Spatial patterns of forest floor properties and litterfall amounts associated with bigleaf maple in conifer forest of southwestern British Columbia

J. R. Chandler, M. G. Schmidt[1], and S. Dragicevic

Department of Geography, Simon Fraser University, Burnaby, British Columbia, Canada V5A 1S6.
Received 16 April 2007, accepted 2 January 2008.

Can. J. Soil. Sci. Downloaded from pubs.aic.ca by Simon Fraser University on 11/12/11
For personal use only.

Chandler, J. R., Schmidt, M. G. and Dragicevic, S. 2008. **Spatial patterns of forest floor properties and litterfall amounts associated with bigleaf maple in conifer forest of southwestern British Columbia**. Can. J. Soil Sci. **88**: 295–313. This study was aimed at detecting the spatial characteristics of forest floor properties and litterfall amounts related to bigleaf maple (*Acer macrophyllum* Pursh) within conifer forest. Two 36-m × 36-m plots, centered on individual dominant bigleaf maple stems, were sampled at 129 systematic locations and tested for forest floor pH, cation exchange capacity, exchangeable cations, and mineralizable N. Tree stem location, forest floor horizon depths and litterfall amounts were measured. The kriging approach was used to visualize overall spatial patterns, Moran's *I* was used to give a global measure of spatial autocorrelation over the sampled region, and local indicators of spatial association (LISA) was used to detect and locate significant spatial clustering of similar values at the local scale. Most soil chemical properties had higher values in locations adjacent to the bigleaf maple stem, up to distances of 2.5 m from the stem on both study plots, and all exchangeable cations were positively spatially autocorrelated ($P < 0.05$) up to distances of 4 m. The majority of bigleaf maple litter (84% on plot 1, 92% on plot 2) was found to be deposited directly beneath the canopy extent. This study provides an understanding of the underlying spatial patterns of bigleaf maple influence on soil properties at plot scale.

Key words: Bigleaf maple, spatial analysis, broadleaf species, plant-soil interactions local indicators of spatial association, forest floor

Chandler, J. R., Schmidt, M. G. et Dagicevic, S. 2008. **Évolution spatiale des propriétés de la couverture morte et de la quantité de débris de l'érable grandifolié dans une forêt de conifères du sud-ouest de la colombie-britannique.** Can. J. Soil Sci. **88**: 295–313. L'etude devait etablir les parametres spatiaux des proprietes de la couverture morte et de la quantite de debris liees a l'erable grandifolie (*Acer macrophyllum* Pursh) dans une foret de coniferes. les auteurs ont methodiquement preleve des echantillons a 129 endroits, sur des parcelles de 36 m par 36 m qui avaient pour centre un erable grandifolie dominant. Ils ont verifie le ph du sol forestier, le pouvoir d'echange cationique et la quantite de N mineralisable. ensuite, ils ont etabli l'emplacement de la tige de l'arbre, l'epaisseur des horizons du sol forestier et la quantite de debris vegetaux. Les auteurs ont recouru au krigeage pour visualiser les tendances globales dans l'espace, a la methode *i* de Moran pour se faire une idee generale de l'autocorrelation spatiale pour la zone echantillonnee et a la technique LISA pour deceler et situer les importants regroupements spatiaux de valeur similaire a l'echelle locale. L plupart des proprietes chimiques du sol se caracterisent par une valeur superieure, aux endroits adjacents a la tige de l'erable grandifolie, jusqu'a une distance de 2,5 m de ce dernier, sur les deux parcelles experimentales. Les cations echangeables presentent tous une autocorrelation spatiale positive ($P < 0{,}05$) jusqu'a 4 m de distance. la majeure partie des debris de l'erable grandifolie (84% sur la premiere parcelle et 92% sur la seconde) sont deposes directement sous la frondaison. L'etude nous aide a comprendre les tendances spatiales associees a l'influence de l'erable grandifolie sur les proprietes du sol au niveau de la parcelle.

Mots clés: Erable grandifolié, analyse spatiale, dicotylédones, interactions plante-sol indicateurs d'association spatiale, couverture morte

Research on tree species' influence on soils [reviewed by Binkley (1995)] has led to some generalizations about the different influences of broadleaves and conifers on soil properties. In contrast to conifers, broadleaves generally have (with some exceptions) litter that decays faster and has higher element concentrations (Fisher and Binkley 2000; Rothe and Binkley 2001; Augusto et al. 2002). Differences in litter inputs between broadleaves and conifers can lead to differences in forest floor properties and possibly nutrient availability. Many studies comparing the influence of broadleaves and conifers on soil properties have used an approach where soil properties were compared on plots beneath the canopies of broadleaves and conifers (Fried et al. 1990; Ogden and Schmidt 1997; Tashe and Schmidt 2003;

[1]*To whom correspondence should be addressed (e-mail: margaret_schmidt@sfu.ca).*

Abbreviations: **DBH**, diameter at breast height; **LISA**, local indicators of spatial association; **SAA**, spatial autocorrelation analysis

Can. J. Soil. Sci. Downloaded from pubs.aic.ca by Simon Fraser University on 11/12/11
For personal use only.

Turk 2006). These studies indicate whether a broadleaf species has an effect on properties of the soil, but they do not provide information about the spatial extent of that influence.

A number of studies have assessed the pattern of influence of individual trees on soil properties. In general, such studies have found the pattern of soil properties under individual trees to have radial symmetry to the tree and some properties (such as pH, exchangeable bases, and N concentrations) have been found to increase with distance from the tree for conifers (Zinke 1962; Crampton 1982; Escudero et al 1991) and decrease with distance from the tree for broadleaves (Escudero et al 1991). Zinke (1962) stated that the pattern in soil properties was related to the effect of leaf litter, bark litter, and the neighboring tree or adjacent opening. Crampton (1982) speculated that the low pH near conifers was associated with minimal flow of acid water down the stem and greater flow of less acid water from the canopy periphery. Escudero et al. (1991) suggested that stemflow was an important influence for oak, whereas the litterfall from pine had an acidifying tendency especially near the base of the trunk. They found the most apparent effects on soil properties at the base of the stems with the intensity of influence decreasing outwards to the edge of the crowns.

Many studies concerning the spatial influence of individual trees on soil properties have used measurements of soil properties at fixed distances from tree stems. These studies either presented trends in the data (without statistical analysis) or ANOVA was used to test whether distance from the tree stem influenced soil properties. More recently some studies have used geostatistical analysis to evaluate spatial relationships between tree species and soil properties (Saetre 1999; Bengtson et al. 2006). The patterns in soil properties described in the literature differ, and these differences appear to relate to such factors as different climates, parent materials and tree species (in particular litter and bark characteristics).

Bigleaf maple (*Acer macrophyllum* Pursh) is a broadleaf tree species that is commonly found in conifer forest of the Pacific Northwest and is thus a good candidate for studying the spatial extent of individual broadleaf trees on surrounding conifer forest. Aside from its ecological contributions to biodiversity (Carey and Harrington 2001; Hartwig et al. 2004) and its potential to be commercially valuable (British Columbia Ministry of Forests 1999), bigleaf maple has traditionally been considered a competitor in Douglas-fir [*Pseudotsuga menziesii* (Mirb.) Franco] stands and is often managed to control its presence (Haeussler et al. 1990).

Previous studies (Fried et al. 1990; Turk 2006) have shown a detectable influence of bigleaf maple on soil properties in conifer forest. These studies, however, used paired plots, and were not designed to examine the spatial pattern of soil properties in relation to bigleaf maple stems in conifer forest. The objective of this study was to explore spatial patterns of forest floor properties (pH, CEC, exchangeable Ca, Mg and K, mineralizable N, horizon depths, and moisture content) and litterfall amounts under the influence of individual bigleaf maple stems growing in conifer forest.

MATERIALS AND METHODS

Study Area

The study area is located within the University of British Columbia's Malcolm Knapp Research Forest, Maple Ridge, British Columbia (49°21′N, 122°31′W). The study area is in the Coastal Western Hemlock biogeoclimatic zone, dry maritime subzone (CWHdm).

The climate is temperate with mean annual precipitation of 1827 mm ranging from 53 mm in the driest summer month to 292 mm in the wettest winter month and the mean annual temperature is 9.8°C with a mean of 17.6°C in the warmest month to 1.9°C in the coolest month (Meidinger and Pojar 1991). The soils within the study area were derived from morainal and colluvial parent materials and are sandy loam Gleyed Dystric Brunisols (Agriculture Canada Expert Committee on Soil Survey 1998).

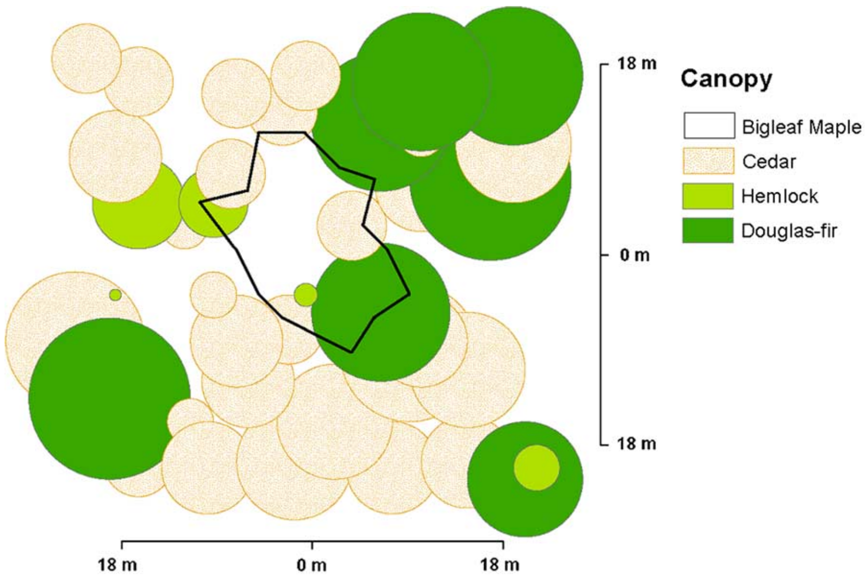
The two stands in this study regenerated naturally following fires that occurred in 1868 and 1931, respectively. The older stand (140 yr) is dominated by Douglas-fir, western redcedar (*Thuja plicata* Donn), and western hemlock [*Tusga heterophylla* (Raf.) Sarg.] with a mix of understory vegetation dominated by sword fern (*Polystichum munitum*) and includes vine maple (*Acer circinatum* Pursh), salal (*Gaultheria shallon*), trailing blackberry (*Rubus ursinus*), and vanilla leaf (*Achlys triphylla*) (Pojar and Mackinnon 1994). The younger stand (75 yr) is dominated by western redcedar and western hemlock, with few Douglas-fir and generally less understory vegetation than in the older stand.

Sampling Design

Two bigleaf maple plots were selected based on the following criteria: (1) a bigleaf maple was dominant within the stand; (2) the bole of the bigleaf maple was no less than 15 m from any other dominant bigleaf maple or broadleaf tree; (3) the bole of the bigleaf maple was no less than 25 m from roads, skid trails, and recently deforested sites; and (4) the plot was undisturbed by other research studies, debris flow, water courses or other influences that could confound the data. Each plot was 36 m × 36 m in size and centered about a single bigleaf maple stem. Plot 1 is in the 140-yr-old stand and plot 2 is in the 75-yr-old stand.

The elevation, slope and aspect of plots 1 and 2 are, respectively, 150 and 180 m, 21 and 11% and southwest- and south-facing. The basal areas for bigleaf maple, western redcedar, Douglas-fir and western hemlock were, respectively, 2, 38, 32 and 2 $m^2\ ha^{-1}$ for plot 1 and 1, 64, 0 and 6 $m^2\ ha^{-1}$ for plot 2. The diameter at breast height and canopy extent from the trunk of the bigleaf maple was 861 mm and 7.92 m for plot 1 and 550 mm and 7.15 m for plot 2. The tree canopy type (bigleaf maple, Douglas-fir, western hemlock, and western red-cedar directly above each sample location was recorded and mapped (Fig. 1).

