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Concluding Remarks

The CoP is a decision-making framework for managing steep coastal terrain. Its flexible framework allows for practicing of due diligence when managing landslide risks in forest operations. One of the strengths of the framework is that it focuses on the principles of risk, not hazard. Organizations that use this approach can define for themselves what constitutes a material adverse effect and acceptable levels of risk. The CoP demonstrates that without legislative requirements, terrain mapping and terrain stability assessment remain key tools in the management of steep coastal terrain.

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Stream Shade as a Function of Channel Width and Riparian Vegetation in the BC Southern Interior

Pat Teti

Since the pioneering stream temperature work by George Brown (1970), ecologists and hydrologists have recognized that reducing shade is the main mechanism by which timber harvesting can increase the temperature of small streams. Therefore, the retention and recovery of shade are logical management objectives on streams in which high summer temperature is an issue.

Guidelines for the retention of stream shade and the protection of riparian areas vary considerably between jurisdictions and between agencies within the same jurisdiction. The state of Oregon requires the retention of all trees within 6.5 m (20 feet) of the high water mark of all streams with domestic or fish use (Robison *et al.* 1999). The state of Washington's watershed analysis manual (Washington Department of Natural Resources 1997) specifies target values for percentage shade for different types of streams. For stream temperature protection, British Columbia's *Forest Planning and Practices Regulation* simply calls for the retention of sufficient shade to prevent a material adverse impact on fish in streams that have been designated as temperature sensitive.

It is recognized that riparian areas are managed for many purposes other than stream temperature and that it is possible for stream temperature to be protected with simple reserves without reference to quantitative shade or temperature criteria. However, increasing emphasis on environmental indicators suggests that forest professionals should have a quantitative understanding of shade on streams where shade is important.

The ability of forest professionals to manage stream temperature in BC is limited by the relative novelty of appropriate shade measurement methods, a lack of baseline shade data, and an absence of quantitative shade guidelines. This paper addresses the first two deficiencies by describing a practical sampling procedure and by quantifying how stream shade varies as a function of simple riparian characteristics.

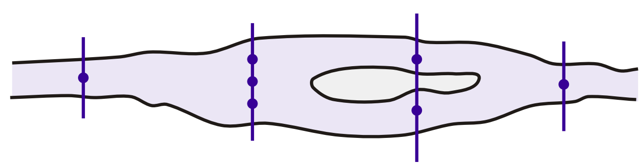
Methods

Many researchers have developed a variety of stream shade parameters and methods to measure them. Brazier and Brown (1973) described a user-made instrument for making ocular estimates of "angular canopy density" or ACD which they defined as percentage shade during the 4 hours at mid-day. They and other authors (Wooldridge and Stern 1979; Beschta *et al.* 1987) argued that shade, or the lack of it, was overwhelmingly important during this period of highest solar irradiance and incident angle. Davies-Colley and Payne (1998) adapted the LAI-2000 to estimate stream shade. Platts *et al.* (1987) and Teti (2001) described simple, portable instruments for measuring shade. Allen and Dent (2001) and Zalewsky and Bilhimer (2004) recommended "effective shade," which they described as the percentage by which shade attenuates direct radiation from sunrise to sunset. Ringold *et al.* (2003) recommended fisheye photography for determining the relationships between stream condition and solar exposure.

Effective shade (similar to the "Global Site Factor" of Ringold *et al.* 2003) may be the ideal stream shade parameter, but it requires canopy density measurements across a 180°-wide field of view. For this study, ACD was chosen as the primary shade parameter because it may strike a balance between physical rigor and simplicity. It can be measured with a spherical ACD meter (Teti 2001), which saves substantial time over photographic methods. Unlike photography, which is typically used to determine shade at a height of about 1 m very accurately, the spherical ACD meter can measure shade within a few centimetres of a stream's surface to ensure that low shade sources are not missed. Both the shade parameter and the instrument used to measure it are important. The suitability of ACD as a shade parameter was tested by performing a paired comparison with effective shade as described below. Teti and Pike (2005) concluded that users of the spherical ACD meter could estimate average ACD to within 10% of the true value with minimal training.

