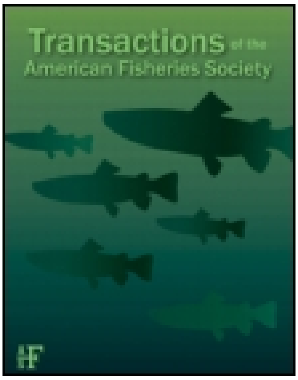

Transactions of the American Fisheries Society
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/utaf20

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Published online: 09 Jan 2011.

To cite this article: Neil H. Ringler & James D. Hall (1975) Effects of Logging on Water Temperature, and Dissolved Oxygen in Spawning Beds, Transactions of the American Fisheries Society, 104:1, 111-121, DOI: 10.1577/1548-8659(1975)104<111:EOLOWT>2.0.CO;2

To link to this article: http://dx.doi.org/10.1577/1548-8659(1975)104<111:EOLOWT>2.0.CO;2

Effects of Logging on Water Temperature and Dissolved Oxygen in Spawning Beds[1,2]

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ABSTRACT

The temperature and dissolved oxygen content of intragravel water were measured in three Oregon coastal streams between June 1968 and June 1969. In 1966, the watershed of one stream had been completely clearcut, and that of a second stream partially clearcut in staggered settings. A third watershed was left unlogged.

Clearcut logging resulted in increased temperature of intragravel water in salmon and trout spawning beds and decreased concentrations of dissolved oxygen. The changes were related largely to reduced forest cover over the stream surface and to deposition of fine sediment in the gravel.

No serious reduction in survival to emergence of coho salmon occurred along with the observed changes in temperature or dissolved oxygen. A decrease in the resident population of cutthroat trout after logging may have been related to these changes.

Streams on the Pacific Northwest Coast provide spawning and rearing habitat for salmon and trout species important in sport and commercial fisheries. These streams also drain watersheds containing valuable timber. Because harvesting of timber can affect the streams, a thorough knowledge of the effects of logging on the stream environment is a prerequisite to management of both fishery and timber resources.

The research described here is part of the Alsea Watershed Study, a 15-year evaluation of the influence of logging on aquatic resources within the Coast Range of Oregon. Our objectives in the present paper are to describe the conditions of temperature and dissolved oxygen that occurred in the stream beds during one year (June 1968–June 1969) in the post-logging period, and to evaluate the significance to salmonids of any change from pre-logging conditions.

Temperature of intragravel water can influence success of salmonid reproduction. High temperature increases the rate of oxygen demand of organic debris in the gravel, and decreases the solubility of atmospheric oxygen in water. Increased temperature also shortens the period of embryonic development and may stimulate migration of fry through the gravel (Bams 1969).

Survival of salmonid embryos and alevins is related to dissolved oxygen concentration and flow rate of intragravel water (Wickett 1954; Coble 1961; McNeil 1966). Laboratory experiments have verified the importance of adequate velocity and dissolved oxygen concentration of intragravel water (Schumway, Warren, and Doudoroff 1964). Sheridan (1962) and Vaux (1962, 1968) have shown that renewal of intragravel dissolved oxygen in many salmon streams results largely from exchange of surface and intragravel water.

The effects of logging activity on temperature and dissolved oxygen in intragravel water have not been adequately evaluated through field studies. Hall and Lantz (1969) reported a 30% decrease in streambed dissolved oxygen after the watershed of one stream was clearcut. The present work was designed to document changes in intragravel conditions, particularly in natural salmon redds, soon after logging.

STUDY AREA

Our study was conducted on three small headwater streams in Lincoln County, Oregon (Fig. 1). The watersheds consist of moderate to steep-sloped valleys typical of those in the

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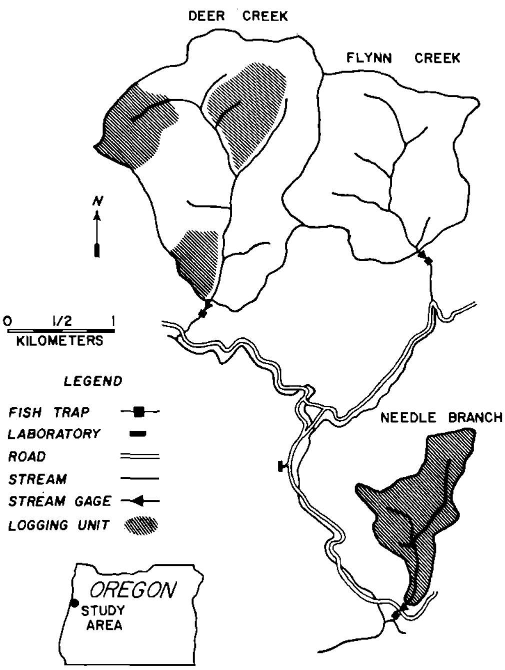

FIGURE 1.—Map of the study watersheds.

