# Stream Shading, Summer Streamflow and Maximum Water Temperature Following Intense Wildfire In Headwater Streams[1]

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Abstract: Adjacent headwater streams were monitored for postfire shade, summer streamflow and maximum water temperature following the 40,000 ha Silver Complex fire in southern Oregon. Average postfire shade (30 percent) for the three streams was considerably less than prefire shade (est.>90 percent). Dramatic increases in direct solar radiation resulted in large but variable increase in maximum water temperature. Increase was greatest in Stream C where temperature increased 10.0°C. Stream B increased 6.2°C. Stream A increased 3.3°C.

Variation in maximum water temperature increase was strongly correlated to summer streamflow ($r^2$ =0.98k and percent total streamside shade ($r^2$ =0.80). The greatest maximum water temperature increase was associated with lowest summer streamflow and total postfire shade. Shade from dead vegetation provided the most shade averaged for all three streams. Shade from dead vegetation was more than three times greater than shade from topography and two times greater than shade from live vegetation. Considerable loss of live vegetation and large but variable increases in maximum water temperature can accompany intense wildfire in headwater streams. Review of the Silver Fire Complex indicates, however, that less than 5 percent of the headwater streams burned in this manner.

## INTRODUCTION

During August through November 1987, over 400,000 ha of forested land in northern California and southern Oregon were burned in lightning-caused fires. Included in the burned area was the 40,240 ha Silver Complex Fire in which three adjacent, intensely burned headwater streams were monitored for postfire shade, summer streamflow, and maximum water temperature. These streams are in timbered lands where drastic changes in the structure of the forest canopy can affect water quality, especially temperature.

Water temperature is a determining factor in the composition and productivity of streams in the Klamath Mountains of southern Oregon and northern California. The temperature of valuable fish-bearing streams can be influenced by reducing forest canopy of riparian vegetation along headwater streams (Brown and others, 1971). Fish are greatly affected directly and indirectly by changes in water temperature. Cold water game fish, an important resource in the Klamath Region, are negatively affected as temperatures increase. Increased temperatures favor the introduction and proliferation of "warm water" species to the detriment of "cold water" species. Water temperature increases also indirectly affect fish through alteration of the stream environment, by increasing the abundance of fish pathogens and algae and by decreasing amounts of dissolved oxygen and aquatic organisms. Many stream temperatures in the area are already at critical levels for cold water game fish. The importance of water temperature as an indicator of water quality has not escaped the attention of land managers and is reflected in its inclusion in State and Federal water quality standards.

Changes in water temperature depend largely upon how much heat is received and the volume of water to be heated (Patton 1973). Heat can be lost or gained by a variety of mechanisms including evaporation, condensation, conduction, and convection. These factors, however, influence stream temperature very little compared to direct solar radiation (Brown 1969). The maintenance of water temperature largely becomes a consequence of the quantity and quality of shade-producing vegetation. Numerous studies have evaluated the effect of loss of shade-producing vegetation upon water temperature. Most of the studies have investigated the effects of forest harvest (Levno and Rothacher 1967, 1969, Brown and Krygier 1970, Meehan 1970, Holtby and Newcombe 1982); far less is known about the effects of wildfire (Helvey 1972). Intense wildfire, by destroying live riparian canopies, can greatly influence the amount of direct solar radiation reaching stream surfaces. Small, headwater streams may be most greatly affected because of low summer streamflows and large surface areas in relation to volumes. Shade from topography and dead riparian vegetation, where abundant, may play critical roles in minimizing temperature increases.

The objective of this study was to determine (1) type and abundance of shade in intensely burned headwater streams, (2) water temperature increases in streams flowing through an intensely burned area, and (3) the relationship

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of streamflow to water temperature increase.

## METHODS

The study was conducted on Bald Mountain within the Silver Fire Complex area on three headwater streams of approximately the same size within .8 km of one another. The three streams drain an area of approximately 420 ha located 40 km west of Grants Pass, Oregon, on the Siskiyou National Forest's Galice Ranger District. Stream orientations are generally northeast. Prefire overstory vegetation was dominated by mature Douglas-fir with understory hardwoods.

