Spatial patterns of soil temperature and moisture across subalpine forest-clearcut edges in the southern interior of British Columbia

T. E. Redding[1,4], G. D. Hope[2], M.-J. Fortin[3], M. G. Schmidt[1], and W. G. Bailey[1]

[1]*Department of Geography, Simon Fraser University, Burnaby, British Columbia, Canada V5A 1S6;*
[2]*British Columbia Ministry of Forests, Kamloops, British Columbia, Canada V2C 2T7; and*
[3]*Department of Zoology, University of Toronto, Toronto, Ontario, Canada M5S 3G5.*
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Redding, T. E., Hope, G. D., Fortin, M.-J., Schmidt, M. G. and Bailey, W. G. 2003. **Spatial patterns of soil temperature and moisture across subalpine forest-clearcut edges in the southern interior of British Columbia**. Can. J. Soil Sci. **83**: 121–130. To investigate if timber harvesting influences spatial patterns of soil microclimate, forest floor soil temperature and moisture were examined across forest-clearcut edges. Transects were sampled during the 2000 growing season across a 1-ha clearcut at a subalpine forest site in the southern interior of British Columbia, Canada. Forest floor temperature measurements were made twice, once under sunny and once under overcast conditions. Moisture status, measured under wet and dry conditions, was expressed as gravimetric and volumetric moisture content and matric potential. Wavelet analysis was used to detect and compare the location of edges in soil properties, and variance partitioning was used to examine the environmental and spatial sources of variability in temperature and moisture. Based on the wavelet analyses, the transition zone, in both temperature and moisture between forest and clearcut occurred at 7–15 m into the clearcut from the south edge and at 8–18 m into the forest from the north edge. Spatial patterns were consistent between clear and overcast conditions and wet and dry conditions. Distance from the edge was a minor source of spatial variability in temperature and moisture relative to the strong contrast between forest and clearcut conditions. The edge influences may have implications for nutrient cycling, plant available water and forest regeneration.

Key words: Soil temperature, soil moisture, forest floor, subalpine forest, wavelet analysis, edge effects

Redding, T. E., Hope, G. D., Fortin, M.-J., Schmidt, M. G. et Bailey, W. G. 2003. **Profil spatial de la température et de la teneur en eau du sol dans la zone séparant la forêt subalpine des secteurs coupés à blanc dans l'intérieur sud de la Colombie-Britannique**. Can. J. Soil Sci. **83**: 121–130. Les auteurs ont étudié l'incidence de la zone de transition entre les secteurs coupés à blanc et la forêt sur la température et la teneur en eau du sol forestier afin d'établir si la récolte du bois modifie le profil spatial du microclimat tellurique. Durant la période végétative de 2000, ils ont donc prélevé des échantillons le long de transects dans une zone de coupe à blanc d'un hectare, en bordure d'une forêt subalpine de l'intérieur sud de la Colombie-Britannique, au Canada. La température du sol a été relevée quand il faisait soleil et lorsque le ciel était nuageux, alors que la teneur en eau a été mesurée par temps sec et humide et exprimée en unités gravimétriques et volumétriques ainsi qu'en fonction de la baisse du potentiel hydrique du sol (potentiel matrique). L'analyse des ondelettes a permis de déceler et de comparer les endroits où les propriétés du sol changent. Par ailleurs, les auteurs ont recouru à la séparation des variances pour établir l'origine spatiale ou environnementale des fluctuations de température et de teneur en eau. Selon l'analyse des ondelettes, la zone de transition entre la forêt et les secteurs coupés à blanc pour la température et l'eau s'étend de 7 à 15 m dans le secteur déboisé, au sud de la lisière de la forêt, jusqu'à 8 à 18 m à l'intérieur de la forêt, au nord de sa bordure. Les profils spatiaux sont cohérents, que le ciel soit dégagé ou couvert et le sol, sec ou humide. La distance de part et d'autre du bord de la forêt n'entraîne qu'une faible variation spatiale de la température et de la teneur en eau, comparativement au fort contraste qui existe entre les conditions relevées dans la forêt et dans le secteur de coupe. Il se peut que les conditions observées dans la zone de transition aient une incidence sur le cycle des éléments nutritifs, sur la quantité d'eau à la disposition des végétaux et sur la régénération de la forêt.

Mots clés: Température du sol, teneur en eau du sol, sol forestier, forêt subalpine, analyse des ondelettes, effets de la zone de transition

Forest harvesting creates edges between harvested and remnant stands. Such edges have been studied to examine their influence on abiotic (e.g., microclimate) (Chen et al. 1995; Cadenasso et al. 1997; Davies-Colley et al. 2000) and biotic (e.g., vegetation composition) (Asselin et al. 2001; Harper and McDonald 2001) variables. Most research on edges and microclimate has been limited to climatic and site conditions that will show the maximum influence on remnant forest stands (Saunders et al. 1999). To enhance understanding of the spatial and temporal influence of forest-clearcut edges on the spatial patterns of microclimate and their impacts on soil properties, it is necessary to measure patterns under a variety of weather and soil moisture conditions (Saunders et al. 1999).

