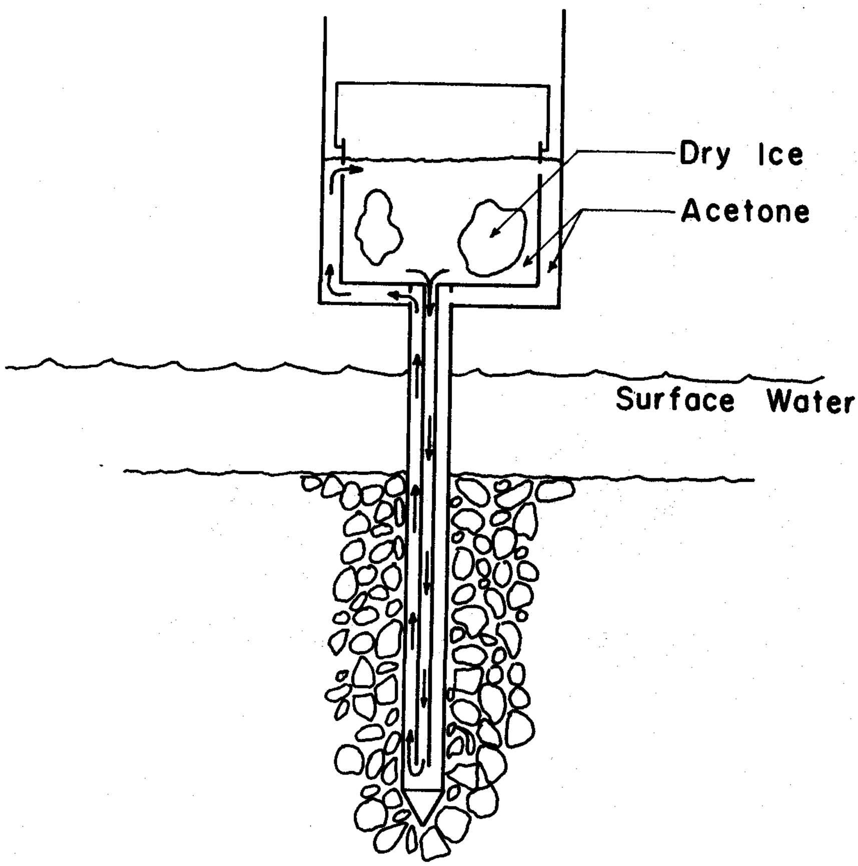
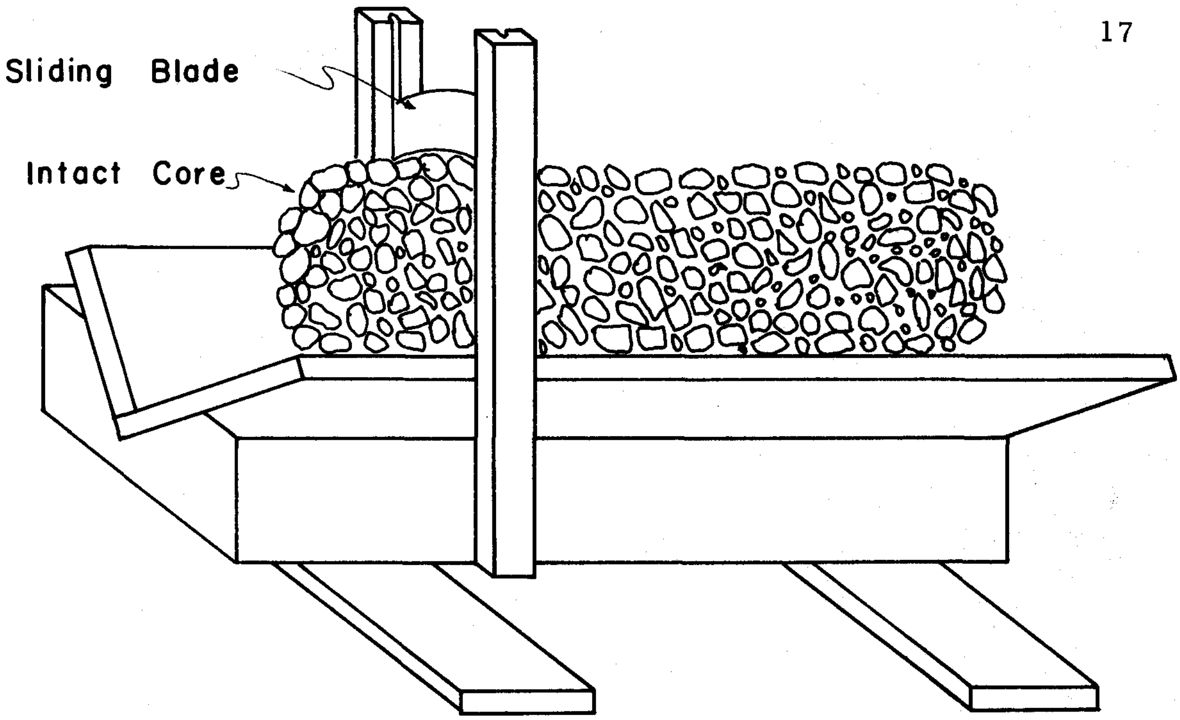
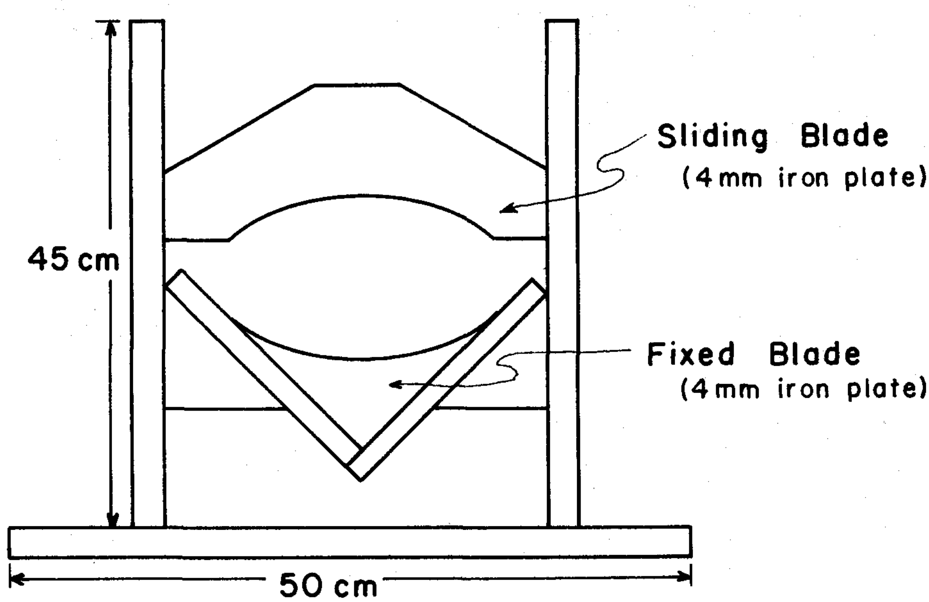


Figure 3. Cutaway view of frozen core sampler in operation. Arrows indicate direction of acetone circulation.



a.



b.

Figure 4. Diagram of core splitter.
a) Frozen core in position for splitting.
b) Front view showing cutting blades.

upper three strata measured approximately 8.3 cm thick, thus representing a vertical column 25 cm deep. The fourth stratum (10-13 cm thick) was below the usual depth of egg deposition. It had a conical shape, and was therefore not completely representative of the 25 to 35 cm depth. Thus, this stratum was discarded.

Each of those strata retained for analysis was cut in two; one portion was kept frozen to be examined for organic content and the other placed in a plastic jar for later analysis of gravel size composition.

Size Composition of the Gravel

Gravel samples were analyzed for size composition with the volumetric technique described by McNeil and Ahnell (1964). Each stratum was washed through a series of sieves having the following square mesh openings (in mm): 50.8, 25.4, 12.7, 6.35, 3.327, 1.65, and 0.833. The sieves were placed on an incline to allow excess water to drain, after which the material caught in each sieve was measured by volumetric displacement and expressed as a percentage of the total volume of the sample.

Organic Material

The percentage of organic material in the gravel samples was determined by weight loss upon ignition. Each stratum was thawed overnight and dried for 24 hours at 105°C. After being cooled in a dessicator, the samples were sieved through a 6.35 mm Tyler sieve. The two resulting fractions were then weighed to the nearest gram on a Toledo balance. A baffle-type sample splitter was used to obtain two 45 to 60 gram subsamples from the fraction passing the sieve. These subsamples were placed in preweighed crucibles, dried for 24 hours at 105°C, and cooled in a dessicator. They were then weighed on a Mettler P-120 balance accurate within 2 mg. The samples were burned at 600°C for five hours in a muffle furnace, and subsequently cooled and reweighed. A mean percentage weight loss of the two subsamples was calculated for the fraction passing the 6.35 mm sieve.

The fraction of the original sample not passing the sieve was inspected visually for organic debris, which was removed and weighed. The weight of the organic material was expressed as a fraction of the weight of gravel retained by the sieve.

Finally, the total percentage of organic material in each stratum was determined as follows:

$$\text{Total \% Organic Material} = \frac{\begin{pmatrix}\text{Weight of frac-}\\ \text{tion} < 6.35\text{ mm}\end{pmatrix}\begin{pmatrix}\text{Mean \% weight loss}\\ \text{of subsamples from}\\ \text{fraction} < 6.35\text{ mm}\end{pmatrix} + \begin{pmatrix}\text{Weight of visible}\\ \text{organic debris}\\ \text{in fraction} > 6.35\text{ mm}\end{pmatrix}}{\text{Total Weight of Sample}}$$

Biochemical Oxygen Demand

Water samples removed from permanent standpipes in the three streams were analyzed for biochemical oxygen demand. Sampling occurred in the summer of 1968. The analysis was modified from that described in Standard Methods for the Examination of Water and Wastewater (1965). Water samples of 140 ml were removed by oral suction and collected in 300 ml bottles. These samples, brought to 20°C by suspension in a water bath, were subsequently saturated with oxygen in a Waring Blendor and placed immediately in two 60-ml glass-stoppered bottles. One bottle was used to determine the initial dissolved oxygen content; the second was incubated at 20°C for five days. The difference in dissolved oxygen between initial and incubated samples was taken as the biochemical oxygen demand.

Temperature and Streamflow

Surface temperatures of the three streams were recorded throughout the study period with Partlow thermographs accurate within 0.3°C. Thermograph probes were also buried 25 cm in the gravel at three points along Needle Branch. Installed in artificially dug redds in June 1968, these probes provided a continuous record of intragravel temperature until September. New redds were dug late in February of 1969, and the probes reburied. Temperature records were obtained from these redds between March and June, 1969.

The temperature in natural redds was studied with a thermister probe accurate within 0.5°C. During the summer of 1968, temperatures at depths from 2 to 50 cm were obtained by forcing the probe into the gravel and reading the temperature directly from a meter. A ruler mounted on a tripod provided a measure of the depth of the probe. Temperature data were obtained in the 1969 redds in March and April by lowering the probe into the redd standpipes.

Streamflow data for each stream were obtained from the U. S. Geological Survey gaging stations.

RESULTS

Dissolved Oxygen

The mean dissolved oxygen concentration in the gravel of Needle Branch was consistently lower than that of Deer Creek during the period of redd occupancy (Figure 5). Each point on the graph represents the mean of a series of highly variable values (Appendix 1). However, t-test comparisons indicated that the differences between streams were significant at the 99 percent confidence level for each 14-day interval except one (Table 3). The mean dissolved oxygen for the entire season in Deer Creek redds was 8.91 mg/l, whereas Needle Branch redds averaged 7.15 mg/l.

Table 3. Mean dissolved oxygen (mg/l) in redds in Deer Creek and Needle Branch during intervals of 14 days and during the entire season (January 15-May 2, 1969).

Dates Included	Deer Creek	Needle Branch	Difference
Jan. 15-Jan. 28	9.27	8.48	0.79
Jan. 29-Feb. 11	9.61	8.20	1.48**
Feb. 12-Feb. 24	9.20	7.46	1.74**
Feb. 25-Mar. 10	8.94	6.88	2.06**
Mar. 11-Mar. 24	8.79	6.94	1.85**
Mar. 25-Apr. 7	8.48	6.58	1.90**
Apr. 8-Apr. 22	8.62	6.38	2.24**
Apr. 23-May 2	8.37	5.93	2.44**
Jan. 15-May 2	8.91	7.15	1.76**

** Difference significant at the 99 percent confidence level.

Thus, Needle Branch redds contained an average of 19.7 percent less dissolved oxygen than those of Deer Creek. As the season progressed,

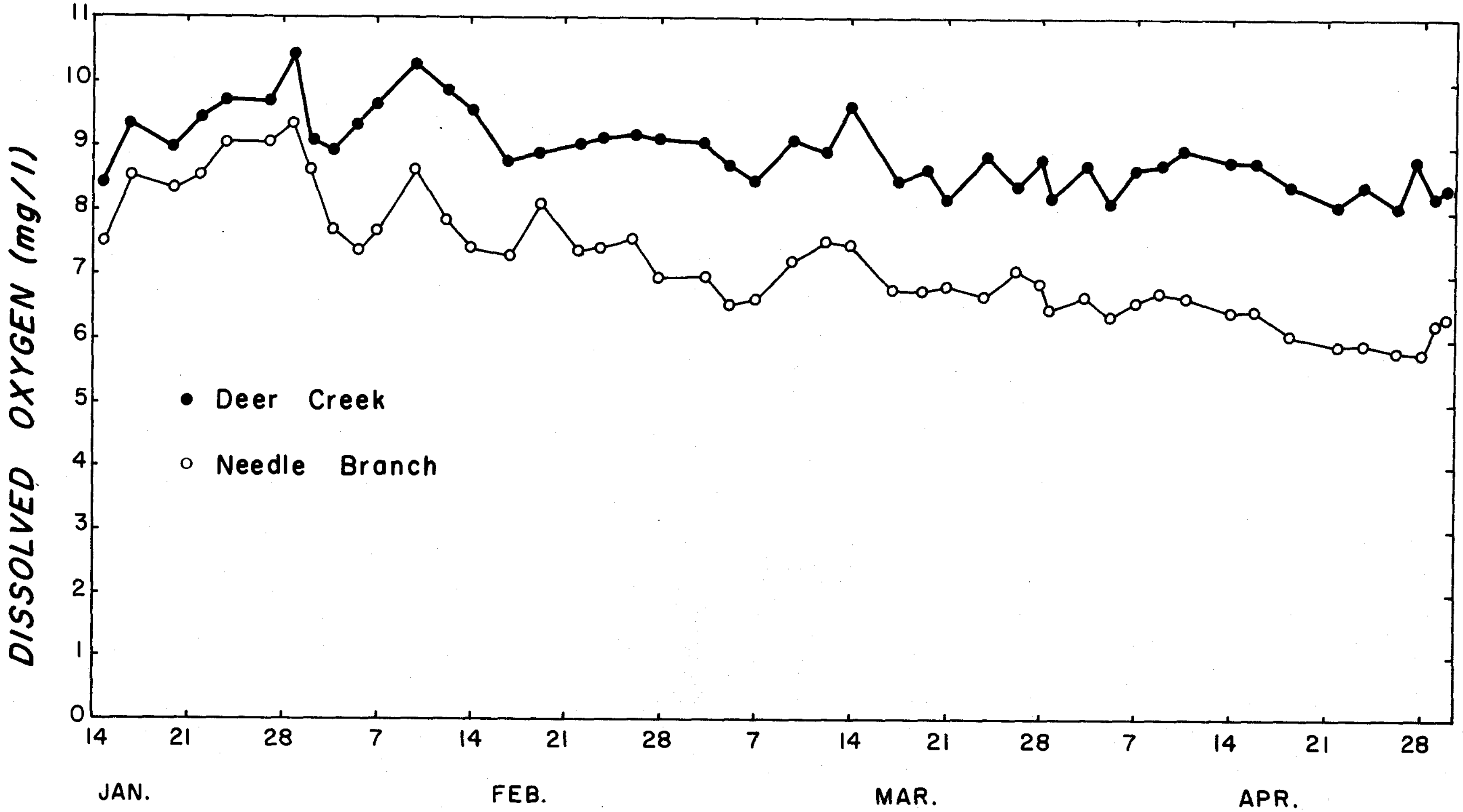


Figure 5. Mean dissolved oxygen in redds in relation to date of sampling (Deer Creek and Needle Branch).

a gradual reduction in mean dissolved oxygen occurred in both streams. Because this reduction was much more prominent in Needle Branch, the difference in mean dissolved oxygen between streams increased during the season. For example, the difference between streams was only 0.79 mg/l during the last two weeks in January, but had increased to 2.44 mg/l during the last two weeks in April.

There was a greater difference between streams in dissolved oxygen measured at permanent (Mark VI) standpipes than existed in the redds (Figure 6). Differences for each biweekly interval except one were significant at the 99 percent confidence level, and mean dissolved oxygen tended to decline as the season progressed (Table 4). The seasonal difference between streams was 2.46 mg/l, in contrast to the 1.76 mg/l difference measured in redds.

Table 4. Mean dissolved oxygen (mg/l) in permanent standpipes in Deer Creek and Needle Branch during intervals of 14 days and during the entire season (January 15-May 2, 1969).

