Effects of Clear-Cutting on Stream Temperature

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Abstract. The principal source of energy for warming streams is the sun. The amount of sunlight reaching the stream may be increased after clear-cut logging. Average monthly maximum temperatures increased by 14°F and annual maximum temperatures increased from 57° to 85°F one year after clear-cut logging on a small watershed in Oregon's coast range. In a nearby watershed where strips of brush and trees separated logging units from the stream, no changes in temperature were observed that could be attributed to clear-cutting.

INTRODUCTION

Timber, water, and sport and commercial fish are the principal resources in the Oregon coast range. The need for delineating the areas of conflict between logging and utilization of the other resources led to the establishment of the Alsea Logging–Aquatic Resources Study in 1958. The purpose of this broadly interdisciplinary study was to determine the effect of logging on the physical, chemical, and biological characteristics of small coastal streams.

The purpose of this paper is to describe the long-term effects of two clear-cuttings on the temperature regime of two small streams in Oregon's coast range. One watershed contained three small clear-cuts; the edges of the clear-cuts were at least 100 feet from the stream. The second watershed was completely clear-cut. An earlier report [*Brown and Krygier*, 1967] described the first-year effect of clear-cutting only during the logging operation on the completely clear-cut watershed. This report reviews results from a network of 18 thermograph stations distributed through the watersheds. The observation period extends from two years before logging through the fourth summer after logging.

Temperature is a significant water quality parameter. It strongly influences levels of oxygen and solids dissolved in streams. Temperature changes can induce algal blooms with subsequent changes in taste, odor, and color of a stream. Warm water is conducive to the growth and development of many species of aquatic bacteria, such as the parasitic columnaris disease. Increased populations of these bacteria may cause fish mortality [*Brett*, 1956]. The growth of fish may be directly affected by water temperature as demonstrated on juvenile coho salmon [*Brett*, 1956]. In short, water temperature is a major determinant of the suitability of water for many uses.

Research has been limited on temperature changes in small streams from land use, although fishery biologists have long been concerned with the effects of deforestation on water temperature. *Meehan et al.* [1969] studied the effects of clear-cutting on the salmon habitat of two southeastern Alaska streams. They noted a statistically significant increase in mean monthly temperatures after logging. The maximum increase in average monthly temperature was about 4°F. The increase in maximum temperature was about 9°F during July and August.

During a study of logging and southeastern trout streams, *Greene* [1950] reported that maximum weekly temperatures recorded during May on a nonforested stream were 13°F higher than those recorded on a nearby forested stream. He noticed also that the maximum temperature dropped from 80° to 68°F after the nonforested stream meandered through 400 feet of forest and brush cover.

Levno and Rothacher [1967] reported large temperature increases in two experimental watersheds in Oregon after logging. The shade provided by riparian vegetation in a patch-cut watershed was eliminated by scouring after large floods in 1964. Subsequently, mean monthly temperatures increased 7°–12°F from April to August. Average monthly maximums increased by 4°F after complete clear-cutting in a second