The area is characterized by rugged steeply dissected terrain and moderately-deep skeletal soils. Soils are similar in all three basins --well drained loams with clay loam subsoils underlain by graywacke sandstone parent material at a depth of 60 to 100 cm. Summers are hot and dry. Most of the precipitation occurs in the mild wet season from November to April.

In September 1987 the Silver Fire swept through the study area. In October 1987 a photo inventory was completed to determine high, moderate, and low intensity burn areas. The three stream basins in the study were classified as high-intensity burns, characterized by complete consumption of crowns of existing vegetation. Field reconnaissance indicated that the majority of the riparian zones burned with high burn intensity; however, there are riparian zones borderinq all three streams that exhibit some burns of moderate and low fire intensity. In moderate intensity burn areas crowns were partially consumed and in low intensity burn areas crowns remain largely intact.

Transects were established and marked for facilitating solar pathfinder measurements. Specifically, half-inch steel rebar was hammered 1 m into left and right banks of each stream. Each pathfinder measurement is 6m apart. There are five transects per cluster and four clusters per stream. Each cluster measures a stream segment 30m long. Site locations for clusters were chosen using a random grid.

A solar pathfinder was used to determine effective streamside shade for the maximum temperature period (Amaranthus 1983). The solar pathfinder consists of a spherical dome that reflects a panorama of the site including shade casting objects. Topographic and dead and live vegetational shade were quantified by viewing the sun's path diagram through the dome and summing shaded radiation values (percent of the days' total potential solar radiation) for each half-hour period for the sun's path on August 1, generally when maximum water temperatures are reached. Topographic, dead and live vegetational shade was individually tallied by differentially examining each shade-producing object as reflected through the spherical dome.

The solar pathfinder was set up between each transect in or as close to the center of the stream as possible. An azimuth and a linear measurement were taken from a bench mark (rebar at transect) and recorded. One technician made all the measurements on all three streams.

Streamflow measurements were made in all three streams on July 25, 1988 using a small flume, which was calibrated by the U.S. Geological Survey. One streamflow measurement was taken per stream. Stream temperatures were taken using calibrated minimum/maximum thermometers installed inside a protective rubber sheath and held in by 1/8-inch cable. The thermometers were installed at the top and bottom of each stream-monitoring area and recorded the maximum water temperature during the period from June 15 to September 15.

Data were subjected to analysis of variance. Means and standard errors were calculated for topographic, dead, live, and total shade. Tukey's multiple range test was used to compare differences ($p \leq 0.05$) among means between streams. Maximum water temperatures, summer streamflow, and total shade values were subjected to simple linear regression and analysis of variance.

## RESULTS AND DISCUSSION

As expected, maximum water temperature was increased through intensely burned sections of streams. Increase was largest in Stream C where temperature increased 10.0°C (table 1). Stream B increased 6.2°C and Stream A increased 3.3°C. Stream A had significantly more shade from topography and live vegetation than Stream B and C (table 2). These two factors contributed to Stream A containing significantly more total shade. Streams B and C did not significantly differ in amounts of topographic, dead, live, or total shade. Dead shade provided the most shade averaged for all streams. Shade from dead vegetation was more than three times greater than topographic and two times greater than live vegetation (table 2).

Table 1--Maximum water temperatures above and below monitored area, stream length and summer streamflow.

| Stream | Max water temp°C | | Stream lgth. (meters) | Streamflow July 25 ($ft^3$/sec) |
|---|---|---|---|---|
| | Above | Below | | |
| A | 16.7 | 20.0 | 2350 | .076 |
| B | 14.4 | 20.6 | 1950 | .053 |
| C | 12.8 | 22.8 | 1500 | .035 |

Table 2--Percent streamside shade from topography and dead and live vegetation for three intensely burned headwater streams in southwest Oregon.*

| | Percent streamside shade (standard error) | | | |
|---|---|---|---|---|
| Stream | Topography | Dead veg | Live veg | Total |
| A | 7.6a(0.79) | 10.8a(1.69) | 16.4a(1.11) | 34.4a(1.07) |
| B | 4.2b(0.61) | 20.8a( .51) | 2.3b(1.31) | 27.3b( .69) |
| C | 3.8b(1.08) | 19.6a(3.08) | 3.4b(2.13) | 26.0b(2.18) |
| All Streams | 5.2(0.68) | 17.0 (1.72) | 7.4 (2.10) | 29.6 (1.46) |

*Columns not sharing the same letter are significantly different, $p \leq 0.05$.