The spatial patterns of microclimate across forest-clearcut edges are controlled by net radiation and modified by site factors, including the orientation of the forest edge, structure of the vegetation, elevation, slope and latitude of the site

[4]*Current address: Department of Biological Sciences, CW405 Biological Sciences Centre, University of Alberta, Edmonton, Alberta, Canada T6G 2E9 (e-mail: tredding@ualberta.ca).*

(Geiger 1965; Chen et al. 1999). The largest contrasts in air and soil temperatures, across edges, and between edges are found between north- and south-facing edges. In the northern hemisphere, into the opening from a south edge (north-facing) there will be a zone of shade and lower air and soil temperatures. At the north edge (south-facing), solar radiation will penetrate into the forest between tree stems, keeping air and soil temperatures elevated for some distance into the forest (Geiger 1965).

Previous research on the spatial patterns of soil temperature and moisture across edges has dealt almost exclusively with mineral soil. Researchers have generally found that soil temperature increases in clearcuts relative to adjacent forest, whereas soil moisture content is usually greater but sometimes less than in adjacent forest (Cadenasso et al. 1997). In subalpine forest ecosystems of the southern interior of British Columbia, the forest floor plays a vital role in forest productivity and nutrient cycling (Hope 1997). The organic forest floor horizons attenuate the energy and water inputs to mineral soils. The temperature and moisture dynamics of the forest floor influence processes such as evapotranspiration (Schaap et al. 1997), N mineralization (Paul and Clark 1996) and CO_2 efflux (Fang et al. 1998). Edge-related spatial patterns of forest floor temperature and moisture may influence forest regeneration (Hansen et al. 1993), decomposition and nutrient cycling (Chen et al. 1995), and the diversity of soil organisms (Hagerman et al. 1999).

Various methods are available to quantify the influence of edges on environmental and biological properties and processes. Wavelet analysis has been used as an edge detection method to characterize the edge response of understory plants (Harper and Macdonald 2001). The use of wavelets for edge detection allows the comparison between the position of the structural edge (location of trees) and the functional edge (location of the transition between forest and clearcut for the variable of interest). Wavelet analysis is well suited for studying spatial patterns across edges as it does not require data normality or stationarity, unlike many other spatial analysis methods commonly used in soil science (McBratney 1998; Lark and Webster 1999).

The edge effect is only one of many factors that influence the spatial variability of soil properties. The variance partitioning methods of Borcard et al. (1992) may be employed to examine the influence of edges on forest floor temperature and moisture relative to other environmental and spatial variables. These methods have been used to describe the influences on the spatial variability of forest soils (Pelletier et al. 1999), and to examine the influence of forest-clearcut edges on seedling regeneration (Asselin et al. 2001).

The objective of this study was to examine spatial patterns of forest floor temperature, moisture content (gravimetric and volumetric) and matric potential across the north and south edges of a subalpine clearcut in the southern interior of British Columbia, Canada. This research addresses gaps in the understanding of the influence of edges on the spatial patterns of soil temperature and moisture by: (1) focusing on the forest floor; (2) measuring spatial patterns of forest floor temperature under contrasting cloud conditions (clear-sky and overcast) and measuring spatial patterns of forest floor moisture under contrasting moisture conditions (wet and dry); (3) examining the influence of the type of moisture measurement on the spatial patterns; (4) applying wavelet analysis as an edge detection method to quantify the spatial patterns across edges; and (5) examining the importance of edges as a source of spatial variability for temperature and moisture relative to other environmental and spatial variables. It was expected that temperature under clear sky would have a stronger edge influence than under overcast conditions and that moisture under dry conditions would have a stronger edge influence than under wet conditions. The information gathered in this study will contribute to knowledge of the influence of forest-clearcut edges on soil processes and their potential forest management implications.

MATERIALS AND METHODS

Study Area

This study was conducted as part of the Sicamous Creek Silvicultural Systems Project, near the town of Sicamous in the southern interior of British Columbia, Canada (50°50′N, 119°55′W). The study area is within the Engelmann Spruce-Subalpine Fir wet cold (ESSFwc2) biogeoclimatic unit (Lloyd et al. 1990). The Sicamous Creek site has an elevation range of approximately 1550 to 1800 m above sea level with a north-facing aspect and slopes of 5–40%. The average annual temperature (1993–2000) measured at the site was 1.2°C, with a mean maximum monthly temperature of 11.5°C in August and a mean minimum monthly temperature of –7.8°C in December (D. Spittlehouse, personal communication, BC Ministry of Forests, Victoria, BC). Deep snow packs on site often last until mid-June, and June to September rainfall averaged 308 mm during 1993–2000 (D. Spittlehouse, personal communication, BC Ministry of Forests, Victoria, BC). The soils on mesic sites are classified as sandy loam-textured Orthic Humo-Ferric Podzols developing on glacial till with a discontinuous fluvial veneer (Hope 1997). The average forest floor depth is 4 cm and humus forms are predominantly Hemimors (Green et al. 1993).

The forest at Sicamous Creek is dominated by subalpine fir (*Abies lasiocarpa*) and Engelmann spruce (*Picea engelmannii*), with a maximum age greater than 300 yr (Parish et al. 1999) and mean canopy tree height of approximately 21 m. Understory vegetation on mesic sites is dominated by a shrub layer of black huckleberry (*Vaccinium membranaceum*) and white-flowered rhododendron (*Rhododendron albiflorum*). The herb layer is dominated by oak fern (*Gymnocarpium dryopteris*) and Sitka valerian (*Valeriana sitchensis*), with red-stemmed feather moss (*Pleurozium schreberi*) being the dominant bryophyte.

