Removal of the Riparian Zone During Forest Harvesting Increases Stream Temperature: Are the Effects Cumulative Downstream?

J. M. Shrimpton
Biology Program, University of Northern British Columbia
3333 University Way, Prince George, BC, V2N 4Z9, Canada
shrimptm@unbc.ca

J. F. Bourgeois
Biology Program
University of Northern British Columbia,
3333 University Way
Prince George, BC, V2N 4Z9, Canada

J. T. Quigley
Faculty of Forestry
University of British Columbia
and Habitat and Enhancement Branch
Fisheries and Oceans Canada
360 – 555 West Hastings Street
Vancouver, BC, V6B 5G3, Canada

D. M. Blouw
Research and Graduate Studies
University of Northern British Columbia
3333 University Way
Prince George, BC, V2N 4Z9, Canada

ABSTRACT

The experimental removal of riparian vegetation was performed to determine the impact on stream temperature. Water that flows through the unbuffered creeks heats more than the water in the buffered creeks. As a consequence, the diurnal change in temperature is greater in the unbuffered creeks. We do not know many of the moderating forces on heat loading that may be at work in northern Interior streams. As a result we have heated selected streams to uncouple changes in temperature from other aspects of the natural environment that often co-vary with temperature. Energy put in as heat is transmitted a considerable distance downstream. The loss of heat after increasing stream temperature at a single point, however, appears to be independent of riparian zone characteristics.

Key words: forest harvesting, riparian vegetation, stream temperature.

Water temperature is an important parameter influencing stream ecology and fish productivity. Stream temperature plays a central role in the aquatic ecosystem because it influences all biological processes including metabolic rates, growth, behaviour, and survival of fish populations. There is a narrow range of temperatures over which salmonids can thrive. At the upper and lower thresholds of this optimum range, fish exhibit behavioural and physiological responses that enable them to maintain homeostasis. Fluctuations in daily temperature are also stressful for fish and impact on energy reserves (Thomas et al. 1986).

Clearcut logging has been directly related to increases in stream temperature in a number of studies (Ringler and Hall 1975, Rishell et al. 1982, Lynch et al. 1984, Holtby 1988). Leaving an undisturbed buffer strip of riparian vegetation adjacent to the stream has been shown to mitigate the increase in stream temperature (Newbold et al. 1980, Barton et al. 1985). The importance of riparian reserves is reflected in harvest prescriptions mandated by the British Columbia Forest Practices Code Act (FPC). The FPC defines the dimensions of buffer strips that must be left adjacent to streams dependent on physical and biological attributes of the streams. For small stream reaches <1.5 m wide, however, the FPC prescribes a 20-m riparian management zone, which allows for a wide range of practices within the riparian zone of the stream, including removal of all timber. Our first objective has been to determine the value of these buffer strips <30 m in width for moderating daily fluctuations in temperature within these small streams in central British Columbia.

Our second objective has been to evaluate the transmission of heat downstream. Due to the high latent heat capacity of water, changes in temperature may be efficiently transmitted downstream. The effect of warming many small streams may, therefore, be incremental, such that the potential cumulative downstream impact may be significant. To evaluate the efficiency of heat transmission downstream, we are manipulating stream temperatures. This approach allows us to uncouple changes in temperature from other

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aspects of the natural environment that often co-vary with temperature (for example discharge, cloud cover, precipitation, air temperature, insolation, groundwater flows). With the wide fluctuations in temperature that we observe, this experimental approach enables us to clearly isolate changes in temperature attributable to harvest practices and their downstream effects. A second major benefit to experimentally manipulating temperature is that we will be able to quantify the fate of the heat loading that is well documented to take place in water courses adjacent to clearcuts. The downstream transmission of upstream temperature events has not been investigated. They may have considerable importance in the incremental impact of harvesting numerous small cutblocks throughout a drainage basin, or throughout an entire watershed.