Oregon Coast Range. Prior to logging they were forested primarily with Douglas fir, a varying percentage of red alder, and a dense understory of salmonberry, vine maple, and salal. Coho salmon (*Oncorhynchus kisutch*) and cutthroat trout (*Salmo clarki*) spawn in each of the streams. There is a great seasonal variation in streamflow. Major freshets usually occur from November to February, when the salmon are spawning, but streamflows drop to a low level during the summer (Table 1). Air temperatures may range from –7 to 32 C, but the temperature of these heavily shaded streams was relatively stable before logging (Table 1).

Access roads were built into the Needle Branch and Deer Creek watersheds in 1965, and logging occurred in 1966. Highlead cable yarding was used in both watersheds. The Needle Branch watershed (71 ha) was entirely clearcut between March and September.

Several significant changes occurred in the stream habitat on Needle Branch soon after logging (Hall and Lantz 1969). During the yarding operation organic debris and sediment were deposited on the stream gravel.

TABLE 1.—*Summary of streamflow and temperature regimes in the study streams before logging, 1959–1965. (Data from U.S. Geological Survey)*

	Streamflow (liters/sec)		Temperature (C)		
Stream	Recorded maximum	Mean annual minimum	Mean	Recorded maximum	Maximum diel range
Deer Creek	5688	8.5	9.6	16.1	2.2
Flynn Creek	3877	4.5	9.7	16.6	2.2
Needle Branch	1415	0.6	9.7	16.1	1.5

Intragravel dissolved oxygen levels dropped to an average of 1.3 mg/liter by 30 June; surface dissolved oxygen dropped to a low of 0.6 mg/liter in ponds formed by logging debris. Surface water temperature reached a maximum of 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 1966. Fall freshets removed much of the debris and sediment from the surface of the spawning gravel. During winter 1966–67, dissolved oxygen in the surface water returned to pre-logging levels, but intragravel dissolved oxygen remained about 3 mg/liter below the pre-logging average. During summer 1967, the maximum stream temperature of 30 C was recorded (Brown and Krygier 1970).

In the Deer Creek watershed, cutting began in May 1966, and yarding was completed by December. Three areas, totaling about 25% of the 305-ha watershed, were logged in staggered settings (Fig. 1). A strip of vegetation, consisting largely of red alder, was left along the stream channel. No significant 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. One of the three clearcut areas was burned in 1967, another in 1968, and the third in 1969 to remove slash.

The Flynn Creek watershed (200 ha) was left unlogged.

METHODS

Temperature. Surface temperatures of the three streams were recorded with Partlow thermographs accurate within 0.3 C. Intragravel temperatures were monitored by thermograph probes buried 25 cm deep in three artificial redds in Needle Branch. The temperature in natural coho salmon redds of all three streams was measured with a thermistor probe accurate within 0.5 C. Temperature data were obtained in March and April by lowering the probe into standpipes that had been placed in the redds. Measurements of temperature during the summer were made by inserting the probe directly into the gravel.

Dissolved Oxygen. Intragravel water in natural redds was sampled from standpipes installed aproximately 4 weeks after spawning was completed. The embryos were presumed least susceptible to disturbance at that time. The pipes were 85-cm lengths of 1.25-cm-diameter PVC plastic, driven to a depth of 25 cm. The lower 8 cm of each pipe was perforated with twenty 4.7-mm holes, as described by McNeil (1962). Nine redds in Needle Branch and 11 in Deer Creek were chosen for sampling. A single standpipe was driven into each of the selected redds. Four additional pipes were equally spaced around each center standpipe at a distance of 30 cm from the center pipe on two redds in each stream. All standpipe and redd locations were identified by distance in meters upstream from the stream gaging weirs (Fig. 1).

During much of the winter, access to Flynn Creek, the unlogged watershed, was not sufficiently reliable for the frequent sampling necessary for oxygen determinations. Koski (1966) established that levels of intragravel dissolved oxygen were similar among all three unlogged streams. Because very little disturbance occurred in Deer Creek after logging, we used oxygen measurements from this stream to compare with those from Needle Branch.