Two sample designs were used within each 36-m × 36-m plot (Fig. 2). The first design consisted of a regular 36-m × 36-m grid centered on the bigleaf maple stem with upslope at the top of the grid and downslope at the bottom of the grid. Flags were placed at each 4-m × 4-m node of the 36-m × 36-m grid and samples were collected from the center of four surrounding nodes ($n = 81$). Within this larger grid was a smaller (7-m × 7-m) grid also centered on the bigleaf maple stem, with flags placed at each 1-m node and samples collected from the center of four surrounding nodes ($n = 49$). Only the central sample point was shared by the large and small grid on a plot. The larger grid was less intensively sampled and covered the entire area of the bigleaf maple canopies and extended into the surrounding conifer forest. The smaller grid was more intensively sampled as



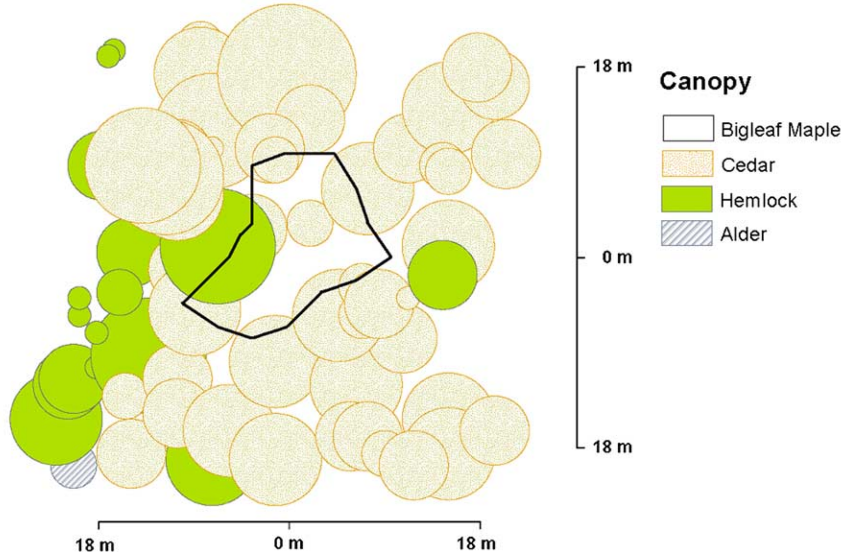


Fig. 1. Canopy extent of trees on plot 1 (above) and plot 2 (below). A single dominant bigleaf maple is located at the center of each 36-m × 36-m plot (canopy outlined by a solid black line).

Can. J. Soil. Sci. Downloaded from pubs.aic.ca by Simon Fraser University on 11/12/11
For personal use only.

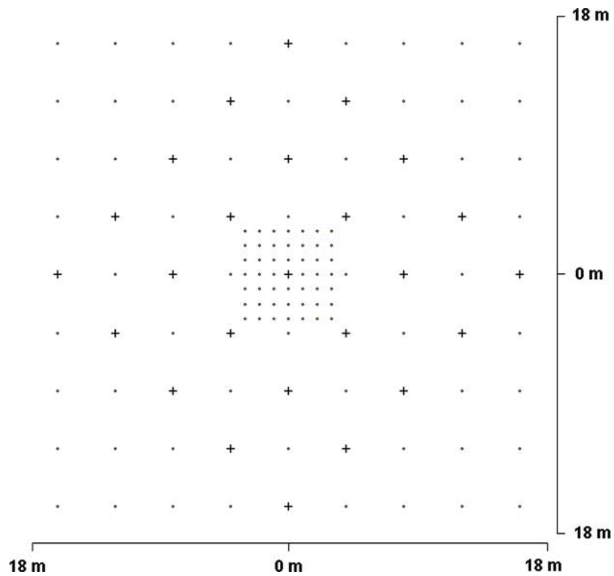


Fig. 2. A 36-m × 36-m grid is centered on a dominant bigleaf maple where forest floor was sampled every 4 m ($n=81$). A nested 7-m × 7-m grid was also centered on the plot tree where forest floor was sampled every 1 m ($n=49$) for a total of $n=129$. A subset of 25 sample locations (denoted by +) from the larger (36-m × 36-m) regular grid was used for intact forest floor and mineral soil core sampling and litterfall collection ($n=25$).

it was beneath the canopy of the bigleaf maples. At these 129 locations on each plot, forest floor samples were collected for analysis of chemical properties and forest floor depths were measured on 2005 Aug. 26 for plot 1 and on 2005 Sep. 02 for plot 2. To collect the forest floor samples, forest floor and mineral soil was removed to expose the soil profile. Forest floor and Ah horizon depths were measured and with a trowel, a section of forest floor (F and H) approximately 10 cm × 10 cm to the depth of the mineral soil was removed.

A subset of 25 sample locations from the larger (36-m × 36-m) sample grid was used for measurements of (i) forest floor water content and forest floor mass; (ii) water content and bulk density of the mineral soil directly beneath the forest floor samples; and (iii) litterfall. The 25 sample locations formed the shape of a diamond 36 m tall and 36 m wide (Fig. 2). Sample locations were 5.65 m apart at right angles and 8 m apart horizontally. An intact forest floor sample (15 cm × 15 cm) was collected at each sample location to the depth of mineral soil. Once the intact forest floor samples were removed, the mineral soil lying directly beneath was collected using a bulk density hammer and cylinder (7.5 cm high × 7.2 cm inner diameter). Forest floor and mineral soil samples were collected on 2005 Aug. 28 for plot 1 and on 2005 Sep. 03 for plot 2.

The 15-cm × 15-cm intact forest floor samples (25) and mineral cores (25) were weighed within 12 h of collection, oven dried at 70°C (forest floor) and 105°C (mineral soil) for 24 h, and then reweighed. Water content, forest floor mass per unit area and mineral soil bulk density were calculated.

Litterfall was collected using 25-cm × 50-cm greenhouse trays with holes in the bottom to allow drainage and lined with 1 mm nylon mesh. On 2005 Sep. 01, greenhouse trays were placed at the 25 sample locations. Litterfall that had accumulated in the trays was collected biweekly over 4 mo (from Sep. 14 until Dec. 22, 2005). The litter samples were oven dried at 70°C overnight and then sorted into the following five categories; bigleaf maple leaves, bigleaf maple samara, cedar bough or scales, Douglas-fir or hemlock needles, and other (small twigs, fern or moss, and insect frass). After sorting, each of the five litter types for all 25 sample locations on both grids for each of eight collection periods was weighed.

Laboratory Analysis

The field-moist forest floor samples were tested for pH (Kalra and Maynard 1991), air-dried and prepared for further chemical analysis by the Ministry of Forests and Range, Research Branch Laboratory, Victoria, BC. Cation exchange capacity and exchangeable cations (Ca, K, Mg) were measured using a standard displacement method ($BaCl_2$) (Hendershot and Duquette 1986) with inductively coupled argon plasma (ICAP) spectrometry to measure the solution. To determine mineralizable nitrogen, forest floor samples were remoistened and incubated for 2 wk at 30°C under anaerobic conditions (Waring and Bremner 1964). The conditions of this incubation result in ammonium (and not nitrate or nitrite) being produced. The ammonium was then displaced from the soil with 1N KCl extractant and measured colorimetrically with a Technicon Autoanalyzer II.

Data Analysis

Three spatial techniques were used to explore the spatial patterns in the data, and each technique had a different purpose. First, kriging was used to visually explore patterns in the data. Second, spatial autocorrelation analysis (SAA) was used to provide a global measure of spatial autocorrelation over the sampled region. Finally, a procedure using local indicators of spatial association (LISA) was used to detect and locate significant spatial clustering of similar values at the local scale. Parametric techniques (ANOVA and *t*-tests) were used to determine significant differences in soil properties within regions (close to the stem, under the bigleaf maple canopy, and beyond the bigleaf maple canopy). Parametric techniques were used by a number of previous researchers who have studied the influence of individual trees on soil properties.

Can. J. Soil. Sci. Downloaded from pubs.aic.ca by Simon Fraser University on 11/12/11
For personal use only.

Can. J. Soil. Sci. Downloaded from pubs.aic.ca by Simon Fraser University on 11/12/11
For personal use only.

Kriging

Kriging is an interpolation method that originated from geostatistics (Matheron 1970). Kriging models the spatial structure of sampled data and enables the prediction of values at unsampled locations. In this study, kriging was used to visualize the spatial distribution of forest floor pH, CEC, Ca, K, mineralizable N, and LFH and Ah horizon depths. Spatially continuous maps of each property over the study region were produced based on the spatial variance of each property. Kriging was carried out using ArcMap GIS software within the "Spatial Analyst" extension (ESRI 1999). For the purposes of kriging, spatial variance was estimated within ArcMap GIS. A universal kriging model (quadratic drift/search radius of 12 points) was used as it is efficient on small study areas such as those in our study (Burrough and McDonnell 1998). The values of all the kriging output surfaces were classified and presented in five discrete classes (highest value = white; and lowest value = black) and then each was overlaid with bigleaf maple canopy extent to assist visual detection of spatial patterns indicating species influence.

Kriging for litterfall amounts did not produce meaningful continuous surfaces as there were too few data points to illustrate the spatial variance that occurred over the sample area. Litterfall maps were created to visualize bigleaf maple litter amounts and the total amounts of litterfall in relation to the bigleaf maple canopy on both plots. The litterfall maps were generated with ArcMap GIS (ESRI 1999) using graduated symbols overlaid with bigleaf maple canopy extent.

Spatial Autocorrelation Analysis

Spatial autocorrelation analysis (Cliff and Ord 1973) was used to test for spatial relationships in soil properties derived from sampling areas of different size and different sampling resolution. With this method, the autocorrelation index of each lag class (m) is designated a significance level. SAA was performed to (i) determine whether a soil property at one sampling location was dependent on the soil state at surrounding sampled points (indicating non-randomness in the data); and (ii) determine how this relationship of dependency varied over space (spatial extent). The strength of the relationship of a soil property over a spatial context (at a particular sample resolution) is translated as an indicator of spatial association, the Moran *I* (Moran 1950; Bailey and Gatrell 1995). The Moran *I* value provides a global measure of spatial autocorrelation over a sampled region. Moran's *I* can be between -1 (strong negative spatial autocorrelation; dissimilar values located near each other) and 1 (strong positive spatial autocorrelation; similar values located near each other), and can also have a value of 0 indicating lack of spatial association.

SAA was carried out with PASSAGE software (Rosenberg 1998). Output from SAA includes correlograms which chart the Moran *I* values by distance class. Three correlograms were created for each of five forest floor chemical properties (pH, CEC, Ca, K, and mineralizable N). The first correlogram used points from the 1-m and 4-m sample grids ($n = 129$; covering 36 m × 36 m); the second used points from the 4-m sample grid ($n = 81$, covering 36 m × 36 m); and the third used points from the 1-m sample grid ($n = 49$, covering 7 m × 7 m). The correlograms show the range in spatial dependency of soil properties. The two sample designs covering the entire 36 m × 36 m sample grids were used to assess spatial dependency in soil properties in conifer forest with bigleaf maple in the center. Correlograms were produced for both the 129 point grid and the 81 point grid in order to compare the results from the two sampling designs. The 7-m × 7-m sample grid was used to assess spatial dependency in soil properties under the bigleaf maple canopy.

Local Indicators of Spatial Association

Local indicators of spatial association (LISA) measure the spatial autocorrelation of each individual location (i.e., the Local Moran) by decomposing the global indicator of spatial association (Moran *I*) into the contribution of each observation (Anselin 1995). In other words, the sum of LISA values for all observations is proportional to a global indicator of spatial association (Anselin 1995). LISA provides four outputs; the first is a significance map showing locations with a significant Local Moran statistic represented with different shades depending on the significance level. The significance map has a filter for four levels of significance ($P = 0.05$, 0.01, 0.001 or 0.0001). The second map shows four types of points where the LISA values are significant: high values of properties surrounded by high values, high values surrounded by low values, low values surrounded by low values, and low values surrounded by high values. High-high and low-low values suggest spatial clustering, while high-low and low-high locations indicate spatial outliers. A box plot and a Moran scatterplot can also be produced with LISA.