Dates Included	Deer Creek	Needle Branch	Difference
Jan. 15-Jan. 28	9.63	7.20	2.43**
Jan. 29-Feb. 11	8.97	8.02	0.95
Feb. 12-Feb. 24	8.76	7.02	1.74**
Feb. 25-Mar. 10	9.36	6.18	3.18**
Mar. 11-Mar. 24	9.37	6.63	2.74**
Mar. 25-Apr. 7	8.06	5.28	2.78**
Apr. 8-Apr. 22	7.91	5.18	2.73**
Apr. 23-May 2	7.65	4.56	3.09**
Jan. 15-May 2	8.72	6.26	2.46**

** Difference significant at the 99 percent confidence level.

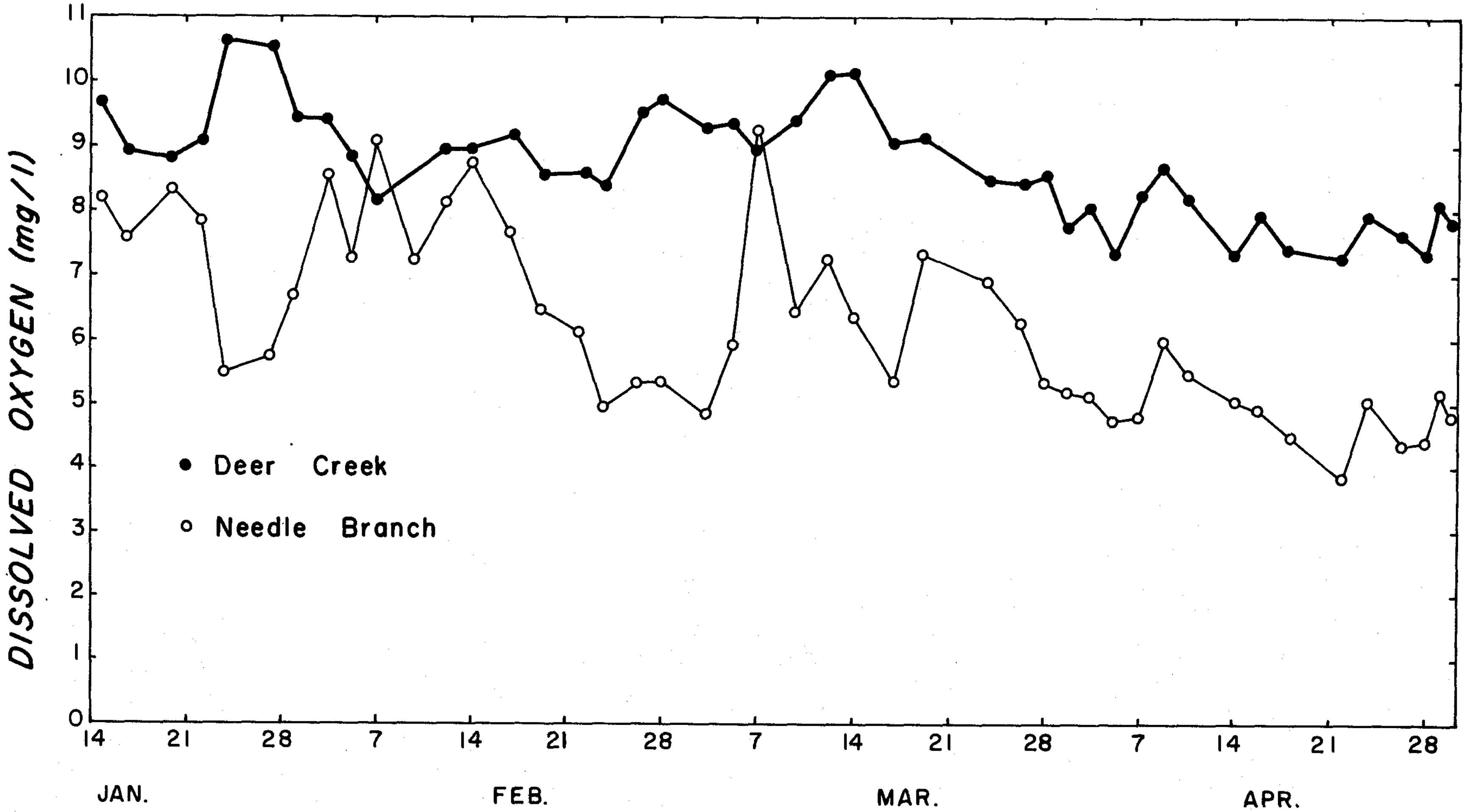


Figure 6. Mean dissolved oxygen in permanent standpipes in relation to date of sampling (Deer Creek and Needle Branch).

In Needle Branch, the mean dissolved oxygen in permanent standpipes underwent far greater changes between sampling days than did the mean dissolved oxygen in the redds. This phenomenon may reflect a less stable gravel bed in the vicinity of the permanent standpipes than existed in the redds; extensive erosion was observed to occur around two of the Needle Branch permanent standpipes. Oxygen levels in the permanent standpipes also tended to be lower than those in standpipes located in redds; a t-test indicated that the difference in mean values (0.89 mg/l for the season) was significant at the 99 percent confidence level. During the last two weeks in April, the dissolved oxygen in permanent standpipes averaged 1.37 mg/l lower than the mean in redds. Apparently, the spawning activities of female salmon significantly improved the intragravel environment of the redds.

Little difference was observed between oxygen levels in the redds and permanent standpipes in Deer Creek. This result suggests that the gravel in Deer Creek prior to spawning provided a better environment than the gravel in Needle Branch, so that the influence of spawning activities was less pronounced in Deer Creek. However, the standpipes in redds and permanent locations in Deer Creek were not in the same area of the stream; all but one of the redds sampled were located 800 meters downstream from the nearest permanent standpipe. If the lower reaches of the stream had inherently lower dissolved oxygen levels, the difference between redds and permanent standpipe locations would be concealed.

Dissolved oxygen levels in both streams showed considerable variation along the streambed. Lateral variation was evident within the redds as well, but in general, individual standpipes provided a good index of oxygen levels within a redd (Appendix 1).

Differences between streams in mean dissolved oxygen may be misleading because of the spatial and temporal variation in the data. Mean dissolved oxygen provides an indication of the quality of intragravel water, but the minimum concentration may be the critical factor in terms of fish survival. Although 6 to 7 mg/l has been suggested as an oxygen concentration required by salmonids in nature, no precise minimum level has been established (Doudoroff and Shumway, 1967). In my study, 6 mg/l was selected as the minimum dissolved oxygen concentration necessary for high survival of coho salmon. In Needle Branch, 5 of 9 redds (56 percent) studied had minimum dissolved oxygen levels below 6 mg/l, and 4 of 11 redds (36 percent) in Deer Creek had such levels. At the permanent standpipe locations, 7 of 9 Needle Branch sites (78 percent) dropped below 6 mg/l, and 3 of 9 Deer Creek sites (33 percent) fell below this concentration. Thus, fewer redds, or potential redds, provided an environment conducive to high survival in Needle Branch than in Deer Creek.

Increases or decreases of intragravel dissolved oxygen in Needle Branch tended to be paralleled by similar changes in Deer Creek. Environmental variables ultimately influencing intragravel water quality were apparently operating simultaneously on both streams. The seasonal reduction in dissolved oxygen levels coincided with generally higher temperatures and lower streamflows. Thus, it appeared that these variables might be influencing the intragravel dissolved oxygen.

In an attempt to determine the relationship of streamflow, temperature, and season to dissolved oxygen, a multiple regression analysis was run. Dissolved oxygen was set as the dependent variable; streamflow, temperature, and date of sampling were set as the independent variables. Separate analyses were made for the redds and permanent standpipe locations in each stream.

When the date of sampling was excluded as a variable, the coefficients of determination for Needle Branch and Deer Creek redds were 0.49 and 0.61, respectively. For permanent standpipe locations, coefficients of 0.41 were obtained in both streams. Thus, except for Deer Creek redds, less than half of the observed variability in mean dissolved oxygen was accounted for by fluctuations in temperature and streamflow.

Inclusion of the date of sampling significantly improved the regression equation. The coefficients of determination for the redds in Needle Branch and Deer Creek were then 0.77 and 0.65, respectively. Values of 0.56 and 0.61 were computed for the permanent standpipes in Needle Branch and Deer Creek, respectively. These improvements suggested that some factor associated with time, such as accrual of sediment to the streambed, was not being taken into account in this regression equation.

The dissolved oxygen concentration of the surface water in Needle Branch averaged 0.57 mg/l lower than that of Deer Creek during the entire season. However, the percentage saturation of dissolved oxygen was almost identical in the two streams. Therefore, the difference in surface dissolved oxygen could be attributed to the physical effect of temperature on solubility.

The temperature of the intragravel water was not obtained at each station sampled, but was found to approximate the surface temperature during the morning hours. Thus, an estimate of the percentage saturation of the intragravel water could be made from the oxygen data collected during the morning (Table 5). The mean percentage oxygen saturation in redds was 76.7 in Deer Creek and 61.8 in Needle Branch for the season. Thus, Needle Branch averaged 19.4 percent lower in percentage saturation than Deer Creek, a difference almost identical to that of the actual concentration of dissolved oxygen. Therefore, the effect of temperature on solubility did not explain the difference between streams in intragravel dissolved oxygen. Furthermore, the reduction in dissolved oxygen as the season progressed was not simply the result of the effect of temperature on solubility, because percentage saturation also decreased with time. In general, the lowest saturation values were associated with the highest temperatures.

Table 5. Mean percent saturation in redds in Deer Creek and Needle Branch during 28-day intervals and during the entire season (January 15-May 2, 1969).

Dates Included	Deer Creek	Needle Branch	Difference
Jan. 15-Feb. 11	79.4	68.9	13.5**
Feb. 12-Mar. 10	76.8	63.7	13.1**
Mar. 11-Apr. 7	75.7	59.0	16.7**
Apr. 7-May 2	74.9	55.5	19.4**
Jan. 15-May 2	76.7	61.8	14.9**

** Difference significant at the 99 percent confidence level.

Prior to logging, Koski (1966) measured the intragravel dissolved oxygen concentration in the study streams. Redds were sampled approximately twice each week from February to June during 1964, and permanent standpipes were sampled at two-week intervals. Mr. Koski has kindly permitted the use of his data for a comparison of dissolved oxygen levels before and after logging (Table 6). Each of the comparisons to be discussed below was made using data collected between February 12 and May 2 of 1964 and 1969.

Table 6. Mean dissolved oxygen (mg/l) in redds and permanent standpipes before and after logging of Deer Creek and Needle Branch (February 12-May 2, 1964 and 1969).

	Deer Creek					Needle Branch				
	Feb. 12-Mar. 10	Mar. 11-Apr. 7	Apr. 8-May 2	Feb. 12-May 2	No. Samples	Feb. 12-Mar. 10	Mar. 11-Apr. 7	Apr. 8-May 2	Feb. 12-May 2	No. Samples
Redds										
1964	10.57	9.71	9.75	10.01	25	11.46	10.28	10.29	10.68	24
1969	9.07	8.64	8.50	8.74	35	7.17	6.76	6.15	6.69	35
Difference	1,50**	1.07**	1.25**	1.27**		4.29**	3.52**	4.14**	3.99**	
Percent Change	14.2	11.0	12.8	12.7		37.5	34.3	40.2	37.4	
Permanent Standpipes										
1964				8.95	7				10.21	7
1969				8.50	34				5.79	34
Difference				0.45					4.42**	
Percent Change				5.02					43.2	

** Difference significant at the 99 percent confidence level.

In 1964, there was no significant difference in dissolved oxygen between the redds of Needle Branch and Deer Creek. Values in permanent standpipes averaged somewhat lower than those in redds, but the difference was not significant at the 95 percent confidence level.

The permanent standpipes in Deer Creek registered a small change in the intragravel environment after logging. The seasonal mean dissolved oxygen was 8.95 mg/l during 1964, and 8.50 mg/l in 1969. The difference was not significant at the 95 percent confidence level.

Deer Creek redds underwent a 12.7 percent reduction in dissolved oxygen between the years 1964 and 1969, and the change was significant at the 99 percent confidence level. However, most of the 1964 redds were located in the upper portion of Deer Creek, whereas the 1969 redds were largely in the lower reaches of the stream. Part of the difference in mean dissolved oxygen may thus reflect differences in the gravel at two widely separated points on Deer Creek, rather than changes in the environment resulting from logging.

In Needle Branch, dissolved oxygen in the permanent standpipes dropped from a mean of 10.21 mg/l in 1964 to 5.79 mg/l in 1969, a reduction of 43.2 percent. The extent of the change is apparent when the number of sites in which the dissolved oxygen fell below 6 mg/l is compared. In 1964, 2 of the 11 sites (22 percent) had minimum dissolved oxygen levels below 6 mg/l, compared to 7 of 9 sites (78 percent) in 1969.

Dissolved oxygen levels in Needle Branch redds averaged 10.68 mg/l in Koski's study, and 6.69 mg/l in the present work. In contrast to Deer Creek redds, the redds in Needle Branch were in similar locations in 1964 and 1969 (Figure 7). The change in mean dissolved oxygen represents a decrease of 37.4 percent following logging. Only 1 of 11 redds (9 percent) had minimum dissolved oxygen concentrations below 6 mg/l in 1964, whereas 5 of the 9 redds (56 percent) had minima below this level in 1969. The change in Needle Branch redds was somewhat less than that in permanent standpipes and may be indicative of the improvement of the redd environment by the digging activities of female salmon.

Organic Material

Organic material, consisting largely of Douglas-fir needles, bark or wood fragments, and small detritus, made up a small fraction of the gravel samples, the values ranging from 0.33 to 7.52 percent by weight. Nearly all (97.6 percent) of the organic debris consisted of material that passed through a 6.35 mm sieve. Only 22 percent of the samples analyzed contained any organic material larger than 6.35 mm.

Variability in organic content was evident within redds and at different locations along the stream (Appendix 2). Organic content

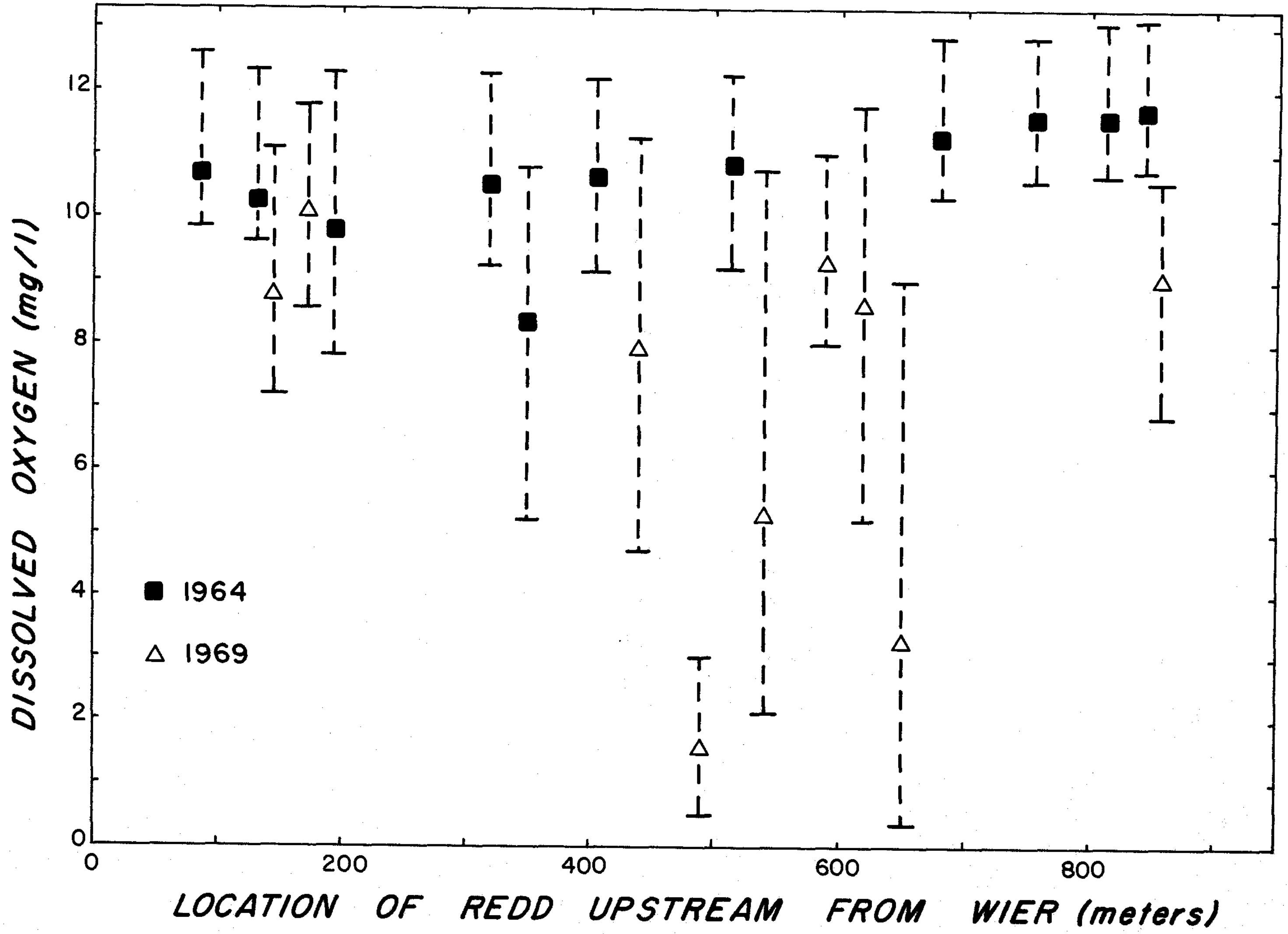


Figure 7. Mean and range of dissolved oxygen levels in Needle Branch redds during 1964 and 1969 (February 12 - May 2).

was directly related to the quantity of fine sediment (< 3.327 mm) in the gravel sample (r = 0.75). Thus, those samples containing the most fine sediment also contained the most organic material (Figure 8). No definite pattern of vertical distribution of organic debris existed, either in the redds or in the former redds (Table 7). Differences between the strata in mean organic content were not significant at the 95 percent confidence level, except in former redds in Needle Branch where Stratum 3 contained significantly greater amounts of organic debris than Stratum 1. There was no apparent pattern to the distribution of organic debris along the length of the stream channel.