METHODS

Assessment of Riparian Reserve Zones

We have been examining environmental changes that occur due to forest harvest practices to evaluate the effectiveness of the FPC in moderating stream temperature variation. In the Torpy River watershed, 150 km east of Prince George, B.C., a cutblock that had a Y-shaped creek (referred to as "Y Creek") flowing through the centre of the block was harvested in January 1996. The 2 forks of the creek have an average width of <1.5 m and discharge of approximately 100 L/min in each fork. A 10-m riparian reserve zone containing deciduous trees and coniferous regeneration trees was left adjacent to both forks of the creek. Over a distance of 350 m on the north fork of Y Creek, we had this riparian reserve zone removed. The south fork reserve was left intact. The 2 forks of the creek are very similar in slope aspect, discharge, and understory vegetation. To observe changes in temperature in Y Creek, we are using remote, self-contained temperature data loggers (Onset Instruments, Cambridge, MA) programmed to record temperature hourly. In the north fork we placed temperature loggers in the stream where it entered the cutblock, and at the top, mid-point, and bottom of the experimental section where the riparian reserve zone was removed. Temperature loggers were placed at similar points in the control south fork. Additionally, temperature was recorded below the confluence.

Instream Heat Manipulation

For the temperature manipulation experiments, water was pumped from a stream using a gasoline-powered, variable-speed Honda portable pump (Model WB15) connected to a noncollapsible hose. The intake consisted of a filter basket covered by fine netting to prevent damage to the pump by sediment. Water was then pumped through propane-powered, instantaneous water heaters (Bosch Booster Pressure Wash Model W400K5, 117,000 btu) and reintroduced into the stream through a diffuser system to ensure mixing. Each diffuser unit was constructed from 5 household showerheads in a manifold-type configuration.

Temperature loggers were deployed in a stream several days before and after the temperature manipulation was scheduled to take place. Two temperature loggers were always placed a few metres upstream from the heating apparatus and the rest were placed downstream at regular intervals in the test stream and in any tributaries present. The loggers were programmed to measure and record temperature every 5 minutes. This enabled us to calculate the background variations in temperature observed in the test streams. Establishing the background conditions was essential in order to quantify the transfer of heated water downstream. The difference between the observed temperatures during the heating experiments and those calculated based on the natural temperature regime of the stream is expressed as ΔH. With this approach we could examine physical factors that affect the rate of heat dissipation following temperature manipulation.

RESULTS

Y Creek

A summary of temperature changes for 1 day in June of 1997 is shown in Figure 1. Water temperatures in the forested areas above the clearcut were very similar in the north (stn. 19) and south (stn. 20) forks of Y Creek, and there was relatively little diurnal change in temperature. The north fork (stn. 6) and south fork (stn. 5) had comparable water temperatures before they entered the experimental area. Water flowing out of the unbuffered north fork (stn. 3) heated more than water flowing out of the buffered south fork (stn. 4). As a result, the diurnal difference in temperature was greater in the unbuffered fork. There was an increase in variance in water temperature that occurred in unbuffered sections of stream relative to forested areas or streams with riparian buffer strips. Water below the confluence (stn. 17) is a rough average of the 2 inflowing streams.

Throughout the early part of the year, the average temperature differential (ΔT) between the upper and lower stations on each fork of the creek was positive (Table 1), but it was greater and showed greater variance on the unbuffered fork. During the fall, ΔT became negative for the unbuffered fork, indicating a decrease in stream temperature as the water flowed through the experimental section. This loss in water temperature was not seen to the same degree for the stream with a 10-m riparian reserve zone.