In addition to the temporary standpipes placed in redds, Mark VI standpipes (Terhune 1958) were permanently installed in the stream bed. The assumption that these standpipes were located in suitable spawning gravel was confirmed by several observations of salmon spawning near the pipes.

Sixty-ml water samples were removed from all standpipes three times weekly from 15 January to 2 May 1969. Winkler titration was

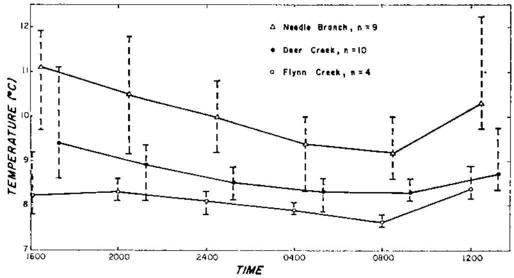

FIGURE 2.—Mean and range of intragravel (25 cm) water temperature in natural redds in the study streams 26–27 April 1969, based on thermistor probe measurements within standpipes.

used to determine the dissolved oxygen content. Each day samples were taken from one stream in the morning and from the other stream during the afternoon. The order of sampling of the streams was alternated throughout the study period to compensate for possible temperature effects on dissolved oxygen.

RESULTS

Temperature

Both the mean temperature and diel fluctuation within the gravel increased in relation to the extent of logging. Between 15 January and 2 June 1969, mean surface temperatures in Needle Branch, Deer Creek, and Flynn Creek were 9.0, 8.3, and 7.5 C, respectively, reflecting differences in the amount of forest cover remaining over the three streams. Continuous intragravel temperatures were not recorded in Deer or Flynn Creeks, but based on results from artificial redds in Needle Branch, the intragravel environment would also be expected to reflect differences in temperature resulting from logging. Measurements made in natural redds during a warm spring day support this expectation (Fig. 2).

The temperature within the gravel in Needle Branch showed considerable diel fluctuation during the winter-spring period of measurement (4 March–2 May). However, this fluctuation was much less pronounced that that of the surface water. Maximum and minimum temperatures within the gravel occurred 1 to 6 hours later that those of the surface water (Fig. 3). Variation in the magnitude and

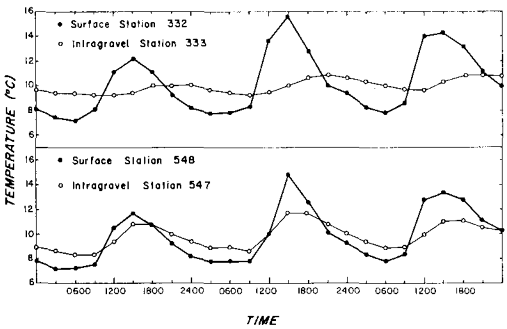

FIGURE 3.—Intragravel (25 cm) and surface temperature at two artificial redd sites in Needle Branch 25–27 April 1969, taken from thermograph records.

TABLE 2.—*Mean and range of temperature (C) of surface and intragravel water in Needle Branch 4 March–2 May 1969, based on thermograph records. Intragravel temperatures from artificial redds*

Surface			Intragravel		
Station	Mean	Range	Station	Mean	Range
17	9.0	4.4–16.1	23	8.9	5.0–13.9
332	8.8	4.4–15.5	333	9.0	6.9–11.1
548	9.0	5.6–15.3	547	9.0	6.1–11.9

timing of fluctuation was evident among the locations studied, but the mean daily temperatures of both surface and intragravel water at all three stations were quite similar (Table 2). The maximum intragravel temperature in the three artificial redds differed by as much as 4 C on several days while fry were in the gravel.

In summer, high intragravel temperatures did not directly influence eggs or alevins, because fry emergence was already complete. However, high water temperature in the summer provided an opportunity to study the influence of highly fluctuating surface temperature on that of the intragravel water. Considerable temperature fluctuation was evident within the gravel in Needle Branch on clear days (Fig. 4), and maxima as great as 21 C were recorded. Mean intragravel temperatures at Stations 333 and 547 were 17.2 and 16.4 C, respectively; surface temperatures near these sites averaged 17.0 and 16.6 C, respectively. Intragravel water temperatures lagged from 2 to 6 hours behind those of the surface water in attaining the diel maximum and minimum, even though the means were quite similar.