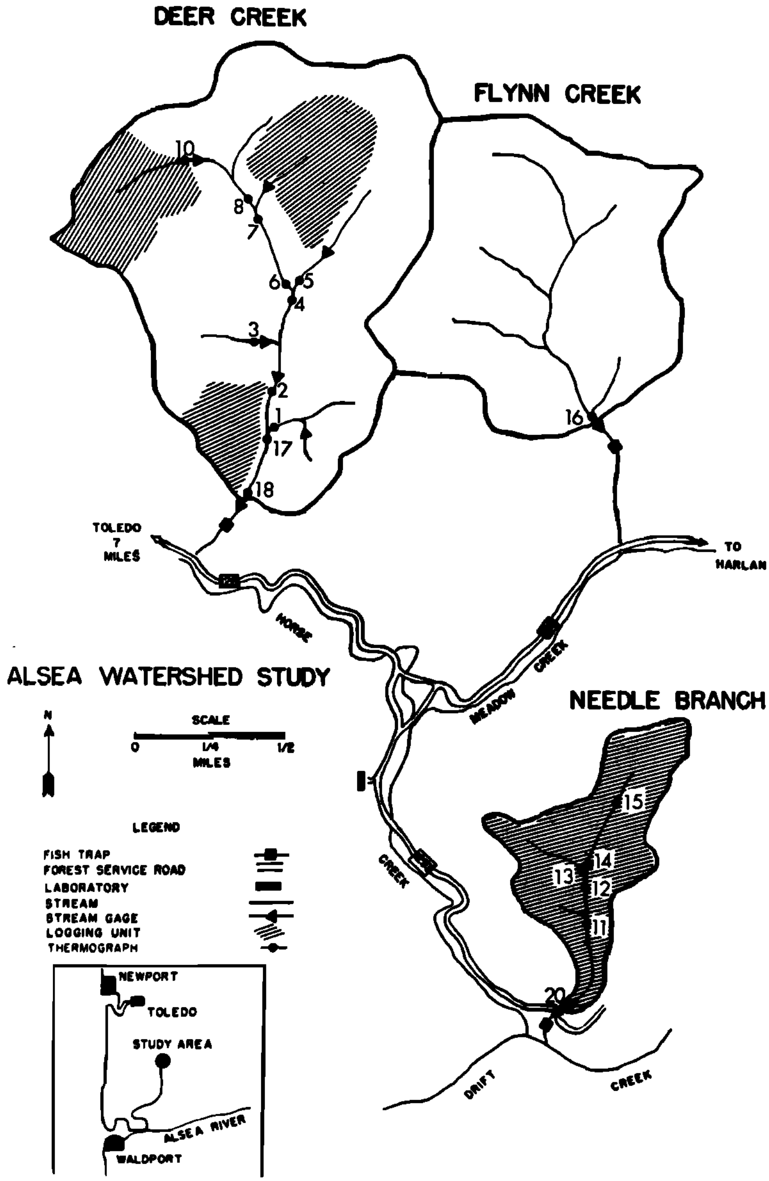

Fig. 1. The watersheds of the Alsea Basin Logging–Aquatic Resources Study.

watershed. The smaller increase in the completely clear-cut watershed was the result of shade from the logging debris that accumulated in the channel.

Patric [1969] compared the effect of two clear-cutting patterns on water quality. Temperatures were unaffected by clear-cutting the upper half of one watershed. Clear-cutting the lower half of the second watershed increased temperatures up to 7°F.

THE STUDY

Three experimental watersheds are included in the Alsea Logging–Aquatic Resources Study (Figure 1). These watersheds, which vary in size from 175 to 750 acres, are located in Oregon's coast range about 10 miles from the Pacific Ocean. Each stream is an important rearing area for coho salmon (*Oncorhynchus kisutch* Walbam) and coastal cutthroat trout (*Salmo clarki clarki* Richardson). In its natural condition, the study area was densely forested with Douglas fir (*Pseudotsuga menziesii* [Mirb.] Franco) and red alder (*Alnus rubra* Bong). The study streams were overgrown with salmonberry (*Rubus spectabilis* Pursh.), vine maple (*Acer circinatum* Pursh.), and other species. Although annual precipitation is about 100 inches, the summer months are generally hot and dry. Summer streamflow regularly drops below 0.20 cubic feet per second (cfs) or 0.17 cubic feet per second per square mile (csm) on Deer Creek, the largest watershed, and to 0.01 cfs or 0.04 csm on Needle Branch, the smallest watershed.