The major factors that were expected to affect stream shade were channel width and the height, or seral stage, of riparian vegetation. Streams were selected in areas where temperature had been identified as a management issue. They were not randomized but were selected to represent a wide range of widths and seral stages of riparian vegetation. Field crews surveyed 44 stream reaches in what are now the Central Cariboo and Cascades Forest Districts. The represented biogeoclimatic zones include Interior Douglas-fir (IDF), Interior Cedar–Hemlock (ICH), Montane Spruce (MS), and Engelmann Spruce–Subalpine Fir (ESSF).

Each sampled reach had relatively homogeneous channel morphology. All channels were single thread, generally flowing in colluvium or alluvium, and with their long profiles locally controlled by dense glacial till or bedrock. Average bankfull widths ranged from 0.7 to 59 m (wetted widths from 0 to 48 m) and average riparian vegetation heights ranged from less than 1 m to more than 20 m. It was difficult to find streams with mid-seral riparian vegetation and our sample contained only one reach in that category. Sixteen reaches had early-seral and 24 reaches had late-seral riparian vegetation (dominated by large conifers). Three reaches were in valley bottoms where riparian vegetation consisted of a mix of large trees and pasture or hayfields and were classified as having riparian vegetation with a mixed-seral stage.



ACD's at points	60	30 40 50	50 60	40
ACD's at sections	60	40	55	40

Figure 1. Example of shade sampling design on part of a stream reach. Numbers are ACD in percentage.

Channels were surveyed between 2001 and 2003 in mid- to late summer when wetted widths and shade would have represented conditions that exist when stream temperatures are high. Several small streams were dry during the 2003 drought and were recorded as having zero wetted width. However, they would be assumed to carry flow in more normal years and their shade values were therefore included. Surveys were completed before there was any significant deciduous leaf-drop.

Data were collected at cross-sections placed at fixed intervals measured along the thalweg at least one bankfull width apart (Figure 1). The plan was to obtain at least 10 cross-sections per reach. Field crews actually obtained 6 to 9 cross-sections on 4 reaches and an average of 18 cross-sections on each of the remaining 40 reaches. The smaller sample sizes were obtained on the widest channel (Horsefly River) where safe access and the availability of homogeneous reaches were limited. Intervals between cross-sections were measured by hipchain on all streams except the Horsefly River where 500-m intervals were measured by taking multiple sightings with a laser rangefinder. Measurements at each cross-section consisted of channel gradient, direction of flow, bankfull and wetted widths, and ACD. Fisheye canopy photos were taken in mid-channel at a subset of cross-sections to allow a later comparison of effective shade and ACD.

Different crews were used in each of the three field seasons and shade was estimated as ACD using a spherical ACD meter (Teti 2001; Teti and Pike

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2005). Where a stream flowed under woody debris, ACD was estimated visually based on crew experience. In addition to the canopy measurements, the field crew categorized the types (herbaceous, deciduous, coniferous, earth, woody debris) and heights (0–1 m, 1–5 m, >5 m) of shade sources. Each reach was categorized as having riparian vegetation at an early-, middle-, late-, or mixed-seral stage.

At cross-sections where wetted width was less than 1.5 m, ACD was measured at one point in mid-channel. Where wetted width was greater than 1.5 m, ACD was measured at 3–5 points at equal intervals left and right of the thalweg (or mid-channel if thalweg was indistinct) but not at the banks (Figure 1). Where an island split streamflow, measurements were taken in each channel and the results averaged; channels judged to carry less than 10% of the flow were ignored. Where low vegetation or overhanging banks provided shade, canopy parameters were measured at the water's surface. The time required to survey 15 cross-sections was about 100 minutes on the smaller streams. ACD was averaged at each cross-section (if multiple measurements were made) and averages of canopy and channel parameters were calculated for the reach.

