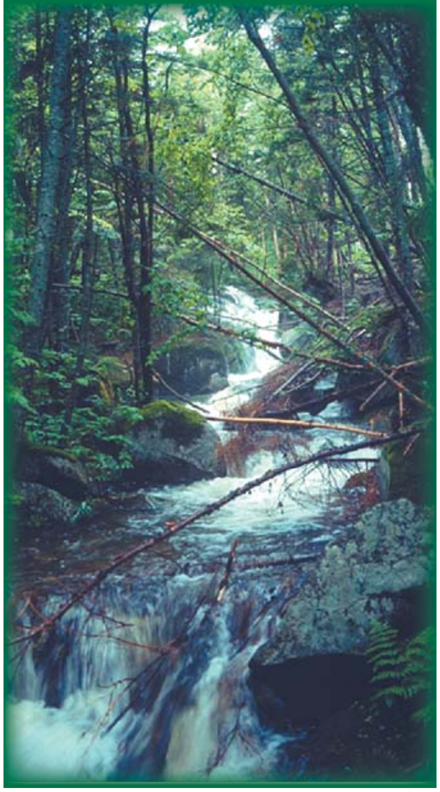
CFRU RR 04-01
July 2004

CFRU Research Report

COOPERATIVE FORESTRY RESEARCH UNIT
UNIVERSITY OF MAINE

Understanding and minimizing the impacts of forest harvesting on stream water temperature is essential to sustainable forest management.



The Effectiveness of Different Buffer Widths for Protecting Water Temperature in Headwater Streams

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ABSTRACT

We evaluated the effect of timber harvesting on water temperature in first-order headwater streams in western Maine. Fifteen streams were assigned five treatments: (1) clearcutting with no stream buffer, (2) clearcutting with 36-ft buffers, both sides, (3) clearcutting with 75-ft buffers, both sides, (4) extensive partial cutting with no designated buffer, and (5) controls (no harvesting during the study). We measured water temperature before and for two years after harvest treatments were applied, both above and below the harvest zone. Streams in the 0-ft buffer treatment showed the greatest increase in mean weekly maximum water temperature following harvesting (2.5-7.9 °F). Streams in the 36-ft buffer treatment showed only minor increases in temperature (<0.9 °F). Streams in the 75-ft buffer treatment, partial-harvest treatment, and control treatment showed no change in the post-harvest years. Temperatures cooled to near normal levels within 328 ft of entering shaded reaches below the harvest blocks on streams in the 0-ft buffer treatment. Stream aspect and groundwater inflow appeared to play significant roles in amplifying or mitigating stream warming, especially for streams in the 0-ft buffer treatment. For the 0-ft treatment group the mean daily fluctuation in stream temperature increased two and a half fold (from 2.5 °F/day to 6.8 °F/day).

INTRODUCTION

Although little is known about the biological processes of small headwater streams (Richardson 2000), there is growing awareness of the ecological importance of intermittent and small first order streams in the freshwater system. This awareness has resulted in scrutiny of regulatory protection of small streams from timber harvesting. Headwater streams can account for 65-75 percent of the cumulative length of all stream and river channels in a watershed (Leopold et al. 1964). Forestland managers are concerned about regulations that might take significant forest area out of timber production along small streams. It is therefore important to understand the role that forested buffers can play in protecting such headwater streams.

Next to siltation of streams, increase in water temperature is a primary concern for timber harvesting. Forest canopies protect small streams from direct solar radiation, the dominant source of heat energy (Brown and Krygier 1970, Sullivan et al. 1990). Studies of stream temperature following timber harvest and canopy removal have shown increases in summertime and diurnal stream temperature (Likens et al. 1970, Lynch et al. 1984, Johnson and Jones 2000, Murray et al. 2000, Macdonald et al. 2003). Temperature increases reported in previous studies have varied depending on the amount of shade retained adjacent to the stream channel (Brown and Krygier 1970, Macdonald et al. 2003), site specific attributes such as variability in stream size, and inputs of groundwater (Sullivan et al. 1990, Caldwell et al. 1991).