In Needle Branch, the redds contained 32.2 percent less organic debris than the former redds, a difference significant at the 99 percent confidence level. The three redds sampled in Flynn Creek did not differ significantly from the former redds, but there were too few sites sampled in Flynn Creek to determine whether redds were comparable to former redds.

Although Needle Branch redds averaged 20.6 percent higher in organic debris than Deer Creek, the difference was not statistically significant. Flynn Creek redds were somewhat higher in organic content than either Needle Branch or Deer Creek redds. The former redds in Flynn Creek, however, contained significantly less organic material than did those in Needle Branch.

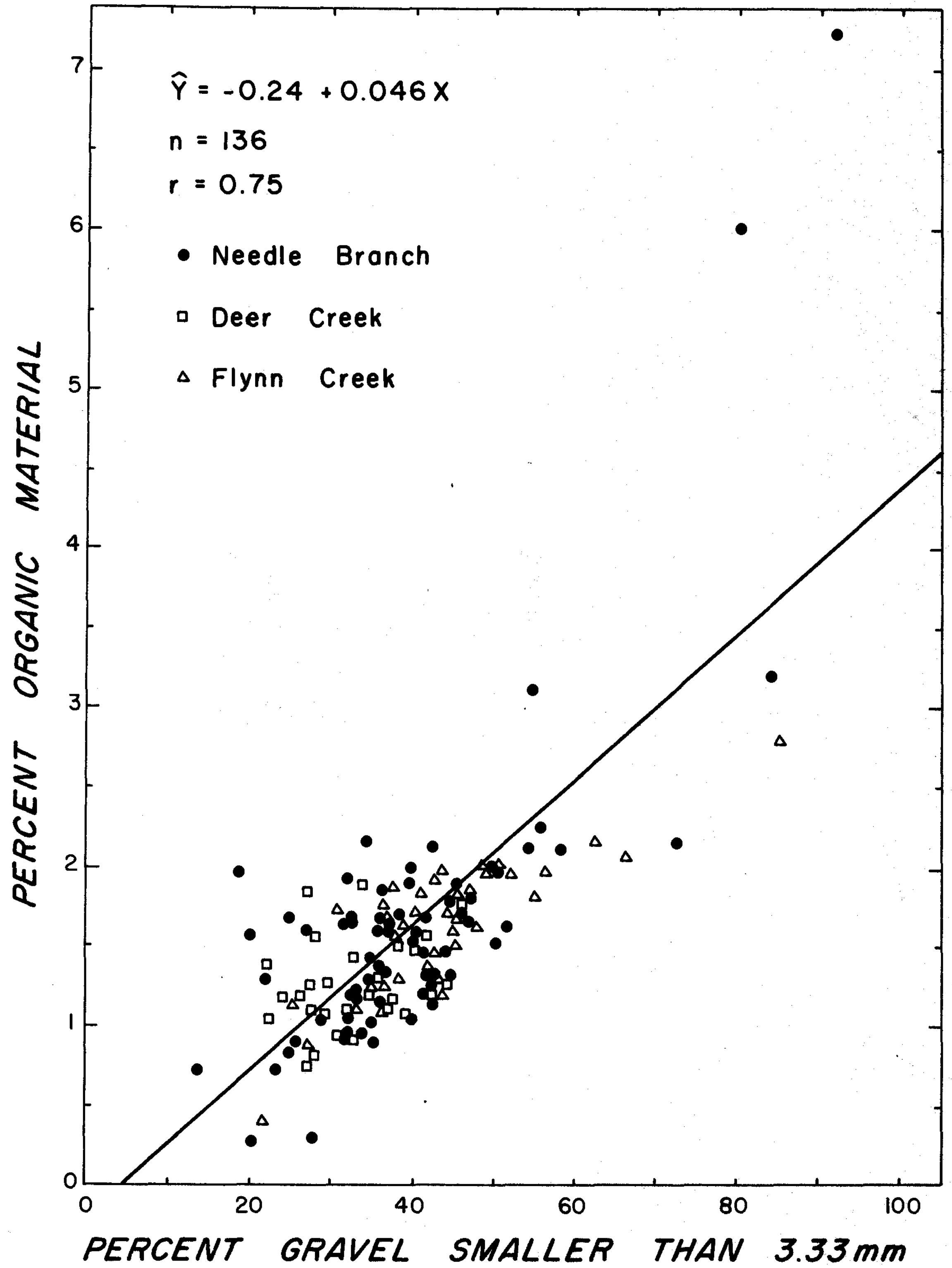


Figure 8. Relationship between organic material and fine sediment in the gravel of the study streams.

Table 7. Percent organic material in gravel samples removed from the study streams (July-August, 1968).

	Needle Branch				Deer Creek				Flynn Creek			
	Mean	Range	No. Redds	No. Samples	Mean	Range	No. Redds	No. Samples	Mean	Range	No. Redds	No. Samples
Redds												
Stratum												
1	1.67	1.01-2.37	8	16	1.16	0.72-1.49	5	10	1.51	1.28-1.85	3	6
2	1.55	0.98-2.29	8	16	1.34	1.04-1.83	5	10	1.72	1.24-2.09	3	6
3	1.21	0.33-2.18	8	16	1.26	0.90-1.72	5	10	1.98	1.19-2.84	3	5
	1.48				1.22				1.74			
Former Redds												
Stratum												
1	1.59	0.82-3.25	6	7	--	--	--	--	1.66	1.08-1.80	5	7
2	2.30	0.76-6.03	6	8	--	--	--	--	1.68	0.85-2.09	5	7
3	2.65	1.30-7.52	6	7	--	--	--	--	1.56	0.48-2.20	5	7
	2.18								1.63			

Biochemical Oxygen Demand

The biochemical oxygen demand of the intragravel water was extremely low during the summer of 1968, averaging 1.95 mg/l for the three streams. The slight differences in biochemical oxygen demand between streams on a given date were not statistically significant, nor were they consistent at successive sampling periods (Table 8). There were no detectable differences among the values for biochemical oxygen demand of the intragravel water of the three streams.

Size Composition of the Gravel

There were relatively small differences in mean gravel size composition among the three depth-strata studied. Because the fine sediment was of primary interest, a mean value for the percentage of particles passing the 0.83 and 3.33 mm sieves was computed for each stratum (Table 9). The mean percentage of fine particles smaller than 0.83 mm decreased slightly with depth in Needle Branch and Deer Creek redds, but in Flynn Creek redds there was practically no difference among strata. Within the former redds in Flynn Creek and Needle Branch, the greatest amounts of fine sediment smaller than 0.83 mm occurred in the third stratum. The distribution of particles smaller than 3.33 mm was similar to that of the particles

Table 8. Biochemical oxygen demand of intragravel and surface water in the study streams (June 27-July 15, 1968).

	Intragravel			Surface		
	Mean	Range	No. Samples	Mean	Range	No. Samples
Needle Branch						
June 27	1.76	1.42-2.51	5	1.78	1.46-2.11	2
July 5	2.02	1.47-3.47	5	1.09	1.02-1.23	3
July 15	1.38	0.90-1.96	9	--	--	--
Deer Creek						
June 27	3.15	0.98-4.58	5	1.06	0.98-1.14	2
Flynn Creek						
June 27	1.82	0.89-3.29	5	1.67	1.25-2.10	2
July 5	1.45	1.26-1.96	6	1.31	1.18-1.43	2
July 15	2.11	1.11-2.98	9	--	--	--

Table 9. Percent gravel smaller than 0.83mm and 3.33mm in each depth-stratum of the study streams (July-August, 1968); Stratum 1 = 0-8.3 cm; 2 = 8.3-16.6 cm; 3 = 16.6-25 cm.

	Needle Branch				Deer Creek				Flynn Creek			
	Mean	Range	No. Redds	No. Samples	Mean	Range	No. Redds	No. Samples	Mean	Range	No. Redds	No. Samples
0.83 mm												
Redds												
Stratum												
1	26.23	11.98-41.58	8	16	24.93	16.11-34.24	5	10	29.90	24.76-34.58	3	6
2	23.72	12.46-44.84	8	16	19.80	12.31-27.13	5	10	29.27	25.22-38.01	3	6
3	22.34	8.08-46.61	8	16	19.64	13.77-26.76	5	10	30.19	15.20-53.49	3	6
	24.10				21.46				29.78			
Former Redds												
Stratum												
1	37.40	14.63-70.01	6	8	--	--	--	--	24.57	21.28-31.78	5	7
2	35.13	15.37-66.25	6	8	--	--	--	--	26.56	16.61-34.01	5	7
3	41.74	19.10-88.02	6	8	--	--	--	--	31.50	14.63-52.62	5	7
	38.08								27.54			
3.33 mm												
Redds												
Stratum												
1	37.39	19.77-56.44	8	16	35.36	27.15-44.08	5	10	41.30	35.57-47.44	3	6
2	36.07	20.33-51.50	8	16	31.48	22.03-41.51	5	10	44.46	37.50-49.79	3	6
3	34.18	14.72-56.31	8	16	31.92	23.20-46.97	5	10	49.71	28.88-87.14	3	6
	35.88				32.92				45.16			
Former Redds												
Stratum												
1	49.61	22.62-84.61	6	8	--	--	--	--	38.06	30.56-46.12	5	7
2	47.40	24.69-80.23	6	8	--	--	--	--	41.97	28.80-51.50	5	7
3	55.66	29.69-91.61	6	8	--	--	--	--	44.88	22.56-67.52	5	7
	50.89								41.64			

smaller than 0.83 mm, except that in Flynn Creek redds sediment tended to increase with depth. None of the differences in sediment content among strata was significant at the 95 percent level when a least significant difference test (Snedecor and Cochran, 1967) was employed.

The use of mean values in making comparisons of the strata obscures the fact that the vertical distribution of fine sediment was highly variable. The distribution of sediment varied in all three streams, not only among redds, but within individual redds as well (Appendix 2). Figure 9 illustrates the variability among and within redds in Needle Branch. In some instances, even visual inspection of the intact cores revealed distinct differences in stratification within redds. Apparently, the pattern of layering of fine sediment is a local phenomenon, rather than one that characterizes the streambed as a whole.

Needle Branch redds averaged 9 percent higher than Deer Creek redds in particles smaller than 3.33 mm. The difference was not significant at the 95 percent confidence level. The three redds sampled in Flynn Creek averaged considerably higher in fine particles than the redds in either Needle Branch or Deer Creek, but the small

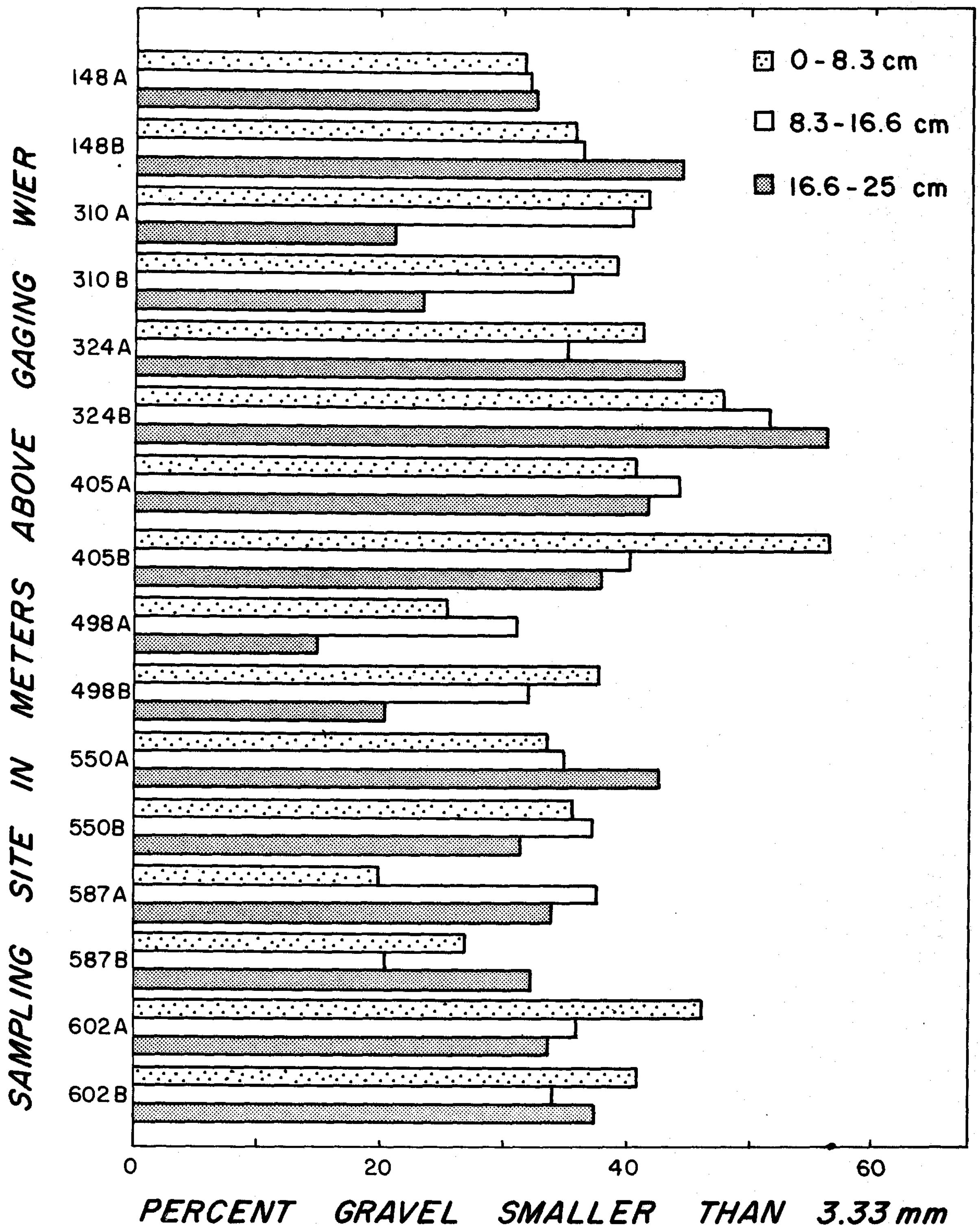


Figure 9. Vertical distribution of sediment in Needle Branch redds.

sample size in Flynn Creek makes definite conclusions difficult.

The redds in Needle Branch contained on the average 29.6 percent less fine sediment (< 3.33 mm) than the former redds, a difference significant at the 99 percent confidence level. Gravel size composition of Needle Branch redds and former redds is shown in Figure 10. The much lower quantity of sediment in the redds than in the former redds suggests that the recent digging activities of coho salmon significantly improved the intragravel environment. That a similar improvement was not detected in Flynn Creek may be the result of the small number of redds sampled there. On the other hand, there may have been little sediment in the Flynn Creek gravel that was subject to removal by spawners.

The former redds in Needle Branch averaged 22.2 percent higher in fine particles than did similar areas in Flynn Creek. The difference was significant at the 99 percent confidence level.

Most of the redds that I sampled were also sampled by Oregon Game Commission personnel, using the device described by McNeil and Ahnell (1964). My values for Needle Branch and Deer Creek

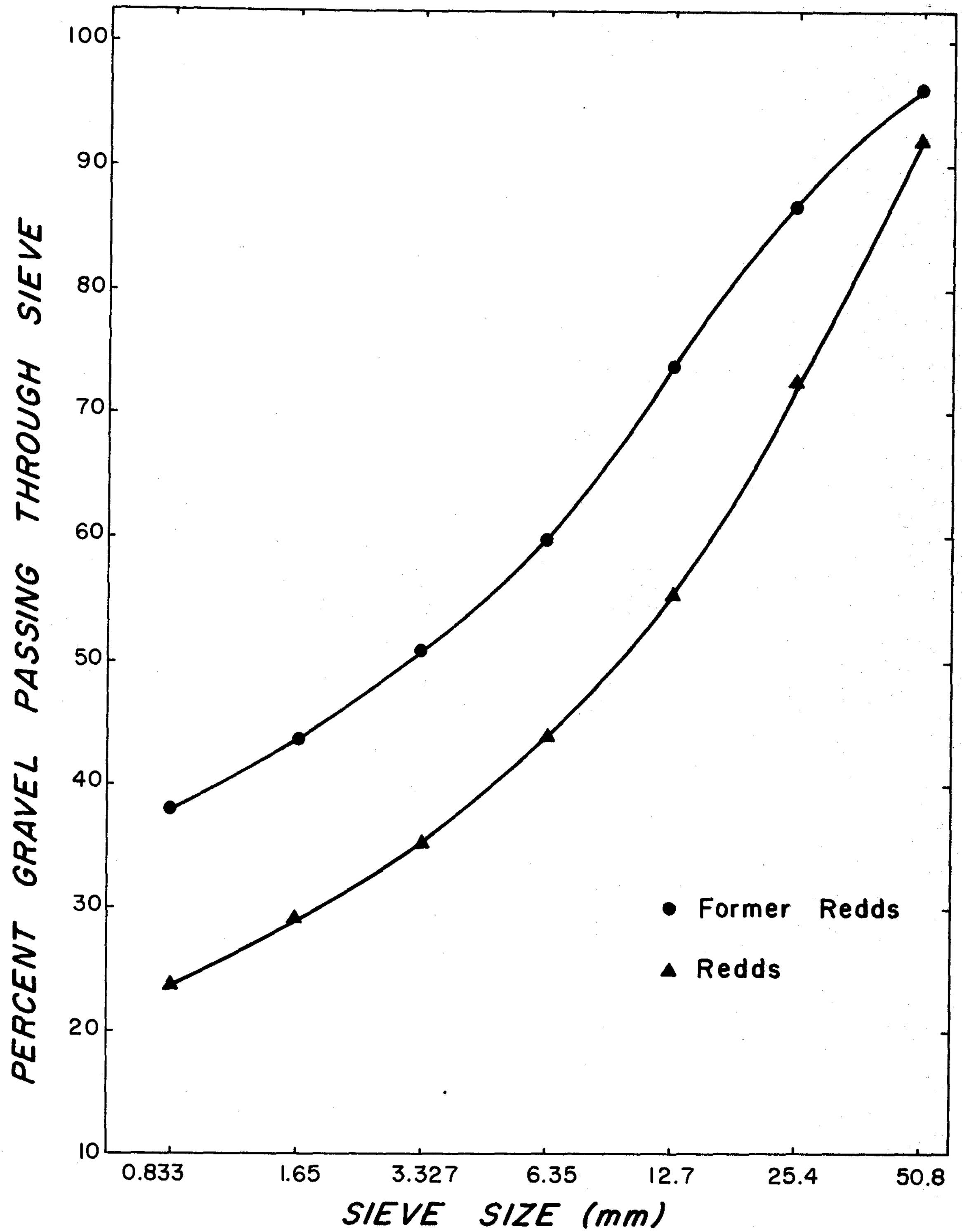


Figure 10. Mean size distribution of gravel in Needle Branch redds and former redds.

redds are considerably lower than those obtained using the standard method, yet the mean values for Flynn Creek are nearly the same (Table 10). T-tests indicated that the difference between samples obtained with the two methods was significant at the 95 percent confidence level for Needle Branch and Deer Creek samples.