The low summer flows described above may seem insufficient to support salmon. The adults, however, spawn in these streams during the high flows of the winter months. Salmon fingerlings live in these streams during the summer. The fingerlings inhabit pools, many of which become nearly isolated during the late summer. In the fall, the yearling fish migrate to the sea

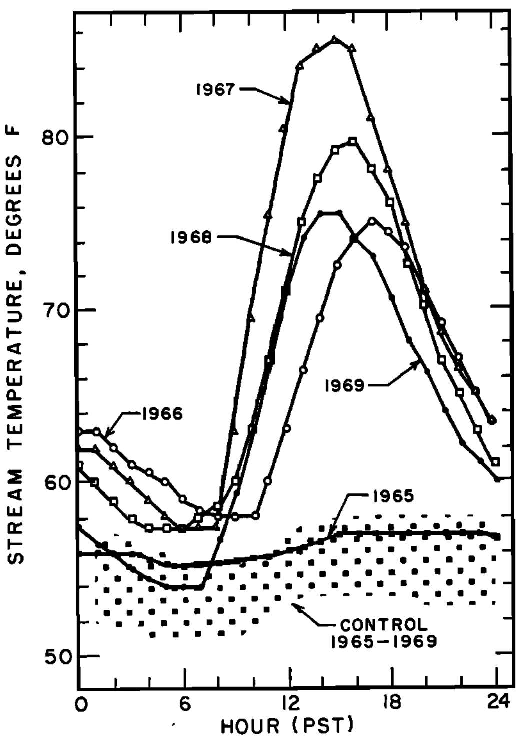

Fig. 2. The temperature pattern on the days of the annual maximum recorded on the clear-cut and uncut control watersheds before (1965), during (1966), and after (1967–1969) logging.

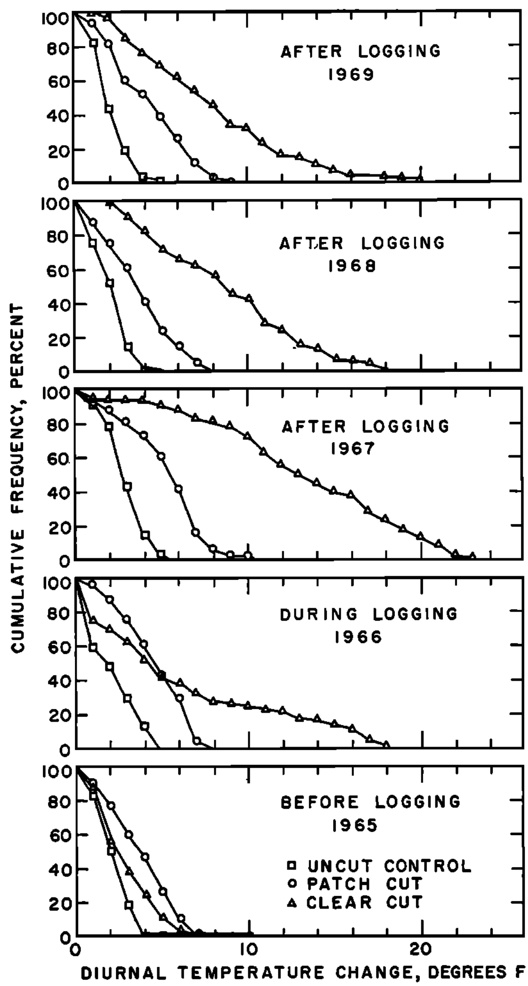

Fig. 3. A frequency distribution of diurnal temperature changes on the clear-cut, patch-cut, and uncut control watersheds before (1965), during (1966), and after (1967–1969) logging for the summer period, June 1–October 1.

when rains again increase streamflow. Before logging, the number of yearling fish passing through the fish trap to the sea ranged from 1809 to 3175 in Deer Creek and from 166 to 630 in Needle Branch [*Hall and Lantz,* 1969].

The study was designed to permit comparison of two different logging patterns. One watershed, Needle Branch (175 acres), was fully clear-cut. A second watershed, Deer Creek (750 acres), was patch-cut; 25% of this area had several clear-cut units. The remainder of the watershed was unlogged. In Deer Creek, strips of vegetation were left along the perennial streams. A third watershed, Flynn Creek (502 acres), was left unlogged as a control. Two small subwatersheds in Deer Creek also served as unlogged controls.