Instream Temperature Manipulations

An example of data from a heating experiment is shown in Figure 2. Hooker's Stream is a north-side S4 tributary of the Lower Torpy River that flows through a cutblock. The

Table 1. Mean temperature difference (ΔT) from 1300 hr to 1800 hr for April–November, 1997. ΔT-Unbuffered is calculated from the difference between temperature stations 3 and 6 on the experimental sections of Y Creek; ΔT-Buffered is calculated from the difference between stations 4 and 5 on the control sections of Y Creek. Distance between stations is 350 m. Station 17 is 50 m below the confluence of the 2 forks of Y Creek. Air temperature is averaged over the month for temperatures recorded between 1300 hr and 1800 hr.

Month	Mean temperature difference (°C)		Stn. 17 temperature	Air temperature
(1997)	ΔT-Unbuffered	ΔT-Buffered	(°C)	(°C)
Apr	-0.19	-0.15	0.35	8.2
May	0.66	0.41	5.76	15.5
Jun	0.73	0.25	9.54	17.4
Jul	0.63	0.31	10.28	19.8
Aug	0.58	0.21	11.74	21.7
Sep	0.24	0.16	9.39	17.3
Oct	-0.01	0.14	4.86	5.0
Nov	-0.09	-0.02	0.44	-1.2

discharge was approximately 150 L/min. A heating experiment was conducted on 8 October 1997 between 1210 and 1740 hr. The heating apparatus was located 158 m upstream from the lower block boundary. This boundary is the edge of the riparian zone along the north bank of the Torpy River. Figure 2 indicates the location of the block boundary, as well as the locations of a deactivated road and 2 tributaries flowing into the test stream.

Figure 2 supports the assumption that energy put into the stream as heat is transmitted a considerable distance downstream. The linear negative slope (-0.0061) of the data indicates that heat from the stream is dissipated at a constant rate of 0.0061°C/m. During a second heating experiment in the morning on 9 October, the heat loading dissipated at a rate of 0.0058°C/m. The slopes of these 2 lines do not differ significantly and there is little difference in dissipation rates between the 2 experiments. There was only a 5°C difference between mean air temperature during both experiments and

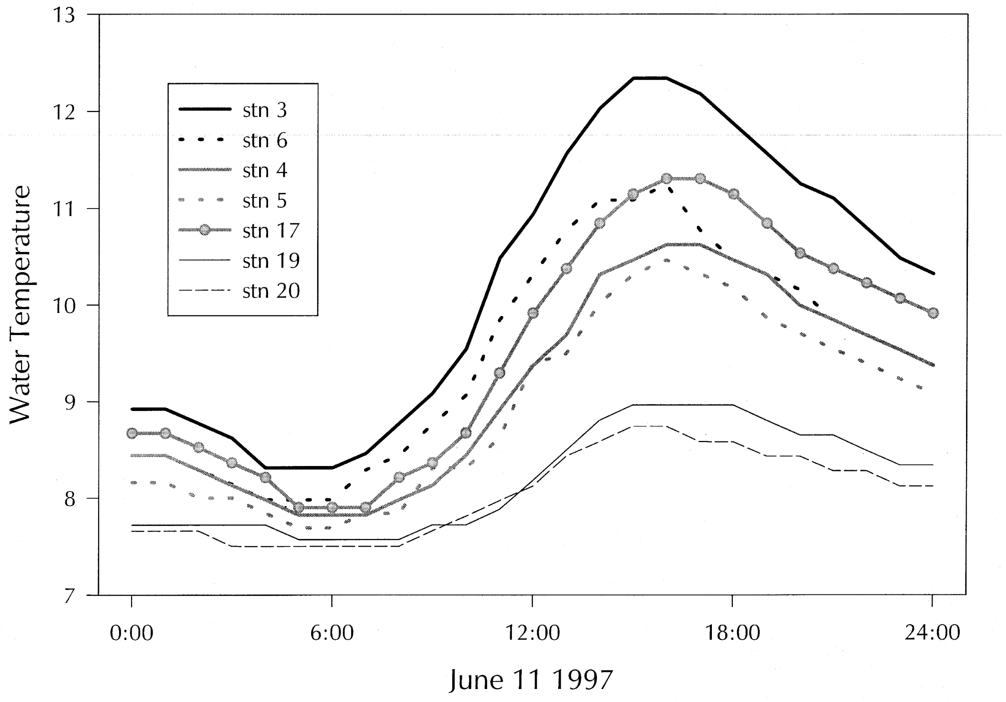

Figure 1. Daily change in water temperature in Y Creek on 11 June 1997. Locations of the temperature recording stations are described in the text.