The mean percentage of fine sediment in the 1968 redds determined from the frozen core samples was not significantly different from that reported by Koski (1966) prior to logging. However, because samples obtained with the frozen core device did not agree closely with those taken with the McNeil-Ahnell sampler, a comparison before and after logging using the two different sampling methods does not seem justified.

Temperature

Summer, 1968

The installation of thermograph probes in Needle Branch in June 1968 occurred after fry emergence was complete. Thus, intragravel temperatures recorded during the summer months did not directly influence eggs or alevins. However, the warm water temperatures in the summer provided an opportunity to study the influence of highly fluctuating surface temperatures on those of the intragravel water. The data also illustrated the temperature regimes

Table 10. Percent fine particles in redds sampled with both the frozen core and McNeil-Ahnell methods.

	Frozen Core (2 Samples per Redd)			McNeil-Ahnell (3 Samples per Redd)		
	Mean	Range	Standard Deviation	Mean	Range	Standard Deviation
Needle Branch (5 redds)						
<0.83mm	27.44	21.16-41.31	6.10	34.53	28.04-39.19	2.99
<3.33mm	39.30	32.43-51.65	5.73	46.93	38.54-54.07	4.09
Deer Creek (5 redds)						
<0.83mm	21.46	14.63-29.38	4.88	30.32	22.20-38.19	3.94
<3.33mm	32.92	24.80-44.19	5.77	42.59	34.92-52.34	4.13
Flynn Creek (3 redds)						
<0.83mm	29.78	22.60-35.86	6.07	30.92	25.67-49.33	7.58
<3.33mm	45.16	36.50-54.58	6.85	44.06	34.88-68.43	9.96

that might be encountered by fish such as pink and chum salmon, which spawn in some regions during the summer months.

The summer of 1968 was considerably cooler than normal, with cloud cover a common occurrence between June and September. Unseasonal rainfall kept streamflows higher than normal. Also, regrowth of understory vegetation in the clearcut watershed provided a small increase in shade over the stream surface. Thus, water temperatures did not reach the maxima attained in the two previous years.

The thermograph data described below include the interval from July 30 through August 15. This was a relatively warm period that may be considered to be representative of summer conditions in the study area. One of the three thermographs functioned improperly during the summer, and data from this graph could not be used.

Considerable temperature fluctuation was evident within the gravel in Needle Branch on clear days (Figure 11), and maxima as great as 21°C were recorded. Mean intragravel temperatures at Stations 335 and 547 were 17.2° and 16.4°C, respectively, whereas the surface temperatures near these sites averaged 17.0° and 16.6°C, respectively. Thus, the mean intragravel temperature was very similar to the mean surface temperature.

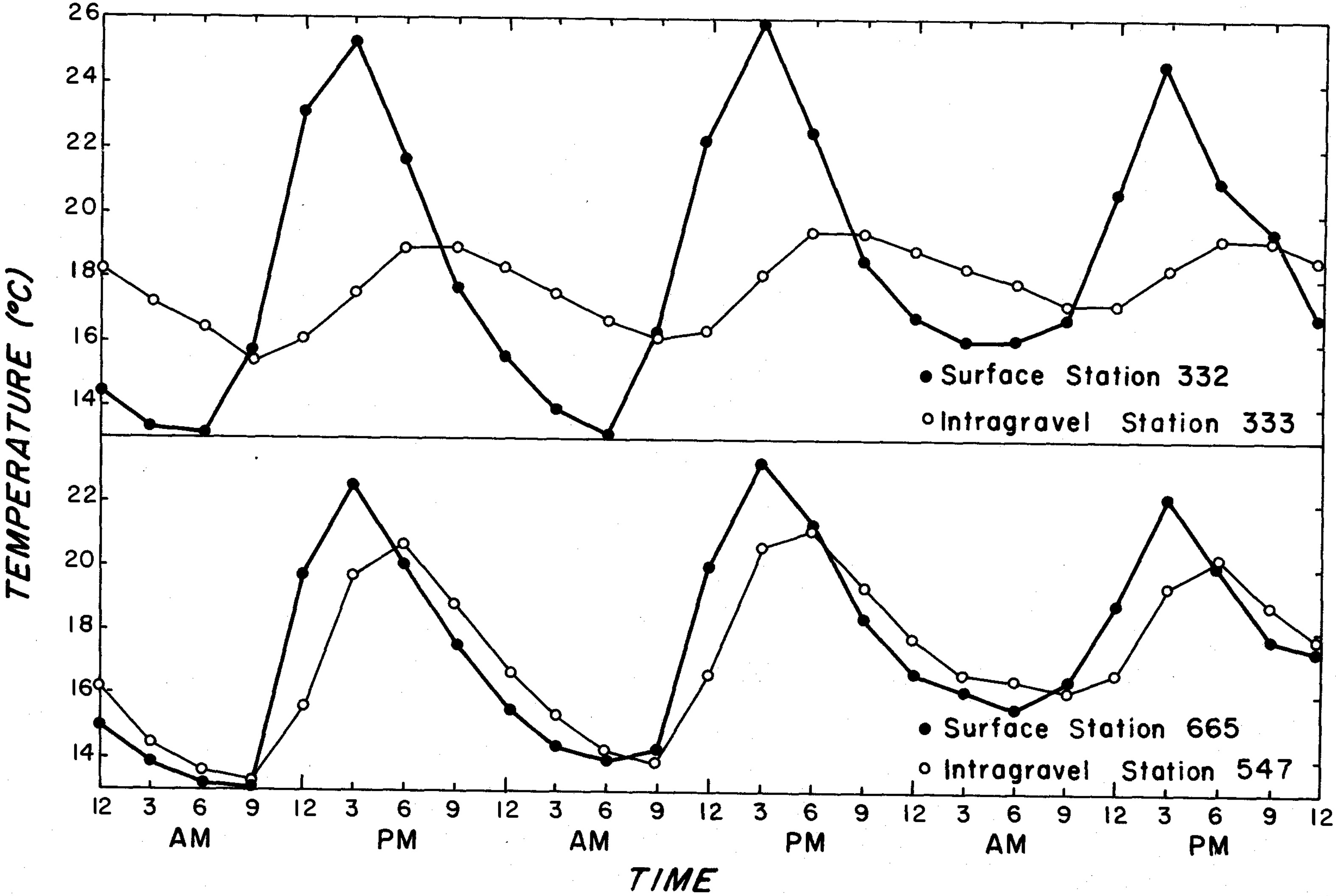


Figure 11. Intragravel and surface temperatures at two sites in Needle Branch (July 30 - August 1, 1968).

The intragravel water temperature lagged from 2 to 6 hours behind that of the surface water in attaining the diurnal maximum. The difference between stations in the amount of lag suggested differences in interchange of surface with intragravel water.

Temperature data obtained between 1 and 4 PM (PST) with the thermistor probe at Stations 333 and 547 indicated a decline of mean temperature with depth (Figure 12). There was a more abrupt change of temperature with depth at Station 333 than at 547. Since a rapid reduction in temperature with depth would indicate an area of low exchange of surface and intragravel water, Station 333 apparently had less exchange than Station 547.

The probable relation between temperature gradient and interchange suggested the use of temperature "profiles" as a means of evaluating the exchange of surface with intragravel water. Profiles were obtained on several dates throughout the summer in four Needle Branch redds. Nine profiles were made per redd within a radius of 30 cm, and a mean temperature was computed for each depth. There was considerable variation among the redds (Figure 13). However, the variation could not be attributed solely to differences in interchange, because the temperature profiles changed with time. Temperature measurements in a redd required 45 to 60 minutes to complete, so that the last redds to be studied in a day had the longest period of exposure to surface water of high temperature. When the

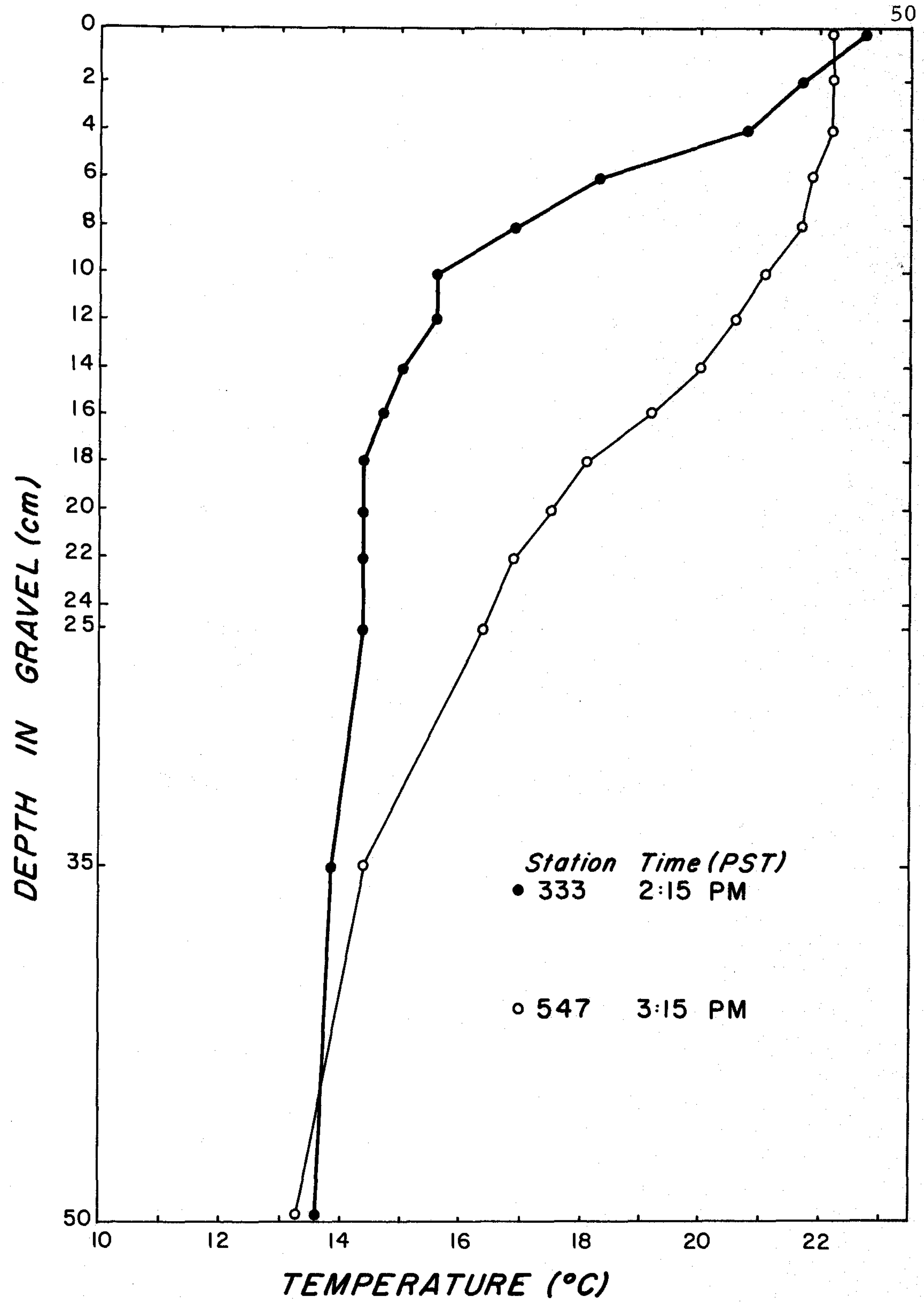


Figure 12. Relationship between mean intragravel temperature and depth during the afternoon hours at thermograph stations in Needle Branch (nine points per station within a 30-cm radius, July 1, 1968).

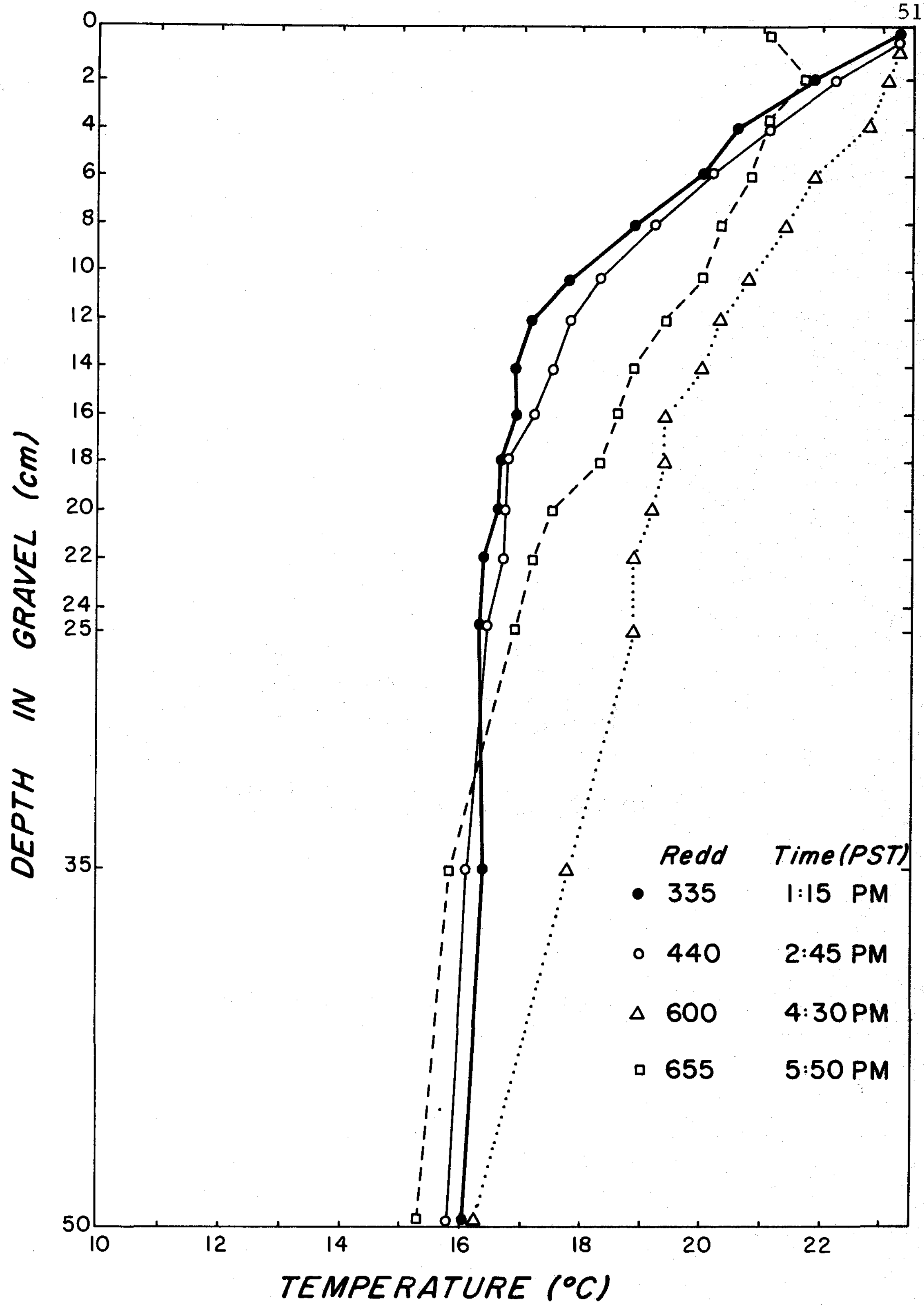


Figure 13. Relationship between mean temperature and depth in Needle Branch redds during the afternoon hours (nine points per redd within a 30-cm radius, July 7, 1968).

sequence in which the redds were studied was altered, the relationship of temperature profiles among redds was changed (Figure 14). Therefore, the temperature profile in a redd could not be used as a quantitative index of interchange. Such an index could have been obtained if simultaneous temperature measurements had been made in all redds.

The change in intragravel temperature with time was indicative of the depth of influence of surface water on the intragravel water. Since the temperature at 50 cm changed with time, the surface water was apparently influencing the intragravel environment to at least that depth. The major temperature changes occurred above 35 cm, however, indicating that most of the exchange occurred above that level.