Eighteen 7-day thermographs, accurate to 0.5°F, were installed in the three watersheds to evaluate the effect of the cutting (Figure 1). Thermographs were placed below each proposed logging unit and at the junction of each major tributary in Deer Creek so that effects within the watershed could be determined. In Needle Branch, thermographs were distributed within the clear-cutting to evaluate the spatial temperature changes occurring in a fully exposed stream. Thermographs were installed in March 1964. Probes were placed in flowing water deep enough to insure complete coverage throughout the year. The years 1964 and 1965 served as control periods, and the years 1966–1969 as treatment periods.

Road building was completed in 1965, but, because the roads were built on ridges, little change occurred that could be interpreted as having any influence on water temperature. Logging began in March 1966 in both watersheds and was completed in August on Needle Branch and in November on Deer Creek. In October 1966, the stream in the clear-cut watershed was cleared of logging debris. After clearing, a well-distributed burn removed most logging debris and streamside vegetation. Reported data extend through September 1969.

RESULTS

The data from this study have been analyzed in two ways. The large changes that occur after clear-cutting are presented graphically. The small changes that occur after patch-cutting required a statistical analysis to ascertain the significance of these changes. The standard statistical technique of regression could not be used because of the nonrandom effects of climate, the lack of independence between successive daily maximums, and the potential alteration of the variance of seasonal temperature distributions by logging. A stationary time series was developed to circumvent these difficulties [*Beck*, 1968]. Time series techniques are commonly used for analysis of weather data where similar difficulties abound. *Jenkins and Watts* [1968] describe the application of this technique to several such problems. Our time series compared daily maximum temperatures recorded June 1–October 1 of the pretreatment years with the daily maximums for the same period during each treatment year. The analysis was applied to data from the control as well as from the patch-cut watershed to ascertain the effects of climate.

Diurnal Temperature Regimes

The temperature patterns recorded on the days of the annual maximum on the clear-cut watershed from 1965 to 1969 are illustrated in Figure 2. The values for 1965 and 1966 occurred at the watershed outlet. The values for 1967, 1968, and 1969 occurred within the cutover unit. A thermograph was installed at 1000 feet above the outlet in the spring of 1967, after intensive sampling showed that the maximum occurred at this location. This inconsistency in the temperature pattern was the result of incomplete removal of shade from the lower portion of the stream channel after logging and burning. The variation in temperatures recorded at the outlet of the unlogged watershed for the same days is also shown. Minimums recorded on the clear-cut watershed are about the same as the maximums recorded on the unlogged control. This phenomenon occurs because travel time through the clear-cut watershed is greater than 24 hours during the low flow period. Convection and nocturnal back radiation are insufficient to cool the water to the same minimums measured on the control. The maximum diurnal fluctuation recorded on the clear-cut watershed was 28°F during 1967. The maximum temperature, 85°F during 1967, represents an increase of 28°F over the prelogging maximum of 57°F for 1965. The decline of maximum temperatures after 1967 represents the rapid return of streamside vegetation in this watershed.

The maximum temperatures recorded on the patch-cut watershed were 60° and 61.5°F for 1965 and 1967, respectively. The maximum diurnal fluctuation during both years was 10°F.

A cumulative frequency distribution of the diurnal fluctuations in temperature at the outlet of all three streams from June 1 to October 1 for the years 1965–1969 is shown in Figure 3. The temperature stability of natural, forested streams is illustrated again in this figure. The maximum fluctuations in temperature before logging in 1965 were 6°, 8°, and 10°F on Flynn

Creek, Needle Branch, and Deer Creek. These maximum fluctuations were not exceeded on Flynn Creek or at any station within Deer Creek during or after logging. On Needle Branch, the maximum fluctuation of 8°F was exceeded 28% of the time in 1966 and 82% of the time in 1967, the year immediately following burning and stream clearance. This percentage dropped to 46% in 1968 and 36% in 1969, again reflecting the regrowth of streamside vegetation.