To estimate the intrinsic relationship between ACD and effective shade, both parameters were measured on 38 digital fisheye canopy photos taken at tripod height above a subset of the streams using methods described in Teti and Pike (2005). Photographed streams had wetted widths ranging from 0 to 6.8 m, bankfull widths from 1.2 to 21 m, and represented 6 early- and 9 late-seral streams. Pixels were classified as either sky or canopy, images were converted to black and white, August ACD was calculated according to Teti and Pike (2005), and mid-August effective shade was calculated from the same binary images using Gap Light Analyzer (www.rem.sfu.ca/forestry/downloads/gap_light_analyzer.htm) with parameters for clear sky conditions.

Results

The observed relationship between ACD and effective shade in a sample of 38 fisheye photos taken along 14 of the streams is shown in Figure 2. The linear regression relationship was effective shade = ACD × 0.79 + 0.13, where $r^2 = 0.93$.

Figure 3 shows average ACD versus average wetted width on streams with mid-, mixed-, and late-seral riparian vegetation. Figure 4 shows the same for streams with early-seral riparian vegetation. Almost all (14 of 16) streams with early-seral riparian vegetation had average wetted widths of 4 m or less. This is an artifact of the relative dearth of deforested larger streams. However, good representation of small streams is useful because they present challenges to managers. Late-seral streams less than 4 m wide (corresponding with those having less than 7 m average bankfull width in this sample) had average ACDs of 53–89% and an overall average of 75%. In contrast, early-seral streams less than 4 m wide had ACDs ranging from 17 to 95% with an overall average of 47%. Most (9 of 14) of these smaller streams with early-seral vegetation had ACDs that were lower than the lowest observed ACD on the smaller streams with late-seral vegetation (53%). The two early-seral streams with the highest ACDs (76 and 95%) received much of their shade from introduced logging debris. The ACDs of late-seral streams

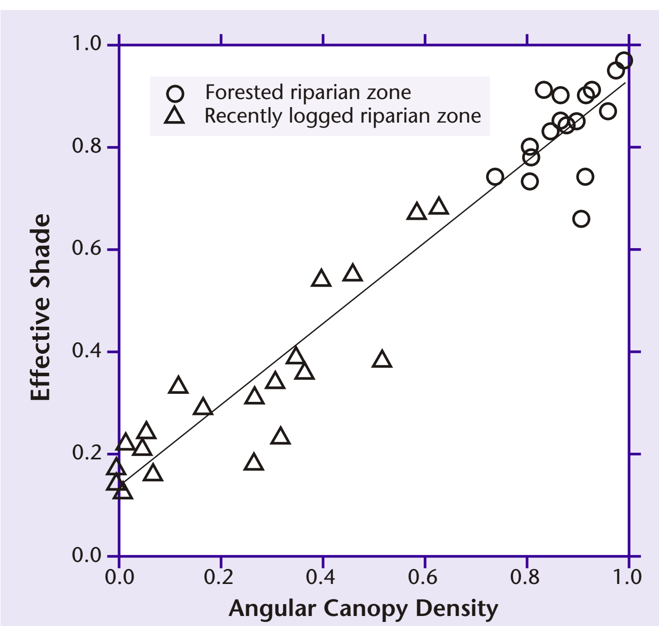

Figure 2. Relationship between effective shade and ACD on individual fisheye photos.

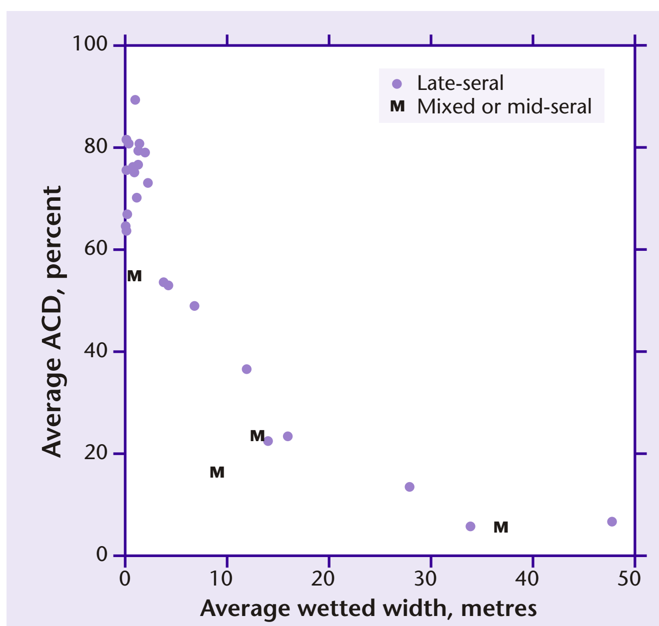

Figure 3. ACD versus wetted width on streams with mid-, mixed-, and late-seral riparian vegetation.