Sampling Design

Five parallel transects were sampled across a 1-ha square (100 m by 100 m) harvested opening (clearcut). The site has a slope of 1–5% with a north aspect, with the north and south edges running east/west. The clearcut was harvested in the winter of 1995–1996. At the time of sampling during July and August 2000, 4-yr-old planted seedlings were approximately 50 cm tall with a ground cover of approximately 3–5%, and there was little advanced regeneration present. Transects were 200 m long, extending 50 m into the forest at both the north and south edges of the 100-m clearcut. The edge was defined as the location of the stems of mature trees separating forest and clearcut. Forest floor samples were collected 1 m apart within 4 m north and south of each edge, 2 m apart from 4 to 20 m from each edge, and 5 m apart at distances between 20 and 50 m within the forest and between 20 and 80 m in the clearcut. A total of 73 samples was collected along each transect, except for three transects where samples were not collected at 50 m into the forest from the north edge due to the presence of a wetland (hence 72 samples). Transects were separated by 5 m east to west. All sample locations were within 2 m east or west of the transect lines in order to avoid sampling unsuitable locations such as site preparation pits and mounds, slash piles, soil wood and exposed mineral soil.

Forest Floor Temperature

Forest floor temperature was measured at a depth of 2 cm from the forest floor surface using copper-constantan thermocouples. Temperature readings were taken using a digital meter (Omega Engineering HH-25TC). Measurements were taken under clear sky (30 July) and overcast (24 August) conditions in the early to mid-afternoon. Both sets of temperature measurements were taken 2 d after precipitation, when the forest floor was moist, but not wet. Each transect was measured sequentially, taking approximately 30 min per transect. A set of five reference locations was measured prior to the measurement of each transect in order to standardize observations among transects. Standardization did not result in large changes in temperature at any single time period, with the greatest being 1.6°C, and the majority being less than 1°C.

Forest Floor Moisture Content

Forest floor moisture content was determined twice at all sample locations. Measurements of wet conditions were taken within 24 h of rainfall under overcast and cool conditions (6 July). Measurements of dry conditions (8 August) were made approximately 2 wk after precipitation under clear skies and warm temperatures. Samples were collected at each location using a fixed-area template for the July sampling, and with grab-samples for the August sampling. Moisture samples were sealed in airtight containers and stored in coolers until weighing (within 48 h of collection). The samples were then oven-dried at 70°C for 48 h and reweighed. Gravimetric moisture content was expressed as kg H_2O kg^{-1} dry forest floor.

Volumetric moisture content was calculated using bulk density values measured for all samples and expressed as m^3 of H_2O m^{-3} of soil. To measure bulk density, fresh litter was removed and all forest floor material was excavated to the mineral soil surface using a 15 by 15 cm template. The forest floor depth was calculated as the average of eight measurements of the sides of each excavated sample. All samples were oven-dried at 70°C for 48 h.

Forest floor matric potential was estimated by deriving Eq. 1 from the soil moisture characteristic curve for *Pinus sylvestris* forest floor presented by Leuschner (1998). The retention curve of Leuschner (1998) was selected because the forest floor description and physical properties of that study were more similar to the Sicamous forest floor material than were those measured in other studies by Plamondon et al. (1972) and Sharrat (1997). The conversion from volumetric moisture content (θ) to matric potential (ψ) used the following relationship

$$\ln\psi = -4.7775 \ln\theta - 10.579 \quad (1)$$

The data in the present study included measurements that are drier than those of Leuschner (1998); hence the interpretation of results for volumetric moisture contents less than 0.1 m^3 m^{-3} merits caution.

Environmental and Spatial Variables

A number of environmental and spatial variables were measured at each sampling location to examine the sources of spatial variability of forest floor temperature and moisture (Redding 2001). Measured variables included: **diffuse non-intercepted radiation** (**DIFN**, an index of canopy openness); microtopography (meso- and microtopographic position, aspect and slope); ground cover (percent cover of: total vegetation, tree, shrub, herb, moss, exposed forest floor, exposed mineral soil, coarse woody debris, slash and rock); mean understory cover height; forest floor type and morphology following Green et al. (1993); and spatial variables (easting, northing, distance from edge, forest/clearcut).

Wavelet Analysis

Wavelet analysis was used to detect edges in the data series (Bradshaw and Spies 1992). The continuous wavelet transform acts similarly to a moving window analysis (Dale and Mah 1998). When the shape of the wavelet function is similar to the shape of the underlying data series, the wavelet variance has a higher value (Dale and Mah 1998). The size of the wavelet function changes along both the X and Y axes, performing a multiscale analysis. The Haar wavelet is best for detecting discontinuities in a spatial data series (Bradshaw and Spies 1992), and was applied herein. The analysis used a continuous wavelet transform at a maximum scale of 10% (20 m). Wavelet analysis was carried out using PASSAGE (Rosenberg 2001), after interpolating the transect data to 1 m spacing with a cubic spline in S-Plus (Mathsoft Corporation 2000). Wavelet analysis was performed on untransformed means of all data except matric potential, which was log transformed (lnψ).