This study used LISA to detect local clusters in forest floor pH, CEC, Ca, K mineralizable N and litterfall at the 129 sample locations on both plots. Local spatial clusters were defined as sets of contiguous locations for which the LISA values are significant (Anselin 1995). To determine the spatial extent of significant local clusters found at the bigleaf maple stem, we measured the distance of contiguous high/high or low/low points (clusters) in eight directions (at 45° angles) from the central point (the tree stem location) and calculated average distances for each soil property. LISA maps were created with GeoDa software (Anselin 2003;

Can. J. Soil. Sci. Downloaded from pubs.aic.ca by Simon Fraser University on 11/12/11
For personal use only.

Anselin et al. 2006) and a significance level of $P = 0.05$ was used.

Parametric Statistics

ANOVA with Tukey multiple comparison tests (Steele and Torrie 1980) were used to detect significant differences in soil properties among three site types: bigleaf maple stem (0 to 2.5 m from the stem); bigleaf maple canopy (2.5 m from the stem to the edge of the bigleaf maple canopy); and conifer (beyond the bigleaf maple canopy extent). The area within 2.5 m of the stem was chosen to represent the area most directly influenced by the stem. ANOVA was used to detect significant site type differences in forest floor pH, CEC, exchangeable bases (Ca, K and Mg), mineralizable N, depths of LFH and Ah horizons. T-tests were used to test significant differences between bigleaf maple and conifer site types ($n = 25$) in litterfall amounts (bigleaf maple leaf; bigleaf maple samara; Douglas-fir/hemlock; cedar; other; and total litterfall) as well as forest floor water content, forest floor mass, and mineral soil water content and bulk density. Parametric statistical analyses were carried out with SPlus (Insightful Corp. 2005) and a significance level of $P = 0.05$ was used.

RESULTS

Forest Floor pH, CEC and Exchangeable Bases

Forest floor pH, CEC and exchangeable bases were interpolated with kriging and the range in value of each property was presented in 5 discrete classes (Figs. 3 and 4). Both plots had higher values of pH, CEC and exchangeable bases near the bigleaf maple stem in the center of the plot, particularly for pH and K at plot 1. Although pH and K at plot 2 did not seem to have distinct concentric patterns, the highest values of the interpolated surfaces occurred near or appeared to originate from the bigleaf maple stem at the center of the plot.

SAA performed on the 129 data points (36 m $\times$ 36 m grid) on each plot indicated that concentrations of all exchangeable cations were positively spatially autocorrelated ($P < 0.05$) up to distances of at least 4 m (Figs. 5 and 6). Over the 36 m $\times$ 36 m grid sampled at 4 m resolution ($n = 81$), CEC, pH, Ca, and K indicated positive spatial dependence (alikeness) that extended from 4 up to 12 m on plot 1 (pH, CEC, Ca) and up to 8 m (pH, CEC, Ca) or 12 m (K) on plot 2. However, on the 7 m $\times$ 7 m grid sampled at 1 m resolution ($n = 49$) these properties were found to be dependent on one another for no more than 2 m and indicated statistically significant negative dependence between 4 and 5 m for all properties, except for K on plot 2.

Significant clusters of high values surrounded by high values for forest floor pH, CEC, and exchangeable Ca and K were detected about the stem of the bigleaf maple (Figs. 7 and 8). The average distance that a cluster of high values surrounded by high values extended from the stem, ranged from 1.4 to 2.5 m. The furthest distances to which the cluster of each chemical property extended from the bigleaf maple stem for the two plots are as follows: 1.4 and 1.6 m for pH; 2 and 1.5 m for Ca; 2 and 1.8 m for CEC; and 2.4 and 2.5 m for K. Outside these clusters located at the stem, most forest floor chemical properties exhibited a narrow ring, or transition zone of significant low values surrounded by high values indicating a rather abrupt transition from one area of influence (i.e., bigleaf maple stem) to another (beyond 2.5 m from bigleaf maple stem).

On both plots, parametric statistics (Tables 1 and 2) showed significantly higher pH, CEC, and exchangeable bases at the bigleaf maple stem and up to a distance of 2.5 m with a decreasing trend with distance from the stem area of influence. Plot 1 CEC and Mg and plot 2 Mg and K decreased with distance from the bigleaf maple stem and were significantly different between all three treatment areas (stem, canopy, and outside the canopy).

Forest Floor Mineralizable N

Kriging maps indicated relatively high amounts of mineralizable N, but also scattered patches of low amounts of mineralizable N beneath the bigleaf maple canopy on both plots. SAA of the 81 observations sampled on the 36-m $\times$ 36-m grid at 4-m resolution indicated positive spatial autocorrelation up to 4 m on plot 1 and 8 m on plot 2 and both plots were negatively autocorrelated at 28 m (Figs. 4 and 5). The 7-m $\times$ 7-m grid sampled at 1-m resolution on plot 1 showed positive spatial autocorrelation at distances of 7 and 8 m. LISA (Figs. 7 and 8) showed statistically significant increases in mineralizable N beneath the bigleaf maple canopy, centered on the bigleaf maple stem on both plots. The furthest distance to which the cluster of high values of mineralizable N extended from the stem was 1.6 m on plot 1 and 1.8 m on plot 2.

Parametric statistics found significantly higher mineralizable N (Tables 1 and 2) at the bigleaf maple stem and within the immediate surrounding area extending up to 2.5 m from the stem on both plots. Plot 2 had significantly different mineralizable N between all three treatment areas (stem, canopy, and outside the canopy), which decreased with distance from the bigleaf maple stem. Plot 1 indicated a similar trend of decreasing mineralizable N with distance from the bigleaf maple stem.

Forest Floor and Ah Horizon Depths

Kriging indicated areas of thicker forest floor near the stem, beneath the canopy, and extending from areas of the canopy on plot 1, but indicated the reverse with thinner forest floor at locations near the bigleaf maple stem and beneath its canopy on plot 2 (Figs. 3 and 4). Thicker Ah horizons seemed to extend beyond the canopy on plot 1 and thinner Ah horizons seemed to be located within close proximity to the stem on plot 2.

Can. J. Soil. Sci. Downloaded from pubs.aic.ca by Simon Fraser University on 11/12/11
For personal use only.

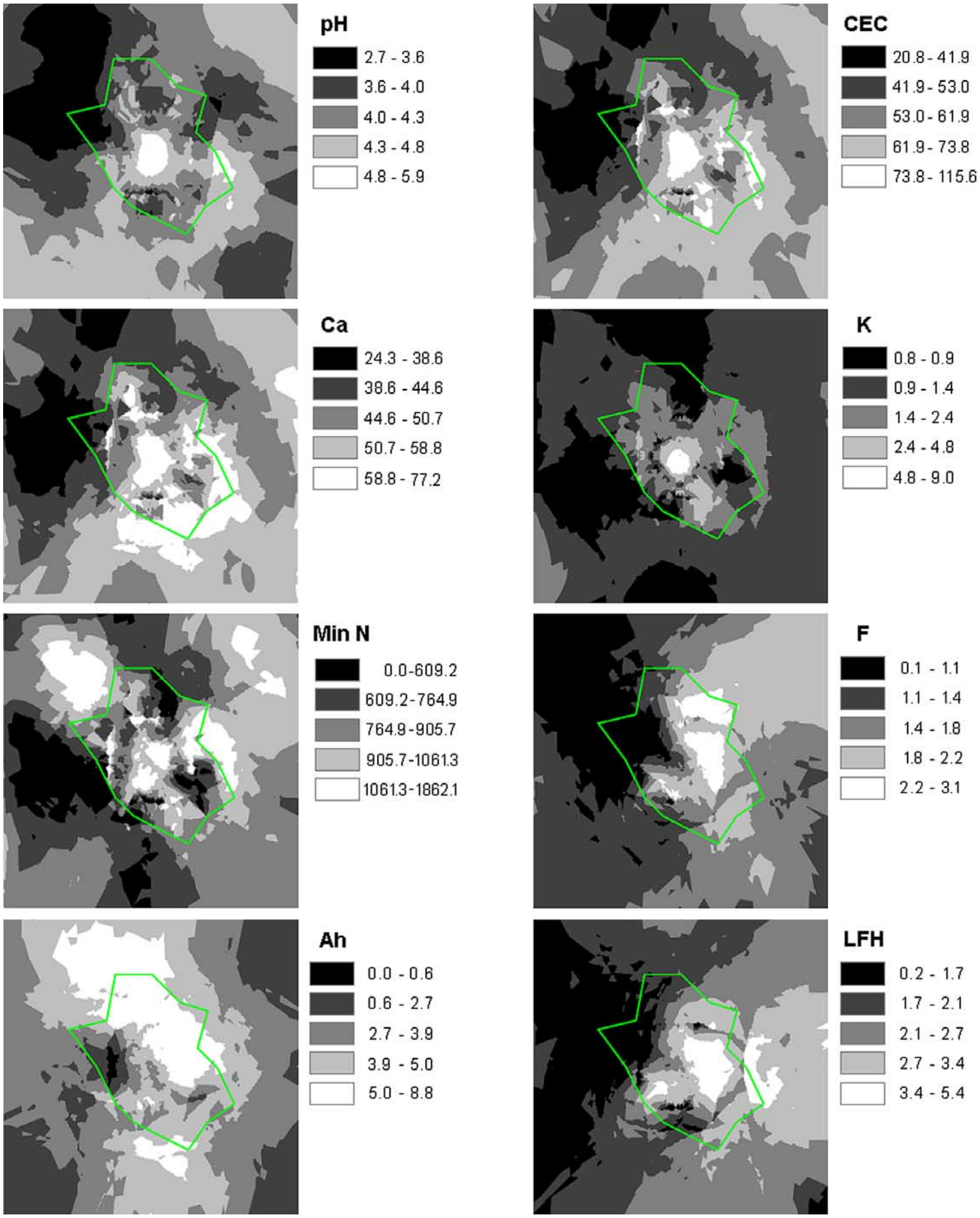


Fig. 3. Plot 1 forest floor pH, CEC ($cmol_c\ kg^{-1}$), Ca ($cmol_c\ kg^{-1}$), K ($cmol_c\ kg^{-1}$) and mineralizable N ($mg\ kg^{-1}$) with depths (cm) of the Ah and F layers and the total forest floor depth (LFH). Values are interpolated with Universal Kriging and classified into five classes. Each kriging map is overlaid with a polygon indicating the canopy extent of a dominant bigleaf maple centered on the 36 m $\times$ 36 m plot.

ANOVA for plot 1 (Table 1) showed the F, LFH, and Ah horizon depths to be significantly thinner in areas beyond the bigleaf maple canopy. Plot 2 LFH horizon depths had an inverse trend with thicker depths in areas beyond the bigleaf maple canopy. ANOVA for plot 2 (Table 2) confirmed the pattern of Ah depths that was detected visually with the kriging method, and found thinnest depths at the stem area of influence that were significantly thinner than the Ah depths beneath the canopy. Mean H depths did not exceed 0.5 cm for either plot and its rare occurrence did not provide the data required to construct a kriging map.