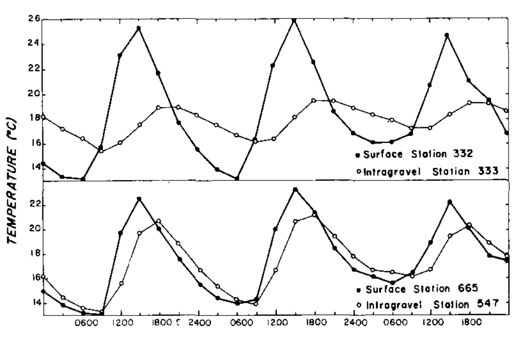

FIGURE 4.—Intragravel (25 cm) and surface temperatures at two artificial redd sites in Needle Branch 30 July–1 August 1968, taken from thermograph records. A surface thermograph was not operated at Station 548 during summer; Station 665 was the nearest upstream record.

The variation between stations in amount of lag suggested differences in rates of interchange of surface with intragravel water. Data obtained on a single warm day between 1415 and 1600 (PST) with the thermistor probe revealed an irregular decline of temperature with depth of the gravel (Fig. 5). This decline was more rapid at Station 333 than at 547; apparently Station 333 had less exchange of surface with intragravel water than Station 547.

Further sampling was undertaken at a series of natural redds to test the possible use of temperature profiles to evaluate the exchange of surface with intragravel water. Variation in temperature with depth was also found among natural redds (Fig. 6). However, the profiles could not be used as a quantitative index to interchange because they changed with time of day. Measurement in one redd required about 45 minutes. When the sequence of sampling was altered, the relationship among redds was changed. Such an index might be useful if nearly simultaneous temperature measurements could be made in all redds.

Nonetheless, the temporal variation in intragravel water temperature provided evidence of the extent of influence of surface water upon intragravel water. There was some evidence of influence as deep as 50 cm in the gravel

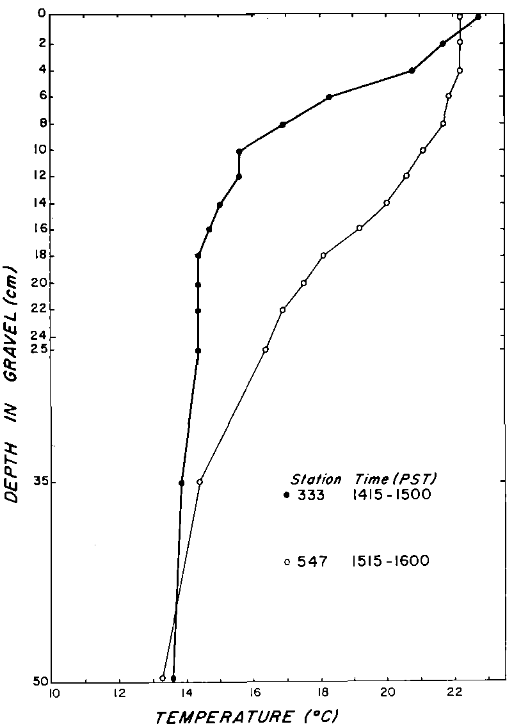

FIGURE 5.—Relation between mean intragravel temperature and depth in two artificial redds in Needle Branch 1 July 1968. Data obtained with thermistor probe at nine points per station in a 60-cm square grid.

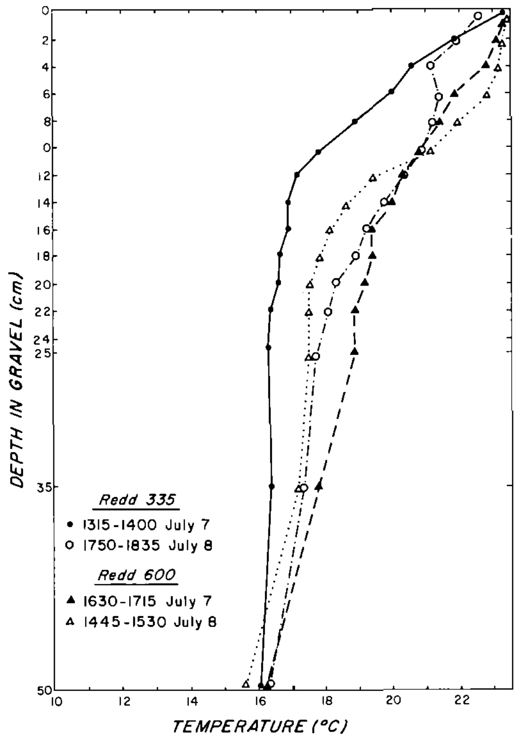

FIGURE 6.—Relation between mean intragravel temperature and depth in two natural redds in Needle Branch on two successive days (nine points per redd in a 60-cm square grid, 7–8 July 1968).

