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Riparian microclimate and evaporation from a coastal headwater stream, and their response to partial-retention forest harvesting

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ABSTRACT

This study focused on a headwater forest stream in coastal British Columbia, Canada. Air temperature, humidity and wind speed were measured at a height of 1.5 m above the stream and at a control site within a clearcut located approximately 1 km from the study stream, both before and after partial-retention forest harvesting along the stream. A specially designed evaporimeter was used to measure evaporation. Laboratory trials confirmed the reliability of evaporimeter measurements. Prior to harvesting, wind speeds were low and vapour pressure gradients above the stream were weak, leading to low rates of evaporation. Following harvesting, the decreased shading and increased ventilation over the stream led to higher wind speeds, lower vapour pressures, higher daily maximum air temperatures, higher stream temperatures and surface vapour pressures, and higher rates of evaporation. A wind function that has been used to estimate stream evaporation in a number of previous studies, but which had not been compared to measured stream evaporation, was found to overestimate evaporation. An empirical wind function fitted to the evaporimeter data differed from three others that have been derived for predicting stream evaporation in that our data did not support the inclusion of an intercept. It is hypothesized that the lack of an intercept for our data reflects the strongly stable conditions over the stream. Further research should measure stream evaporation over a broad range of streamflow and meteorological conditions, with particular attention to the role of atmospheric stability.

1. Introduction

Stream temperature is a critical aspect of water quality, and there has been increasing concern about the effects of climate change, land use and water management on stream thermal regimes and their consequences for aquatic ecology (Webb et al., 2008), including in-stream respiration and carbon cycling (Perkins et al., in press). The most rigorous approach to predicting the effects of environmental change on stream temperature is through the use of physically based models that simulate the stream heat budget. Solar radiation is the main driver of diurnal and seasonal variations in stream temperature, and a substantial body of research has focused on quantifying its influence and developing methods for modelling its variability and sensitivity to changes in riparian vegetation (e.g., Rutherford et al., 1997; Chen et al., 1998; Johnson, 2004; Leach and Moore, 2010). Less attention has focused on the turbulent fluxes of sensible and latent heat, although they can be important at open sites during the cool seasons (Webb and Zhang, 1997; Hannah et al., 2008; Leach and Moore, 2010). In addition, because evaporation tends to increase with increasing water temperature, the associated heat loss can be an effective cooling mechanism that imposes an upper limit on stream temperature during summer (Benner and Beschta, 2000). Stream evaporation is also important as a control on riparian microclimate, typically producing cooler and moister conditions than in upslope areas (Brosofske et al., 1997; Danehy and Kirpes, 2000), which can influence the characteristics of riparian vegetation and a range of ecological interactions (Chen et al., 1999; Rykken et al., 2007).

A substantial body of literature has examined the effects of clearcut harvesting with and without riparian buffers on stream temperature at a broad range of sites (e.g., Brown and Krygier, 1970; Beschta and Taylor, 1988; Johnson and Jones, 2000; Macdonald et al., 2003; Gomi et al., 2006; Gravelle and Link, 2007; Groom et al., 2011; Janisch et al., 2012; Rex et al., 2012). Fewer studies have focused on the response of riparian microclimate to forest harvesting. Brosofske et al. (1997) documented changes in microclimatic gradients between riparian and upland zones as a result of

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clearcutting with and without riparian buffers. The effects of partial cuts or thinning treatments on aspects of near-surface microclimate have been studied by Marenholtz et al. (2010), who focused on upland sites, and Rykken et al. (2007), who focused on riparian zones. Bladon et al. (2006) and Rambo and North (2009) examined the effects of thinning treatments on canopy-level microclimates. Rex et al. (2012) documented the effects of streamside variable-retention harvesting on riparian air temperature for headwater streams at sub-boreal forest sites. In addition to the limited base of empirical knowledge of harvesting influences on riparian microclimate, we are unaware of any studies that measured headwater stream evaporation rates, either before or after harvesting.

Evaporation rates from water bodies depend primarily on water temperature (which controls the vapour pressure at the water surface), atmospheric vapour pressure and wind speed. They also depend on atmospheric stability, which is a function of wind speed and the difference in temperature between the water surface and the overlying air, and on fetch, which is the spatial extent of the body in the direction of air flow. Small streams (e.g., up to a few m or so in width) have insufficient fetch to permit the use of methods such as eddy covariance and profile methods to measure evaporation. As an alternative, most field and modelling studies have used empirical wind functions to compute the turbulent heat fluxes over small streams (e.g., Brown, 1969; Rutherford et al., 1997; Hockey et al., 1982; Johnson, 2004; Sridhar et al., 2004). Wind functions for predicting evaporation from lakes and ponds have been developed and tested in a range of studies (e.g., Kohler, 1954; Ryan et al., 1974; Adams et al., 1990; Tanny et al., 2008). However, these functions may not be valid for prediction of evaporation from streams due to the lower fetch associated with small streams and the possibility for wind-sheltering by the stream banks. In addition, there is evidence that evaporation is higher from flowing water than still water, at least under some meteorological conditions (Benner, 2000).