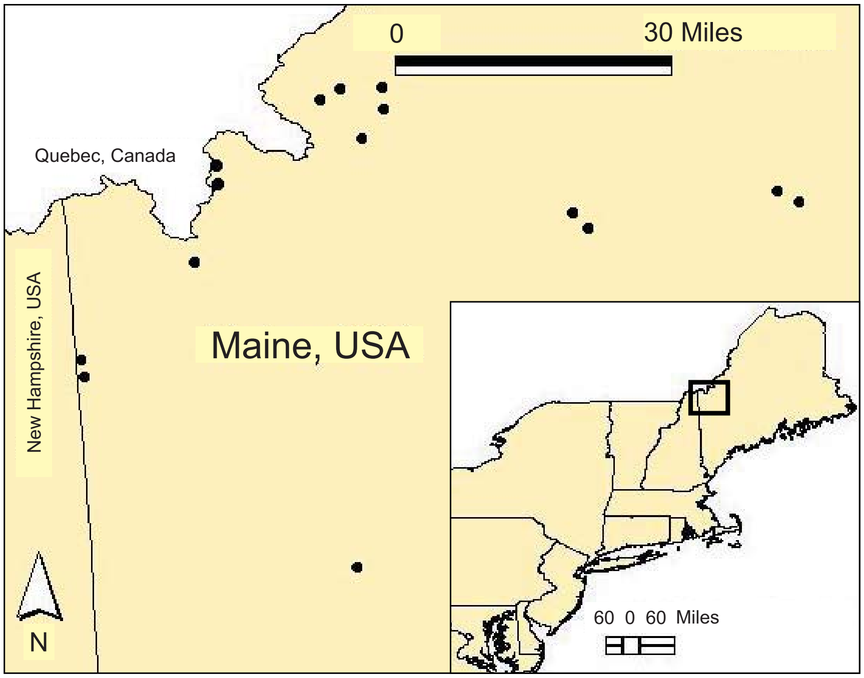

Figure 1. Locations of 15 study sites in Western Maine

Here we report results from an ongoing before-and-after harvest experiment along small headwater streams in western Maine. One purpose of the study is to examine the effectiveness of different buffer widths for protecting water temperature in small streams. We included a treatment that removed all overstory canopy adjacent to the stream in order to evaluate a worst-case scenario for solar input.

METHODS

We established 1,640 ft long study segments on 15 headwater streams in small watersheds (74-481 acres (A)) throughout western Maine (within a 62 mile radius of 45°00’00” N, 70°20’00” W, Figure 1). At the beginning of the study the forest adjacent to each study segment was dominated by mature closed-canopy cover (>85%) at least 49 ft tall. Average bankfull width ranged from 6.2-13.8 ft and stream gradient ranged from 5-18%. Canopy closure was measured ~4.6 ft above the stream channel using concave spherical densiometers before and after harvest operations.

The study followed a B-A-C-I design (Before-After-Control-Impact) (Stewart-Oaten et al. 1992, Smith et al. 1993). Water temperature measurements were taken in each stream in the pre-treatment year (2001) and in each of two post-treatment (post-harvest) years (2002, 2003) to evaluate effects of the different treatments. Each of the 15 streams was assigned to one of five different treatments:

(1) clearcut harvest zone (less than 30ft^2/A residual basal area) leaving no retention buffer (0-ft treatment),

(2) clearcut harvest zone with 36-ft buffers on both sides of the stream (36-ft treatment),

(3) clearcut harvest zone with 75-ft buffers on both sides of the stream (75-ft treatment),

(4) selection cut retaining at least 60 ft^2/A residual basal area in the harvest zone, without a specified buffer width (partial-harvest treatment), and

(5) no harvest (control treatment).

Harvests within a 656 x 984 ft harvest zone on each side of the stream were carried out in the fall or winter between 2001 and 2002 (Figure 2). Partial harvesting was allowed in all of the buffers (to a minimum of 60 ft^2/A).