Like the other parameters measured in this study, the temperature was not homogeneous throughout a redd (Figure 15). The temperature within a lateral distance of 60 cm varied as much as 7.5°C at 4 cm depth and 3.3°C at 25 cm depth in Needle Branch redds.

Temperature profiles were obtained in Deer and Flynn Creeks during periods of comparable insolation to that existing during sampling of Needle Branch. In Deer Creek, a relatively small temperature gradient characterized the intragravel environment (Figure 16). Differences among Deer Creek redds apparently reflected differences in surface water temperature along the stream. A temperature

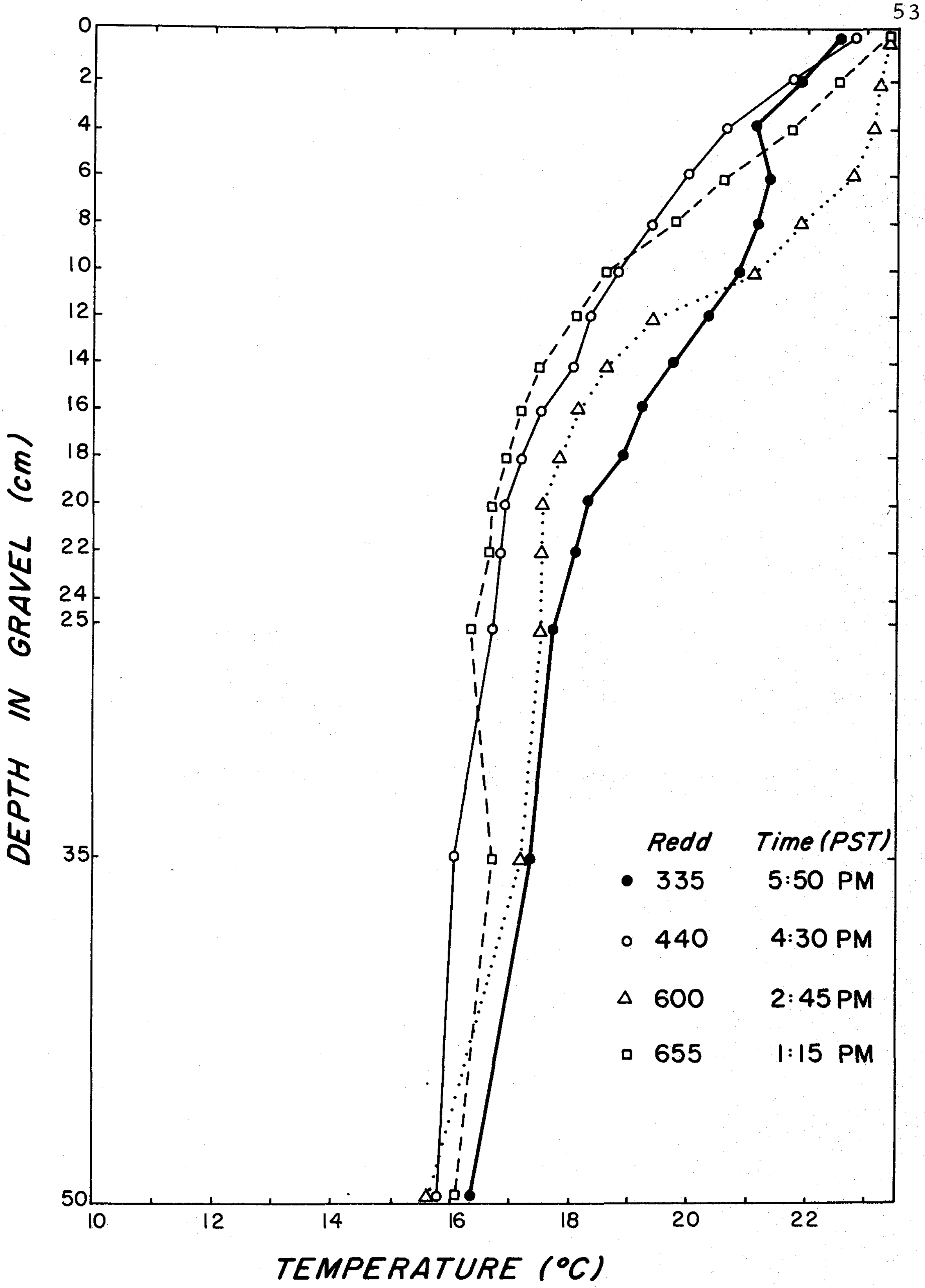


Figure 14. Relationship between mean temperature and depth in Needle Branch redds during the afternoon hours (nine points per redd within a 30-cm radius, July 8, 1968).

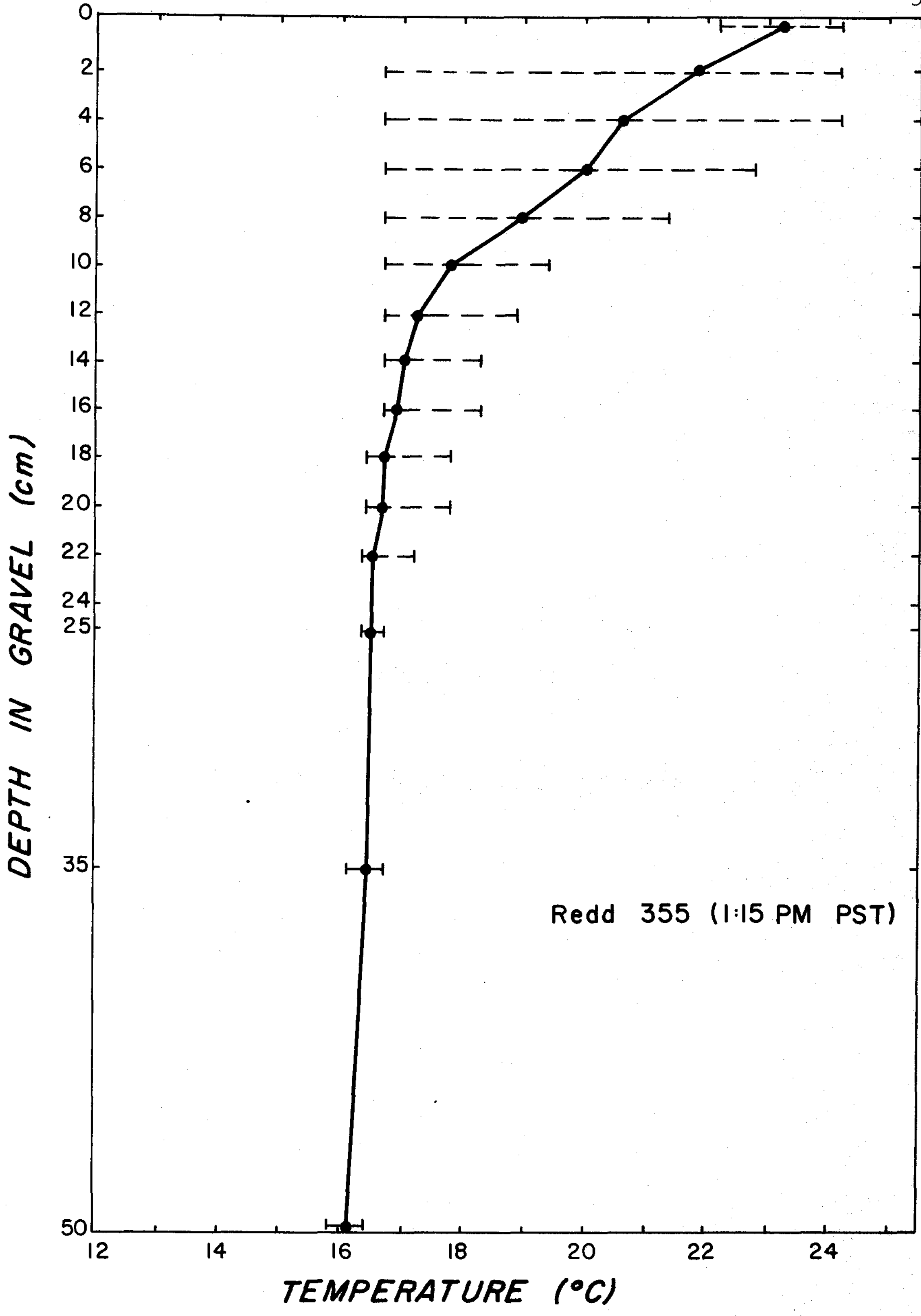


Figure 15. Temperature variation (mean and range) among nine points within a radius of 30 cm in a Needle Branch redd (July 7, 1968).

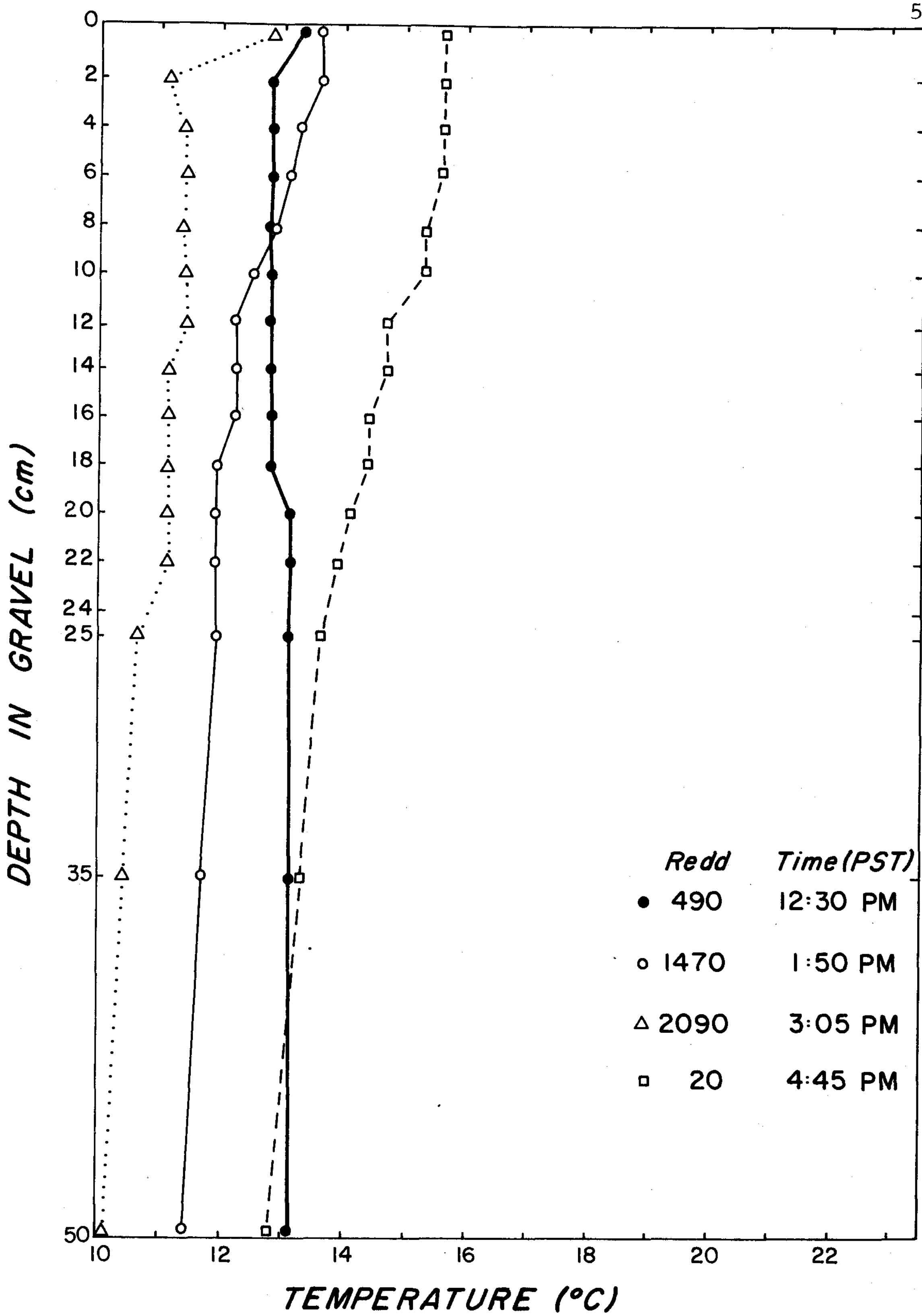


Figure 16. Relationship between mean temperature and depth in Deer Creek redds during the afternoon hours (nine points per redd within a 30-cm radius, July 27, 1968).

gradient was practically non-existent in Flynn Creek.(Figure 17). The surface temperature fluctuated much less in these shaded streams than in Needle Branch, so that the intragravel temperature could be expected to more closely parallel that of the surface water. Deer and Flynn Creeks may also have had generally greater interchange than Needle Branch, so that surface and intragravel temperature were similar. In view of the different surface temperature regimes among the streams, however, this conclusion is probably not justified.

Winter and Spring, 1969

The temperature recorded within the gravel in Needle Branch showed considerable diurnal fluctuation as early as March, although the fluctuation was much less pronounced than that of the surface water. Maximum and minimum temperatures occurred from one to six hours later than those of the surface water (Figure 18). Variation in the magnitude and timing of temperature fluctuations was evident among the locations studied, and was presumably indicative of different rates of exchange between surface and intragravel water at the three sites.

Differences in intragravel temperature maxima as great as 4.2°C occurred among locations on Needle Branch during the period in which fry still inhabited the gravel environment (Figure 19).

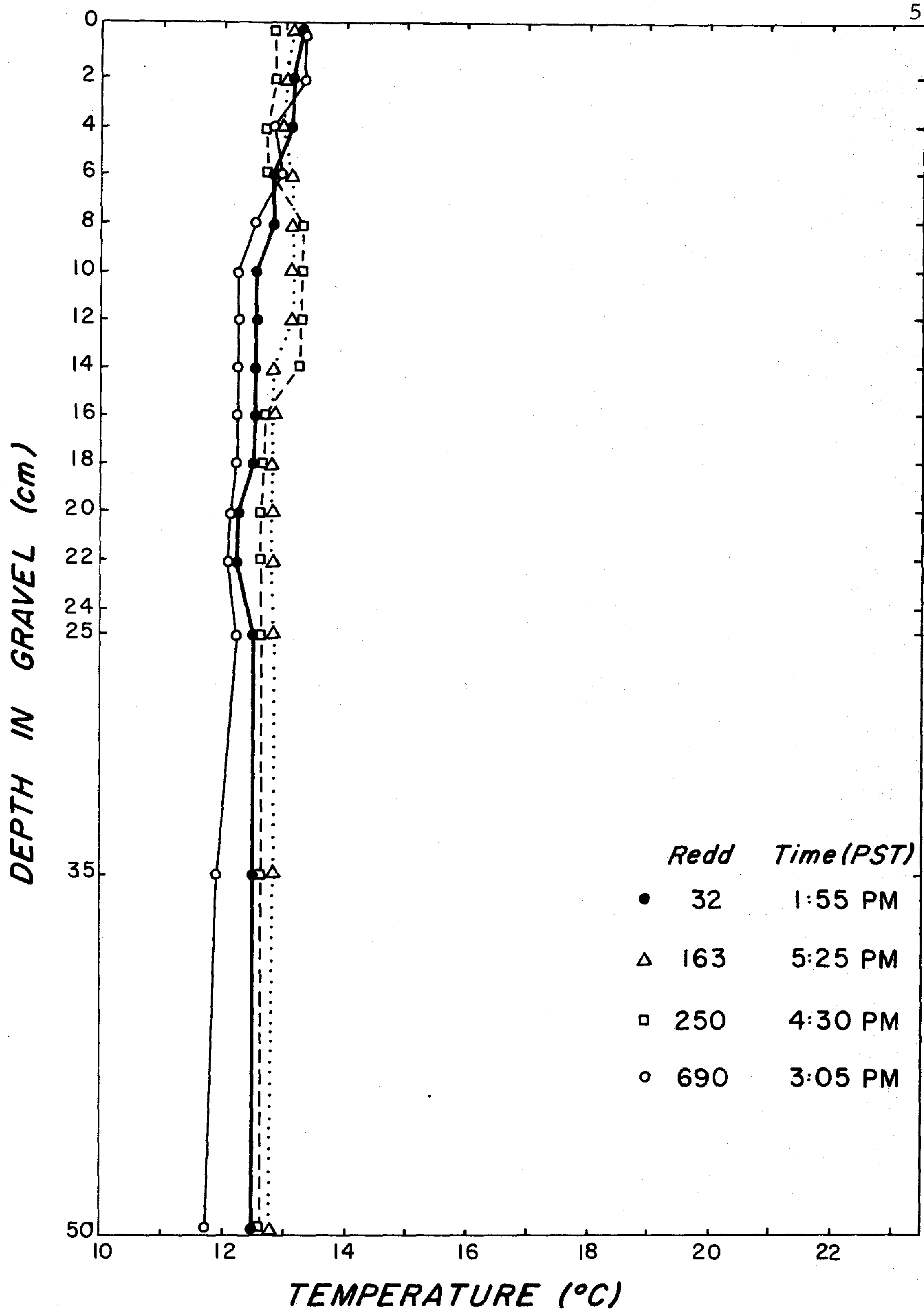


Figure 17. Relationship between mean temperature and depth in Flynn Creek redds during the afternoon hours (nine points per redd within a 30-cm radius, July 29, 1968).