greater than 4 m wide decreased from 53% at a stream width of 7 m, to 5% at a width of 34 m. Average ACDs on one stream with mid-seral riparian vegetation and three streams with mixed-seral vegetation were less than or equal to ACDs on late-seral streams of similar width.

Figure 5 shows frequency distributions of average ACDs on streams with early- and late-seral vegetation and having wetted widths less than 4 m.

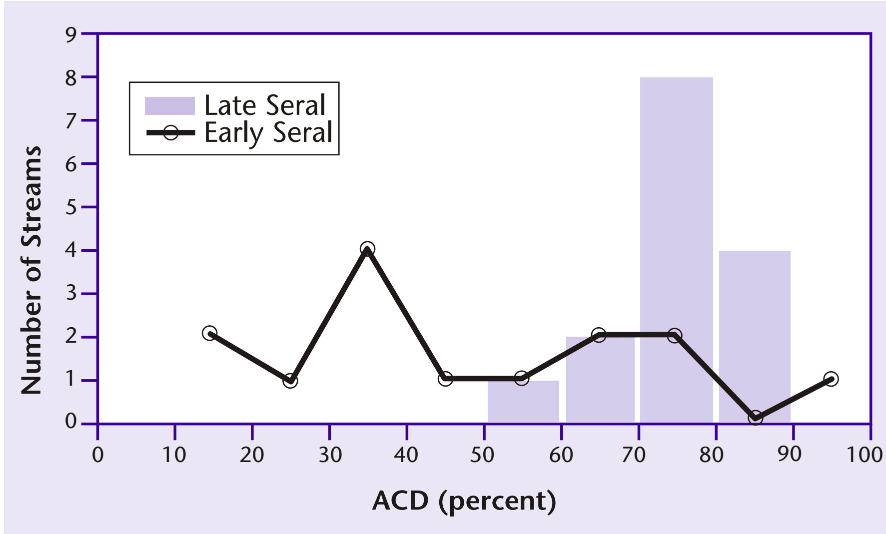

Figure 5. Frequency distributions of average ACD on streams with early- and late-seral riparian vegetation with average wetted widths less than 4 m.

Discussion

These results support the following simple conceptual model for shade on forested streams in the southern Interior of BC. In the presence of late-seral riparian vegetation, average ACD on streams with wetted widths of less than a few metres is normally 60–90%, and is provided by a combination of overstorey and understorey vegetation, and by channel banks and woody debris. Clearcutting the riparian areas of these small streams tends to reduce average shade from high (75%) to medium (47%) levels. However, shade on small streams that lack late-seral riparian vegetation is highly dependent on small-scale features.

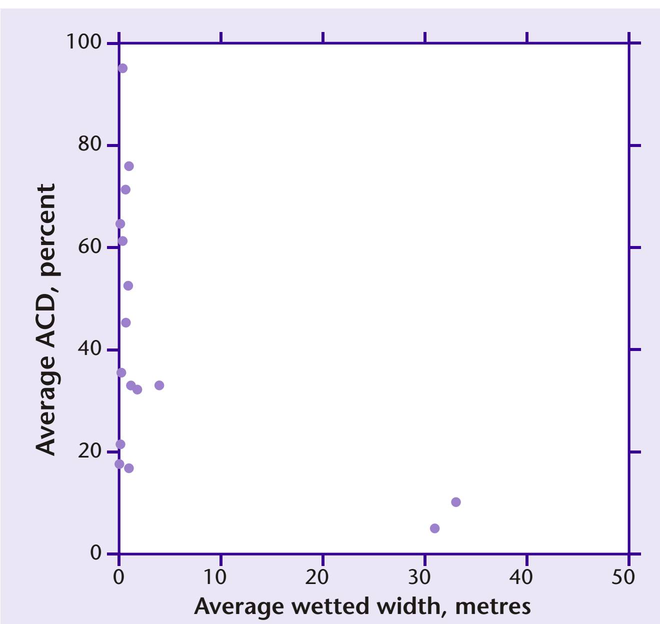

Figure 4. ACD versus wetted width on streams with early-seral riparian vegetation.