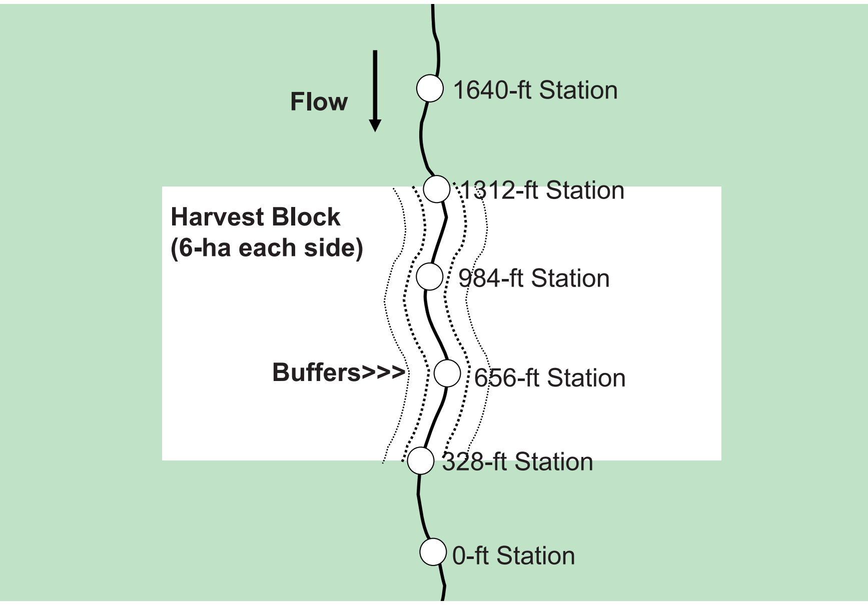

Figure 2. Schematic of experimental layout. 15 streams (3 streams per treatment) were used in the study.

RESULTS

Canopy closure

Canopy closure over the 15 streams averaged 93% in the pre-harvest year (range = 87-98%). In the post-harvest year canopy closure was reduced by more than 70% in the 0-ft treatment group. In the 36-ft treatment group canopy closure decreased by less than 10% while canopy closure was unchanged in the other 75-ft treatment, the partial-cut treatment, and the controls (see Figures 3 and 4).

Seasonal maximum temperatures pre- and post-harvest

The mean hourly temperature increased only a small amount (1.8-3.6 °F) in the 0-ft treatment streams in the post-harvest years, and less than 1.8 °F for the 36-ft treatment streams (Figure 5). However, the seasonal maximum temperature increased substantially for streams in the 0-ft treatment. For example, the maximum observed water temperature at the 328-ft station for Kibby stream (0-ft treatment) in the pre-harvest year was 61.3 °F (Figure 5), whereas the maximum temperature in 2002 and 2003, after the canopy had been removed, was 73.0 °F and 71.6 °F, respectively. By contrast, change in seasonal maximum water temperature following harvest for the 36-ft treatment group was -1.8 °F to 5.4 °F, indicating that the retained canopy was effectively protecting the stream from solar radiation. None of the streams in the 75-ft, partial-harvest, or control treatments showed any significant change in maximum seasonal water temperature following harvesting (Figure 5).

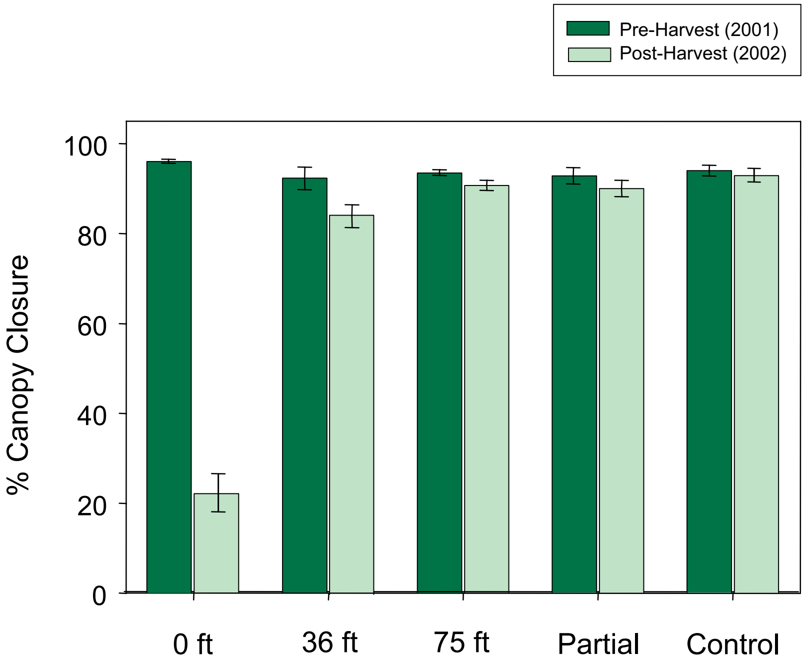

Figure 3. Mean canopy closure within the harvest zone for each treatment group in the pre-harvest year (2001) and the first post-harvest year (2002).

Mean weekly maximum

A more relevant biological measure of stream temperature is mean weekly maximum temperature. This is because a single warm day is not likely to affect fish survival, whereas several warm days running can affect survival.