The outlet stations are representative of the changes that occurred within each watershed. Temperature fluctuations generally decreased with distance upstream in the patch-cut watershed. The most remote station (station 15) in the clear-cut watershed performed similarly to the outlet of Deer Creek.

Monthly Maximum Temperatures

Clear-cut. Maximum daily stream temperatures averaged by month for one year before and four years after logging are shown for the outlets of the clear-cut and unlogged watersheds in Figure 4. Except for the most remote station

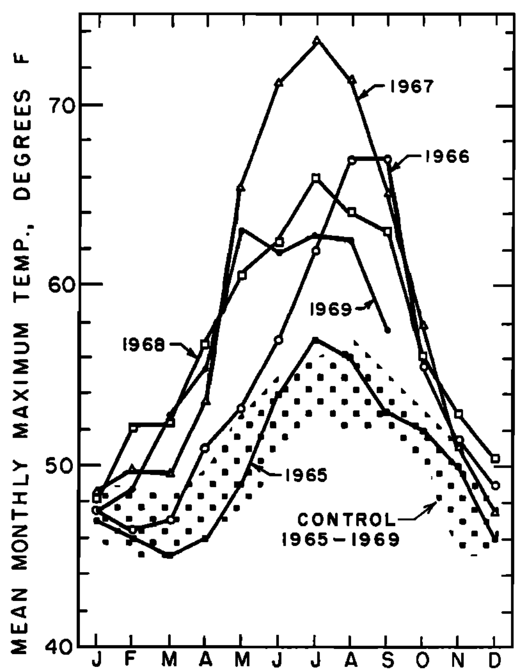

Fig. 4. Mean monthly maximum temperatures for the clear-cut and uncut control watersheds before (1965), during (1966), and after (1967–1969) logging.

TABLE 1. A Time Series Analysis of the Difference between Daily Maximum Temperatures of Streams before and after Patch-Cutting for the Period of June 1 to October 1

	Temperature Change, °F		
Watershed	1966	1967	1968
Flynn Creek (unlogged)	0.8	2.3*	0.3
Deer Creek (patch-cut)	0.4	1.9*	−0.4

* Significant at the 5% level of probability.

(station 15), the changes recorded at the outlet station are representative of those occurring at the other stations within the clear-cut watershed. Again the highest temperatures occurred during 1967, the year after stream clearance and slash burning. The mean monthly maximum for July increased from 57°F in 1965 to 71°F in 1967. The trend toward the prelogging condition is shown again in this figure.

Patch-cut. The frequency diagram illustrates the nearly constant pattern of daily temperature fluctuation recorded on the patch-cut watershed throughout the study (Figure 3). A time series was required to determine whether the small increases observed initially were the result of logging or climatic differences between years. The results of the time series are presented in Table 1. Significant changes in the summer maximum temperatures were observed at the outlets on the control and patch-cut watershed one year after logging. The larger changes observed on the control indicate that climatic factors, and not the patch-cutting, were responsible for this increase. During 1966 and 1968, summer maximums in the stream of the patch-cut were nearly the same as those observed before logging. The 10 internal stations exhibited smaller changes in temperature than the outlet station. These data show that patch-cutting, which leaves streamside strips of brush and trees, did not alter the temperature patterns of the adjacent stream.

Other inferences about the temperature patterns may be drawn from these data. Clearly the patterns in summer temperatures of forested streams are relatively constant from year to year. The small differences between years listed in Table 1 and the statistical significance of a

2° change illustrate little variability in average maximum temperature for a summer.

DISCUSSION

A detailed description of the hydrologic and atmospheric factors affecting water temperature was given earlier [*Brown*, 1969]. The most important environmental factor governing temperature change is solar radiation received at the stream surface.