Prefire monitoring in this area indicates that headwater streams generally average greater than 90 percent total streamside shade (Amaranthus, unpublished data). Average postfire total shade was nearly 30 percent for intensely burned streams. This represents a considerable loss of shade compared to prefire levels. Dramatic increases in direct solar radiation resulted in large but variable increases in water temperature. Water temperature increases were similar to those from other studies in Oregon investigating the effects of clearcutting on water temperature (Brown and Krygier 1967, Levno and Rothacher 1967). However, in the clearcutting experiments temperature increased more dramatically over a shorter stream reach. Unlike clearcutting, wildfire results in standing dead vegetation and where it is abundant it may help minimize temperature increases. In this study 57 percent of the postfire shade was provided by dead vegetation. Removal of dead vegetation shade from riparian zones by timber salvage or other postfire activities should be carefully considered where water temperatures reach critical levels for fish.

Variability in maximum water temperatures for the three stream strongly correlates with summer streamflow ($r^2 = 0.98$, fig. 1). Maximum water temperature increase was inversely proportional to summer streamflow. Stream A had the highest streamflow and thus the greatest volume of water to be heated. Stream C had the least streamflow and thus the least volume of water to be heated. Water in Stream A, compared to Stream C, would travel more rapidly through the intensely burned section of stream, thereby decreasing time of exposure to direct solar radiation. Stream B would have intermediate characteristics between Streams A and C. These factors appear to influence maximum water temperature increase in headwater streams.

Considerable loss of live vegetation and large, but variable increases in maximum water temperature can accompany high intensity wildfire in headwater streams. However, review of the Silver Fire Complex Area indicates that less than 5 percent of the headwater streams burned in this manner and that postfire maximum water temperatures have not appreciably increased at the mouth of large downstream tributaries draining the fire area (P.A. Carroll, unpublished data)[3]. Numerous factors can account for this. Some authors have noted water temperatures decrease as streams passed through shaded areas downstream from open areas (Hall and Lantz 1969, Levno and Rothacher 1969). There may be some recovery of stream temperature in shaded areas downstream from high-intensity burn areas, although previous measurements of temperature recovery downstream from harvest areas (Amaranthus, unpublished data) and other studies (Brown and others 1971, Brazier and Brown 1973) have not demonstrated this cooling effect. Inputs of cooler ground water, increased summer streamflow following wildfire, and mixing cooler water from unburned tributaries would help minimize water temperature increases downstream. The amount of cooling would be largely dependent upon the magnitude of groundwater inputs, increase in streamflow and cooler water from unburned streams.

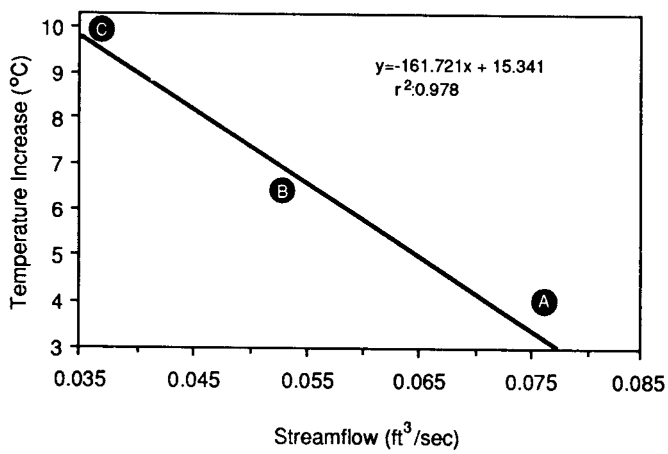


Fig. 1--Relationship of summer streamflow (X) to maximum water temperature increase (Y) for three intensely burned headwater streams (A, B, and C).