Substantial shade recovery can occur on these streams in several years but this factor was not addressed in this study. The two most shaded small streams lacking late-seral riparian vegetation contained large amounts of logging debris. If this shade source were eliminated, as it probably should be for other habitat reasons, logging would have decreased ACD on these streams by an even larger amount. Caldwell *et al.* (1991) also found that logging debris could provide substantial shade on Type 4 (smaller perennial) streams in the state of Washington.

As wetted width increased from about 4–40 m (bankfull widths of 15–60 m) shade from late-seral riparian vegetation decreased from about 60 to near 0%. Shade geometry would suggest that shade on early-seral streams would decrease more rapidly.

This paper assumes that it is sufficient to characterize stream shade on a reach by the mean, but common statistical tests for differences between means assume that samples are composed of independent observations. However, some of the stream reaches in this survey had clumpy vegetation, resulting in observations that were not independent as indicated by lag 1 autocorrelation coefficients. Figure 6 shows ACDs plotted versus distance on the two streams with the highest autocorrelation coefficients. This relationship has not been well documented previously in the scientific literature and could be an issue depending on the purpose of the survey. A lack of independence is not a problem in this study because tests for differences between means are not being performed. However, to make statistical inferences, the appropriate assumptions and the accuracy of the measurement method are important. This would be particularly true for regulatory compliance. Sampling and data presentation methods need to address the purpose of the study. For example, a shade restoration or

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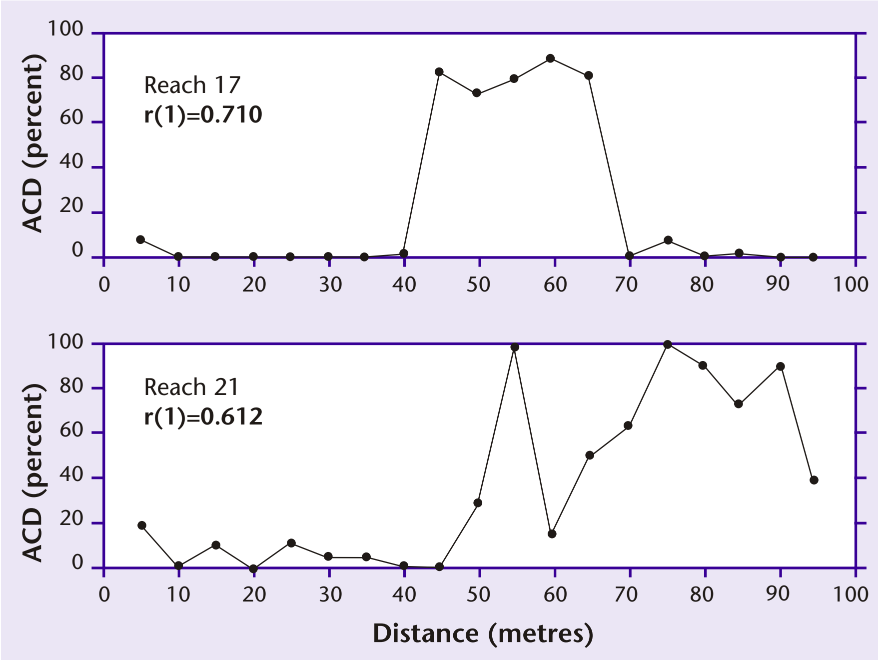

Figure 6. ACD profiles on the two streams with the highest autocorrelation coefficients.

long-term monitoring plan for a high-value fish stream may benefit more from shade profiles (as in Figure 6) or two-dimensional shade maps than from estimates of mean shade alone.