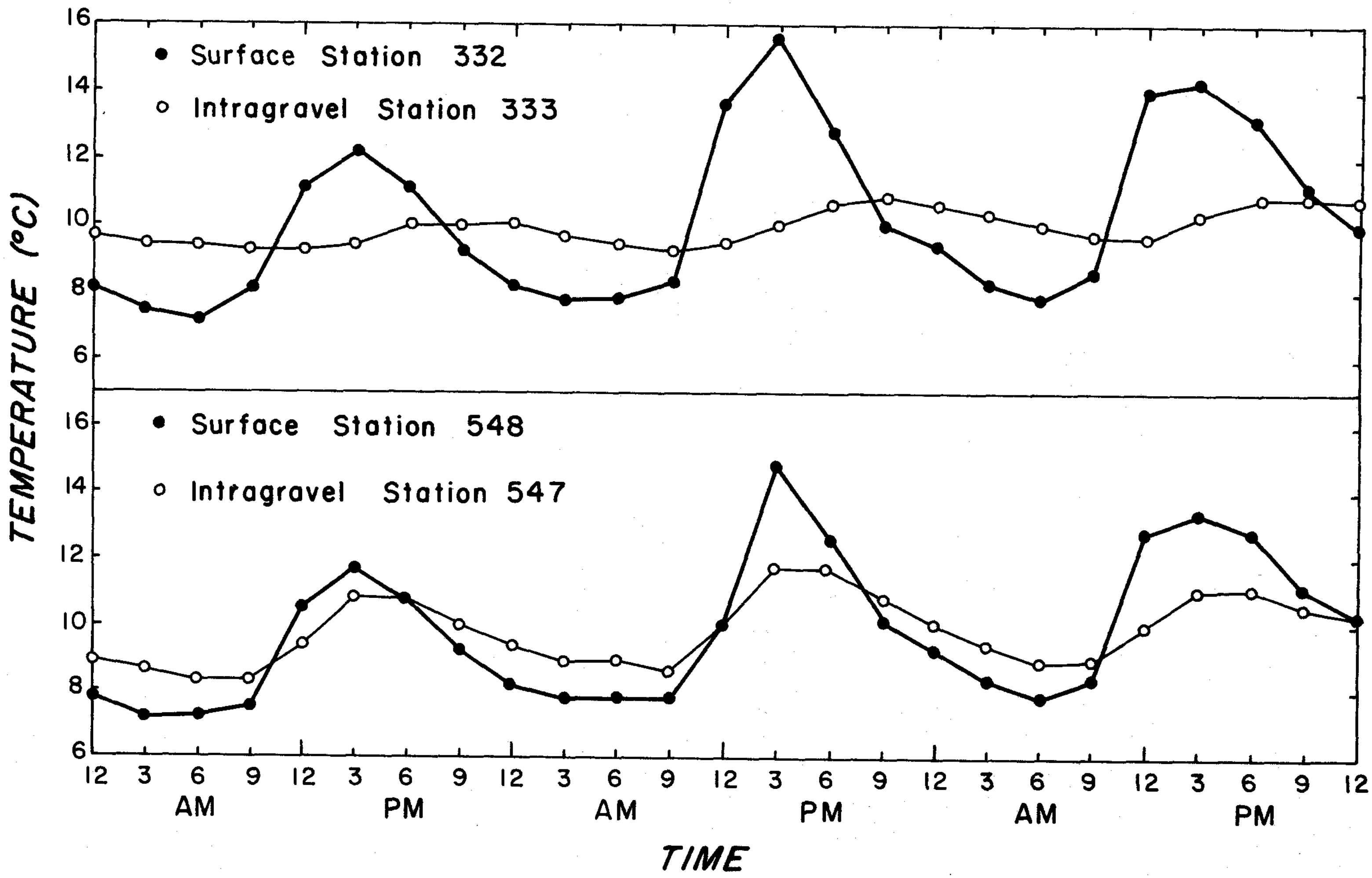


Figure 18. Intragravel and surface temperatures at two sites in Needle Branch (April 25-27, 1969).

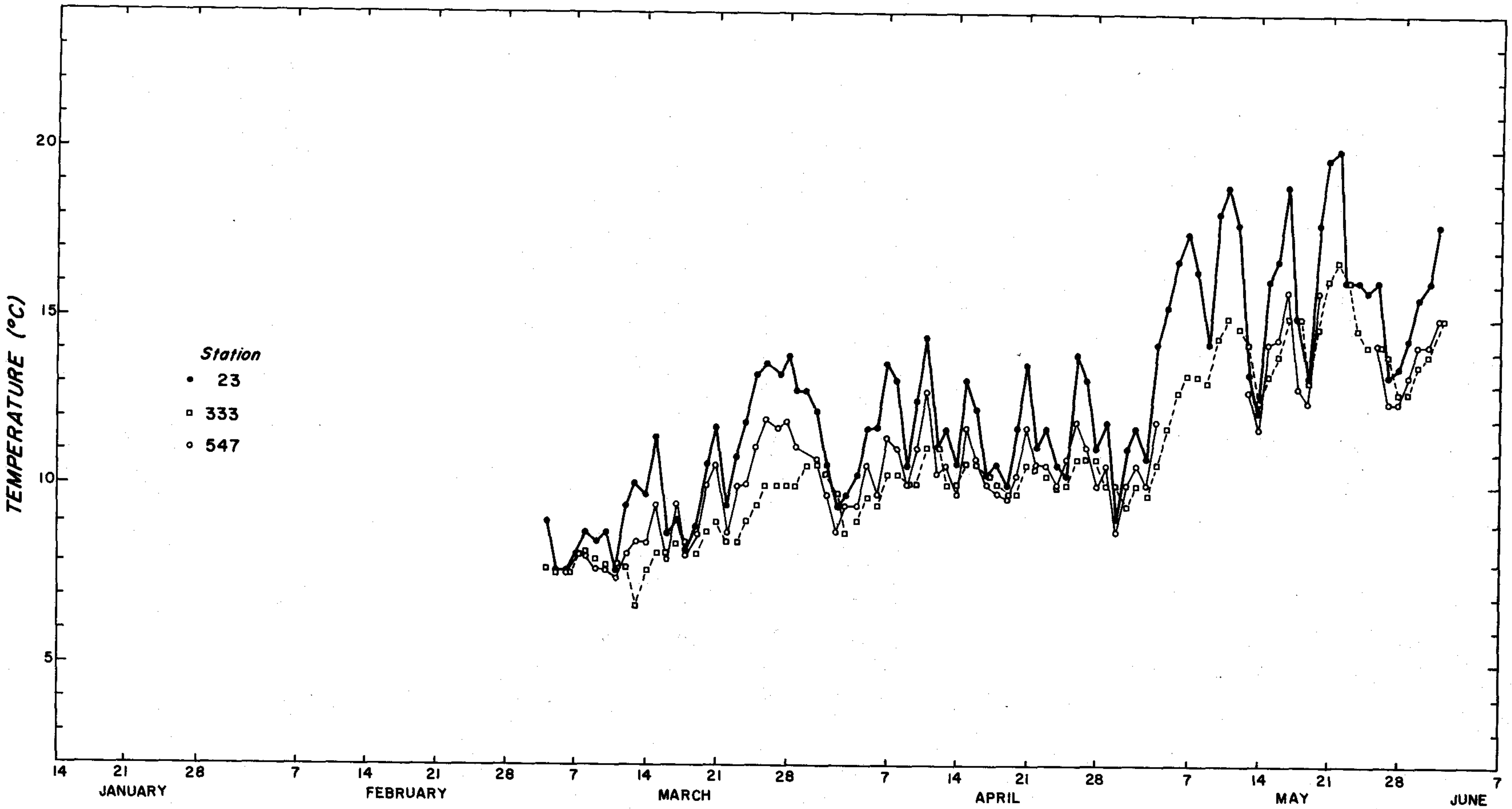


Figure 19. Maximum daily temperature of the intragravel water at three stations in Needle Branch (March 3 – June 2, 1969).

However, mean daily temperatures, averaged over three-hour intervals, were almost identical at the three locations. The thermograph at Station 547 failed to record for two weeks in May. However, the mean computed from temperatures recorded between March 3 and May 2 was 8.9°C at Station 23, and 9.0°C at Stations 333 and 547. For the period between March 3 and June 2, mean temperatures at Stations 23 and 333 both averaged 10.3°C. Those stations with the highest maxima also had the lowest minima (Figure 20), so that the resulting mean temperatures were approximately the same. The mean surface and intragravel water temperatures were also very similar at the three stations (Table 11). In effect, the temperatures fluctuated about a common mean.

Table 11. Mean temperature (°C) of intragravel and surface water in Needle Branch (March 4-May 2, 1969).

Intragravel		Surface	
Station		Station	
23	8.9	17	9.0
333	9.0	332	8.8
547	9.0	548	9.0

Continuous intragravel temperatures were not obtained in Deer Creek or Flynn Creek, but continuous records of surface temperatures were available for each stream. The mean surface temperatures in Needle Branch, Deer Creek, and Flynn Creek were 9.8, 8.3, and 7.5°C, respectively, between January 15 and June 2.

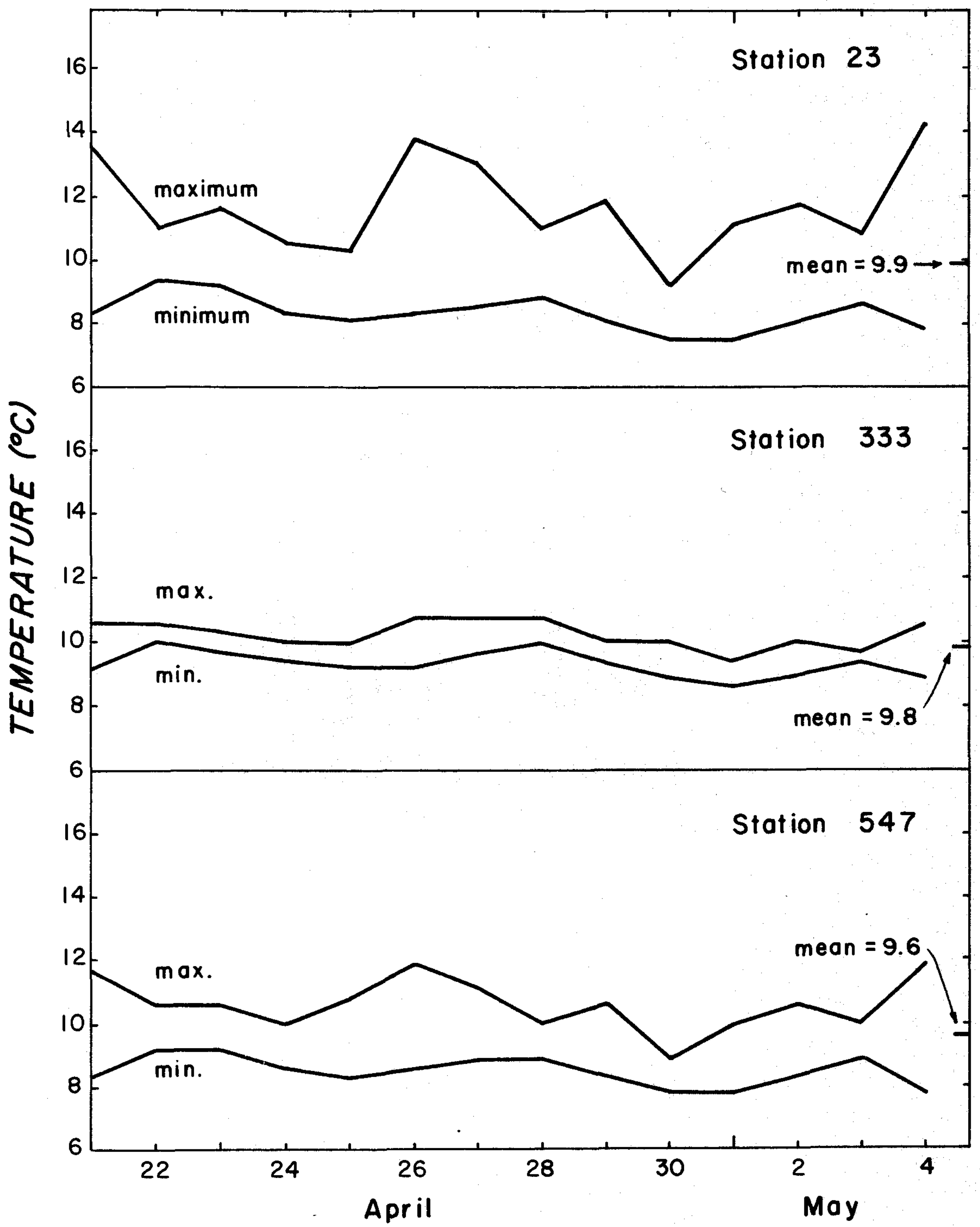


Figure 20. Maximum and minimum temperature of the intragravel water at three stations in Needle Branch (April 21-May 4, 1969).

Maximum daily temperatures in the streams are shown in Figure 21. These results reflect differences in the amount of forest cover over the three streams. The data from Needle Branch suggested that mean intragravel temperatures on Flynn and Deer Creeks would be very close to mean surface temperatures. Thus, the intragravel environment would be expected to reflect differences in temperature resulting from logging. This statement is supported by temperature measurements made within standpipes of the natural redds in each stream (Figure 22). Both the mean temperature and the fluctuation in temperature increased in relation to the extent of logging.

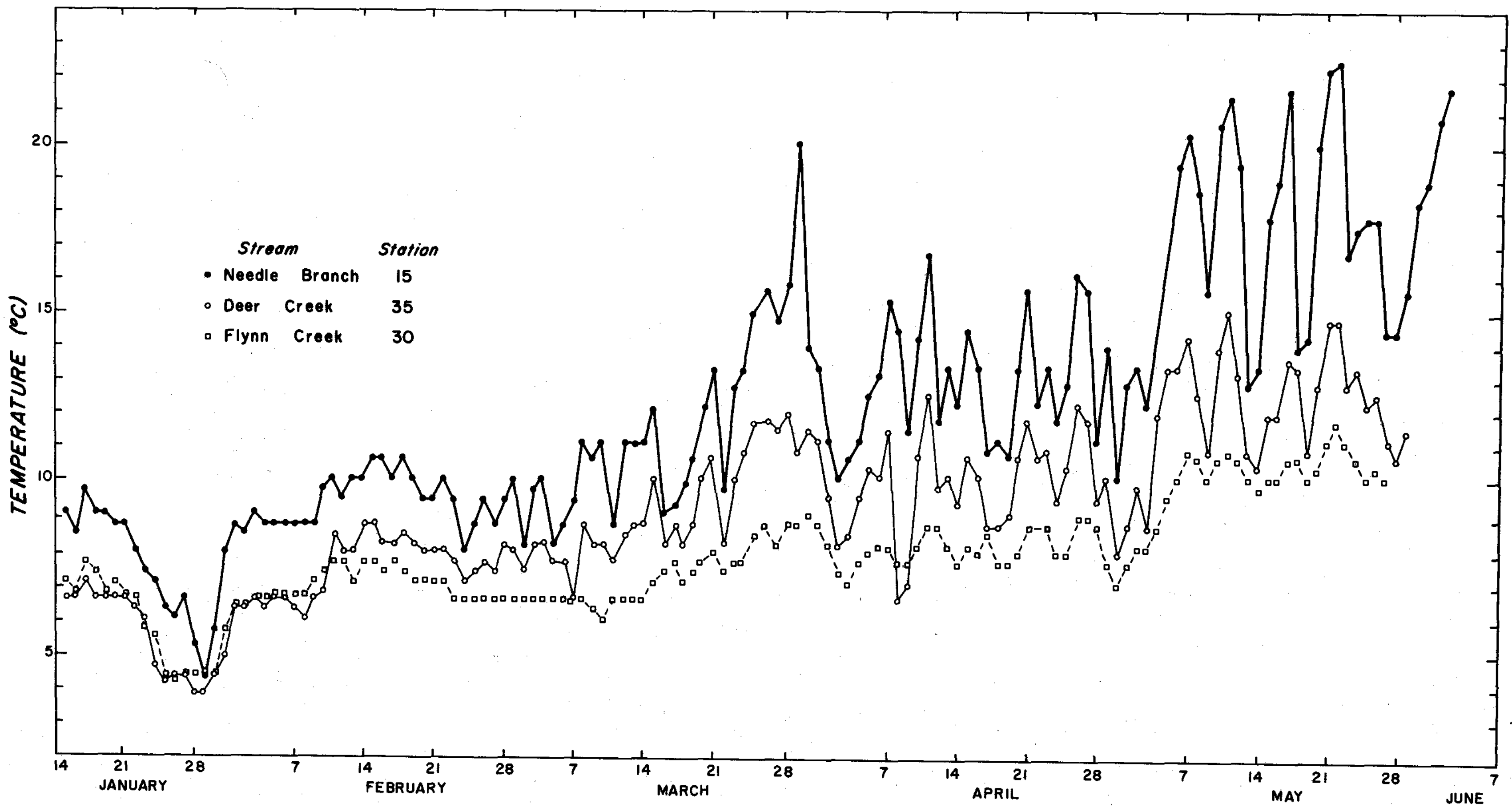


Figure 21. Maximum daily temperature of the surface water in the study streams (January 15 - June 2, 1969).

