

DURATION OF STREAM TEMPERATURE INCREASES FOLLOWING FOREST CUTTING IN THE SOUTHERN APPALACHIAN MOUNTAINS

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ABSTRACT: Cutting timber along small streams in the southern Appalachian Mountains increases water temperature. Although the effect is assumed to be short-lived because of rapid regrowth of dense vegetation, timber harvest in streamside shade zones on National Forest land is carefully regulated to minimize temperature changes and maintain trout habitat. Clearcutting all vegetation over 2.5 cm DBH from a 59.6-ha south-facing watershed in western North Carolina allowed both the magnitude and duration of water temperature increases to be studied. About 958 m² of stream were exposed. Daily maximum temperatures at the downstream margin of the cutting were increased an average of 3.3°C the first two summers after cutting. The increases declined in the next three summers to 1.2°C. Daily minimums were increased about 1.3°C both winter and summer, but only in the first year. The daily range of water temperatures (maximum minus minimum) was increased during all five summers. A method for predicting water temperature changes was tested and found to overestimate the summer increases.

(KEY TERMS: water temperature; stream temperature; thermal pollution; forest cutting.)

INTRODUCTION

Wooldridge and Stern (1979) and Patton (1973) have reviewed the literature and summarized the impacts of forest cutting upon stream temperature. Removal of forest cover from cold-water streams has repeatedly been shown to increase summer water temperatures. Only a few studies have reported changes in other seasons, changes in minimum temperature and the daily temperature range or studied how long temperature effects last. The duration and magnitude of temperature increases are limited by rapid regrowth of forest vegetation typical for the mountains of the eastern United States. For example, summer maximum water temperatures were less under an 8-year-old regrowing hardwood forest in western North Carolina than under an uncult stand (Swift and Messer, 1971). Even in the first year after cutting, buffer strips or streamside shade zones reduce or eliminate temperature increases (Swift and Baker, 1973; Burton and Likens, 1973; Brown and Krygier, 1970).

This study describes changes, after clearcutting, of both minimum and maximum water temperatures in all seasons and during five years of forest regrowth.

THE EXPERIMENT

A cable logging experiment on a 59.6-ha watershed at the Coweeta Hydrologic Laboratory began in spring 1977. The climate of this south-facing slope in the Appalachian Mountains of North Carolina is characterized by high precipitation (1,770 mm/year) and moderate temperatures (12.8°C annual mean). The elevation of the watershed ranges from 720 m at the V-notch weir to 1,065 m. The total length of flowing stream is 2,052 m, 55 percent of which is in the central channel. The maximum stream width at a pool 36 m above the weir is 2.4 m.

The vegetation on this experimental basin had been undisturbed since a woodland grazing demonstration 28 years earlier. Before logging, the basal area was 25.3 m²/ha on 3,058 stems/ha > 2.5 cm (Boring, *et al.*, 1981). During logging, essentially all living vegetation was cut. Clearcutting adjacent to all branches of the stream was completed by late August 1977. Debris was removed from the lower two-thirds of the main stream channel as a condition of the timber sale contract. All other logging slash was left where it fell. Approximately 38 percent of the 1,535 m² of stream surface was shaded, mainly by dead logging debris bridging the narrow channel. Minor areas of stream covered by overhanging banks or road culverts were included in the shaded percent but topographic shading was judged to be negligible at midday.

Regeneration of vegetation was mainly stump and root sprouts although approximately 34 percent of the first year total biomass was in herbaceous plants and vines (Boring, *et al.*, 1981). Herbaceous plants are not a significant part of the mature forest but play an important role in providing the initial shade cover of a regrowing forest. Most woody vegetation was distributed as scattered sprout clumps. In fall 1977, the year of cutting, the leaf biomass of streamside vegetation was only 16 percent of that for the pre-cut forest. At the end of the second and third growing seasons (1978 and 1979), the streamside leaf biomass had reached 60 and 78 percent of the pre-cut amount and by the end of

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the 1981 growing season, only about 100 m of the wider stream channel above the weir remained unshaded.