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Variability in maximum water temperatures for the three streams also correlates with total postfire shade ($r^2$=0.80, fig. 2). Stream A had the greatest total postfire shade and thus the least direct radiation reaching the water surface. It is unlikely, however, that the 8 percent increase in shade between Stream A and C could alone explain the 6.7°C decrease in maximum water temperature increase. Other factors could be influencing changes in water temperature between the streams such as the width-to-depth ratio of the channel. This could greatly affect the surface area and length of time water is exposed to radiation.

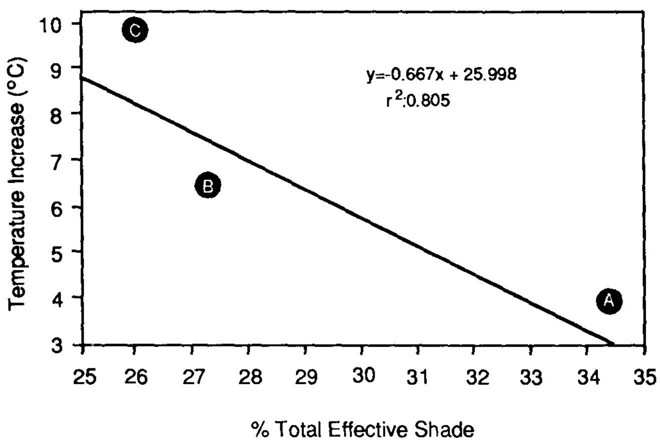


Fig. 2--Relationship of total shade (X) to maximum water temperature increase (Y) for three intensely burned headwater streams (A, B, and C).

REFERENCES


Amaranthus, M.P. 1983. Quantification of effective streamside shade utilizing the solar pathfinder. USDA For. Serv. Region 6. Siskiyou National Forest, Grants Pass, Oregon.

Brazier, J.R.; Brown, G.W. 1973. Buffer strips for stream temperature control. Res. Paper 15. Corvallis: Forest Research Laboratory, School of Forestry, Oregon State University.

Brown, G.W. 1969. Predicting temperature of small streams. Water Resources Res. 5(1):68-75.

Brown, G.W.; Krygier, J.T. 1967. Changing water temperatures in small mountain streams. J. Soil Water Conserv. (22):242-244.

Brown, G.W.; Krygier, J.T. 1970. Effects of Clear-cutting on stream temperature. Water Resources Research 6(4):1131-1140.

Brown, G.W.; Swank, G.W.; Rothacher, J. 1971. Water temperature in the steamboat drainage. Res. Paper PNW-119, Pac. Northwest Forest & Range Experiment Station, USDA For. Serv., Portland, OR: 17p.

Hall, J.D.; Lantz, R.L.. 1969. Effects of logging on the habitat of Coho salmon and cutthroat trout in coastal streams. Northcote, T.G., ed. University British Columbia, Vancouver, B.C., Symposium on salmon and trout in streams. 1969:355-375.

Helvey, J.D. 1972. First-year effects of wildfire on water yield and stream temperature in North Central Washington. In: Proceedings of a National Symposium on Watersheds in Transition, Fort Collins, Colorado, pp. 308-312.

Holtby, B.; Newcombe, C.P.. 1982. A preliminary analysis of logging-related temperature changes in Carnation Creek, British Columbia. In: Hartman, G., Proceedings of the Carnation Creek Workshop, a 10-year Review, Malaspina College, British Columbia, Canada, pp. 81-99.

Levno, A.; Rotchacer, J.. 1967. Increases in maximum stream temperature after logging old growth Douglas-Fir watersheds. United States Department of Agriculture, Forest Service Research Note PNW-65, Portland, Oregon 12pp.

Levno, A.; Rotchacer, J.. 1969. Increases in maximum stream temperature after slash burning in a small experimental watershed. United States Department of Agriculture, Forest Service Research Note PNW-110, Portland, Oregon, 7pp.

Meehan, W.R. 1970. Some effects of shade cover on stream temperature in Southeast Alaska. United States Department of Agriculture, Forest Service Research Note PNW-113, Portland, Oregon, 9pp.

Patton, D.R. 1973. A literature review of timer harvesting effects on stream temperatures: research needs for the southwest. United States Department of Agriculture, Forest Service Research Note. Rocky Mountain Forest & Range Experiment Station. RM-249, Fort Collins, Colorado.