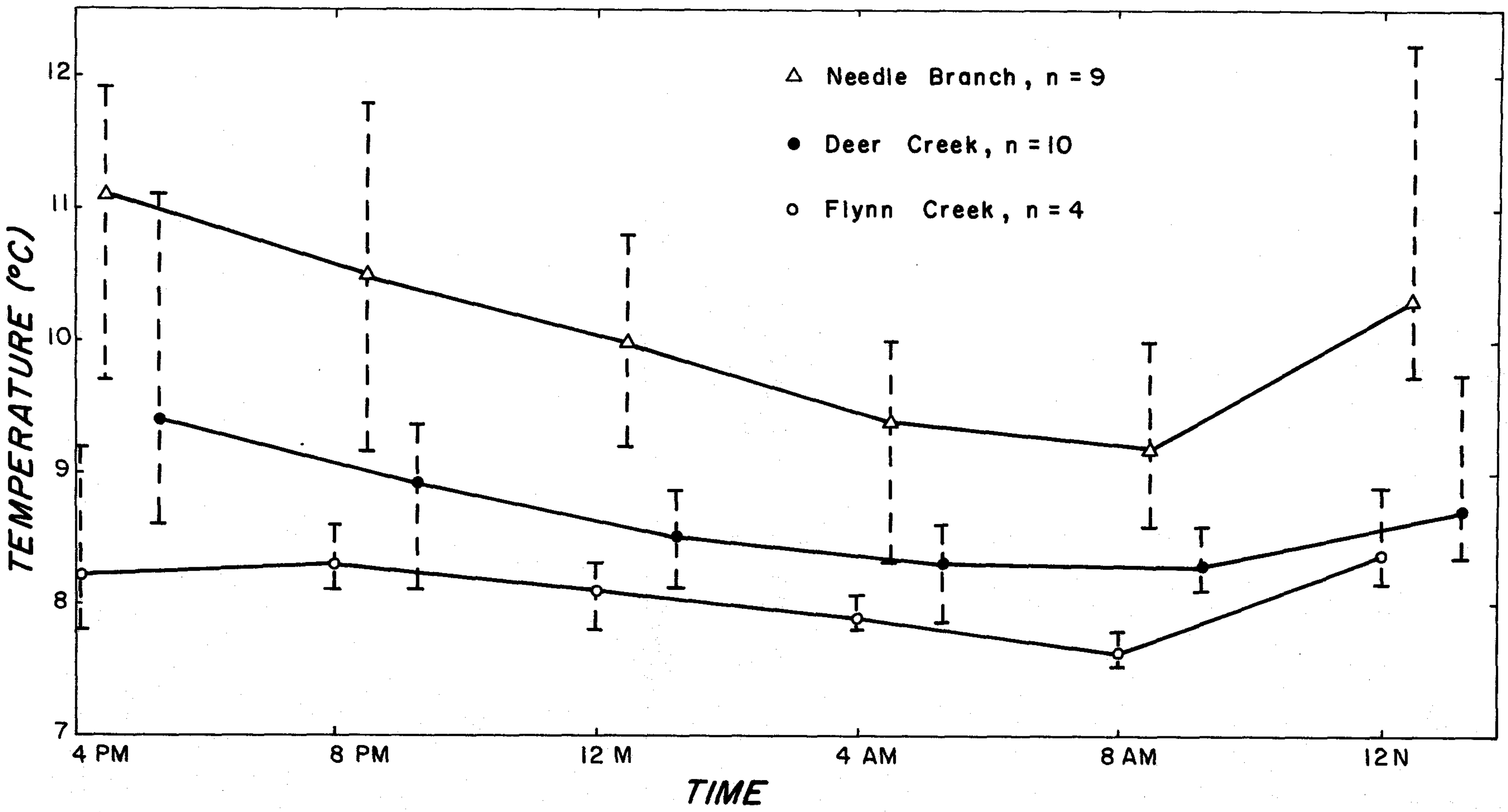


Figure 22. Mean and range of intragravel water temperature in redds in the study streams (April 26-27, 1969).

DISCUSSION

Each of the parameters measured in this study was shown to be highly variable. Only dissolved oxygen offered clearcut evidence that logging of Needle Branch produced changes in the intragravel environment. However, the relatively small differences between streams in organic content, fine sediment, and temperature, all point toward a subtle change in the intragravel environment of Needle Branch that resulted in a reduction in dissolved oxygen. Although some changes in Deer Creek were associated with logging, the changes were relatively minor. The importance to salmonid survival of changes in the intragravel environment will now be considered, and the interaction among environmental variables will be discussed.

Dissolved Oxygen

The importance to developing salmonid embryos of an adequate supply of dissolved oxygen has been demonstrated in a number of studies. Laboratory experiments have shown that any reduction in dissolved oxygen below saturation reduces fry size and delays hatching in coho salmon and steelhead trout (Shumway, Warren, and Doudoroff, 1964). Garside (1959) reported that incubation of lake trout embryos at dissolved oxygen concentrations of 2.5, 5.0 and 7.5 mg/l resulted in retardation of development rates and abnormalities in head and trunk. In a field study in the Alsea streams, Coble (1961) found a correlation between dissolved oxygen and embryonic survival of steelhead trout in artificially-constructed redds. He also showed that the effects of dissolved oxygen concentration and apparent velocity[1] on survival were inseparable. Thus, apparent velocity measurements provided no more information than dissolved oxygen measurements. Koski (1966) reported a relatively low correlation between dissolved oxygen and survival to emergence of coho salmon in natural redds. He suggested that the relation between survival and dissolved oxygen was complicated by the effect of gravel size on survival to emergence.

In a study of the behavioral ecology of coho salmon, Mason (1969) showed that fry incubated at low dissolved oxygen levels were less successful in competition in artificial streams than those incubated at high dissolved oxygen levels. The majority of emerging coho fry leave their natal streams within a few months of emergence (Chapman, 1962). Therefore, it is probable that fry subjected to low levels of dissolved oxygen will eventually have to compete downstream with fish which developed at high dissolved oxygen

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[1] Apparent velocity is the rate of flow divided by the cross-sectional area of the bed through which the water has passed. The actual velocity is greater than the apparent velocity where part of the cross-sectional area is occupied by gravel particles or other objects.

concentrations.

The spatial and temporal variation in dissolved oxygen found in this study are indicative of a highly variable environment. Similar results have been reported in Alaskan streams, in which seasonal changes in dissolved oxygen as great as 6 mg/l have been observed (McNeil, 1962). In my study the lowest dissolved oxygen levels generally occurred during the last four to six weeks of redd occupancy, well after the hatching period of most embryos. The significance of this result is suggested by the work of Hays, Wilmot, and Livingstone (1951). They found that the dissolved oxygen which limited metabolism increased from 2.8 mg/l 20 days after fertilization to 7.0 mg/l just before hatching in Atlantic salmon. After hatching, the limiting concentration dropped to 4.4 mg/l, apparently due to active respiration across the gill membranes. Thus, the lowest oxygen concentration to which the developing fish were exposed in the study streams generally occurred after the critical embryonic stages.

In my study, part of the variability in dissolved oxygen in both redds and permanent standpipe locations was accounted for by changes in streamflow. This result agrees with that reported by Wickett (1954), who found a direct relationship between the apparent velocity of the intragravel water and streamflow (gage height) in a British Columbia stream. Sheridan (1962) reported that dissolved oxygen levels decreased as stream levels dropped in Alaskan streams. He found considerable variation in dissolved oxygen in gravel bars that were alternately exposed and covered with water. McNeil (1968) demonstrated reduced dissolved oxygen levels in Alaskan streams when flows were abnormally low in late summer soon after spawning; low survival of pink and chum salmon eggs accompanied the low streamflow.

The difference between the intragravel dissolved oxygen levels in Deer Creek and Needle Branch cannot be attributed to the difference in streamflow. Prior to logging the oxygen levels in redds of both streams were similar, despite the greater flow in Deer Creek. Although the precipitation during the three years following logging was generally less than that recorded prior to logging, the resulting decrease in annual streamflow does not provide an explanation for the reduction of dissolved oxygen in Needle Branch. In February and April of 1969, mean streamflows exceeded those recorded in 1964 (Preliminary data: U. S. Geological Survay), yet dissolved oxygen levels during these months were lower in 1969 than in 1964. Factors other than streamflow, including organic debris, fine sediment, and temperature, would appear to account for the reduction in dissolved oxygen in Needle Branch.

Organic Material and Biochemical Oxygen Demand

The quantity of organic debris in the gravel, together with salmon eggs or embryos, insects and other organisms, determine the oxygen demand on the intragravel water (McNeil, 1968). Organic content would be expected to be influenced by two factors associated with logging. One is the increase in suspended organic sediment, some of which eventually finds its way to the gravel surface (Cooper, 1965). The other is the direct addition of bark, needles, and other logging debris associated with cable yarding across the stream or felling of trees near the stream channel. Thus, logging activities could bring about a reduction in intragravel dissolved oxygen by increasing the organic material in the gravel.

In two Alaskan streams, the greatest amounts of organic material were found in the smallest gravel size groups (McNeil and Ahnell, 1964). Thus, the quantity of sediment in the gravel was assumed to provide an index of the relative amount of organic material present (McNeil, 1966). This assumption is supported by the results of the present study, in which a positive correlation was found between organic material and fine sediment in the gravel. If most of the organic material had consisted of large debris, this relationship would not exist. However, less than 3 percent of the organic content in the gravel consisted of particles larger than

6.35 mm. Apparently, stream clearance after logging, high winter streamflow, and spawning activity of female salmon removed a majority of the larger material.

Although there were somewhat greater amounts of organic material in the redds of Needle Branch than in Deer Creek, the difference was not statistically significant. Thus, the reduction in dissolved oxygen in Needle Branch cannot be attributed to a large increase in organic debris in the redds. It is possible, however, that even small increases in organic content could contribute to the observed dissolved oxygen reduction.

It is probable that the oxygen demand in areas upstream from redds influences the amount of dissolved oxygen supplied to the redds. Thus, although the organic content in redds may be little affected by logging, an increase in organic debris in the remainder of the streambed could ultimately influence the dissolved oxygen in the redds. The former redds in Needle Branch contained significantly more organic material than those in Flynn Creek. This result cannot be considered evidence that the entire streambed in Needle Branch contained more organic debris than that of Flynn Creek. However, the evidence does not contradict this hypothesis.

The generally small differences in organic content among streams were paralleled by the biochemical oxygen demand of the intragravel water. Although the sampling program was not extensive, the statement may be made that the biochemical oxygen demand was very low, and differences between streams could not be demonstrated. Apparently, it is the organic debris entrapped within the gravel that is exerting the oxygen demand, rather than dissolved or colloidal material present in the water itself.

Size Composition of the Gravel

A considerable body of evidence has shown that sedimentation of spawning gravel is detrimental to eggs and alevins developing there. After reviewing the available literature on the effects of sediment on aquatic life, Cordone and Kelly (1961) concluded that sedimentation could be harmful to salmon embryos. They also concluded that even moderate increases in sediment could be detrimental.

Stuart (1953), as cited in Koski (1966), described the direct effects of sediment on eggs and fry. He found that silt particles adhered to the chorion of the eggs, which when exposed over long periods, died without hatching. Continuous addition of sediment to sac-fry resulted in serious inflammation of the gill membranes, eventually causing death.

Fine sediment may also influence the permeability of the gravel, and thus the rate of delivery of dissolved oxygen to eggs and alevins. In gravel removed from pink salmon streams in

Alaska, permeability was found to be inversely related to the percentage of particles smaller than 0.83 mm (McNeil and Ahnell, 1964). Laboratory experiments have demonstrated that deposition of sediment on or within the gravel reduces the permeability of the gravel. The resulting reduction in intragravel dissolved oxygen reduces the survival of chum salmon eggs and alevins within the gravel (Cooper, 1965).

Several laboratory experiments have shown that survival to emergence of coho salmon is related to the amounts of sediment in the gravel (Shapovalov and Berrian, 1940; Shaw and Maga, 1943). The first analysis of the influence of particle size on survival to emergence of coho salmon in natural streams was made by Koski (1966). He determined the survival in redds in each of the Drift Creek study streams, and found the highest negative correlation between survival and percentage of particles smaller than 3.33 mm. He showed that fine sediments may act as a physical barrier to emerging fry, either by entombing them within the gravel or by prolonging the period of emergence. Recent laboratory experiments have demonstrated that fine particles act as a physical barrier to emergence. When dissolved oxygen levels were kept near saturation, percentage survival to emergence decreased as the percentage of fine particles (1-3 mm) increased (Hall and Lantz, 1969).

Studies in Alaskan streams have shown that logging can result in increased sedimentation in spawning gravel (Sheridan and McNeil, 1968). In an analysis of pre- and post-logging data from the Alsea streams, Lantz detected an increase in fine sediment in redds of Needle Branch and Deer Creek.[2]

One of the primary objectives of the gravel analysis in the present study was to test the hypothesis that fine particles are deposited in layers within the streambed. If layering actually occurs, even a small increase in sediment due to logging could be of significance to eggs and alevins within the gravel. A stratum of fine particles at or near the surface would tend to reduce the exchange of surface and intragravel water, thereby reducing the dissolved oxygen available to the fish. Such a stratum could also act as a physical barrier to emerging fry.

Layering was shown to characterize many of the redds studied, but no consistent pattern of stratification was found. There was no evidence to indicate that logging resulted in a change in the vertical distribution of fine sediment in salmon redds. It is possible that thin layers of sediment existed in the gravel, but that they were not

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[2] R. L. Lantz. Personal communication. Oregon Game Commission, Corvallis. June, 1969.

detected within the 8.3-cm thick strata studied. However, no such thin layers were evident from visual inspection of the core samples.

Deposition of a layer of sediment on the gravel surface was observed in Needle Branch immediately after logging. My results indicate that this layer was either removed by fall freshets or incorporated into the gravel matrix. Whether the increase in intragravel sediment following logging resulted largely from this original sediment layer, or from further addition of sediment, is unknown. Probably both processes were operating.

The redds contained significantly less sediment than the former redds, suggesting that the digging activities of female salmon reduced the sediment content of redds. Such a reduction in fine sediment following spawning of pink and chum salmon has been noted in streams in Alaska (McNeil and Ahnell, 1964) and British Columbia (Cooper, 1965).

More fine sediment was detected in Needle Branch than in Deer Creek redds. Although not statistically significant, this result was supported by the comparison of the streams made by the Oregon Game Commission. The greater sediment content of Needle Branch would appear to be a factor contributing to the observed reduction in dissolved oxygen.

Evaluation of the Frozen Core Sampler

Gravel sampling with the frozen core device proved feasible. In large streams where surface and intragravel flows exceed those of the study streams, several hours might be required to obtain a sample. Even under ideal conditions the method involves greater time and expense than the McNeil-Ahnell technique, and cannot be considered a routine sampling procedure. However, field studies of the vertical distribution of fine particles are possible with the new method. The device may also prove useful in studying the distribution of fish, insects, and perhaps microorganisms within stream gravel.

The discrepancy between analyses of samples removed with the McNeil-Ahnell sampler and the frozen core device on two of the streams seemed to be due to some factor other than chance variation. However, I was unable to identify the cause of the differences between samples. That individual differences in analysts could have accounted for the observed results seems unlikely, since the Flynn Creek samples that I analyzed agreed closely with those examined by the Oregon Game Commission. Laboratory tests in gravel beds of known composition will be needed to determine whether the two methods give divergent results.

Temperature

Several workers have reported increases in stream temperature resulting from logging, including Eshner and Larmoyeaux (1963), and Brown and Krygier (1967). Brown (1967) showed that temperature increases in small mountain streams are largely the result of direct solar radiation on the stream surface, rather than of convection or conduction. He developed prediction equations relating stream water temperature to the amount of forest removal. Although Brown was concerned largely with summer temperature increases, the results of my study indicate that winter and spring water temperatures may also bear a relation to the amount of forest cover along the stream.

Relatively little work has been done on the influence of surface water temperature on the intragravel water. Wickett (1954) reported that intragravel and surface water temperatures were similar during the morning hours, but lagged up to 18 hours in attaining the diurnal maximum. Sheridan (1961) used thermocouples buried at depths of 0 to 55 cm to study temperature gradients within stream gravel in Alaskan streams. He found little temperature gradient within the gravel, but did obtain evidence that salt water in intertidal areas was warming intragravel water to a depth of 30.5 cm.

In my study, mean surface temperatures were shown to approximate mean intragravel temperatures in the clearcut stream.

Apparently, ground water did not influence the temperature at 25 cm, at least at the three sites studied. If mean intragravel temperatures in Flynn and Deer Creeks equalled their mean surface temperatures, small differences among streams in intragravel temperature would be expected from January 15 to June 2. These differences were observed in the natural redds of the three streams. Further analysis indicated that mean differences among streams were considerable from May 2 to June 2, although less than ten percent of the fry still remained in the gravel during this interval. Needle Branch averaged 13.3°C, whereas Deer and Flynn Creeks averaged 10.6° and 9.8°C, respectively, during this period.

In view of the different temperature regimes in the streams, several effects of temperature on eggs and alevins merit consideration. Donaldson (1955) exposed chinook salmon eggs to upper lethal temperatures for varying lengths of time, and then removed them to more optimal temperature conditions where the aftereffects were observed until the fry stage. Mortalities greater than 90 percent occurred after ten days exposure at 67°F (19.5°C), after 16 days at 65°F (18.4°C), and after 25 days at 63°F (17.2°C). Combs and Burrows (1957) found that chinook salmon embryos would develop normally at temperatures between 35°F (1.7°C) and 60°F (15.6°C). Although data on coho salmon embryos are not available, it is probable that their temperature requirements are similar to those of chinook embryos. In Needle Branch, the highest temperature recorded during embryonic development (November 17, 1968, to March 1, 1969) was 10.5°C. Fingerlings, and presumably alevins, of coho salmon can tolerate temperatures as high as 75°F (23.9°C) (Brett, 1952). The highest intragravel temperature in Needle Branch prior to complete fry emergence was 19.7°C, and this temperature was maintained for only a few hours on May 21. Thus, it is probable that the alevins, as well as the embryos, were not subjected to lethal high temperatures in the intragravel environment.