Temperature recorders were installed just above the weir of the logged watershed and on an adjacent uncut stream. Measurements began three years before the forest was cut and are continuing. The measurement sites have similar upstream drainage areas and stream lengths. Data were recorded by remote bulb recording thermographs with 7-day charts. The sensing bulbs were immersed in flowing water and shaded from direct sunlight. The chart trace was checked for accuracy with a thermometer observation each time a chart was changed. Air temperature was recorded at climatic stations within and adjacent to the logged watershed. Daily minimum and maximum temperatures were picked from the charts to the nearest 0.6°C . Temperatures of the streams were similar before logging. The daily difference (experimental minus control) between maximums for the two streams and the daily difference between minimums were calculated for the period of record. Shifts in magnitude of between-stream differences for either maximum or minimum temperatures are taken to be measures of changes in the temperature of the experimental stream. Monthly means of these daily differences were used in this analysis.

RESULTS

During the 34 months before cutting, both the maximum and minimum temperatures were always warmer in the experimental stream and temperature differences between streams varied seasonally (Figure 1). Small differences of less than 1°C occurred in late summer and fall of 1974 and 1975, but temperatures were 1.0° to 2.4° warmer in the experimental stream in spring 1975 and spring and summer 1976. Year-to-year fluctuations in air temperature were small and could not explain variations in stream temperature between the three precutting years. The average monthly difference across the precut period was $+0.9^{\circ}\text{C}$ for the daily minimum and $+1.5^{\circ}\text{C}$ for the daily maximum (standard error $< 0.18^{\circ}\text{C}$).

After the forest was cut, monthly differences between maximum water temperatures were consistently larger suggesting that maximum temperatures were increased in all seasons for the duration of the study. Differences between minimum temperatures increased during the first two years and then declined.

The largest differences in maximum temperatures occurred in June 1978 and was 5.4°C greater than the mean difference of precut months. The average increase over pretreatment maximum temperatures was 3.3°C during the first 17 months after cutting. The peak increase in minimum temperature difference occurred immediately after cutting in August 1977; the average increase was 1.3°C for the 17-month period. Both minimum and maximum temperatures of the stream were also raised after cutting.

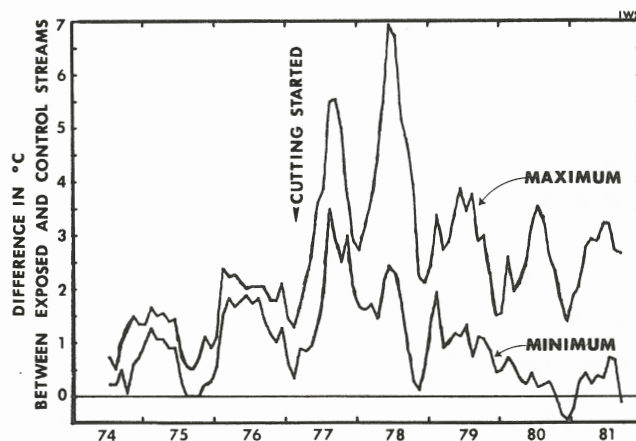


Figure 1. Monthly Mean Differences for Minimum and Maximum Water Temperatures Between the Experimental and Control Streams.

After the 1979 growing season, both differences were less. The difference between monthly minimums declined to an average of 0.4°C below pretreatment levels for the last three years, whereas, maximum differences averaged 1.2°C above pretreatment levels.

The sustained increase in maximum water temperature differences, in contrast to the declining minimums (Figure 1), suggests that the daily range of water temperature was dramatically and consistently increased after cutting. The temperature recordings confirm that the range was increased by 3° to 4°C in summer and fall 1978. Smaller increases in range occurred thereafter in each season.