(Fig. 6). The major temperature changes occurred above 35 cm, however, indicating that most of the interchange occurred above that level.

There was also considerable spatial variation within a single redd (Fig. 7). Four redds in Needle Branch were sampled on several dates during summer 1968. The temperature within a 60-cm square grid varied as much as 7.5 C at 4-cm depth and 3.3 C at 25 cm.

Practically no temperature gradient existed in Flynn Creek, and the gradient in Deer Creek was relatively small (2 C). These data were obtained during periods of insolation comparable to those existing during sampling of Needle Branch. 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.

Dissolved Oxygen

The mean dissolved oxygen concentration in salmon redds of Needle Branch was consistently lower than that of Deer Creek during the period that embryos and alevins were in the gravel (Fig. 8A). T-test comparisons made over 2-week intervals indicated that the differences between streams were significant at the 99% confidence level for each interval except one. Needle Branch redds contained an average of 20% less dissolved oxygen than those of Deer Creek. The mean dissolved oxygen for the entire season (14 January–2 May) in Deer Creek redds was 8.91 mg/liter, whereas Needle Branch redds averaged 7.15 mg/liter. A gradual reduction in dissolved oxygen occurred in both streams over the season. Because this reduction was more pronounced in Needle Branch, the difference in mean dissolved oxygen between streams increased during the season.

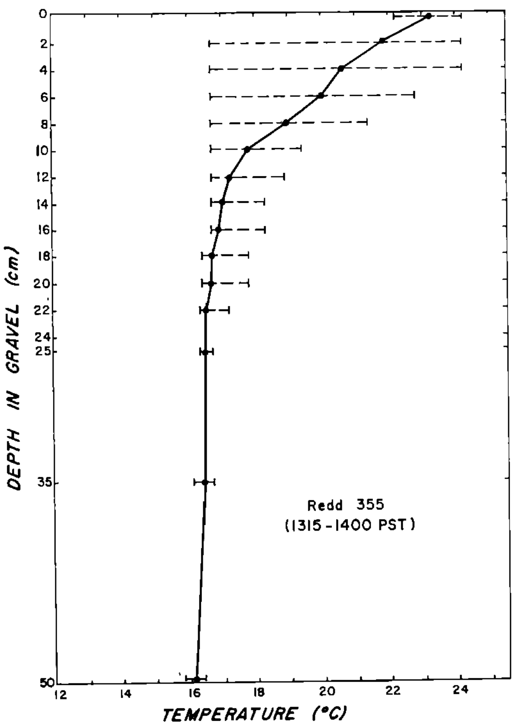

FIGURE 7.—Temperature variation (mean and range) among nine points in a 60-cm square grid in a natural redd in Needle Branch 7 July 1968.

In the permanent standpipes the seasonal difference between streams was 2.46 mg/liter (Fig. 8B), in contrast to the 1.76 mg/liter difference measured in redds. Again, mean dissolved oxygen tended to decline throughout the season, and the differences between the two streams were statistically significant for each 2-week interval but one.

Differences in mean dissolved oxygen between streams may be misleading because of spatial and temporal variation in the data. The minimum concentration is more likely to be critical for fish survival. Although 6 to 7 mg/liter has been suggested as an oxygen concentration required by salmonids in nature, no precise minimum level has been established (Doudoroff and Shumway 1970). For the purposes of our analysis on coho salmon, 6 mg/liter was selected. In Needle Branch, 5 of 9 redds studied had minimum dissolved oxygen levels below 6 mg/liter, and 4 of 11 redds in Deer Creek had such levels. At the

TABLE 3.—*Mean dissolved oxygen (mg/liter) in redds and permanent standpipes before and after logging in Deer Creek and Needle Branch, 12 February–2 May 1964 and 1969*

	Deer Creek			Needle Branch		
Year and location	Mean	Number of standpipes	Number of days sampled	Mean	Number of standpipes	Number of days sampled
Redds						
1964	10.01	10	25	10.68	11	24
1969	8.74	11	35	6.69	9	35
Difference	1.27[a]			3.99[a]		
Permanent standpipes						
1964	8.95	9	7	10.21	9	7
1969	8.50	9	34	5.79	9	34
Difference	0.45			4.42[a]		

[a] Difference statistically significant ($P < 0.01$).

permanent standpipes, 7 of 9 Needle Branch sites dropped below 6 mg/liter, whereas only 3 of 9 Deer Creek sites fell below this concentration. Although these differences were not statistically significant, the probability level for standpipes ($P = 0.08$, Fisher exact probability test) suggested that fewer potential redds provided an environment conducive to high survival in Needle Branch than in Deer Creek.