In Alaska, pink and chum salmon spawn during the summer months. Considerable increases in temperature have been recorded in portions of Alaskan streams flowing through clearcut areas, but temperatures directly lethal to eggs and alevins have not been observed. In relatively small clearcuts, the maximum recorded temperature has been 16.1°C (Meehan, 1968). However, the results of the present study indicate that higher temperatures would be expected where the entire length of a stream is exposed to direct sunlight.

The effects of sublethal temperatures may influence the ultimate survival of fish within the gravel. An increase in temperature decreases the amount of oxygen that is soluble in water, so that somewhat less oxygen would be available to eggs and alevins in a clearcut stream. This effect appeared to be of minor importance in the present study. The dissolved oxygen in the surface water of Needle Branch averaged only 0.57 mg/l lower than that of Deer Creek as the result of differences in temperature. The intragravel water in the two streams was, therefore, subject to renewal by surface water of very similar oxygen content. Furthermore, the estimates of percentage saturation of intragravel water indicated that the physical effect of temperature on solubility was not the cause of the differences in dissolved oxygen between streams.

Increased temperature also increases the rate of chemical and biological decomposition of organic detritus in the gravel, and thereby indirectly reduces the dissolved oxygen available to eggs and alevins. It is probable that the negative correlation of dissolved oxygen within the gravel with water temperature was largely a result of increased oxygen demand at higher temperatures. By removing organic material from the intragravel environment, however, rapid decomposition during the warm summer months could be beneficial in the clearcut stream. This phenomenon may partially explain the low biochemical oxygen demand of the intragravel water that was found during my study.

At the same time that dissolved oxygen levels are reduced by high temperatures, respiratory rates of eggs and alevins increase, so that higher oxygen concentrations are required to maintain the organism (McNeil, 1968). Further, the oxygen tension necessary to saturate hemoglobin in salmonids increases with temperature (Irving, Black, and Safford, 1941). Thus, even small temperature increases may produce multiple effects which taken together could be of real significance to the survival of fish within the gravel.

Some other effects of increased temperature may partially compensate for the detrimental influence on the intragravel environment. The developmental rate of the salmon embryo is related to the temperature of the water. An approximate estimate of the number of days to hatching may be made from the accumulated temperature units, each unit equaling one degree Fahrenheit above freezing for one day (Leitritz, 1959). For the purpose of illustration, it may be assumed that approximately 775 temperature units are required for development of coho salmon embryos to the stage at which hatching occurs (Shapovalov and Berrian, 1940). The mean water temperature during the estimated period of egg incubation in Needle Branch was 7.8°C (46.1°F), while in Deer and Flynn Creeks the temperature averaged 6.3°C (43.4°F). If all other factors were equal, eggs in Needle Branch would have hatched in 55 days, whereas those in Deer and Flynn Creeks would have required 68 days to hatch. The higher temperature in Needle Branch would also be expected to promote more rapid development of the alevins, so that fry would be prepared to leave the gravel earlier than the fry of Deer or Flynn Creeks. Another effect of temperature increase is that of stimulating fry migration through the gravel and into the surface water (Bams, 1969). Thus, the fish in Needle Branch would tend to spend less time in the intragravel environment than would those in Deer or Flynn Creeks. This conclusion has been borne out by observations of the time from egg deposition to emergence on the three streams.[3]

Survival in the Study Streams

The real criterion of the significance of changes in the intragravel environment resulting from logging is the response of fish populations to these changes. The Oregon Game Commission has determined the survival to emergence of coho salmon in each of the study streams for three years before and three years after logging. Each year four to seven redds per stream are covered with a fry trap of nylon netting and the fry emerging from the trap enumerated (Phillips and Koski, 1969). From the weight of the spawning female, an estimate of the number of eggs deposited in each redd can be made, and the percentage survival to emergence calculated. The values range from 0 to 82 percent. There is considerable variation in the mean survival for each stream, even under natural conditions.

[3] R. F. Severson. Personal communication. Oregon Game Commission, Corvallis. June, 1969.

For example, the survival to emergence in three years prior to logging in Needle Branch averaged 25, 22, and 44 percent (Lantz, 1967). The variability is so great that it would be difficult to attribute any but gross changes in survival to the effects of logging.

In Needle Branch, the mean percentage survival to emergence was 17 percent during the first year following logging. This value was somewhat below average but within the range of variation recorded prior to logging of one of the other study streams. Survival during the second and third years after logging was within the range recorded under natural conditions.[4] Thus, the relatively subtle changes in the intragravel environment were not reflected in the fry emergence data. It is probable that some increase in mortality of coho fry occurred as the result of changes in the gravel, but that the change could not be separated from natural variation. However, no drastic reduction in survival to emergence can be attributed to the observed environmental alteration.

Survival to emergence is not the only criterion of the significance of changes in the intragravel environment. Fry must not only emerge from the gravel, but must cope with a rigorous stream environment for a year, and in some cases two years, prior to the

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[4] R. L. Lantz. Personal communication. Oregon Game Commission, Corvallis. June, 1969.

seaward migration. Emerging fry that are small because of low dissolved oxygen levels, or weak due to emergence through fine sediment, may not survive to the smolt stage.

Preliminary analysis of the number of smolts leaving the logged streams indicates that no serious reduction in numbers of coho has occurred following logging.[5] Perhaps competition among fry subjected to similar suboptimal conditions results in about the same number of fish that would survive under natural conditions. As mentioned earlier, however, a majority of coho fry leave the natal stream soon after emergence, thus coming into competition with fish from other watersheds. The fate of these nomadic fry is still unknown, but at least some probably contribute to the adult population. If so, then it seems likely that fry developing in the most favorable environment would be more successful in surviving to enter the fishery than those developing in a marginal environment.

The first coho that developed in the post-logging intragravel environment in Needle Branch will return as spawners in the winter of 1969-70. Predation, parasitism, fishing mortality, and other factors are not constant from year to year, so that the number of

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[5] J. D. Hall. Personal communication. Oregon State University, Corvallis. June, 1969.

spawners is highly variable. Thus, detection of the effects of the change in the intragravel environment on the number of returning adults may be impossible. However, if adequate numbers of coho continue to spawn in the clearcut stream, the observed changes in the environment may be considered within the range to which the coho is adapted.

No data on the survival to emergence of cutthroat trout are available for the study streams, but the population of resident fish has been reduced to 27 percent of its prelogging level (Hall and Lantz, 1969). Whether the reduction resulted from the changes detected in the intragravel environment, or from other alterations in the stream, is unknown. The response of the cutthroat trout population suggests that fish species differ in their ability to withstand an altered environment.

The changes observed in this study are indicative of the impact of logging activities on the spawning bed environment of small, headwater streams. Environmental alteration resulting from logging would be expected to vary in areas having different soil conditions, topography, and vegetation. Further, the importance of these alterations to fish populations may be closely linked to the life history or resiliency of the species involved. Thus, the changes detected in this study cannot be considered unimportant until their effects are evaluated in terms of a number of salmonid species in varied habitats.

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APPENDICES

APPENDIX 1

Dissolved Oxygen Concentration (mg/1) of Intragravel Water in Needle Branch and Deer Creek (January 15-May 2, 1969).

Needle Branch

Location in Meters Above or Below Wier	Mean	Minimum	Maximum	No. Samples
Redds				
134*				
A	9.61	7.54	12.04	47
B	9.25	7.99	10.70	47
C	8.93	7.30	11.11	47
D	9.46	7.22	12.08	47
E	8.95	7.62	10.38	47
168	10.13	8.51	11.80	46
405	7.95	4.70	11.27	47
447	1.60	0.49	3.00	46
487	5.31	2.11	10.74	47
547	9.34	8.03	11.03	47
551*				
A	9.03	4.86	11.68	47
B	8.34	4.30	11.19	47
C	8.69	5.19	11.16	47
D	9.50	6.65	12.08	47
E	8.99	5.72	11.76	47
600	3.23	0.32	9.00	47
778	9.07	6.89	10.54	47
Permanent Standpipes				
102	10.31	8.76	11.84	45
296	8.24	1.62	11.51	44
442	3.30	0.32	11.35	44
474	2.24	0.32	10.21	42
550	9.79	7.95	12.08	45
600	6.64	0.53	12.08	44
632	4.93	0.61	11.35	45
692	5.39	2.47	10.50	45
772	4.86	1.01	11.47	44

*Redds with multiple standpipes

APPENDIX 1 (Cont.)

Deer Creek

Location in Meters Above or Below Wier	Mean	Minimum	Maximum	No. Samples
Redds				
-113 -110*	10.06	8.63	12.12	47
A	8.49	5.68	11.43	43
B	10.15	8.72	11.76	42
C	9.99	6.61	11.51	41
D	9.97	7.42	11.72	43
E	10.56	8.80	12.08	42
-43	5.82	1.42	10.05	45
-45	9.36	4.54	11.31	46
17	9.52	6.40	11.51	45
32* A	10.50	8.59	12.73	41
B	9.26	6.40	11.92	41
C	10.71	9.04	12.65	41
D	10.42	8.15	12.65	41
E	9.94	7.70	12.57	40
37	8.05	1.22	11.51	46
104	5.49	3.85	10.54	43
122	9.46	7.05	11.19	47
158	10.88	9.73	12.08	47
1930	9.22	7.70	10.90	43
Permanent Standpipes				
964	10.66	8.43	12.04	45
1110	5.85	2.59	10.86	44
1190	9.91	7.01	11.59	45
1330	6.82	4.82	11.43	41
1450	10.14	8.43	12.00	45
E. 132	10.40	8.84	11.43	45
1630	9.01	6.89	11.92	45
1670	5.11	0.97	11.84	45
1805	10.01	8.11	12.16	45

*Redds with multiple standpipes

APPENDIX 2

Percentages of Fine Particles and Organic Material in Three Depth-Strata of the Study Streams

Needle Branch

Location		Fine Sediment Percent <0.83 mm	Mean	Percent <3.33 mm	Mean	Organic Material Percent	Mean
Redds							
148 A	1	21.62		31.53		1.218	
	2	21.60	20.62	31.62	31.85	1.219	1.120
	3	18.64		32.39		0.923	
148 B	1	21.83		35.44		1.009	
	2	21.18	23.98	36.19	38.65	1.647	1.506
	3	28.94		44.32		1.863	
310 A	1	32.06		41.74		1.274	
	2	22.37	22.83	40.08	34.22	1.527	1.044
	3	12.86		20.86		0.330	
310 B	1	27.93		38.89		1.650	
	2	21.88	21.16	35.28	32.43	1.437	1.285
	3	13.68		23.12		0.768	
324 A	1	29.79		41.01		1.123	
	2	26.28	30.01	35.00	40.14	1.379	1.308
	3	33.95		44.42		1.422	
324 B	1	32.49		47.15		1.754	
	2	44.84	41.31	51.50	51.65	1.983	1.973
	3	46.61		56.31		2.181	
405 A	1	29.06		40.47		1.877	
	2	28.51	27.54	44.23	42.11	1.365	1.564
	3	25.05		41.64		1.449	
405 B	1	41.58		56.44		2.368	
	2	27.17	32.22	40.09	44.77	1.591	1.786
	3	27.90		37.78		1.398	
498 A	1	15.76		25.35		1.724	
	2	17.22	13.69	31.07	23.71	1.625	1.373
	3	8.08		14.72		0.771	
498 B	1	27.41		37.63		1.845	
	2	20.59	20.11	32.00	29.91	1.621	1.267
	3	12.34		20.10		0.336	

APPENDIX 2 (Cont.)

Location		Fine Sediment Percent <0.83 mm	Mean	Percent <3.33 mm	Mean	Organic Material Percent	Mean
Redds							
550 A	1	21.03		33.33		1.900	
	2	20.90	22.04	34.98	37.03	2.292	2.104
	3	24.18		42.78		2.119	
550 B	1	25.58		35.44		1.650	
	2	26.72	23.71	37.12	34.58	1.583	1.388
	3	18.82		31.19		0.932	
587 A	1	11.98		19.77		1.950	
	2	20.63	16.47	37.67	30.44	1.242	1.493
	3	16.79		33.88		1.287	
587 B	1	14.14		26.76		1.584	
	2	12.46	16.29	20.33	26.40	1.549	1.428
	3	22.26		32.12		1.150	
602 A	1	35.75		46.27		1.796	
	2	25.88	28.38	35.89	38.65	0.982	1.266
	3	23.52		33.79		1.019	
602 B	1	31.60		40.99		2.058	
	2	21.24	25.57	33.80	37.42	1.686	1.725
	3	23.87		37.46		1.431	
Former Redds							
113	1	34.12		50.13		1.523	
	2	33.39	33.00	44.82	45.31	1.771	1.532
	3	31.50		41.00		1.300	
131 A	1	18.05		25.61		0.823	
	2	15.37	17.51	24.69	26.66	0.765	0.890
	3	19.10		29.69		1.073	
131 B	1	31.87		42.34		1.161	
	2	44.82	54.90	53.74	62.56	3.225	3.969
	3	88.02		91.61		7.522	
216	1	67.56		87.66		--	
	2	35.17	48.57	50.17	63.57	2.022	1.839
	3	42.97		52.87		1.656	
236	1	30.36		40.54		1.678	
	2	29.72	29.52	41.54	42.39	1.347	1.512
	3	28.48		45.09		--	

APPENDIX 2 (Cont.)

Location		Fine Sediment Percent <0.83 mm	Mean	Percent <3.33 mm	Mean	Organic Material Percent	Mean
Former Redds							
370	1	32.63		43.39		1.369	
	2	33.38	33.59	47.38	47.53	16.54	1.512
	3	34.77		51.83		--	
752 A	1	70.01		84.61		3.250	
	2	66.25	60.93	80.23	74.64	6.029	3.803
	3	46.52		59.09		2.129	
752 B	1	14.63		22.62		1.312	
	2	22.95	26.71	36.62	44.45	1.547	1.696
	3	42.54		74.10		2.228	
Deer Creek							
Redds							
15 A	1	16.58		27.15		1.182	
	2	17.16	17.54	31.15	30.50	1.095	1.255
	3	18.89		32.61		1.489	
15 B	1	16.21		27.15		0.716	
	2	15.19	18.10	22.11	27.84	1.038	1.036
	3	22.89		34.26		1.353	
1205 A	1	31.63		40.72		1.028	
	2	22.31	23.50	33.47	33.89	1.154	1.125
	3	16.57		27.48		1.194	
1205 B	1	31.63		41.59		1.219	
	2	21.17	23.05	29.69	32.40	1.058	1.160
	3	16.36		25.91		1.202	
1220 A	1	34.24		44.08		1.383	
	2	27.13	29.38	41.51	44.19	1.541	1.549
	3	26.76		46.97		1.724	
1220 B	1	26.23		37.67		1.282	
	2	19.86	23.47	34.91	37.21	1.294	1.288
	3	24.34		39.06		--	
1455 A	1	29.40		37.04		1.135	
	2	24.08	24.98	32.36	33.85	1.826	1.286
	3	21.46		32.14		0.896	
1455 B	1	29.48		40.76		1.494	
	2	25.11	25.00	39.27	33.85	1.465	1.287
	3	20.41		30.81		0.901	

APPENDIX 2 (Cont.)

		Fine Sediment				Organic Material	
Location		Percent <0.83 mm	Mean	Percent <3.33 mm	Mean	Percent	Mean
Redds							
E. 175 A	1	17.80		29.16		1.388	
	2	12.31	14.63	22.03	24.80	1.465	1.358
	3	13.77		23.20		1.220	
E. 175 B	1	16.11		27.66		0.822	
	2	13.71	14.93	28.27	27.55	1.509	1.216
	3	14.98		26.73		1.318	
Flynn Creek							
Redds							
-76 A	1	34.58		43.45		1.303	
	2	38.01	35.86	49.79	47.33	2.086	1.804
	3	35.00		48.76		2.023	
-76 B	1	26.38		39.11		1.600	
	2	25.22	35.03	37.50	54.58	1.812	2.085
	3	53.49		87.14		2.842	
-18 A	1	25.96		35.57		1.276	
	2	27.28	22.81	45.05	36.50	1.607	1.442
	3	15.20		28.88		--	
-18 B	1	33.46		44.44		1.696	
	2	28.01	28.38	47.30	44.06	2.041	1.858
	3	23.68		40.44		1.836	
236 A	1	34.27		47.44		1.854	
	2	31.77	34.02	45.34	49.85	1.559	1.799
	3	36.02		56.78		1.984	
236 B	1	24.76		45.34		1.332	
	2	25.31	22.60	41.80	38.62	1.242	1.254
	3	17.73		36.25		1.189	
Former Redds							
-61 A	1	21.28		35.84		1.590	
	2	31.07	34.99	51.50	51.62	2.086	1.947
	3	52.62		67.52		2.166	
-61 B	1	23.03		41.52		1.395	
	2	33.00	33.85	48.27	51.03	1.600	1.732
	3	45.53		63.29		2.201	

APPENDIX 2 (Cont.)

		Fine Sediment				Organic Material	
		Percent		Percent			
Location		<0.83 mm	Mean	<3.33 mm	Mean	Percent	Mean
Former Redds							
28							
	1	31.78		46.12		1.797	
	2	34.01	35.09	43.69	48.12	1.900	1.852
	3	39.47		54.56		1.859	
113 A							
	1	20.02		32.81		1.084	
	2	16.61	17.09	28.80	28.06	1.084	0.805
	3	14.63		22.56		0.481	
113 B							
	1	29.21		43.49		1.462	
	2	25.94	28.85	42.41	43.61	1.540	1.563
	3	31.41		44.93		1.540	
133							
	1	22.69		30.56		1.798	
	2	20.27	19.78	36.83	31.04	1.659	1.574
	3	16.37		25.72		1.266	
148							
	1	23.95		36.06		1.795	
	2	25.00	23.13	42.27	37.98	1.968	1.713
	3	20.45		35.60		1.375	