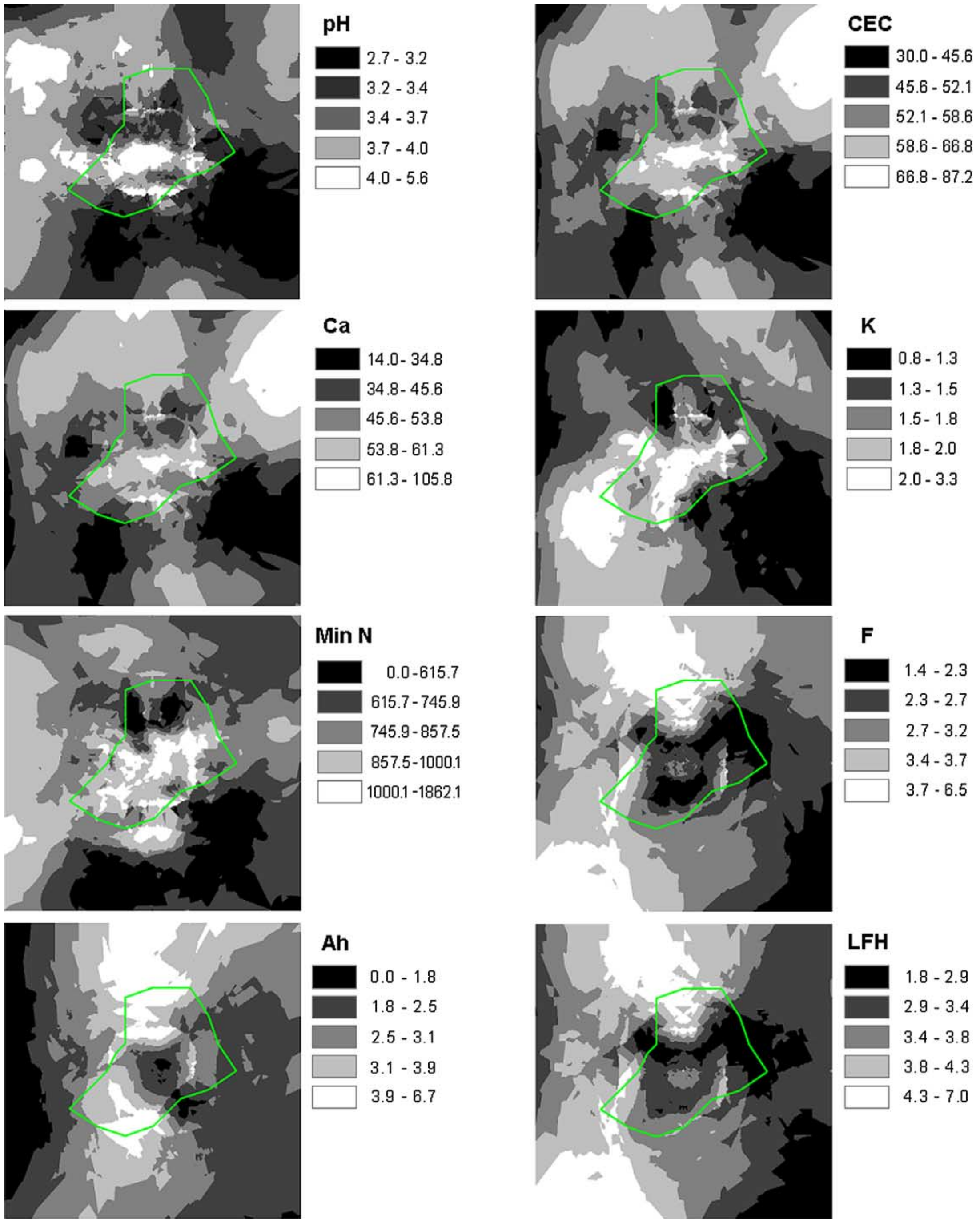


Fig. 4. Plot 2 forest floor pH, CEC (cmol$_c$ kg^{-1}), Ca (cmol$_c$ kg^{-1}), K (cmol$_c$ kg^{-1}) and mineralizable N (mg kg^{-1}) with depths (cm) of the Ah and F layers and the total forest floor depth (LFH). Values are interpolated with Universal Kriging and classified into five classes. Each kriging map is overlaid with a polygon indicating the canopy extent of a dominant bigleaf maple centered on the 36-m × 36-m plot.

Litterfall, Forest Floor Mass, Mineral Soil Bulk Density and Water Content

The largest amounts of bigleaf maple litterfall occurred beneath the bigleaf maple canopy on both plots, however, total litterfall amounts at sample locations were greater outside the bigleaf maple canopy on plot 2 (Fig. 9). LISA showed clusters of significantly positive spatial association of high amounts of litterfall beneath and at locations adjacent to the bigleaf maple canopy on both plots (Figs. 7 and 8). Parametric statistics showed

Can. J. Soil. Sci. Downloaded from pubs.aic.ca by Simon Fraser University on 11/12/11
For personal use only.

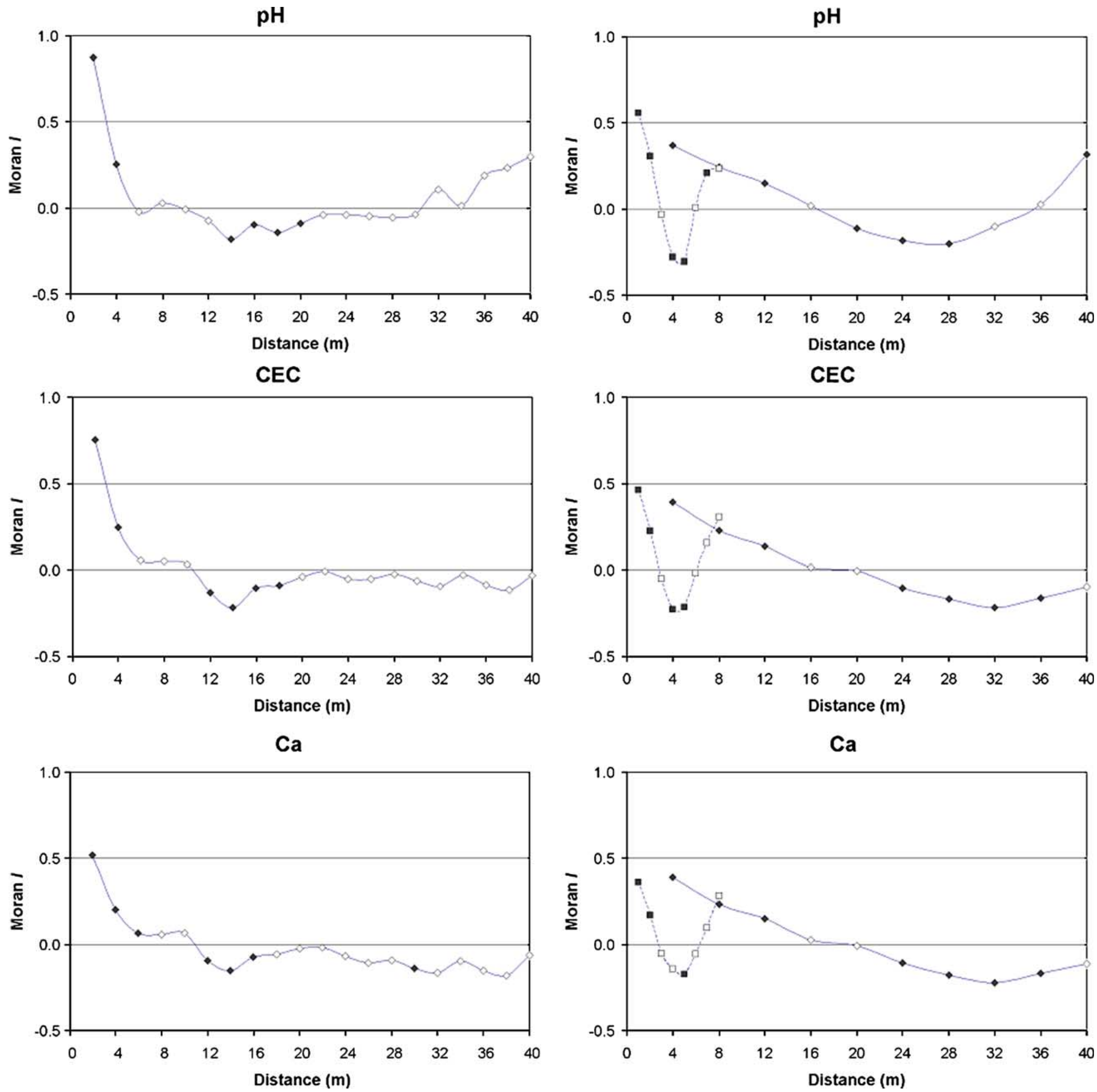


Fig. 5 (*Continued on p. 304*).

Can. J. Soil. Sci. Downloaded from pubs.aic.ca by Simon Fraser University on 11/12/11
For personal use only.

significantly higher bigleaf maple and total litterfall amounts beneath bigleaf maple canopy types compared with beneath conifer canopy on both plots (Tables 3 and 4). The majority of bigleaf maple litter (84% on plot 1, 92% on plot 2) was found to be deposited directly beneath and oriented with bigleaf maple canopy extent.

No significant differences in forest floor mass or mineral soil bulk density were found between bigleaf maple and conifer canopies, although a trend of greater mineral soil bulk density beneath conifer canopy was found (Tables 3 and 4). Plot 2 had significantly greater forest floor and mineral soil water content beneath bigleaf maple canopy compared with areas not beneath bigleaf maple canopy. This trend also occurred on plot 1 although no significant differences between the site types were found.

DISCUSSION

Influence of Bigleaf Maple on Forest Floor Properties

Greater values for forest floor pH and exchangeable base concentrations found beneath bigleaf maple are likely related to base-rich litterfall (Valachovic et al.

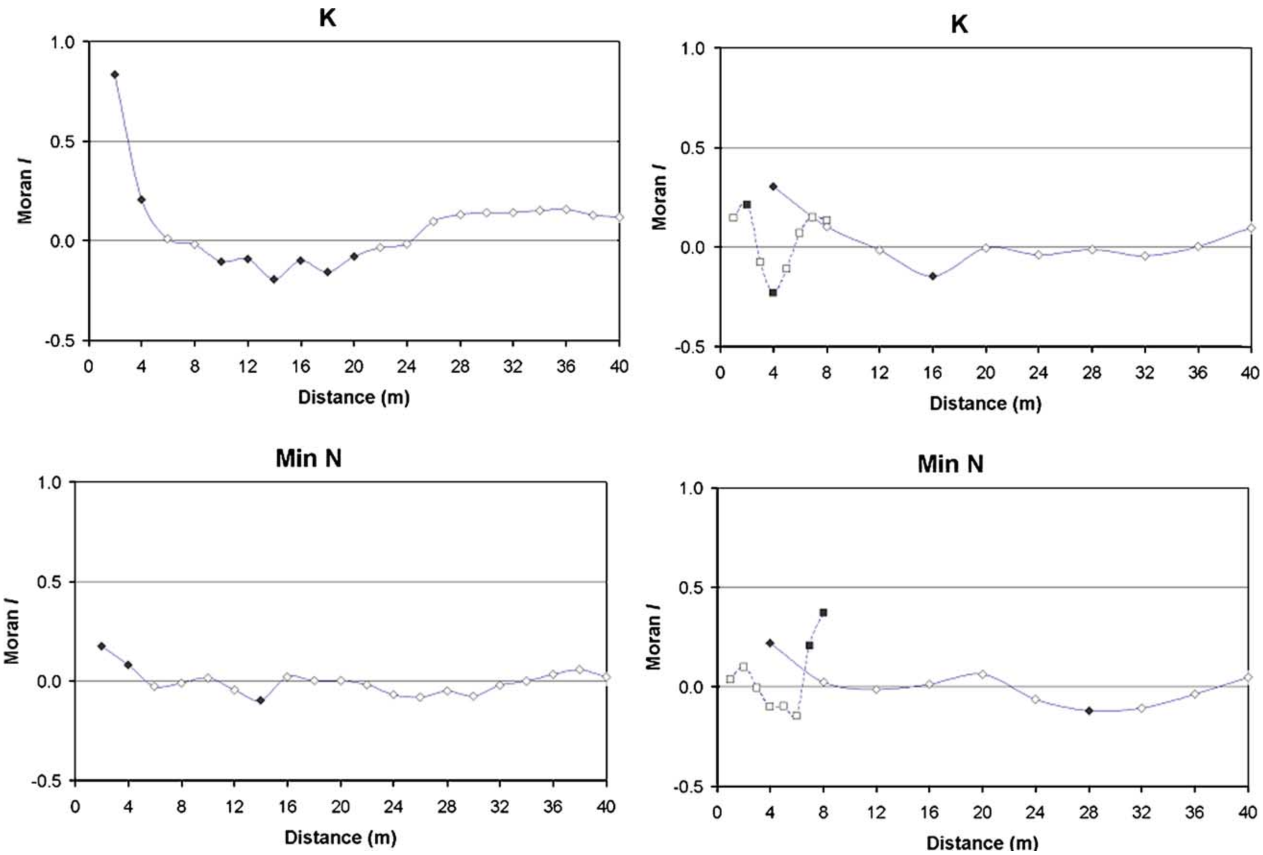


Fig. 5. Plot 1 correlograms of forest floor acidity, chemical properties (cmol$_c$ kg^{-1}) and mineralizable N (mg kg^{-1}) sampled on a 36-m × 36-m grid at 1 and 4 m resolution ($n = 129$) (left) and decomposed into the 2 sample grid resolutions (1 and 4 m) (right). Bold points indicate significant Moran I values ($P < 0.05$).