Where there is a rapid change in adjacent values along a data series, there will be a relatively large increase in the wavelet variance (Bradshaw and Spies 1992). Consistent data have a low wavelet variance. The location of each wavelet variance peak was compared with the original data series to determine whether a peak was related to a change at the edge or to inherent variability in the data. Peaks in wavelet variance were classified as being a single dominant peak (clear spatial discontinuity) or multiple peaks (poorly defined spatial discontinuity).

Variance Partitioning

Variance partitioning (Borcard et al. 1992) was used to examine the sources of spatial variability in the forest floor temperature and moisture. This method allowed the variation in a response variable (or variables) to be partitioned into the following classes: pure environmental, spatially structured environmental, pure spatial and unexplained (Borcard et al. 1992). Variance partitioning was performed using (partial) **redundancy analysis** (**RDA**), a method of direct gradient analysis that compares groups of response and explanatory variables, and finds the multidimensional axes that explain most of the variation in the response variables using the explanatory environmental and spatial variables (ter Braak 1998). The two groups of response variables used were forest floor temperature (clear sky and overcast) and volumetric moisture content (wet and dry).

All variables were assessed for normality, and transformed (standardized) as required to allow better identification of the relationships among the variables in minimizing the overshadowing effects of certain variables having a wider range than others. The temperature and moisture data sets were split into three sets: all samples, forest samples and clearcut samples. A total of six variance partitioning analyses was used to compare the sources of variability between the different data subsets. All variance partitioning analyses were carried out using RDA in CANOCO (ter Braak 1998).

The inclusion of additional insignificant explanatory variables is likely to increase the amount of variation explained by chance alone (Borcard et al. 1992; Okland and Eilertsen 1994). For this reason, it is preferable to find the combination of the minimum number of explanatory variables that explains the maximum amount of variability (Okland and Eilertsen 1994). Explanatory variables were removed if they had high inflation factors (covariance) and/or a low contribution to explained variability as determined using a forward selection procedure (ter Braak 1998). For all data sets, the number of environmental variables retained was less than 10 and a maximum of three spatial variables was used to partition the variance of each data set.

RESULTS

Forest Floor Temperature

Forest floor temperature under clear sky conditions showed a strong contrast between the forest and clearcut (Fig. 1). The wavelet analysis of the clear sky temperature data showed that the south boundary occurred at 8 m into the opening (58 m) and the north boundary occurred at 10 m into the forest (160 m) (Fig. 2, Table 1). The forest floor temperature under overcast conditions was lower than clear sky temperatures, but had a similar pattern. The wavelet analysis for overcast conditions located the south edge at 58 m and the north edge at 161 m (Fig. 2, Table 1). Wavelet peaks along the south edge were more clearly defined than those along the north edge (Fig. 2).

The variance partitioning indicated that environmental variables exerted the strongest influence on the spatial variability of forest floor temperature (Table 2). However, the spatially structured environmental component was relatively large when all samples were included in the analysis, indicating a strong contrast between forest and clearcut conditions. Within the forest or clearcut, the influence of the spatially structured environmental component decreased substantially (Table 2). The primary environmental influence on forest floor temperature was a negative correlation with moisture content under dry conditions. For all samples and for forest samples alone, the DIFN had the second strongest influence on soil temperature, while in the clearcut DIFN had little influence. Distance from the edge had only a minor influence on temperature in the clearcut and was not retained in the analyses for all samples or for forest samples.

Forest Floor Moisture Content

Gravimetric moisture content was lower in the clearcut than in the forest in both wet and dry conditions (Fig. 1). The wavelet analysis located the boundaries for the wet measurements at 7 m into the clearcut (57 m) at the south edge and 8 m into the forest (158 m) at the north edge, while the dry conditions had boundaries at 61 m and 161 m (Fig. 2, Table 1). The south edges had single dominant peaks for wet and dry conditions, and the north edges had multiple peaks (Fig. 2).

The pattern of volumetric moisture content across the edges was not as clear as for gravimetric moisture content (Fig. 1). Greater variability in volumetric moisture content was related to the variability of forest floor bulk density, which was slightly higher in the clearcut than in the forest, with no clear edge-related patterns (Redding 2001). The spatial pattern of volumetric moisture content was quite similar to that of gravimetric moisture content both in wet and dry conditions. The transition between forest and clearcut at the south edge was stronger for gravimetric moisture content, volumetric moisture content and matric potential in dry than in wet conditions (Fig. 1). The wavelet analysis located the south edge at 7 m into the opening (57 m) in wet conditions and at 12 m into the opening (62 m) in dry conditions (Fig. 2, Table 1). The edge detection for the north edge located the boundaries at 168 m for wet and at 162 m for dry conditions, both with multiple peaks (Fig. 2, Table 1).

Forest floor matric potential showed a clear change across the edge for both wet and dry conditions (Fig. 1). The asymmetrical pattern found with the other moisture and temperature variables was present. The wavelet analysis at the south edge had a single peak at 55 m in wet and a single peak at 64 m in dry conditions (Fig. 2, Table 1). The north edge had a single peak at 166 m in wet conditions and multiple peaks around 166 m in dry conditions (Fig. 2, Table 1). The wet conditions data showed that most locations are well above the **permanent wilting point** (**PWP**) threshold (defined as –1.5 M Pa) (Fig. 1). Under dry conditions, many of the samples from the clearcut and forest at the north edge were below the PWP threshold, indicating potential moisture limitation.

