The Effects of Forest Practices on Stream Temperature

A Review of the Literature

by

Patrick Teti, M.Sc., P.Geo.
Research Hydrologist
pat.teti@gems7.gov.bc.ca
250-398-4752

B.C. Ministry of Forests
Cariboo Forest Region
200 - 640 Borland St.
Williams Lake, B.C. V2G 4T1

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Introduction

A literature search was done in 1998 by a combination of computer searches at the UBC Library, searches of a personal collection, and a search of the World Wide Web. This yielded more than 40 references spanning 30 years. The list is not considered exhaustive but it is sufficiently complete to reflect the history and current state of knowledge on the effects of forest management on stream temperature. Emphasis in obtaining and reviewing the references was placed on:

- increases in summertime stream temperature associated with logging, and
- publications from the last ten years.

The literature review did not address the following topics:

- the biological effects of high stream temperatures on aquatic biology or
- the effect of lakes on stream temperature.

The Effect of Logging on Summertime Stream Temperature

Research papers published in the 1960's and 1970's showed that logging could increase summertime stream temperatures in the range that is detrimental to fish. For example, Levno and Rothacher (1967) found that logging increased water temperature after 55% of a watershed was cleared and trees were felled along all major streams. However, Brown (1970) addressed the stream temperature issue in a more precise way. He recognized that solar radiation falling on a stream was one of the most significant variables associated with summertime stream heating and that it was the removal of riparian vegetation, rather than timber harvesting in the watershed per se, which most directly affects stream temperature. Brown developed a simple quantitative method for estimating the increase in daily maximum temperature that would occur between two points on a stream. His model requires ephemeris based solar radiation data (from tables), the increase in area of stream exposed, and stream discharge. Brown's method has been cited many times in subsequent literature due to its simplicity, physical basis, and reasonable accuracy.

In the early to mid 1980's, the scientific literature documents case studies in which an increase in summertime stream temperature was found to be correlated with logging, including some examples from British Columbia. For example, Holtby and Newcombe (1982) found a 7 degree C increase in the mean temperature of Carnation Creek between May and October after 39 percent of the watershed had been clearcut. This is discussed further under Cumulative Effects, below.

Like Brown, other researchers have attributed stream temperature increases to the removal of riparian vegetation. Brownlee, et. al. (1988) studied water quality along three small streams east of Prince George which had been logged to the streambanks for part of their length. They found an increase in mean stream temperature of 1 to 3 degrees C. More importantly, they found that maximum temperatures on the warmest days were 4.5 to 9 degrees C greater downstream from clearcuts than upstream.

Hewlett and Fortson (1982) observed logging related temperature increases in the Southeastern U.S. which provide some evidence of stream heating beyond what could be explained by riparian exposure. They attributed this to timber harvesting in gently sloping areas which warmed shallow groundwater and suggested that this could result in stream heating even with a substantial buffer strip in place. However, their conclusions may not represent conditions elsewhere because no other similar results were found during this review.

In their own review of the literature, Beschta, et. al. (1987) identified direct solar radiation on streams as the primary factor influencing temperature change in summer and that buffer strips can therefore be effective at preventing stream temperature increases. Like Wooldridge and Stern (1979), they suggested that the concept of “canopy density” as an optical measure of the exposure of a stream to sunlight could be improved by “angular canopy density” or ACD, which expresses the percentage of the sun’s actual path between 10 AM and 2 PM (standard time) in mid to late summer that is obscured by vegetation. This can be determined for any given point on the stream by a simple field observation, similar to an overhead canopy density measurement.

It is useful to note that increased summertime stream temperature can have a positive effect on fish in a cool climate. For example, Thedinga, et. al. (1989) found more salmon fry in stream reaches that were logged to the banks than in unlogged reaches flowing through forests of sitka spruce and western hemlock in southeast Alaska. The condition of the fish was better too. However, this study is only representative of streams that are cooler than the optimum during the summer.

Adams and Sullivan (1989) discussed the physics of stream temperature and made some useful and novel conclusions. They found that stream depth is the most important geometric parameter which characterizes stream size for energy transfer purposes. Stream depth affects the amount of diurnal temperature fluctuation about the mean daily temperature. They also concluded that under equilibrium conditions, daily mean stream temperature is always very near the daily mean air temperature. This is because the rate of heat transfer between air and water increases rapidly with increasing temperature differential. A related conclusion is that riparian vegetation removal has only a modest effect on mean stream temperature, while at the same time having a large effect on the daily temperature fluctuation. This is because increased heat gain in the day is partially offset by increased heat loss at night.