Temperature differences between watersheds and all of the temperature anomalies within the clear-cut watershed can be explained in terms of shade differences. The patch-cuts on Deer Creek did not produce any significant changes in temperature in the main stream. Strips of timber 100 feet long were left beside each perennial stream; the amount of shade on the stream surface was essentially unchanged. On Needle Branch, little shade remained after the clear-cutting and burning were completed. As a result, large changes in annual and daily patterns of temperature were observed.

The principal cause of high water temperature following logging is stream surface exposure to direct insolation and not increased soil temperature on the clear-cut slopes as suggested by *Eschner and Larmoyeux* [1963]. Satisfactory predictions of temperature have been made on Deer Creek and Needle Branch with net radiation as the primary parameter. On these same streams we found that the maximum rate of net thermal radiation added to the unshaded stream in the clear-cut watershed was more than 10 times that added to the shaded stream in the patch-cut watershed. These differences are reflected in the postlogging temperature patterns of each stream and help explain the temperature stability of most forested streams.

For a given level of solar radiation or heat, stream temperature is inversely proportional to volume. As a result the temperature patterns of small, shallow streams typical of headwaters regions may be increased significantly by any changes in the solar radiation. Stream discharge in the clear-cut watershed regularly drops to 0.01 cfs during the hot summer months. Thus the large changes in temperature recorded after the shade was removed from this stream were to be expected. The flow regime of this small stream is typical of many western Oregon streams that must support salmon and trout during the period of low flow.

Can the results of this study be classified as typical of western Oregon conditions or were they merely caused by unusually hot summers? The maximum temperature of 85°F recorded for the clear-cut and burned watershed is undoubtedly close to the maximum temperature that could occur for this size of clear-cut watershed and stream. Because of its small size, the stream responded to each clear day with high temperatures, regardless of the previous day's weather. Even if only one clear hot day had occurred, this temperature would have been observed. The records of mean monthly temperatures and the frequencies of diurnal change present data for longer periods. The number of days of sunshine, overcast, fog, and rain influence such results. Long-term records of sunshine are not available for the study area. Records at nearby stations, however, indicate that the period of study was not abnormal.

Duration of temperature effects following clear-cutting is the subject of continued observation in these experimental streams. Temperature amelioration is related to shade development. As stream bank vegetation becomes reestablished, temperatures drop accordingly. In many of the watersheds of the Pacific Northwest, regrowth occurs very rapidly on moist sites. On the basis of our data, it seems that summer maximums may approach prelogging levels within six years after logging has completely exposed the stream if vigorous invasion of such moist-site species as alder, salmonberry, elderberry, and vine maple occurs. The decline of high temperatures noted in Figures 2, 3, and 4 after the 1967 maximum on Needle Branch illustrate this recovery. The stream's temperature patterns are well on the way to returning to the prelogging condition.

Our research reported here and a companion study [*Brown*, 1969] have illustrated the effect of two patterns of logging on the temperature of small coastal streams and the amelioration of the effect with time. These results, however, have raised several questions about temperature control in the management of fishery, forest, and water resources. Foremost among them is the effect of high temperatures, such as those recorded during 1967 in the clear-cut watershed, on fish. Earlier work [*Brett*, 1952] indicated that at 27.5°C (81.5°F) the time required to induce 50% mortality in a population of coho salmon fry is only 70 minutes. But no unusual mortality in coho was observed during this study even though stream temperatures were often above this limit for 4 to 6 hours.

The study illustrated the benefit of strips of vegetation alongside small streams for temperature control. The width, density, species composition, and costs incurred when planning streamside strips are only a few of the questions posed by forest managers.

Finally, this study should encourage water resource agencies to engage in further studies of the aquatic habitat in small streams and its relation to land use. Although the temperature changes recorded are defined as thermal pollution in Oregon's current water quality standards [*Oregon Sanitary Authority*, 1967], the effect on the coho fishery would suggest that a more precise definition is required. Such a definition, of course, will require a better understanding of the response of the aquatic system to temperatures in the lethal and sublethal ranges.

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