In the post-harvest years, the mean weekly maximum temperature in the 0-ft treatment group increased between 2.5 °F and 7.9 °F reaching

Figure 4. A stream in the 0-ft buffer treatment in the first post-harvest year.

a post-harvest mean weekly temperature between 59.4 °F and 63.3 °F (Table 1). Mean weekly maximum in the 75-ft treatment group increased between 1.8 °F and 2.5 °F. No change greater than 1.8 °F was observed in 75-ft buffer, partial harvest, or control treatment groups (Table 1).

Daily Temperature Fluctuation

Another measure of temperature change is daily fluctuation in stream temperature. Continuous temperature traces (Figure 6) illustrate how daily fluctuation in temperature changed for a representative stream in each treatment.

In the pre-harvest year (2001), all 15 streams showed a seasonal mean daily diurnal fluctuation between 1.3 °F and 4.0 °F (mean=2.9 °F) at the 328-ft station. In essence, these relatively cold small headwater streams are highly buffered from the effects of solar radiation when full canopy conditions exist.

In the post-harvest years the mean diurnal fluctuation at the 328-ft station increased significantly in all 0-ft treatment streams and all 36-ft treatment streams. For the 0-ft treatment streams, the mean diurnal fluctuation increased from 2.5 °F (2001) to 6.3 °F (2002) and 6.8 °F (2003). For the 36-ft buffer streams the mean diurnal fluctuation increased from 3.5 °F (2001) to 5.7 °F (2002) and 4.3 °F (2003). Kibby stream (in the 0-ft treatment) showed the most dramatic change in daily temperature fluctuation after the harvest, increasing from a mean fluctuation of 2.7 °F per day (2001) to 8.8 °F (2002) and 8.6 °F (2003) per day (Figure 6).

DISCUSSION

Water temperature and diurnal fluctuations in temperature increased especially in 0-ft treatment streams. Post-harvest increases in stream temperature were driven by increased solar radiation reaching the stream channel (Brown and Krygier 1970). Streams in the 0-ft treatment group had little canopy cover (0-37%) following the timber harvest as compared to pre-harvest (90+% cover). Streams

Table 1. Mean weekly maximum temperature (°F) from June 15-August 15, 2001 (pre-harvest) and 2002 and 2003 (post-harvest)

Treatment	Stream	Pre-Harvest (2001)	Post-Harvest (2002)	Post-Harvest (2003)
0-ft buffer	Kibby	55.4	62.8	63.3
	PP1	57.6	60.1	63.1
	Sk1	55.4	59.4	60.1
36-ft buffer	Bald Mt.	60.1	62.4	62.2
	Caratunk	58.6	60.4	61.2
	Sk2	53.4	no data	55.4
75-ft buffer	MG2	43.0	43.5	43.5
	Roxbury	58.5	58.1	59.2
	Sand	57.6	57.4	57.7
Partial Harvest	MG1	55.2	55.0	55.2
	PP2	57.4	57.6	59.2
	UpCup	56.3	56.3	56.5
Control	Appleton	54.3	54.5	54.9
	Bryant	57.2	56.5	56.8
	Dud	57.4	56.7	56.8