Riparian Buffers

The terms “leave strips”, “buffer strips”, “riparian buffers”, “riparian reserves”, and “reserve zones” are different terms for the practice of leaving trees next to streams. In this review they are used to reflect the wording of the different authors.

The value of riparian buffers in mitigating stream temperature increases was recognized early. Brown (1971) even noted that on very small streams adequate shade may be provided by brush species. Wooldridge and Stern (1979) tested Brown's equation and established criteria for buffer strip management. They looked at buffer strip width and the amount of timber removed from buffers as predictors of stream temperature increases. They concluded that angular canopy density, measured optically along the path of maximum incoming solar radiation, is a better predictor of buffer effectiveness than buffer width. If used correctly, angular canopy density automatically accounts for the varying shade requirements of streams of different width and azimuth, as well as the local effects of different riparian vegetation and topography.

By the late 1980's, it was clear that the increased exposure of streams to sunlight was the key factor and that increased stream temperature could be mimimized with adequate riparian buffers. However, the width of riparian buffer that is required has been the subject of considerable discussion. A narrow buffer would seem to be better than none at all but only if it does not blow down. Indeed, a windthrown riparian buffer may be worse than none at all by introducing sediment and woody debris (Salo and Cederholm, 1981). Therefore, where buffers are to be used, 10 metres has been recommended by some as a minimum width (Martin, et. al., 1985; Davies, and Nelson, 1994).

The minimum widths of riparian buffers required by various jurisdictions in western North America are difficult to compare due to different stream classification systems and the allowance of partial cutting within buffers in some cases. Belt, et. al., (1992) give a good review of riparian buffers and a summary of riparian buffers and the requirements of the states of Idaho, Washington, California, and Oregon. Beschta, et. al. (1987) documented angular canopy density as a function of buffer strip width and concluded that buffer widths of 30 metres or more generally provided the same level of shading as that of an old growth forest in western Oregon and northern California.

Prescriptions for buffers of fixed width have the advantage of being simple. However, the literature indicates that such prescriptions will not be efficient at providing protection of fish habitat per unit volume of timber left on the site. Rather, it suggests that maximum benefit per unit volume of timber can be achieved by designing riparian buffers to maintain some desired portion of angular canopy density on a reach by reach basis. However, this involves additional costs in the form of labour.

Rashin and Graber (1992) evaluated the effectiveness of the state of Washington's riparian regulations for Type 1-3 streams in achieving the objectives for maximum temperature. These regulations require the retention of 50 to 75 percent of the pre-harvest shade. They found that this prescription was not effective at meeting water temperature objectives at 6 of the 13 sites but they concluded that the standards could have been met by using more site specific criteria for managing the retention of shade.

Stream Temperature Models

Sullivan, et. al. 1990 evaluated various models for predicting forestry related temperature increases across the state of Washington, including Brown's model and 3 other stream reach models. They concluded that the reach model developed by Adams and Sullivan (1989) was one of the best in terms of accuracy and practicality. They found that two of the basin models are potentially useful but that none are ready for routine use. They concluded that the idea of dispersing harvesting with the aid of a basin temperature model introduces unnecessary complexity.

Thermal Recovery

If the presence of riparian vegetation is recognized as the key factor in protecting stream temperature, then it follows that the temperature of a cleared stream will return to normal over time as riparian vegetation grows back. This is referred to as “thermal recovery”.

Only two studies were found which document diminishing temperature effects in a cleared stream over time. In a paired watershed study on the south coast of B.C., Feller (1981) found that the summertime temperature increase associated with clearcuttting lasted for 7 years. Harr and Fredriksen (1988) found that increased temperature in a stream on the Oregon coast had mostly disappeared within 3 years of logging.

Based on the literature, the best predictor of both the initial post-logging temperature rise and thermal recovery over time would appear to be angular canopy density. Beschta, et. al (1987) found that angular canopy density approached that of old growth within about 10 years on the coast, about 20 years in the Cascades, but only about 50 percent of old growth after 20 years at higher elevations in the Cascades. McGurk (1989) suggested that there would be full recovery of stream shading 20 years after logging at a California site.

These studies of the recovery of stream temperature and angular canopy density over time are not easily compared to one another or extrapolated to other sites.