Variance partitioning showed that the spatial variability of moisture content was strongly controlled by environmental, rather than spatial sources (Table 2). The dominant sources of environmental variability for all data sets were bulk den-

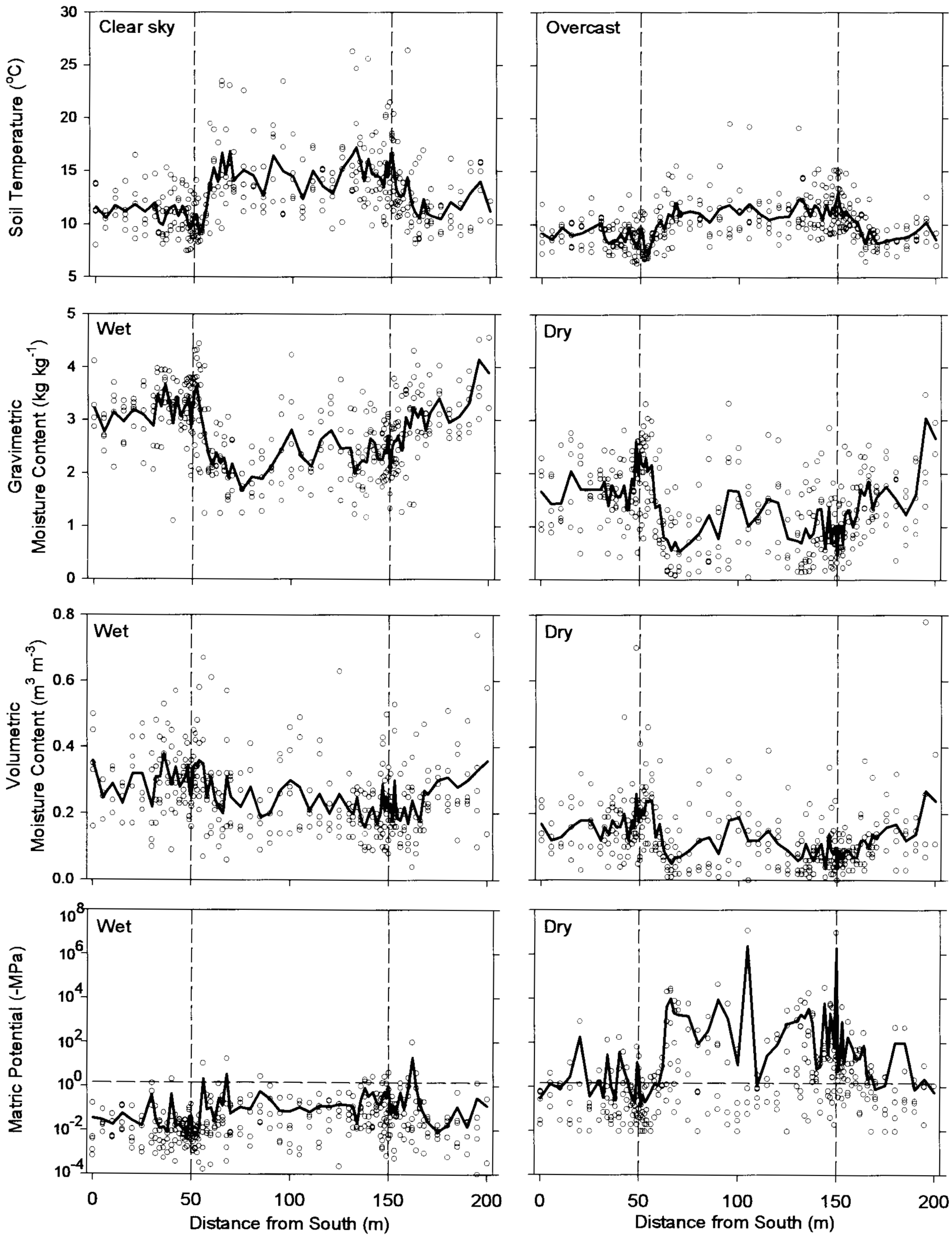

Fig. 1. The trend of forest floor temperature and moisture along N–S transects across a 1-ha opening. Vertical dashed lines denote the south (50 m) and north (150 m) edges. Open circles are individual measurements, solid black lines are the means of all individual measurements at each location along the distance axis. Soil temperature was measured under clear-sky (30 July) and overcast conditions (24 August). Moisture content was measured under wet (6 July) and dry (8 August) conditions. The horizontal dashed lines on the matric potential graphs are the estimated permanent wilting point (–1.5 MPa).