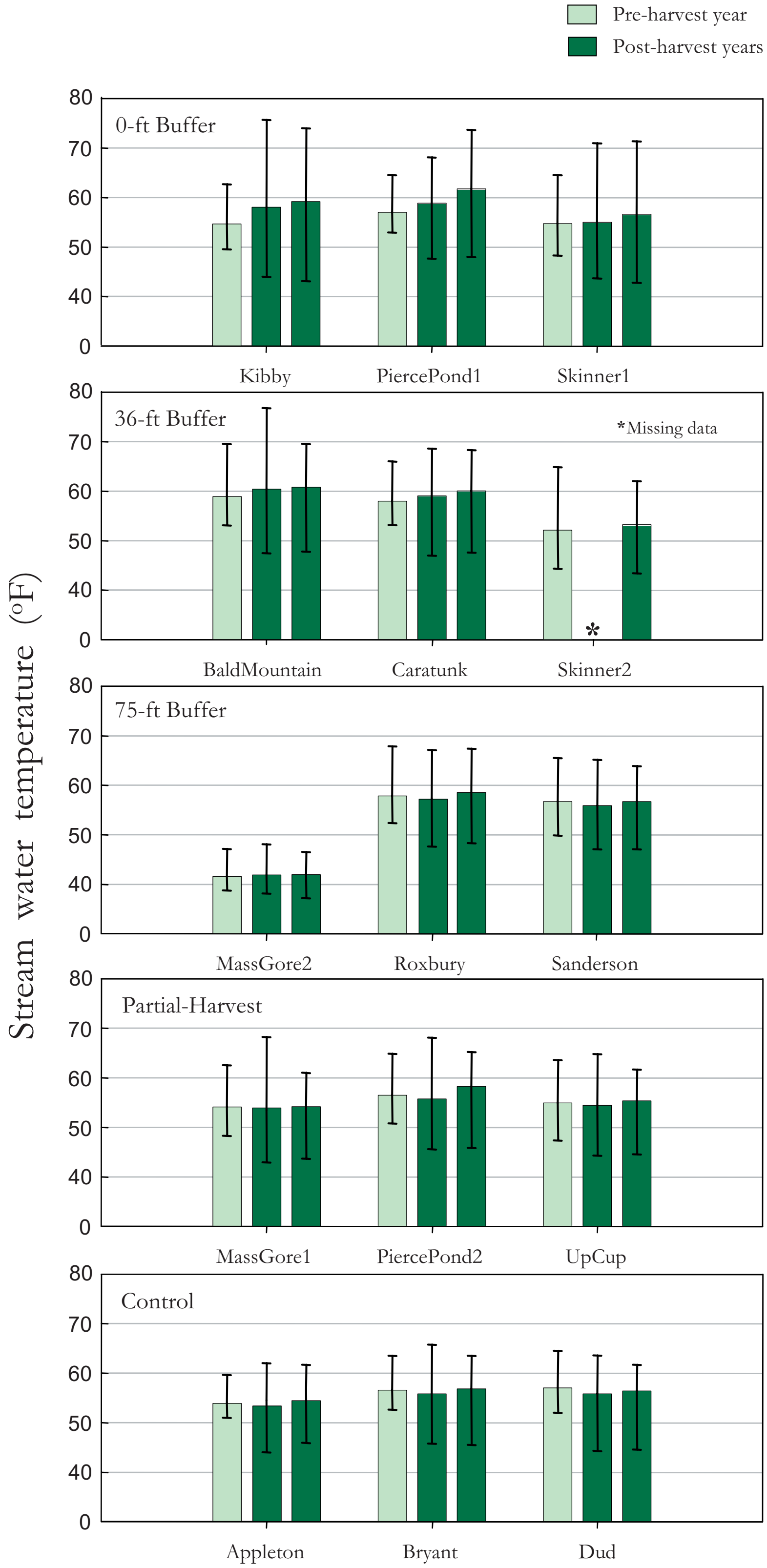

Figure 5. Average seasonal water temperature recorded at the downstream end of the harvest zone (328 ft station, see Figure 1) from June 15-August 15 in the pre-harvest year and the two post harvest years. Vertical lines in each bar represent minimum and maximum water temperature recorded each year (not standard error).

in the 0-ft treatment exhibited the largest increases in mean weekly maximum temperature (2.5 °F -7.9 °F) and diurnal fluctuation (3.8 °F - 4.3 °F). The 36-ft buffers retained more than 80% of canopy cover over the stream channel and normal stream temperature behavior was largely maintained. Streams in the 75-ft, partial harvest, and control treatment groups did not show any change in mean weekly maximum temperature greater than 0.9 °F or any changes in diurnal fluctuation.

Elevation of water temperature is a concern because aquatic organisms are adapted to living in systems within a particular temperature range at which body size, fecundity, and survival are optimized (Vannote and Sweeney 1980). The greatest mean weekly maximum water temperature in the 0-ft treatment group ranged from 59.3-63.3 °F. These values were 2.5-7.9 °F greater than pre-harvest temperatures, but still well below the optimal temperature for brook trout growth of 66.2 °F (Brungs and Jones 1977) and the lethal thermal stress levels of 75.2 °F (EPA 1986). Temperature increases can alter macroinvertebrate community composition (Noel et al. 1986) but documented temperature thresholds have not been established for these organisms.

Stream aspect and groundwater inflow appeared to play significant roles in amplifying or mitigating stream warming, especially for streams in the 0-ft buffer treatment.