Cumulative Effects

It has been suggested by several researchers that stream temperature increases are cumulative. Beschta and Taylor (1988) described an increase in the average daily maximum stream temperature of 6 degrees C over a 30 year period during which time a cumulative index of forest harvesting was also increasing. Holtby and Newcombe (1982) suggested that summer increases in stream temperature in Carnation Creek were proportional to the basin area logged. These papers implied that stream temperature would increase in direct proportion with increased timber harvesting in a watershed. Researchers have subsequently avoided this interpretation in favor of the riparian model. In fact, Holtby (1987) reinterpreted the Carnation Creek results and concluded that summertime stream temperature increases were proportional to the length of stream bank logged and that this was directly related to the increased penetration of sunlight to the stream.

It is useful to note that temperature effects are certainly cumulative to some extent. For example, the temperature of a cool stream flowing into an open clearcut exposed to the sun would be expected to increase continuously, although not at a constant rate, in the downstream direction. However, as the water temperature increases, the rate of heat loss back to the atmosphere would also increase and the temperature of the stream would tend to level off. For example, in California, McGurk (1989) observed that a stream which had been warmed in a clearcut cooled by 1 or 1.5 Celsius as it flowed back into the trees within a distance of 130 metres. He suggested that the natural temperature would be recovered within 1.6 km.

The state of Washington does not require riparian buffers on their Type 4-5 waters which are smaller headwater streams, are generally non-fish bearing, and correspond with British Columbia’s S4, S5, and S6 streams. In many cases, Washington’s Type 5 streams would not have surface flow in late summer, like B.C’s S6 streams. Sullivan, et. al. (1990) identified the need to determine whether the warming of Type 4-5 waters could have a significant effect downstream. They concluded that stream temperatures in general could be adequately protected by administering the existing regulations on a site by site basis.

Caldwell, et. al. (1991) also addressed the question of temperature impacts within and downstream from Type 4-5 waters in western Washington associated with logging to their banks. They found that their temperature responds as predicted by temperature models used on larger streams (Sullivan, et. al., 1990). They found that the maximum temperature of these streams was strongly influenced by elevation and that it did not rise above a maximum equilibrium temperature, even though air temperature did. An interesting observation about the implementation of regulations was that landowners had voluntarily left buffers on many of the larger Type 4 streams in western Washington. The authors concluded that the individual and cumulative effects of these streams on Type 3 waters (third order streams) is minimal due to the much larger size of the Type 3 streams and the distance between the Type 4 confluences. They suggest that on Type 3 streams greater than 7 km from the watershed divide, the temperature of Type 4 streams will have virtually no effect.

Summary

The scientific literature strongly indicates that the removal of riparian vegetation increases the summertime temperature of streams. It also indicates that these temperature increases should be minimal in streams where shading has been maintained by effective buffers. Effective buffers are those which maintain shading of streams close to natural levels and is best measured by *angular canopy density*. For a stream reach, this is defined as the percentage of the sun’s path between 10 AM and 2 PM (standard time) in mid to late summer which is obscured by vegetation, averaged across point measurements within the wetted perimeter.

There is good evidence in the literature that fixed width buffers are less effective at minimizing stream temperature increases than buffers designed to minimize increases in angular canopy density based on site specific measurements. Because the RMA Guidelines specify fixed width buffers, it is therefore likely that they would not maximize stream temperature protection per unit volume of timber left on site.

One of the most important implications from the literature is that the downstream effects of stream temperature increases in smaller, non-fish bearing streams may small. According to Doughty and Sullivan (1991) and Caldwell, et. al. (1991), the cumulative temperature effects on third order streams due to the harvesting related heating of first and second order streams is expected to be minimal. Their work suggests that there is a diminishing benefit to be gained by riparian buffers on non-fish bearing streams as one goes upstream from a fish-bearing stream, depending on the size difference between the non fish-bearing and fish-bearing stream. In the case of a large size difference such as an S4 or S6 entering an S2, the literature suggests that the potential influence of the smaller stream would be negligible. However, in the case of an S6 entering an S4, or an S5 entering an S2 or S3, the potential effect of the smaller stream would be larger.

No references were found on the role of large lakes and tributaries of large lakes in controlling lake outlet temperature. However, large lakes are expected to have unique effects on lake outlet temperature that would overwhelm the effects of inflowing tributaries due to their large surface areas and volumes.

The time required for “thermal recovery” after riparian logging will depend on the factors that affect solar radiation, including stream width, stream azimuth, and local topography as well as the factors that affect revegetation. Incorporating thermal recovery into the management of stream temperature could be based on an empirical relationship between angular canopy density and years since logging, grouped according to different types of sites.

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