Can. J. Soil. Sci. Downloaded from pubs.aic.ca by Simon Fraser University on 11/12/11
For personal use only.

2004; Turk 2006). In contrast to our study, Fried et al. (1990) found no significant differences in forest floor pH or exchangeable bases concentrations at any of five sites studied. Turk (2006), on the other hand, found higher forest floor pH but unchanged exchangeable base concentrations.

We found evidence that bigleaf maple may have a positive influence on N availability. Forest floor mineralizable N was significantly higher near the bigleaf maple stems compared with beneath surrounding conifers. Greater N availability beneath bigleaf maple may be due to rapid rates of decomposition (Harmon et al. 1990) and relatively high N concentrations of bigleaf maple litter (Valachovic et al. 2004). The finding of potentially greater N availability beneath bigleaf maple in our study is similar to findings of previous researchers (Tashe and Schmidt 2003; Turk 2006).

Thinner forest floor depths, smaller forest floor mass, thicker Ah depths and lower bulk density of the surface mineral soil were expected beneath bigleaf maple, due to the faster decomposition of bigleaf maple litter compared with conifer litter (Turk 2006) and subsequent incorporation of humus into surface mineral soils by soil organisms. The expected trends were found for depths of forest floor on plot 2 and Ah on plot 1; however, no differences in forest floor mass or surface mineral soil bulk density were found. Turk (2006) found significantly thinner forest floors and thicker Ah horizons beneath bigleaf maple as compared with conifer plots in a study of 12 paired plots. The lack of differences in forest floor mass in our study may be partially due to greater inputs of total litterfall in bigleaf maple plots (for plot 1) while time may also play a role as the older bigleaf maple on plot 1 had forest floor over two times heavier than the younger bigleaf maple. Turk (2006) found significantly greater forest floor mass and lower mineral soil bulk density in bigleaf maple as compared with conifer plots and Fried et al. (1990) found no differences in forest floor mass between bigleaf maple and conifer plots.

Both forest floor and mineral soil had greater water content beneath bigleaf maple than beneath conifers on plot 2. The summer when sampling occurred was relatively dry with no precipitation for 9 d, then 1 d of light precipitation four days previous to sampling plot 2. It is possible that the conifers were more efficient at extracting soil water held at higher tensions, thus resulting in drier soils beneath conifers. Furthermore,

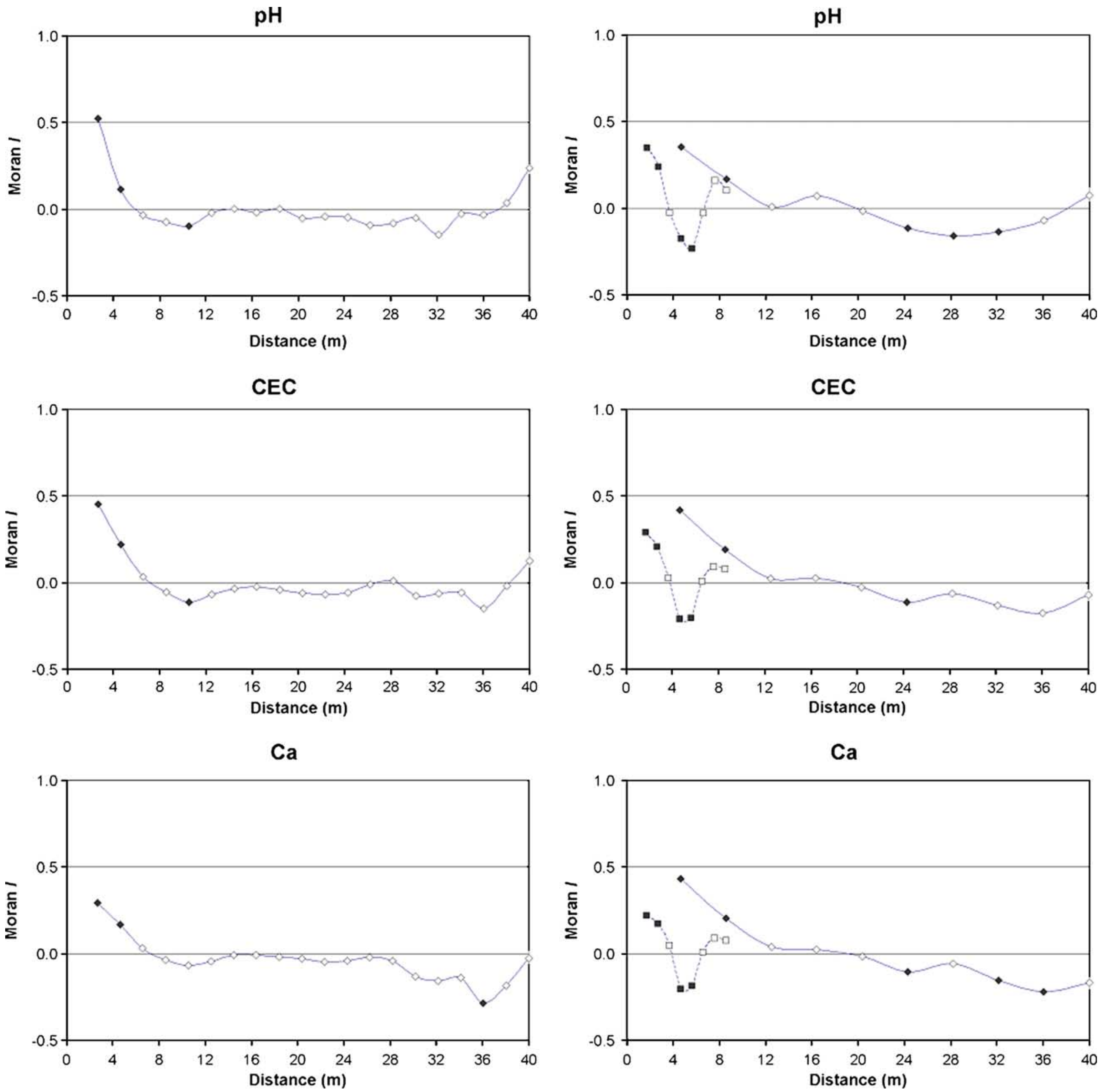


Fig. 6 (*Continued on p. 306*).

Can. J. Soil. Sci. Downloaded from pubs.aic.ca by Simon Fraser University on 11/12/11
For personal use only.

the dense crowns of conifer trees may have intercepted rainfall to a higher degree than bigleaf maple trees, resulting in higher soil water content under bigleaf maple.

Influence of Bigleaf Maple on Litterfall

The current study found that significantly higher amounts (84 and 92%) of bigleaf maple litter were deposited directly beneath the bigleaf maple canopy than outside the canopy. On both plots, total litterfall amounts were higher under bigleaf maple canopy than under conifer canopy, with plot 1 total litterfall being significantly higher. This difference between the canopy types did not occur on plot 2 and this could be due to the difference in age (140 and 75 yr) of the bigleaf maple plot trees. On both plots, conifer litterfall weights were lower beneath bigleaf maple canopy, although no significant differences between site types were found.

Our results for plot 1 are similar to those of Turk (2006) who found greater total autumn litterfall in bigleaf maple as compared to conifer plots and of Fried et al. (1990) who found that all bigleaf maple sites in their study had higher annual litterfall weights than conifer sites. Our study found that the amount of conifer

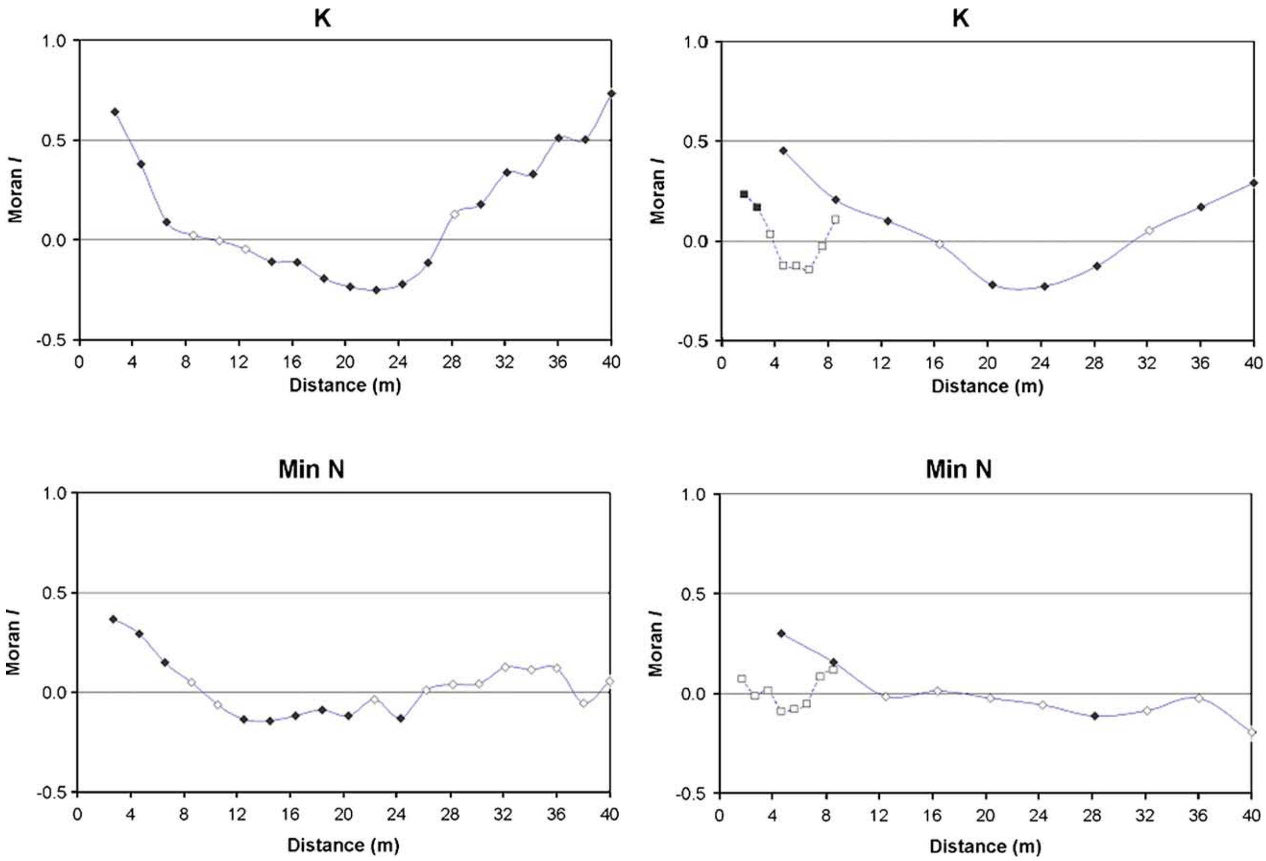


Fig. 6. Plot 2 correlograms of forest floor acidity, chemical properties (cmolc kg^{-1}) and mineralizable N (mg kg^{-1}) sampled on a 36-m × 36-m grid at 1 and 4 m resolution ($n = 129$) (left) and decomposed into the two sample grid resolutions (1 and 4 m) (right). Bold points indicate significant Moran I values ($P < 0.05$).

Can. J. Soil. Sci. Downloaded from pubs.aic.ca by Simon Fraser University on 11/12/11
For personal use only.

litterfall was considerably greater than bigleaf maple litterfall beneath bigleaf maple canopy, which is similar to findings of Ogden and Schmidt (1997) who found that the vine maple plots in the autumn had a total amount of vine maple leaf litterfall that was significantly lower than the amount of conifer needle litterfall.