There appear to have been few empirical studies that fit or tested wind functions for computing stream evaporation. Jobson (1980), Fulford and Sturm (1984) and Gulliver and Stefan (1986) calibrated the coefficients in a wind function using an energy-budget approach. Benner and Beschta (2000) made direct measurements of evaporation rates using evaporation pans submerged in the stream. Webb and Zhang (1997) presented a Dalton-type equation that provided reasonable agreement with measurements at a streamside evaporation pan. That equation has been used in several later studies (e.g., Moore et al., 2005; Hannah et al., 2008; Chikita et al., 2010; Leach and Moore, 2011), but has not been tested against measured stream evaporation.

The objectives of the current study were as follows: (1) to develop and test an evaporimeter designed specifically to measure stream surface evaporation from headwater streams; (2) to fit a wind function for computing evaporation from meteorological observations, and to compare it to previously published wind functions for evaporation from streams; and (3) to quantify the influence of partial-retention forest harvesting on riparian microclimate and evaporation.

2. Methods

2.1. Field site and logging treatment

The study was conducted in the University of British Columbia Malcolm Knapp Research Forest (MKRF), located approximately 60 km east of Vancouver, Canada. The area has a maritime climate with relatively dry summers and wet mild winters. Mean annual precipitation varies between 2000 and 2500 mm over the study sites, with about 70% of the total annual precipitation falling between October and April. Snowfall accounts for approximately 15% of the annual precipitation due to the low elevation and relatively warm maritime climate.

This study focused on Griffith Creek, a headwater stream gauged by a concrete weir about 560 m downstream of the stream head (Fig. 1). Griffith Creek ranges in elevation from 365 m above sea level (masl) at the weir to 405 masl near the stream head. The drainage area at the weir is 10 ha. Bankfull width averages about 1.5 m. Prior to logging, the forest consisted of mature second growth trees approximately 30–40 m tall, with a canopy cover greater than 90%. Tree species were dominated by western hemlock (*Tsuga heterophylla*), western red cedar (*Thuja picata*), and Douglas-fir (*Pseudo-tsuga menziesii*), from most to least abundant, respectively. The harvesting treatment involved removal of 50% of the basal area from within the cut block, including the riparian zone. Smaller stems were removed, leaving the larger stems for harvest at a later date. Logging started in September, 2004, and was completed by the end of November, 2004. The logging was only conducted on the lower 250 m of Griffith Creek (above the weir) (Fig. 1) because logging was not feasible in the upper portion of the basin. Timber was removed using skidders on the east side of Griffith Creek, and by high-lead cable yarding on the steeper slopes west of the creek. Analysis of paired pre- and post-logging hemispherical photographs indicates that canopy closure decreased by about 14% due to the logging treatment (Guenther, 2007). Riparian shrub cover along Griffith creek was sparse in both the pre- and post-logging periods.

2.2. Weather measurements and calculations

A weather station was installed over the stream at a location 400 m downstream of the stream head and 160 m upstream of the weir, at an elevation of 375 masl. Air temperature and relative humidity were measured by a Campbell Scientific CS500 sensor with stated accuracies of ±0.5 °C for temperature and ±3–6% for relative humidity. Wind speed was measured with a Met One anemometer with a stall speed of 0.447 m s^{-1}. Instruments were scanned every 10 s by a Campbell Scientific CR10x data logger; observations were averaged and stored every 10 min. Instruments were mounted on a tripod about 1.5 m above the water surface. The station was removed during logging operations. A weather station using the same instrumentation and programming was installed in a clearcut at a site approximately 1 km southeast of and 200 m lower in elevation than the Griffith Creek station. Taking into account down time associated with the forest harvesting operations and power supply failures, the common period of record for the riparian and open weather stations lies dominantly in the months of May to October from 2003 to 2006 (i.e., two years each of pre- and post-harvesting data for the warm season).

Saturation vapour pressure was computed from temperature using the following relation:

$$e_{sat}\ (T) = 0.611\ \exp\left[\frac{aT}{T+b}\right] \quad (1)$$

where T is in °C, e_{sat} is in kPa, and the coefficients a and b are given by $(a, b) = (17.27, 237.26)$ for $T > 0$ °C and $(a, b) = (21.87, 265.5)$ for $T \leq 0$ °C. Atmospheric vapour pressure (e_a) was computed as

$$e_a = e_{sat}(T_a) \times \frac{RH}{100} \quad (2)$$

where RH is the relative humidity (%). Vapour pressure at the water surface (e_w) was computed as

$$e_w = e_{sat}(T_w) \quad (3)$$

where T_w is water temperature (°C). Vapour pressure deficit (vpd) was computed as

$$vpd = e_{sat}(T_a) - e_a \quad (4)$$