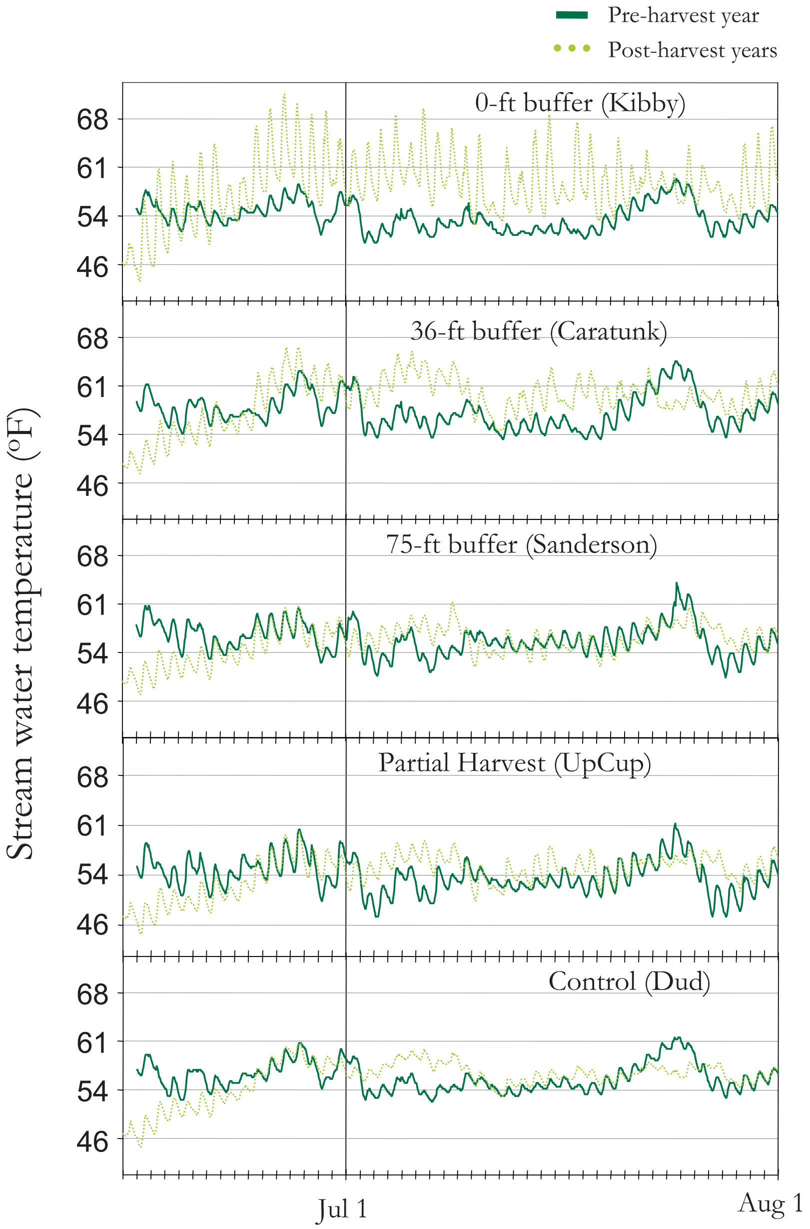

Figure 6. Continuous (hourly) traces of water temperature from one stream in each of the five treatments, in the pre-harvest year (dark green line) and in the post-harvest year (light green line). The daily fluctuation in temperature is represented by the undulations in the traces.

KEY CONCLUSIONS

- Complete canopy removal on 984-ft sections of headwater streams can raise mean weekly maximum temperatures by as much as 7.9 °F. However, observed temperature increases did not exceed thermal limits for brook trout.
- Temperature increases on small streams are driven by direct solar radiation. Thus, orientation of the stream plays a role in determining the effect of complete canopy removal. To keep temperature changes to a minimum, small streams with southeasterly to southwesterly drainages may deserve a narrow buffer (e.g., 36 ft or 11 m).
- Even when no buffer is retained in clearcut harvests, stream temperature recovers to near normal within about 328 ft below the harvest zone, if the stream flows through mature closed canopy forest.
- This study suggests small headwater streams do not require buffers to maintain temperature requirements for brook trout. However, temperature does increase with full or nearly-full canopy removal, and daily temperature flux can increase two or three fold over normal flux in small streams.

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Funding for this study was provided by the University of Maine Cooperative Forestry Research Unit, National Council for Air and Stream Improvement, Inc., Plum Creek Timber Company, and Manomet Center for Conservation Sciences.

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