Influence of Bigleaf Maple on Spatial Patterns of Forest Floor Properties and Litterfall

Previous studies (Zinke 1962; Crampton 1984; Escudero 1991) found that soil properties create circular patterns in relation to the distance from the stem and in relation to the canopy of individual trees. For example, soil pH has generally been found to be lowest near the tree stem, increasing with distance from the tree for conifers (Zinke 1962; Crampton 1982) and highest near the tree stem, decreasing with distance from the tree for broadleaves (Escudero 1991). In our study, kriging maps showed high values for forest floor chemical properties (including pH) near the tree stem and a complex pattern away from the stem with a general trend of lower values away from the bigleaf maple canopy. The complex pattern shown in the kriging maps indicates that there are other factors (than bigleaf maple canopy versus conifer canopy) that influenced the patterns in forest floor properties in our study. These include such factors as tree species cover (other than bigleaf maple), microtopography, canopy openness, canopy structure, and understory cover. For example, previous researchers (Turner and Franz 1985; Collins et al. 2001) have shown that forest floor properties (pH, mineralizable N and total Ca and K concentrations) are generally higher under western redcedar than under western hemlock. Future research could attempt to incorporate other

Fig. 7. Plot 1 LISA maps overlaid over the 36-m × 36-m sample grid (black points) and a polygon indicating the bigleaf maple canopy extent. Maps indicate clusters of spatially associated forest floor chemical properties (pH, cation exchange capacity, mineralizable N and exchangeable Ca, K and bigleaf maple litterfall). Black squares indicate clusters of high values of soil properties surrounded by high values; grey squares indicate high values surrounded by low values. Black crosses indicate low values surrounded by low values; grey crosses indicate low values surrounded by high values ($P < 0.05$).

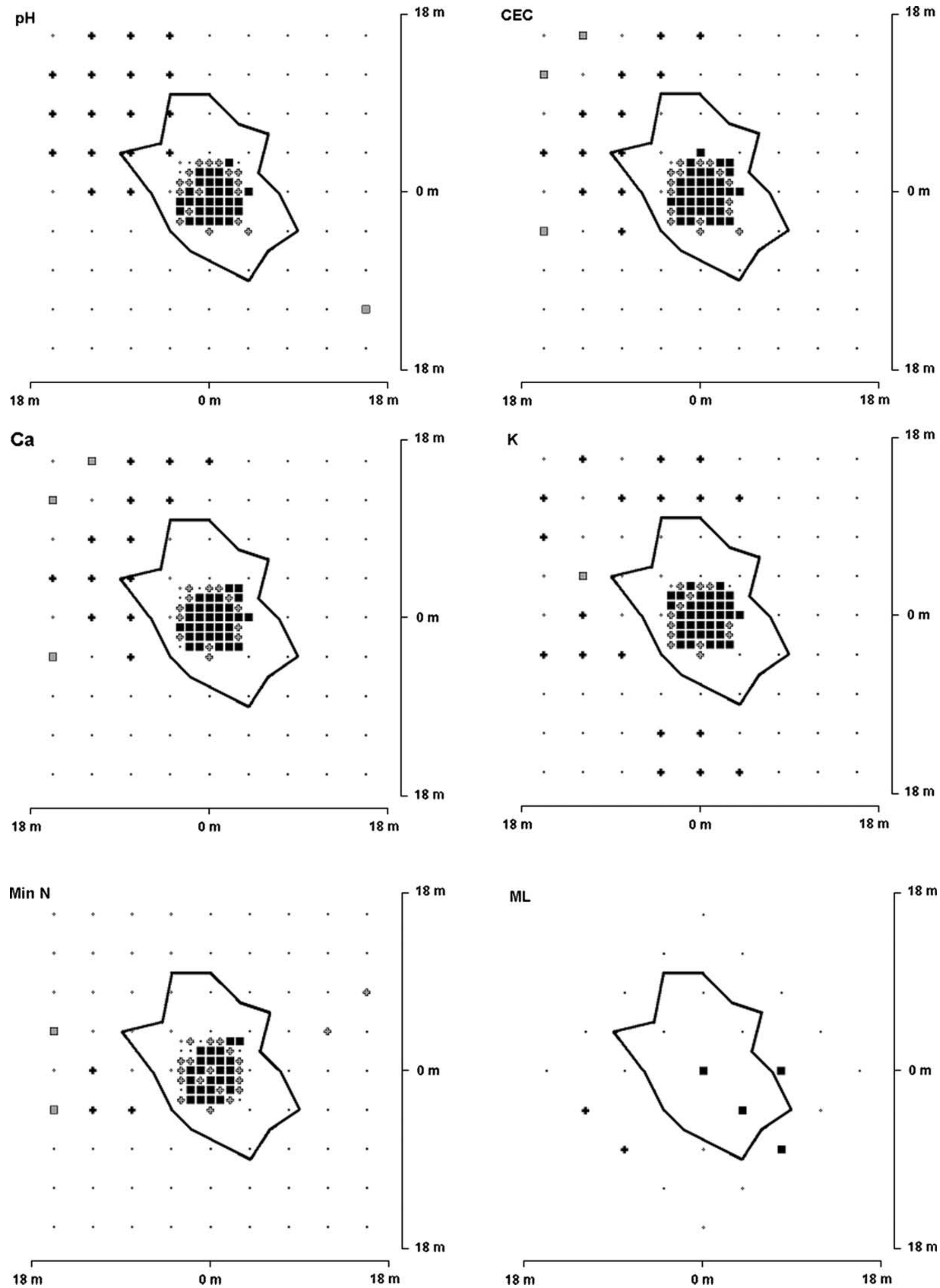


Fig. 7

Can. J. Soil. Sci. Downloaded from pubs.aic.ca by Simon Fraser University on 11/12/11
For personal use only.

Can. J. Soil. Sci. Downloaded from pubs.aic.ca by Simon Fraser University on 11/12/11
For personal use only.

factors than bigleaf maple cover that influence patterns in forest floor properties around individual trees.

The extent of influence of the impact of individual bigleaf maple stems on forest floor properties was not as great as expected. We had expected to find a significant influence of bigleaf maple trees beneath the bigleaf maple canopy due to inputs from litterfall and throughfall. We also expected to measure an impact of the individual bigleaf maple stems some distance away from the bigleaf maple canopy as we expected some litter to fall some distance away from the canopy. LISA showed that the distances of influence from the bigleaf maple stems ranged from 1.4 to 2.5 m for the measured forest floor chemical properties. The mean canopy extent from the trunk of the bigleaf maple was 7.92 and 7.15 m for plots 1 and 2, respectively, yet most of the measured difference in soil properties occurred within 2.5 m of the stems. This suggests that stemflow in addition to litterfall likely influenced the soil properties and that stemflow may have played a significant role. Furthermore, we found that the bigleaf maple litter falls primarily beneath the bigleaf maple canopy and much of it falls near the stems.

Stemflow production and the residence time and chemical enrichment of intercepted precipitation on the above ground vegetative surface of trees are partially determined by species-specific differences in canopy structure (e.g., branching geometry, orthogonally projected branch area, branch count), and properties of the bark (tissue chemistry, porosity, texture, water-holding capacity and air-drying rate (Levia and Frost 2003). The canopy structure and properties of the bark of bigleaf maple may be such that stemflow is enriched in nutrients and this may partially account for the patterns of high values of chemical properties near bigleaf maple stems. The bigleaf maple stems may behave as nutrient rich hot spots within generally nutrient-poor conifer forest.

The canopies of the two bigleaf maple individuals were not concentric, but had a non-symmetrical branching pattern and observations of other bigleaf maples reveals that this is often the case for this species. The canopy structure of the trees may have influenced the patterns in the forest floor properties. Forest floor had higher nutrient values including significantly higher exchangeable Mg concentrations beneath the canopy of both trees than forest floor outside the canopy extent. The concept of tree influence potential (IP) has been used to assess spatial patterns related to species influence (Saetre 1999; Bengtson et al. 2006). The IP concept often assumes that the influence of a tree is symmetrical in space and is proportional to the diameter at breast height (DBH). We found that the younger bigleaf maple (75-yr) in our study has a much smaller DBH compared with the older bigleaf maple (140 yr), yet the spatial extent of stem influence, as indicated by LISA clusters, was relatively similar to that of the larger, older tree for most properties. We would suggest that for bigleaf maple one cannot assume that the influence of the tree is symmetrical in space or that it is proportional to the DBH and that an index of tree influence for bigleaf maple should include the size, positioning and orientation of the tree canopy. In our study, the influence of bigleaf maple can be generalized as stem influence with significant increases in forest floor chemical properties that extends approximately 2.5 m from the stem and with trends of increased forest floor chemical properties that mirrors the canopy extent.

Analytical Techniques to Study Species Influence on Soils: Kriging, SAA, LISA and ANOVA

Kriging methods were useful for visual interpretations of patterns of soil properties relative to individual bigleaf maple stems and for the data exploration that lead to confirmatory approaches of SAA and LISA, statistical techniques that lend support to the visual interpretations. In future work, other statistical techniques such as those used by Saetre (1999) and Bengtson et al. (2006) could be used in addition to LISA.

SAA was used to estimate the spatial structure of soil properties by providing a measure of the strength of the relationship of dependence between data points. The correlograms for the 7-m $\times$ 7-m grid (near the bigleaf maple stem) show a distinct pattern with a transition zone at about 3 m for most properties on both plots that occurs between significant positive autocorrelation from 0 to 2 m and significant negative autocorrelation at 4 m. The 36-m $\times$ 36-m grid ($n = 129$ and $n = 81$) covers a larger sample region (both near and away from the bigleaf maple stem) and the local pattern created by the influence of the bigleaf maple stem is likely overshadowed by the overall influence of the surrounding conifers. This may partially explain the different patterns in the correlograms for the 7-m $\times$ 7-m and 36-m $\times$ 36-m grids. It is also possible that the apparent shorter range of spatial dependence in the 7-m $\times$ 7-m sample grid as compared with the larger 36-m $\times$ 36-m grid is partially due to the relatively low number of comparisons at longer distances (e.g., above 3 m). Finer sampling, such as 1-m intervals, would have been more desirable over the 36-m $\times$ 36-m plots, but the cost of such sampling is considerable. Future work could

Fig. 8. Plot 2 LISA maps overlaid over the 36-m $\times$ 36-m sample grid (black points) and a polygon indicating the bigleaf maple canopy extent. Maps indicate clusters of spatially associated forest floor chemical properties (pH, cation exchange capacity, mineralizable N and exchangeable Ca, K and bigleaf maple litterfall). Black squares indicate clusters of high values of soil properties surrounded by high values; grey squares indicate high values surrounded by low values. Black crosses indicate low values surrounded by low values; grey crosses indicate low values surrounded by high values ($P < 0.05$).

Can. J. Soil. Sci. Downloaded from pubs.aic.ca by Simon Fraser University on 11/12/11
For personal use only.