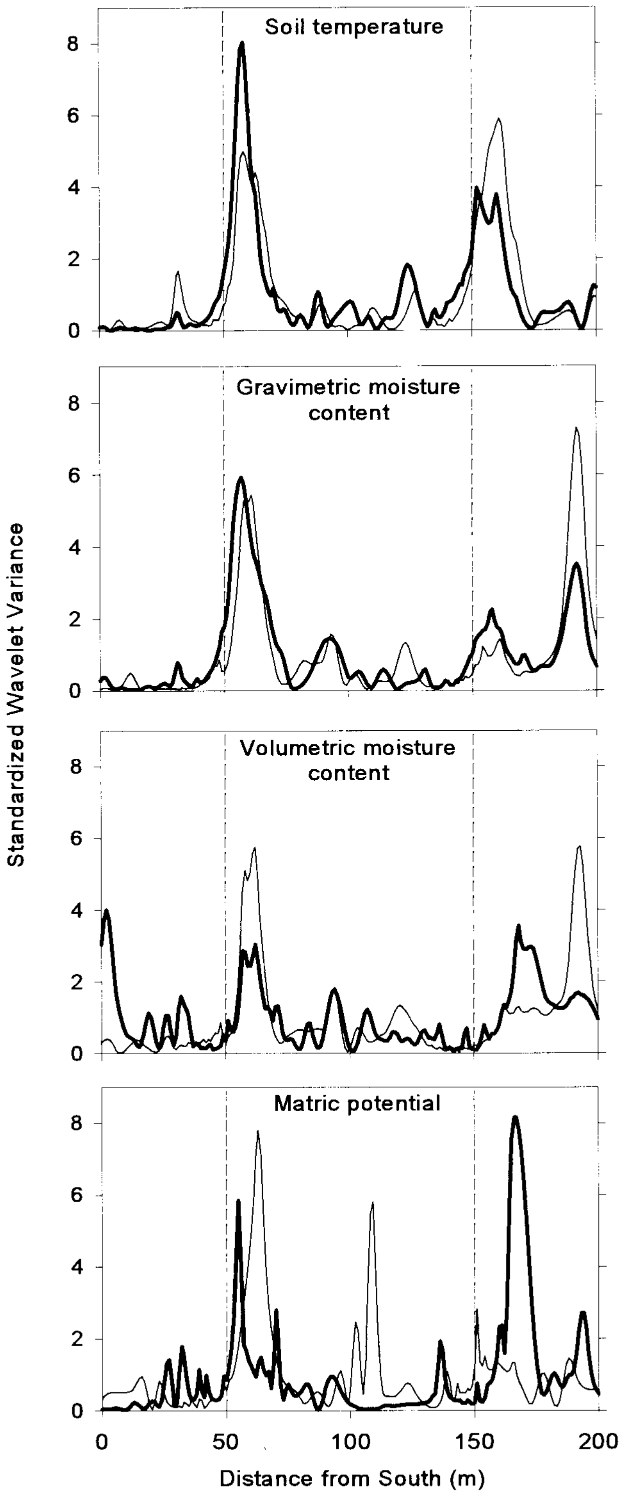

Fig. 2. Standardized wavelet transforms of clear sky (30 July) or wet (6 July) conditions (thick line) and overcast (24 August) or dry (8 August) conditions (thin line) during the 2000 growing season. The wavelet transforms have been standardized where the mean equals 1.

sity and overcast soil temperature. Volumetric moisture content was positively correlated with bulk density, and negatively correlated with overcast soil temperature. In the forest samples, the importance of bulk density relative to soil temperature was greater than with all samples or clearcut samples alone. Spatial influences on the pattern of moisture content were small, and the unexplained variability was low relative to the soil temperature analyses (Table 2). The forest-clearcut contrast for moisture content was not as strong as it was for soil temperature.

Table 1. Results of wavelet analysis for forest floor temperature and moisture variables. Values are the location, in meters, of the wavelet peak nearest each edge. Underlined values denote multiple peaks and non-underlined values are single dominant peaks. The south edge is at 50 m and the north edge is at 150 m

	Distance along transect (m)	
Measurement	South Edge	North Edge
Clear sky soil temperature (30 July)	58	<u>160</u>
Overcast soil temperature (24 August)	58	161
Wet gravimetric moisture content (6 July)	57	<u>158</u>
Dry gravimetric moisture content (8 August)	61	<u>161</u>
Wet volumetric moisture content (6 July)	<u>57</u>	<u>168</u>
Dry volumetric moisture content (8 August)	62	<u>162</u>
Wet matric potential (6 July)	55	166
Dry matric potential (8 August)	64	<u>166</u>

DISCUSSION

Forest Floor Temperature

The forest-clearcut edge had a strong influence on forest floor temperature, which increased into the opening from the south edge for 8 m and decreased into the forest from the north edge for over 10 m. Mineral soil temperature at 7 cm depth at Sicamous Creek was suppressed for up to 12 m into a 10 ha clearcut at the south edge and elevated for up to 6 m into the forest at the north edge under clear sky conditions (D. Spittlehouse, personal communication, BC Ministry of Forests, Victoria, BC). In other forest types, edge effects into the forest influence mineral soil temperatures for between 10 and 30 m, and are strongly dependent on edge orientation (Chen et al. 1995; Bauhus 1996; Cadenasso et al. 1997; Davies-Colley 2000).