no measurable rainfall during either of the heating experiments on Hooker's Stream. In additional experiments we found air temperature to have more of an effect on the dissipation of heat.

Heat dissipation was linear with distance from the heat source. As the stream flow passed across roads, the temperature signal was more variable. The overall net rate, however, did not change appreciably. Figure 2 also shows the rate of heat dissipation for the stream flowing through a cutblock and through an unharvested reach. The loss of heat from the stream continues at a constant rate. There appears to be no difference between the rate of heat loss through the cut block or the reaches with riparian vegetation adjacent to the stream.

DISCUSSION

Water temperature of streams increases following clearcut logging. The principal cause of elevated water temperature following logging has been attributed to increased surface exposure due to direct insolation (Brown and Krygier 1970, Sinokrot and Stefan 1993). The retention of buffer strips adjacent to streams has been reported to be effective in limiting increases in stream temperature attributable to forest harvesting (Hewlett and Fortson 1982, Barton et al. 1985), and riparian buffer strips of 30 m were found to provide sufficient shading and prevent increases in stream temperature. In British Columbia, the FPC does not require buffer strips of this size to be retained on small streams <1.5 m wide. The presence of a 10-m riparian buffer strip, however, does moderate increases in stream temperature. The removal of this 10-m riparian reserve strip resulted in substantial differences in heat gain between the forks of Y Creek (Table 1).

Diel fluctuations in stream temperature also increase following clearcut harvesting (Lynch et al. 1984). Retention of riparian reserves adjacent to streams limits diel fluctuations in temperature. This is shown by the diel fluctuations in temperature that were greater in the unbuffered stream than in the buffered stream (Fig. 1). Although the daily fluctuations in stream temperature are less due to the presence of a riparian buffer strip, they were still much greater than temperature oscillations observed in both streams prior to entering the cutblock. Above the cutblock, both streams showed mean daily temperature oscillations of <1.0°C. Heating of streams with riparian buffer strips of this width, therefore, will still occur.

Following clearcut harvesting within the Carnation Creek watershed on Vancouver Island, Holtby (1988) reported an increase in mean stream temperature for all months of the year. There was variation over the year in the magnitude of the increase in water temperature, which was greatest in August and smallest in December. In contrast, we found that removal of the riparian zone resulted in increases in water temperature (ΔT positive) only during the summer months. In April, October, and November, water flowing through the