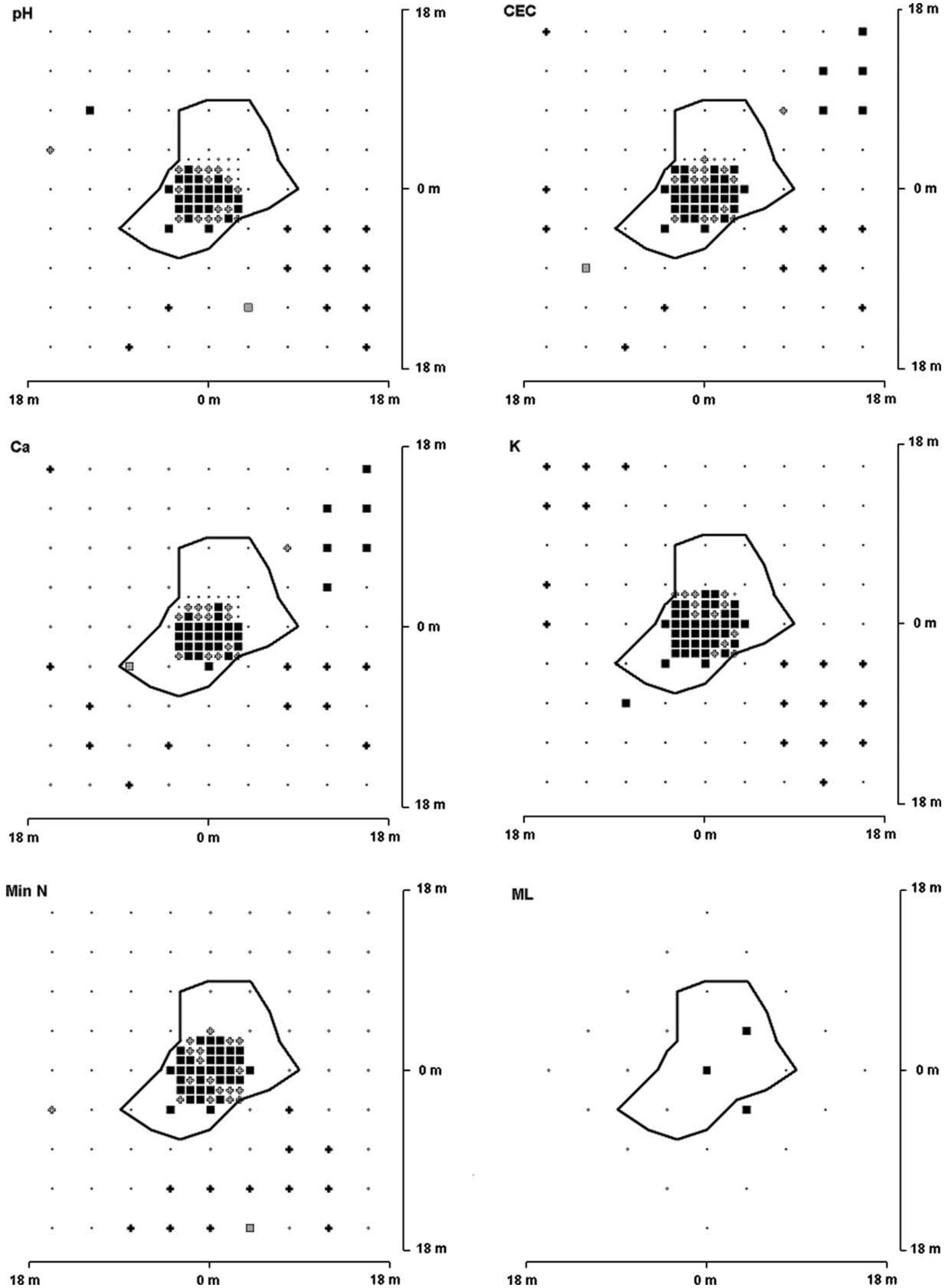


Fig. 8

Can. J. Soil. Sci. Downloaded from pubs.aic.ca by Simon Fraser University on 11/12/11
For personal use only.

Table 1. Plot 1 mean values and ANOVA (with Tukey multiple comparison test) of forest floor chemical properties and horizon depths (cm) beneath an individual bigleaf maple at three site types; bigleaf maple stem [within 2.5 m from the stem (n = 21)]; bigleaf maple canopy [2.5 m from the bigleaf maple stem to the bigleaf maple canopy edge (n = 50)]; and conifer [not under bigleaf maple canopy (n = 58)]

Forest floor property	Bigleaf maple stem		Bigleaf maple canopy		Conifer		Prob. (*F*)
pH	4.97*a*	(0.59)[z]	4.23*b*	(0.32)	4.07*b*	(0.50)	< 0.001[y]
CEC ($cmol_c\ kg^{-1}$)	80.11*a*	(13.36)	60.83*b*	(10.64)	54.35*c*	(13.82)	< 0.001
Exch Ca ($cmol_c\ kg^{-1}$)	67.81*a*	(10.97)	53.51*b*	(9.74)	48.39*b*	(13.70)	< 0.001
Exch K ($cmol_c\ kg^{-1}$)	3.82*a*	(3.15)	1.66*b*	(0.57)	1.09*b*	(0.37)	< 0.001
Exch Mg ($cmol_c\ kg^{-1}$)	7.86*a*	(2.33)	4.71*b*	(1.16)	3.48*c*	(0.91)	< 0.001
Mineral N ($mg\ kg^{-1}$)	1054.68*a*	(269.48)	840.57*b*	(198.65)	801.82*b*	(229.49)	< 0.001
F	1.67*ab*	(1.04)	1.80*a*	(0.83)	1.37*b*	(0.62)	0.019
H	0.33	(0.64)	0.41	(1.03)	0.17	(0.54)	0.27
L, F and H	3.17*a*	(1.97)	2.95*a*	(1.57)	1.93*b*	(0.95)	< 0.001
Ah	4.86*a*	(3.19)	4.50*a*	(2.60)	3.26*b*	(2.18)	0.011

[z]Values in parentheses are standard deviations.
[y]Underlined values indicate significant differences (P < 0.05).
a, *b* Values with different letters in the same row are significantly different (P < 0.05).

compare the effect of various sample designs on results of analyses.

LISA statistics were effective at refining the global SAA findings by locating statistically significant local patterns of positive and negative spatial association. LISA was also used to determine the spatial extent of influence at a scale finer than the 1 m, despite the 1-m sample resolution because an average distance from the central location within a cluster can be calculated.

The LISA results indicated that most of the values in the smaller 7-m × 7-m grid were significant for most properties, whereas a smaller proportion of the values outside of the grid were significant. It is possible that a higher proportion of significant values in the 7-m × 7-m grid compared with outside of the grid were due to the shorter distance between sampling points in the 7-m × 7-m grid. However, the 7-m × 7-m grid surrounds the bigleaf maple stem and is under bigleaf maple canopy, whereas the area outside of the 7-m × 7-m grid is away from the stem and much of the region is not under bigleaf maple canopy. Therefore, the pattern (a contiguous area of high values surrounded by high values near the stem) seen is likely related to the bigleaf maple stem.

Parametric statistics involve the use of models that test for significant differences in groups by comparing their variance to the overall observed variance (Triola et al. 1999). To produce robust results, assumptions are required by the model; interval or ratio scale of measurement; normality; independence; and homogeneity of variances. One sample, two-tailed, Kolmogorov-Smirnov tests of composite normality showed that pH, CEC, Ca, and mineralizable N were normally distributed; they satisfy the second assumption for parametric analysis. However, the properties are spatially autocorrelated; SAA found positive and negative spatial relationships between observations indicating that they are not independent of one another. The data also do not exhibit homogeneity of variances; LISA statistics found clusters of spatial association indicating nonstationarity across site types; while parametric tests also indicated significant differences between site types. Non-parametric measures could be considered for similar studies

Table 2. Plot 2 mean values and ANOVA (with Tukey multiple comparison test) of forest floor chemical properties and horizon depths (cm) beneath an individual bigleaf maple at three site types; bigleaf maple stem [within 2.5 m from the stem (n = 21)]; bigleaf maple canopy [2.5 m from the bigleaf maple stem to the bigleaf maple canopy edge (n = 40)]; and conifer [not under bigleaf maple canopy (n = 68)]

Forest floor property	Bigleaf maple stem		Bigleaf maple canopy		Conifer		Prob. (F)
pH	4.03*a*	(0.45)[z]	3.59*b*	(0.38)	3.59*b*	(0.39)	< 0.001[y]
CEC ($cmol_c\ kg^{-1}$)	65.29*a*	(9.21)	56.91*b*	(7.95)	53.75*b*	(10.97)	< 0.001
Exch Ca ($cmol_c\ kg^{-1}$)	54.62*a*	(7.52)	48.18*b*	(7.18)	46.31*b*	(10.48)	0.0018
Exch K ($cmol_c\ kg^{-1}$)	2.13*a*	(0.42)	1.79*b*	(0.29)	1.56*c*	(0.36)	< 0.001
Exch Mg ($cmol_c\ kg^{-1}$)	7.34*a*	(1.97)	5.57*b*	(1.12)	4.42*c*	(0.95)	< 0.001
Mineral N ($mg\ kg^{-1}$)	998.22*a*	(193.74)	868.82*b*	(175.67)	750.84*c*	(166.77)	< 0.001
F	2.40*a*	(1.11)	2.40*a*	(0.82)	3.16*b*	(1.15)	< 0.001
H	0.00	(0.00)	0.05	(0.15)	0.05	(0.15)	0.32
L, F and H	3.05*ab*	(1.18)	3.09*a*	(0.83)	3.68*b*	(1.25)	0.011
Ah	1.98*a*	(0.83)	2.91*b*	(1.32)	2.56*ab*	(1.50)	0.04

[z]Values in parentheses are standard deviations.
[y]Underlined values indicate significant differences (P < 0.05).
a, *b* Values with different letters in the same row are significantly different (P < 0.05).

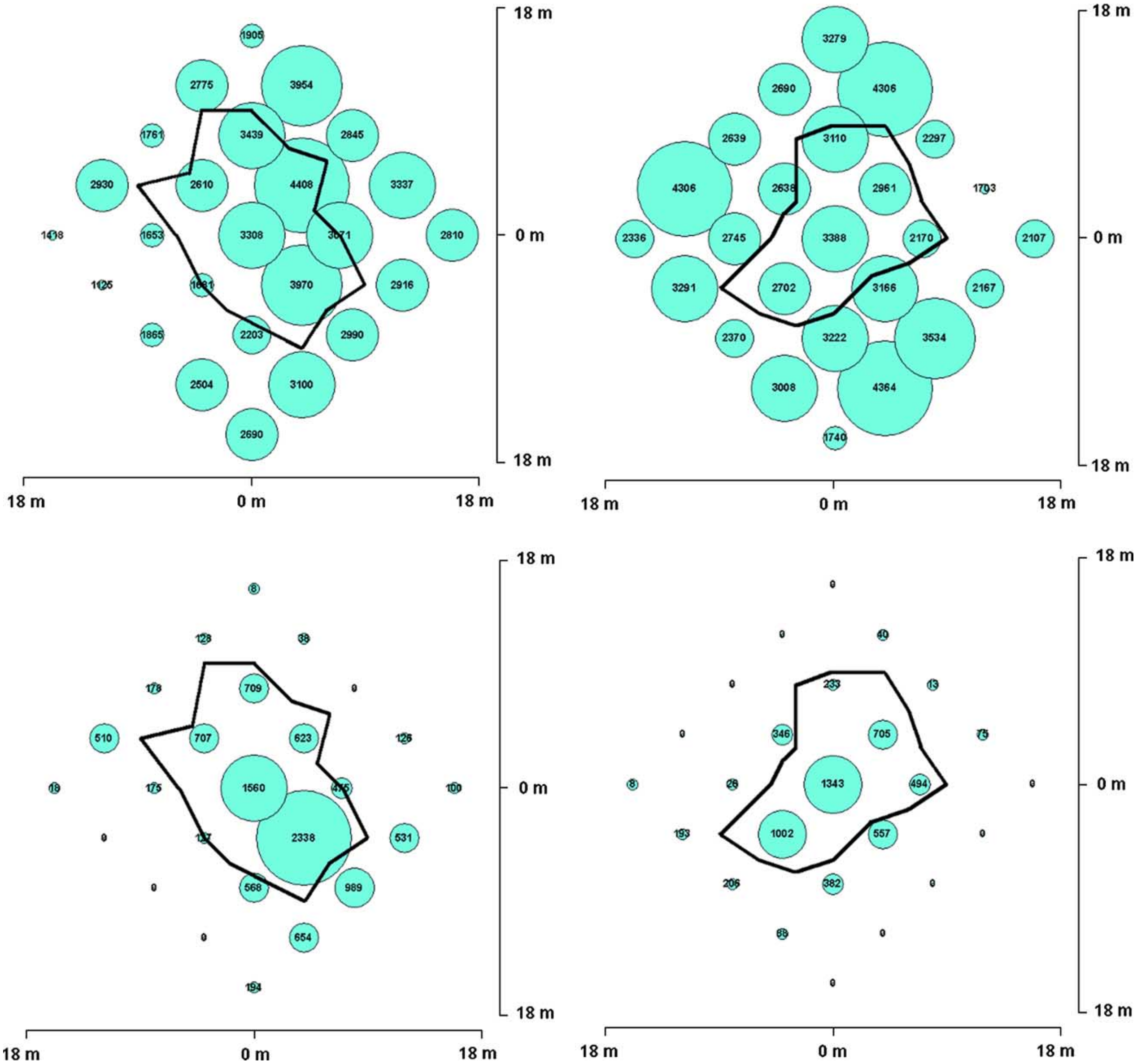


Fig. 9. Plot 1 (left) and plot 2 (right) total litterfall (kg ha^{-1}) (above) and total bigleaf maple litterfall (kg ha^{-1}) (below) collected between Sep. 01 to Dec. 22, 2005 ($n = 25$). Each plot was a 36–m $\times$ 36-m grid centered on a dominant bigleaf maple stem. Bigleaf maple canopy extent is indicated by a black polygon and litterfall amounts are presented as graduated circles.