Moisture content had a strong influence on forest floor temperature, with a negative correlation between temperature and volumetric moisture content under dry conditions. DIFN did not have a strong influence on the spatial pattern of forest floor temperature within the forest, indicating that temperature under small canopy gaps was not higher than under closed canopy. When the data set included all samples, DIFN had a stronger positive correlation. This is likely due to DIFN having a strong forest-clearcut contrast, with boundaries coinciding with the structural edge (Redding 2001). Using calculations of solar geometry and stand height, the theoretical sun/shade boundary into the clearcut from the south edge would have extended 13.4 m on 30 July and 17.65 m on 28 August. These calculations are made with the assumption that the south edge is a consistent 21 m high. However, given the open nature of the edge structure, it is likely that the sun/shade boundary

Table 2. Results of variance partitioning for forest floor temperature and volumetric moisture content for all data combined (All), the dataset for forest locations (Forest) and the dataset of clearcut locations (Clearcut)

	Percentage of total variance within each category					
	Temperature			Moisture		
	All	Forest	Clearcut	All	Forest	Clearcut
Environment	21.2	19.0	28.2	50.3	53.7	50.8
Environment + Space	16.0	5.0	7.9	7.6	8.0	10.4
Space	2.1	1.5	8.7	0.3	0.7	0.3
Unexplained	60.7	74.5	55.2	41.8	37.6	38.5

would be closer to the edge, as indicated by the forest floor temperature measurements.

Forest floor and mineral soil temperatures respond to the influences of incoming solar radiation and surface characteristics (Oliver et al. 1987). Mineral soil temperature generally decreases with increasing density of vegetation and canopy cover and increasing soil moisture content (Oliver et al. 1987; Balisky and Burton 1995). These influences should be the same for forest floor, as any energy warming the mineral soil will have first passed through the forest floor. For the present study, the results from the variance partitioning indicate that neither vegetation cover nor microtopography was influential in determining the spatial pattern of forest floor temperature in the forest or clearcut. It is not clear why vegetation cover is not a strong control on forest floor temperature, but may be due to the overriding influence of the forest-clearcut contrast, or an artifact of the short temporal data record. It is possible that microtopographic features in the present study were smaller than those measured by Balisky and Burton (1995) or Schmidt et al. (1998) where a strong microtopographic influence on mineral soil temperature was measured. The difference in temperature regime between forest and clearcut should decrease as the opening regenerates (Griffiths and Swanson 2001).

The influence of different sky conditions (clear vs. overcast) did not alter spatial patterns of forest floor temperature across the edges. However, the absolute temperature and magnitude of change across the edge was affected by the sky conditions. These differences are likely due to differences in solar irradiance reaching the ground surface. The similarity in pattern under different conditions indicates that microtopography and vegetation structure influence forest floor temperature in a similar manner under different radiation conditions, while the magnitude of the variability is primarily influenced by atmospheric conditions. At the north edge, the transition between clearcut and forest, indicated by a strong wavelet peak, was more pronounced under overcast than clear sky conditions. Overcast conditions may lead to a decrease in sunflecking (Reifsnyder et al. 1971) and associated localized temperature increases at the forest floor, which would result in increased spatial variability and multiple peaks in the wavelet transform.

Forest Floor Moisture Content

The forest-clearcut edge had a strong influence on forest floor moisture. Forest floor moisture content was higher in the forest than clearcut, and decreased for 7–11 m into the opening from the south edge, and 8–11 m into the forest from the north edge. Only two previous studies were located that examine changes in soil moisture from opening (old field and clearcut) to forest, and in both studies, no clear edge-related patterns in mineral soil moisture were detected (Cadenasso et al. 1997; Paterson 1997). A number of studies have considered edge influences on mineral soil moisture content by starting at the edge and measuring into the forest. A study in old-growth Douglas-fir forests in Washington state found that mineral soil volumetric moisture content increased from the edge for 30–60 m into the forest (Chen et al. 1995). In a German beech forest, mineral soil moisture content was highest in the opening and had lower values at the north edge and in the forest (Bauhus 1996).

The structure of the vegetation at the edge may influence the spatial pattern of forest floor moisture. Open edges appear to have different influences from those with dense vegetation sidewalls (Didham and Lawton 1999; Matlack 1993). The edges at the Sicamous Creek site are very open with little tall understory vegetation filling gaps between the stems of canopy trees. This openness may provide greater opportunity for drying that arises from horizontal advection of energy from clearcut to forest. This would likely influence the north edge, where increased soil temperature extends into the forest, more than the south where the shade effect moderates temperatures at the edge.

Gravimetric and volumetric forest floor moisture content measurements corresponded closely to the spatial pattern of forest floor temperature. Increased forest floor temperature should decrease forest floor moisture content in the clearcut because of enhanced surface evaporation; however, it is generally accepted that mineral soil moisture content increases immediately after clearcutting as a result of decreased evapotranspirational demand (Elliot et al. 1998). It is unlikely that lower soil moisture in the clearcut was a result of greater evapotranspiration by understory vegetation, but rather due to greater surface evaporation due to incoming solar radiation and elevated soil temperatures.

Bulk density had the strongest influence on the spatial pattern of forest floor moisture content and had a stronger influence on the forest samples than on the clearcut samples or on all the samples combined. The strong influence of bulk density was expected, given that volumetric moisture content integrates the influence of the physical properties of the forest floor on moisture content. The second strongest correlation was a negative relationship of moisture content with soil temperature under overcast conditions, indicating that forest floor moisture content is lower where forest floor temperature is higher.