Apparently, spawning activities of the salmon improved the intragravel environment of the redds, or the fish were able to select the more suitable areas for spawning. Oxygen levels in Needle Branch redds were significantly higher (0.89 mg/liter) than those of the permanent standpipes, which were located in comparable riffle areas ($P < 0.01$). Dissolved oxygen in Needle Branch varied much less in redds than in permanent standpipes, also suggesting a more suitable environment in the redds.

Oxygen levels in natural redds were measured in one previous year during the study by Koski (1966). His data were used to make the following comparisons of dissolved oxygen levels before and after logging, between 12 February and 2 May of 1964 and 1969 (Table 3). There was no significant difference in dissolved oxygen between redds of Needle Branch and Deer Creek in 1964. Values in permanent standpipes averaged somewhat lower than those in redds, but the difference was not statistically significant. Little

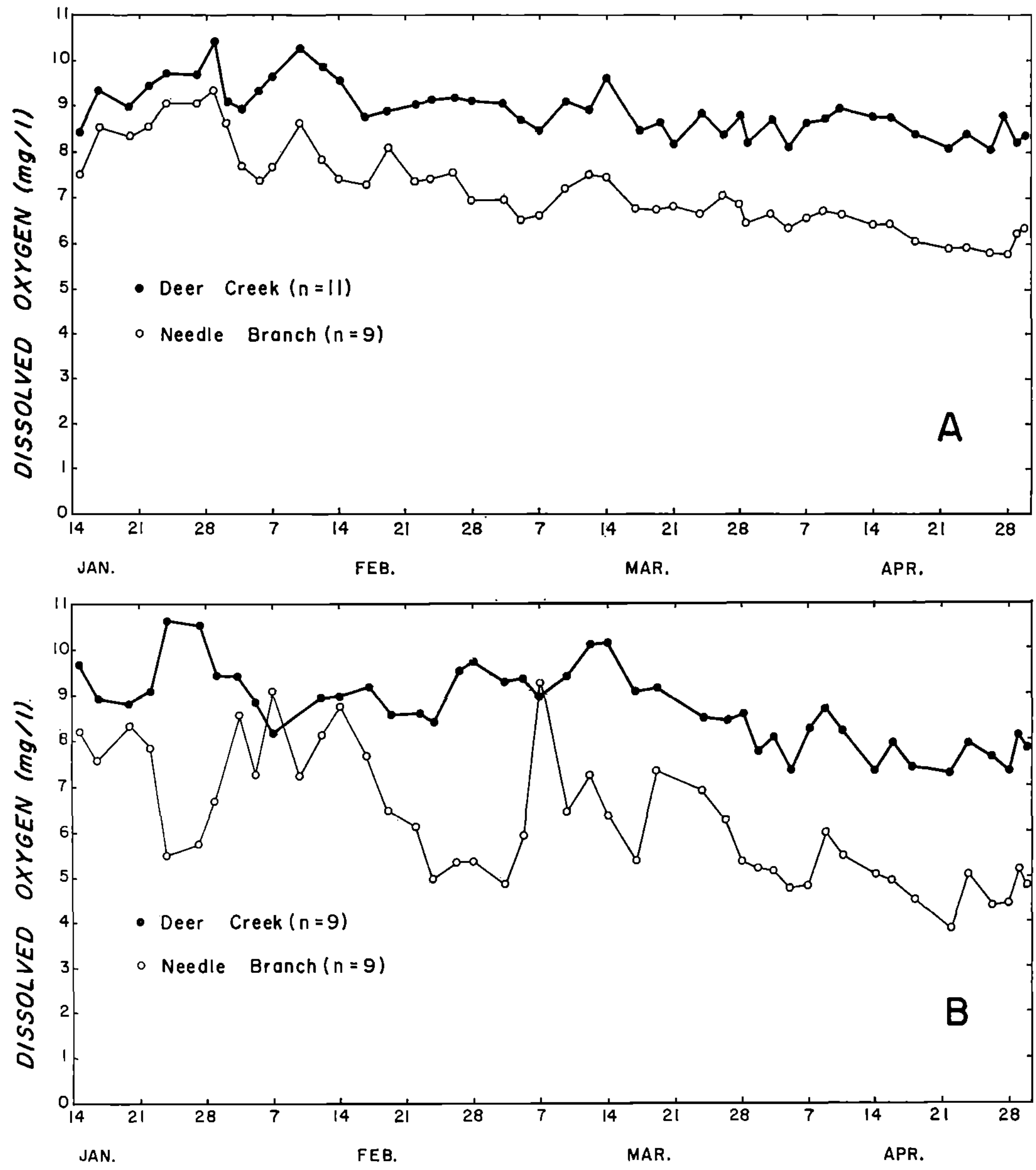

FIGURE 8.—Mean dissolved oxygen taken from standpipes in spawning gravel of Deer Creek and Needle Branch during 1969. A. Natural redds. B. Permanent standpipes.

change in dissolved oxygen occurred at the permanent standpipes in Deer Creek after logging. The redds, however, showed a 13% reduction in dissolved oxygen ($P < 0.01$). In Needle Branch, dissolved oxygen in the permanent standpipes dropped 43% between 1964 and 1969; oxygen levels in the redds were reduced 37% ($P < 0.01$).

DISCUSSION

We have demonstrated significant differences among the study streams in the temperature and dissolved oxygen levels of water flowing through spawning gravels. The inference that clearcut logging was responsible for the observed differences is supported by data from other cooperators in the study, and by the results of previously published work.

An increase in suspended sediment in the stream water (Brown and Krygier 1971) and increased sediment levels in the gravel (unpublished data, Oregon State Game Commission) have been documented in the clearcut stream. Deposition of fine sediment in gravel interstices has been shown to reduce exchange of surface with intragravel water (McNeil and Ahnell 1964; Cooper 1965).

The sizable temperature gradients we encountered were probably caused partly by reduced interchange of surface and intragravel water as a result of sedimentation. Wickett (1954) found the largest gradient between surface and intragravel temperatures in a heavily silted section of stream. The temperature lag between surface and intragravel water was shortened from 18 hours to 0–6 hours upon washing the silt out of this section of stream bed. Sheridan (1961) buried thermocouples at depths up to 55 cm in Alaskan streams and found little temperature gradient within the gravel. He did, however, find evidence that salt water in intertidal areas warmed intragravel water to a depth of 30 cm. Brown (1972) inserted thermocouples into the gravel bed of a small clearcut Oregon stream and found a gradient of 0.05 C or less between the surface and 5 cm, and a maximum gradient of 1.1 C between the surface and 20 cm. Unlike Needle Branch, the stream bed was highly porous.