Can. J. Soil. Sci. Downloaded from pubs.aic.ca by Simon Fraser University on 11/12/11
For personal use only.

because the soil properties studied do not meet the criteria of independence over space as required for robust parametric significance testing. Alternatively, a conservative level of significance ($P = 0.001$) could be used when analyzing spatially autocorrelated data with parametric statistics (Saetre 1999).

CONCLUSIONS

This study showed that patterns in forest floor properties were related to individual bigleaf maple stems growing within conifer forest. In general, highest values for pH, CEC and exchangeable base concentrations were found close to the bigleaf maple stems with decreasing values away from the stems. The most notable influence of single bigleaf maple stems was found near the stems (up to 2.5 m from stems) and this may be attributed to nutrient-rich stemflow associated with bigleaf maple. The increased pH, CEC and exchangeable base concentrations found beneath bigleaf maple may have a positive influence on nutrient availability to surrounding conifers.

The high level of sampling and of analysis used in this study is warranted when one is investigating the patterns and processes related to single-tree influence on soil

Table 3. Plot 1 mean forest floor (FF), mineral soil (MS) properties and litterfall beneath ($n=10$) and outside ($n=15$) bigleaf maple canopy extent

Property	Bigleaf maple canopy		Conifer		P (t-test)
Bigleaf maple leaf (kg ha^{-1})	899.47	(666.11)[z]	166.35	(211.74)	<0.01[y]
Bigleaf maple samara (kg ha^{-1})	156.89	(138.61)	84.50	(57.99)	0.08
Douglas-fir/hemlock (kg ha^{-1})	1054.58	(691.13)	1029.60	(611.24)	0.93
Cedar (kg ha^{-1})	719.20	(302.55)	747.85	(418.03)	0.86
Total conifer litterfall (kg ha^{-1})	1731.92	(754.02)	1805.60	(648.57)	0.80
Other (kg ha^{-1})	429.42	(195.62)	342.45	(264.57)	0.40
Total litterfall (kg ha^{-1})	3101.68	(799.63)	2416.75	(762.48)	0.04
FF weight/unit area (g cm^{-3})	1.91	(0.85)	1.99	(0.77)	0.81
MS bulk density (g cm^{-3})	0.55	(0.23)	0.67	(0.21)	0.19
FF water content (g g^{-1})	44.46	(15.04)	39.61	(19.67)	0.53
MS water content (g g^{-1})	50.93	(44.78)	30.74	(31.11)	0.20

[z]Values in parentheses are standard deviations.
[y]Underlined values indicate significant differences at $P<0.05$.

Table 4. Plot 2 mean forest floor (FF), mineral soil (MS) properties and litterfall beneath ($n=6$) and outside ($n=19$) bigleaf maple canopy extent

Property	Bigleaf maple canopy		Conifer		P (t-test)
Bigleaf maple leaf (kg ha^{-1})	747.20	(362.16)[z]	64.67	(102.85)	0.00[y]
Bigleaf maple samara (kg ha^{-1})	0.00	(0.00)	0.93	(2.72)	0.42
Douglas-fir/hemlock (kg ha^{-1})	322.13	(130.76)	489.39	(424.18)	0.36
Cedar (kg ha^{-1})	1685.73	(509.74)	1992.88	(785.91)	0.38
Total conifer litterfall (kg ha^{-1})	2007.87	(485.78)	2482.27	(681.23)	0.13
Other (kg ha^{-1})	179.60	(49.46)	327.58	(326.84)	0.29
Total litterfall (kg ha^{-1})	2934.67	(442.78)	2875.45	(814.91)	0.87
FF weight/unit area (g cm^{-3})	0.79	(0.15)	0.68	(0.36)	0.49
MS bulk density (g cm^{-3})	0.51	(0.24)	0.66	(0.24)	0.20
FF water content (g g^{-1})	144.31	(29.52)	107.71	(27.40)	0.010
MS water content (g g^{-1})	50.67	(47.48)	25.88	(12.64)	0.04

[z]Values in parentheses are standard deviations.
[y]Underlined values indicate significant differences at $P<0.05$.

Can. J. Soil. Sci. Downloaded from pubs.aic.ca by Simon Fraser University on 11/12/11
For personal use only.

properties. The results indicate that distance from tree stems may be an important factor to consider in traditional plot-based field experiments.

ACKNOWLEDGEMENTS

The authors would like to thank UBC's Malcolm Knapp Research Forest for granting access to its lands. We would also like to thank T. Turk, M. Dickinson, I. Eichinger and T. Thomson for field and laboratory assistance. This study was supported by Natural Sciences and Engineering Research Council of Canada Discovery grants (MS and SD).

Agriculture Canada Expert Committee on Soil Survey. 1998. The Canadian system of soil classification. 3rd e. Canada Department of Agriculture, Ottawa, ON. Publ. no. 1646,

Anselin, L. 1995. Local indicators of spatial association. Geogr. Anal. **27**: 93–115.

Anselin, L. 2003. GeoDa. Version 0.9.5-i. Copyright 1998-2004. Spatial Analysis Lab, University of Illinois, Urban, IL. [Online] Available: https://www/geoda/uiuc.edu.

Anselin, L., Syabri, I. and Kho, L. 2006. GeoDa: An introduction to spatial data analysis. Geogr. Anal. **38**: 5–22.

Augusto, L., Ranger, J., Binkley, D. and Rothe, A. 2002. Impact of several common tree species of European temperate forests on soil fertility. Ann. For. Sci. **59**: 233–253.

British Columbia Ministry of Forests. 1999. Bigleaf maple managers' handbook. Government of British Columbia, Victoria, BC. 105 pp.

Bailey, T. C. and Gatrell, A. C. 1995. Interactive Spatial Data analysis. John Wiley and Sons, New York, NY. 432 pp.

Bengtson, P., Falkengren-Grerup, U. and Bengtsson, G. 2006. Spatial distributions of plants and gross N transformation rates in a forest soil. J. Ecol. **94**: 754–764.

Binkley, D. 1995. The influence of trees on forest soils – processes and patterns. *In* Proceedings of the trees and soil workshop Pages 1–33 *in* D. J. Mead and I. S. Conforth, eds. Agronomy Society of New Zealand Special Publication no. 10. Lincoln University Press, Canterbury, New Zealand.

Burrough, P. A. and McDonnell, R. A. 1998. Optimal interpolation using geostatistics. Pages 132–161 *in* Principles of geographical information systems. Oxford University Press, New York, NY.

Carey, A. and Harrington, C. 2001. Small mammals in young forests: implications for management for sustainability. For. Ecol. Manage. **154**: 289–309.

Cliff, A. D. and Ord, J. K. 1973. Spatial autocorrelation. Pion Press, London, UK.

Can. J. Soil. Sci. Downloaded from pubs.aic.ca by Simon Fraser University on 11/12/11
For personal use only.

Collins, D. B., Feller, M. C., Klinka, K. and de Montigny, L. 2001. Forest floor nutrient properties in single- and mixed-species, second growth stands of western hemlock and western redcedar. Northwest Sci. **75**: 407–416.

Crampton, C. B. 1982. Podzolization of soils under individual tree canopies in southwestern British Columbia, Canada. Geoderma **28**: 57–61.

Crampton, C. B. 1984. Concentric zonation of gleyed soils under individual tree canopies in southwestern British Columbia, Canada. Geoderma **32**: 329–334.

Escudero, A., Hernandez, M. and Arco, J. 1991. Spatial patterns of soil composition around isolated trees. Dev. Geochem. **6**: 507–517.

ESRI. 1999. ArcMap Version 9.0. Copyright 1999–2004 ESRI Inc., Redlands, CA.

Fisher, R. F. and Binkley, D. 2000. Ecology and management of forest soils. John Wiley & Sons, Inc., New York, NY.

Fried, J. S., Boyle, J. R., Tappeiner, J. C., II, and Cromack, K., Jr. 1990. Effects of bigleaf maple on soils in Douglas-fir forests. Can. J. For. Res. **20**: 259–266.

Haeussler, S., Coates, D. and Mather, J. 1990. Autecology of common plants in British Columbia: A literature review. BC Ministry of Forests and Canadian Forest Service. FRDA Report 158. Victoria, BC. 272 pp.

Harmon, M. E., Baker, G. A., Spycher, G. and Greene, S. E. 1990. Leaf-litter decomposition in the *Picea/Tsuga* forests of Olympic National Park, Washington, USA For. Ecol. Manage. **31**: 55–66.

Hartwig, C. L., Eastman D. S. and Harestad, A. 2004. Characteristics of pileated woodpecker (*Dryocopus pileatus*) cavity trees and their patches on southeastern Vancouver Island, British Columbia, Canada. For. Ecol. Manage. **187**: 225–234.

Hendershot, W. H. and Duquette, M. 1986. A simple barium chloride method for determining cation exchange capacity and exchangeable cations. Soil Sci. Soc. Am. J. **50**: 605–608.

Insightful Corp. 2005. S-PLUS® version 7.0. Copyright 1988, 2005. Insightful Corp., Seattle, WA.

Kalra, Y. P. and Maynard, D. G. 1991. Methods manual for forest soil and plant analysis. Minister of Supply and Services Canada, Ottawa, ON. 116 pp.

Levia, D. F. and Frost, E. E. 2003. A review and evaluation of stemflow literature in the hydrologic and biogeochemical cycles of forested and agricultural ecosystems. J. Hydrol. **274**: 1–29.

Matheron, G. 1970. La théorie des variables régionalisées, et ses applications. Les Cahiers du Centre de Morphologie Mathématique de Fontainebleau. Fontainebleau: Fascicule 5.

Meidinger, D. and Pojar, J. 1991. Ecosystems of British Columbia. Ministry of Forests. Special Report Series 6. Victoria, BC. 330 pp.

Moran, P. A. P. 1950. Notes on continuous stochastic phenomena. Biometrika **37**: 17–23.

Ogden, A. and Schmidt, M. 1997. Litterfall and soil characteristics in canopy gaps occupied by vine maple in a coastal western hemlock forest. Can. J. Soil Sci. **77**: 703–711.

Pojar, J. and Mackinnon, A. 1994. Plants of Coastal British Columbia. Lone Pine Publishing, Vancouver, BC. 527 pp.

Rosenberg, M. S. 1998. Pattern analysis spatial statistics and geographic exegis (PASSAGE) Version 1.1. Copyright 1998–2004.

Rothe, A. and Binkley, D. 2001. Nutritional interactions in mixed species forests: a synthesis. Can. J. For. Res. **31**: 1855–1870.

Saetre, P. 1999. Spatial patterns of ground vegetation, soil microbial biomass and activity in a mixed spruce-birch stand. Ecography. **22**: 183–192.

Steele, R. G. D. and Torrie, J. H. 1980. Principles and procedures of statistics: A biometrical approach. 2nd ed. McGraw-Hill Book Co., New York, NY. 633 pp.

Tashe, N. C. and Schmidt, M. G. 2003. The influence of vine maple on forest floor and mineral soil properties in coastal temperate forests. Can. J. Soil Sci. **83**: 35–44.

Triola, M. F., Goodman, W. M. and Law, R. 1999. Elementary statistics. First Canadian edition. Addison-Wesley, Toronto, ON. 852 pp.

Turk, T. 2006. The role of bigleaf maple in soil chemistry and nutrient dynamics in coastal temperate rainforests. MSc. Thesis, Geography, Simon Fraser University, Burnaby, BC.

Turner, D. P. and Franz, E. H. 1985. The influence of western hemlock and western redcedar on microbial numbers, nitrogen mineralization, and nitrification. Plant Soil. **88**: 259–267.

Valachovic, Y. S., Caldwell, B. A., Cromack, Jr., K. and Griffiths, R. P. 2004. Leaf litter chemistry controls on decomposition of Pacific Northwest trees and woody shrubs. Can. J. For. Res. **34**: 2131–2147.

Waring, S. A. and Bremner, J. M. 1964. Ammonium production in soil under waterlogged conditions as an index of nitrogen availability. Nature **201**: 951–952.

Zinke, P. 1962. The pattern of influence of individual forest trees on soil properties. Ecology **43**: 130–133.