The variance partitioning analysis indicates that the influence of distance from the edge on the spatial patterns of forest floor temperature and moisture content was a minor source of variability relative to the large contrast between forest and clearcut. Our results are similar to those of Peltonen et al. (1997), who used canonical correspondence analysis to examine the influence of forest-clearcut edges on the distribution of bark beetles. They found that distance from the edge was a much less important source of variability than the difference between the forest and clearcut. However, in a study of edge influence on seedling regeneration, Asselin et al. (2001) found that distance from the remnant stand was the strongest influence on the spatial distribution of natural regeneration. It therefore seems that different physical and biological properties and processes are influenced differentially by the proximity of a forest-clearcut edge.

The topography of the study site was not related to the spatial pattern of moisture content in contrast to previous studies that have found that site topography (Potts et al. 1983) and microtopography (Schmidt et al. 1998) were strong influences on moisture distribution. In general, moisture content is greater in depressions or pits relative to uplands or mounds. In the present study, there may not have been enough variability in site topography and microtopography to produce an influence. The difference in elevation from the local ground surface between the bottom of pits and top of mounds was rarely greater than ± 0.15 m. The pits and mounds measured by Schmidt et al. (1998) were never less than ± 0.3 m, and up to 1 m, from the local ground surface.

As matric potential provides a measurement of moisture availability to plants and soil organisms in the forest floor, it is concluded that under wet conditions (within 24 h of precipitation), most sampling locations were not moisture limited. After approximately 2 wk without precipitation, the matric potential was beneath the PWP threshold at many sample locations within the clearcut and in the forest at the north edge. This moisture deficit may inhibit regeneration of conifer seedlings planted in the forest floor layer (Potts 1984) and may affect soil faunal and floral activity (Paul and Clark 1996). However, the matric potential results must be interpreted cautiously because of uncertainty in the water retention characteristics of forest floor material. Forest floor moisture characteristic curves are uncommon and are highly variable (Plamondon et al. 1972; Sharrat 1997; Leuschner 1998). Similar issues have been encountered for peatland environments (Letts et al. 2000) when trying to estimate hydrologic properties using models such as Campbell (1974) or van Genuchten (1980). The lack of measured retention curves for forest floor material has implications for understanding moisture influences on seedling growth, soil microbial processes, energy exchange and evapotranspiration from the forest floor surface.

There are forest management implications of the measured patterns in forest floor temperature and moisture. Seedling growth may decrease along the south edge of clearcuts in subalpine forests such as Sicamous Creek, due to decreased soil temperature and light relative to the rest of the clearcut. Other research has shown decreased seedling growth along south edges of clearcuts in coastal Oregon (Hansen et al. 1993). However, in different ecosystems, the growth-limiting factors may be different, and a south edge (e.g., cooler and wetter) could represent a better growth environment than a north edge (e.g., warmer and drier). As smaller openings have a larger ratio of edge to cut area, relative to larger openings, any edge influences will be more pronounced in small openings. Edge influences thought to be detrimental for regeneration will need to be considered in forest management planning.

Wavelet Analysis and Variance Partitioning

Wavelet analysis allowed comparison of the position of the structural edge (location of trees) and location of the transition between forest and clearcut for the variable of interest. This method worked well for data that showed clear boundaries. For data that have less well-defined boundaries, it may be possible to clarify the wavelet variance by using a larger maximum scale to integrate the wavelet variance over a larger portion of the data series (similar to a larger moving window).

The amount of unexplained variability from the variance partitioning analyses was within the range of those found in other studies using this technique (e.g., Borcard et al. 1992; Pelletier et al. 1999; Asselin et al. 2001). Moisture content had lower unexplained variability than temperature, likely due to the strong influence of bulk density. The large unexplained variability was likely due to the influence of unmeasured variables that affect the spatial pattern of temperature and moisture (Borcard et al. 1992).

CONCLUSIONS

Forest floor temperature and moisture had different spatial patterns across south and north forest-clearcut edges at Sicamous Creek. The south edge had decreased temperature and increased moisture for 7–15 m into the clearcut. The north edge had increased temperature and decreased moisture for 8–18 m into the forest. These results show that changes in temperature and moisture do not coincide with the structural location of the edge. Differences between the structural edge and the transition between forest and clearcut conditions for temperature and moisture are driven by the spatial distribution of solar irradiance. The transitions at the south edge were generally better defined than at the north edge, apparently due to the greater variability in interaction between structural elements of the forest edge with solar irradiance at the north edge as compared to the south edge.

Wavelet analysis and variance partitioning provided complementary methods for evaluating the influence of edge effects on forest floor temperature and moisture regimes. Wavelet analysis provided a robust method of determining the influence of the edge, and variance partitioning helped to elucidate the relative importance of environmental and spatial sources of variability.

Future research should examine the spatial patterns of soil temperature and moisture under a greater array of environmental and weather conditions in order to generalize results across the managed forest landscape. It would be useful to examine patterns with time since harvesting, as differences in vegetation structure between forest and clearcut decrease with time and spatial trends should become less pronounced (Griffiths and Swanson 2001). If results from studies on edge influences on soils and microclimate are added to a theoretical framework based on the physical environment and an energy balance regime, models could be constructed that will have utility across the landscape. Such knowledge would improve our ability to predict the impacts on soil temperature and moisture of various harvesting scenarios, from the level of individual openings to the landscape scale.

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