Teti and Pike (2005) found that 5 operators using the spherical ACD meter made estimates of average ACD that were 2–11 percentage points lower than those made by analyzing digital fisheye images by computer. This implies that ACDs may have been underestimated in this survey. However, the variations in ACD due to environmental factors were so large in this sample that any errors in the estimation of reach average ACD would not change the general nature of the results. The same can be said for the differences between ACD and effective shade in Figure 2.

A paired comparison of ACD and effective shade on fisheye photographs indicated that these two parameters contain very similar information. They differ mainly because effective shade accounts for shade from sunrise to sunset while ACD accounts for it only between 10 a.m. and 2 p.m. However, according to Gap Light Analyzer, 70% of direct radiation on a clear day in mid-August occurs during this 4-hour period at our latitude (52°). Differences between ACD and effective shade at specific points in Figure 2 can be explained by the relative amount of shade at mid-day versus morning and evening. More specifically, the positive y-intercept in the regression between effective shade and ACD reflects the fact that ACD approaches zero as overhead gaps approach an angular radius of 50° from the zenith, even though there may be shade before 10 a.m. or after 2 p.m. However, the relatively small value for the y-intercept reflects the fact that shade before 10 a.m. and after 2 p.m. is not as important as shade during mid-day, which is consistent with Brazier and Brown (1973), Wooldridge and Stern (1979), and Beschta *et al.* (1987). The other factor that contributes to the observed relation between ACD and effective shade is that canopy density tends to increase with increasing angles from the zenith. In our sample of fisheye photos, average canopy densities within zenith angle intervals of 0–30, 30–60, and 60–90° were 30, 51, and 83%, respectively.

Shade on small streams can be considerably higher at the water surface than at tripod height, particularly in the absence of an overstorey. Therefore, what might be assumed to be the greater accuracy of the fisheye photographic method is not necessarily obtainable on small streams due to the impracticality of placing the camera lens at the water's surface. The handheld spherical ACD meter described by Teti (2001) has an advantage over most photographic methods under these circumstances.

Conclusions

Logging the riparian areas of small forest streams (corresponding with S4, smaller S3, and S6 streams) in the southern Interior of BC tends to reduce ACD from high to medium levels. However, without large riparian trees, ACD on this type of small stream can be low, medium, or high depending on the geometry of understorey vegetation, the channel cross-section, and woody debris. Natural shade levels decrease steadily as wetted channel width increases to about 30 m, at which point the seral stage of riparian vegetation may have little effect on average shade on a reach. However, late-seral riparian vegetation tends to ensure consistently high reach average ACD levels on small streams.

Natural shade levels on larger streams whose wetted widths exceed the height of adjacent trees are so low that radiation budgets are essentially independent of riparian vegetation. This helps explain why some stream temperature modellers (e.g., Bartholow 1989; Caissie *et al.* 2005) have found that other factors have a greater effect on the summer stream temperature than stream shade. However, when stream shade varies over much of its range, it typically has a greater effect on summer stream temperature than does air temperature (e.g., Bartholow 2000).

In a previous Streamline article (Teti 2004), I posed three questions:

1. How much shade is there on forested streams?
2. How much does riparian harvesting reduce shade?
3. How fast does shade recover after harvesting?

This article provides first approximations in answer to the first two questions. This information could assist professionals and resource agencies in writing clear and enforceable regulations or plans where riparian practices are an issue due to summer stream temperature concerns. Repeated shade surveys are needed to address question #3.

A characteristic of average shade on a stream reach is that, without vegetation disturbance, it is essentially constant from mid- to late summer. In contrast, the summer temperature of a small stream is highly variable, with much of the annual range sometimes occurring over a single day. This variability makes it difficult to detect shade-related changes in average or maximum stream temperature over time. Therefore, to protect the summer temperature of small streams from changes in riparian vegetation, it is suggested that (1) regulations and guidelines may be best expressed in terms of quantitative targets for shade rather than temperature; and (2) these targets be expressed in terms of effective shade, ACD, or other parameter that is closely related to the radiation budget of forest streams.

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