Large diel fluctuations in surface water temperature also contributed to our observed gradients. On cloudy days, when temperature fluctuations were minimal in Needle Branch, little or no temperature gradient was found.

The decreases in dissolved oxygen in the clearcut stream were evidently caused largely by the increased level of fine sediments in the gravel. Sheridan (1962) and Vaux (1962; 1968) concluded that renewal of intragravel dissolved oxygen occurred largely through exchange of surface with intragravel water. One artificial addition of sediment to an Alaskan stream did not result in reduction of dissolved oxygen levels in the stream bed (Shapley and Bishop 1965), but levels of sediment were much below those found in Needle Branch. We did not find significantly more particulate organic material in the gravel of the clearcut compared with the control stream (Ringler 1970), in spite of a large volume of fine organic debris deposited in the stream during logging.

The moderate decrease in dissolved oxygen in Deer Creek may also have been related to sedimentation. Two landslides associated with road building increased suspended sediment levels during 1965–66 (Brown and Krygier 1971). The percentage of fine sediment in Deer Creek redds has increased over pre-logging levels (unpublished data, Oregon State Game Commission).

Temperature was not a major factor in the oxygen decrease. The dissolved oxygen concentration of surface water in Needle Branch averaged 0.57 mg/liter lower than that of Deer Creek from mid-January through April. During this same period, surface water temperature in Needle Branch averaged 1.1 C higher than Deer Creek. The percentage saturation was almost identical in the two streams; thus, the difference in surface dissolved oxygen could be attributed to the physical effect of temperature on solubility. This effect represents about 25% of the difference between streams in intragravel dissolved oxygen. An increased rate of oxygen demand of organic material in Needle Branch at the higher temperature may have also contributed to the decrease in intragravel dissolved oxygen. Although our data do not allow an estimate of this effect, it was probably relatively minor.

Changes in streamflow were evidently not responsible for the oxygen decrease in Needle Branch. Total annual runoff (Harris 1973) and summer low flow (Harr and Krygier 1972) *increased* following clearcut logging.