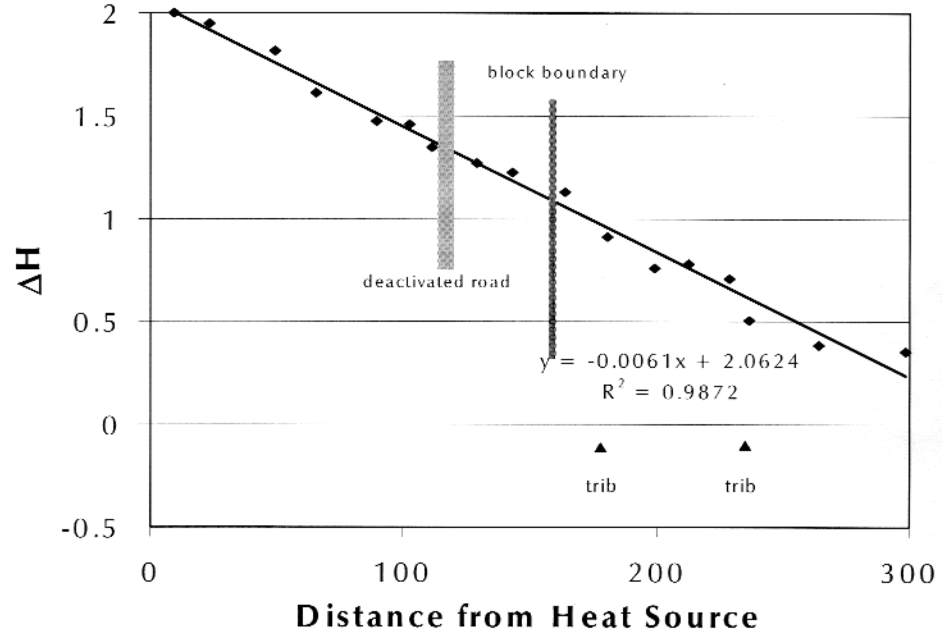

Figure 2. Results of a heating experiment conducted on an S4 stream on the north side of the Torpy River. ΔH represent the difference between the observed temperatures during the heating experiment and what was expected based on the natural changes in water temperature.

unbuffered experimental section of the stream lost heat and decreased in temperature (Table 1). A loss of heat was also seen in the stream with a buffer strip during these months, but ΔT was smaller. The loss of heat from streams during fall and winter months has also been reported for streams flowing through harvested area in Pennsylvania (Rishel et al. 1982). Ambient air temperature is an important factor in heat gain and loss in these small streams and likely accounts for these findings.

The difference in heat gain between the protected and unprotected forks was easily measurable over the short distance involved (350 m). Presumably, the increase in temperature over longer unbuffered distances will be greater. The continued transmission of heat downstream is reflected in the water temperature of station 17 (Fig. 1). Water temperature below the confluence of the 2 forks of Y Creek reflects blended water from the experimental and control reaches. The fact that the temperature was a rough average of temperatures in the 2 forks of the stream suggests that heating of water within the clearcut is transmitted downstream with considerable efficiency. Temperature gains on a watershed level following forest harvesting have been documented. Ringler and Hall (1975) found the mean water temperature of streams in Oregon increased with extent of the watershed clearcut. The extent of harvest within a watershed, therefore, will affect the magnitude of temperature changes. Incremental increases in water temperature from many clearcuts may result in a cumulative increase in water temperature.

The rate of heat loss is linear over distance (Fig. 2). The decrease in ΔT with increase in distance from the heat source in our heating experiments is a result of heat loss due to long-wave radiation, heat loss due to evaporation of water from the water surface, convection of heat across the air-water interface, and conduction of heat to the streambed (Brown 1969, Sinokrot and Stefan 1993). In heat loading of streams, thermal radiation has been shown to be the dominant source of energy, but other components are not negligible. Radiation of heat from the stream to the atmosphere, therefore, may be the most important component of heat flux to cool the stream. If this is the case, we would not expect forest canopy to affect the rate of heat loss. The constant rate of heat loss within the clearcut and within the unharvested reach indicate that riparian vegetation has little influence on dissipation of heat. Other factors, therefore, affect the rate of heat loss. Air temperature will affect the evaporative flux and convective flux of heat. Temperature manipulation experiments conducted at night when air temperature is lower result in higher rates of heat loss from the streams. Increases in wind speed will also affect the convective flux and evaporative flux of heat from the stream. Streambed substrate was predominantly gravel, which has been found to have low thermal conductivity (Brown 1969).

Changes in stream temperature following timber removal have been documented in our research. The downstream transmission of upstream temperature events has considerable importance to cumulative heat loading following harvesting of numerous small cutblocks throughout a drainage basin, or throughout an entire watershed. As harvest practices cause incremental heat loading, considerable impacts may occur with respect to the cold-adapted salmonids that are the mainstay of the British Columbia fishing economy.

ACKNOWLEDGEMENTS

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