Brown (1970) proposed an equation which allows the maximum change in water temperature to be estimated if area of exposed stream, flow rate, and net radiation for the exposed stream can be measured or estimated. The equation can be adjusted for topographic and vegetative shading and for heat storage in the streambed (Forest Service, 1980). Estimated increases were calculated and compared to observed maximum water temperatures from the set of 40 days in August to September 1977 and June to July 1978 that had the greatest observed increases. The unshaded area of stream was used and the other corrections were unneeded. Estimated increases were 13° to 18°C for days when 3° to 6°C rises were measured.

DISCUSSION

The temperature increases reported for this stream exceed North Carolina water quality standards which require that the temperature of mountain streams may not be increased 2.8°C above the natural water temperature, and trout water temperatures may not be increased by more than 0.5°C nor exceed 20°C (North Carolina Administrative Code, Title 15, Chapter 2B). National Forests are

managed to reduce the heating of mountain streams and protect trout habitat; clearcutting is limited to considerably smaller areas than this study site and buffer or shade strips are left next to the wider streams. Thus, the temperature record of this experiment is an example of an extreme case where a large area of stream is exposed on a south slope.

In the first two years after clearcutting, temperatures in all seasons were raised. Both daily minimums and maximums were warmer, the daily means increased, and the daily range expanded. By the third year, leaf biomass in the streamside area had reached 78 percent of that for mature forests but some increase in stream temperature was still apparent five years after cutting. Prolonged influence may be due to the type and stature of the regrowing vegetation. Three years after cutting, only 38 percent of the streamside leaf biomass was produced by woody plants. The young vegetation was too short to completely shade the wider portions of the stream channel, but vines and tall herbaceous plants did shade much of the middle and upper reaches of the stream.

Temperature increases developed late in the first summer, in August through October. The largest increases in daily maximum water temperatures occurred in June-July 1978, the second summer after cutting began. The largest increases would have come during the first year if all the streamside forest had been cut in the spring. Instead, only the midportion of the stream network (39 percent of the unshaded water surface) was cut by May. Forty-seven percent of the unshaded water surface was in the lower portion of the watershed. Until the vegetation around this lower 487 m of the stream was cut in August 1977, the water heated in the upstream area was probably cooled by shading and dilution before reaching the temperature measurement point, a phenomenon observed elsewhere by Swift and Baker (1973). Midsummer maximum temperatures remained well above those in the control stream through 1981 and probably will continue above normal for several more seasons. A declining trend of about 0.3°C per year is suggested by data from 1979 through 1981, although more rapid temperature recovery may occur as streamside forest regrows to shade the lower stream.

Winter minimums were increased only during the first and part of the second seasons. By the third and fourth winters, minimum water temperatures were below those experienced before the forest was cut. This finding is not unusual. Lee and Samuel (1976) and Reinhart, *et al.* (1963), report 2°C reductions of winter minimum stream temperatures and Burton and Likens (1973) found lowered minimums even in October. A possible explanation for the reduced winter minimums in the later years of this study would be the alteration of the energy balance between the water surface and streamside vegetation. Because the solar altitude is low in winter, young vegetation can shade the stream and moderate the heating of the water. In addition, longwave radiation toward the night sky is not blocked by short vegetation, thus, the water is cooled more than when a forest canopy is present to intercept and hold part of the

energy. This explanation was not confirmed experimentally at Coweeta.

Estimated stream temperature increases were two to five times greater than observed increases. The differences between estimated and measured temperature changes could be due to stream length and the time a parcel of water is exposed to heating. The model assumes a channel length of less than 610 m, whereas, the main channel of this stream is nearly twice that length. The duration of exposure in this long channel could be longer than the two hours of the day receiving the peak solar radiation used in the calculations. However, doubling the exposure time to obtain a lower average radiation gives only a minor reduction of estimated temperature. Hewlett and Fortson (1982) also found a large difference, but in the opposite direction, between the measured and estimated temperature increases after clearing a Georgia Piedmont watershed. Brown's equation is a simple representation of several complex energy exchange processes. These studies indicate a need for further development of the stream temperature equation before it can be applied in the southeastern United States.

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