The impact of logging activities on the fish populations is a major concern of the Alsea Watershed Study. Sufficient data exist to evaluate the significance to salmonids of the observed changes in temperature and oxygen in the study streams.

High temperatures may have caused some direct mortality in Needle Branch. The highest intragravel temperature recorded during embryonic development was 10 C. However, temperatures as high as 20 C were recorded when some coho alevins were still in the gravel. Recent research suggests that alevins are much more sensitive to high temperature than are fry or larger juveniles. Chinook salmon alevins reared several weeks beyond complete yolk absorption showed substantial reduction in survival above 12 C (Eddy 1972).

The increased temperature could also have influenced ultimate survival of the fry by affecting developmental rate of the embryos. The mean water temperature during incubation in Needle Branch was 7.8 C, while in the other streams the temperature averaged 6.3 C. Based solely on temperature relations, embryos in Needle Branch would have hatched 13 days earlier than those in Deer or Flynn Creeks. The higher temperature in Needle Branch should also have promoted more rapid development of the alevins, and stimulated migration of fry through the gravel and into the surface water (Bams 1969). The prediction of earlier emergence of fry in Needle Branch is supported by observations of the time from egg deposition to emergence in the three streams (unpublished data, Oregon State Game Commission). Whether a change in time of emergence adversely affects a population deserves further study.

The importance of an adequate supply of dissolved oxygen to developing salmonid embryos has been demonstrated in a number of studies (Doudoroff and Shumway 1970). In an Alaskan stream, the largest and fastest developing embryos and alevins of pink salmon came from spawning gravel characterized by high levels of dissolved oxygen (Wells and McNeil 1970). A relatively low correlation ($r = 0.24$) between minimum dissolved oxygen and survival to emergence of coho salmon was found in natural redds in our study streams, but the relationship was complicated by the effect of gravel size on survival to emergence (Koski 1966). Our results indicate that the lowest dissolved oxygen levels generally occurred during the last 4 to 6 weeks of intragravel life, well after the critical hatching period of most embryos.

Coho fry incubated at low levels of dissolved oxygen were found to be less successful in competition in artificial streams than those incubated at high oxygen levels (Mason 1969). Because a large proportion of emerging coho fry leave their natal streams within a few months of emergence (Chapman 1962), fry subjected to low levels of dissolved oxygen in the headwaters might eventually have to compete downstream with fish from the other streams that developed at higher oxygen concentrations. The reduction in intragravel dissolved oxygen following clearcut logging may, therefore, have had a subtle effect on coho survival, not easily detected in our study.

Previous research suggests that the observed changes in temperature and oxygen should have had a significant effect on the fish populations in our clearcut stream. Analysis of data on fish populations is not complete, but from preliminary figures it appears that the coho salmon has been little affected, whereas the population of cutthroat trout has been severely reduced.

Biologists from the Oregon State Game Commission, employing a nylon fry trap (Phillips and Koski 1969), determined the survival to emergence of coho salmon in each of the study streams. Survival following logging has been generally within the pre-logging range (unpublished data, Oregon State Game Commission). Apparently, coho fry emergence has not been seriously affected by the changes in the intragravel environment. We did attempt to relate fry survival to intragravel conditions by planting coho eggs in the gravel of all three streams during 1968–69, but technical difficulties resulted in failure of the experiment.

No data on the survival to emergence of cutthroat trout are available for the study streams, but the population of resident cutthroat has been reduced to about one-third of its pre-logging level (unpublished data, Oregon State Game Commission). This reduction has persisted through 6 years following logging, and may be related to the observed changes in the intragravel water. The responses of the cutthroat and coho populations suggest that salmonid species differ in their ability to withstand an altered environment.

The changes in temperature and dissolved oxygen observed in our study represent some of the impacts of logging activities on the spawning beds of small, headwater streams. Environmental alterations resulting from logging would be expected to vary with the logging method, 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. The changes reported here should be evaluated for other salmonid species in varied habitats.

ACKNOWLEDGMENTS

This study was supported by a research assistantship from the Oregon State Game Commission. R. L. Lantz and H. J. Campbell provided unpublished data and offered many helpful suggestions. The cooperation and field assistance of R. F. Severson and D. M. Anderson contributed notably to the study. We appreciate the use of unpublished data on dissolved oxygen provided by K Koski. Drs. W. J. McNeil, G. W. Brown, and D. W. Narver reviewed earlier versions of the manuscript and offered useful suggestions.

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