# INFLUENCE OF BIGLEAF MAPLE (*ACER MACROPHYLLUM* PURSH) ON SOIL PROPERTIES IN A CONIFER FOREST OF SOUTHWEST BRITISH COLUMBIA

by
Julia Chandler
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# APPROVAL

**Name:** **Julia Rae Chandler**

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**Examining Committee:**

**Chair:** **Dr. Tracy Brennand**
Associate Professor
Department of Geography, SFU

---

**Dr. Margaret Schmidt, Associate Professor**
Senior Supervisor
Department of Geography, SFU

---

**Dr. Suzana Dragicevic, Associate Professor**
Supervisor
Department of Geography, SFU

---

**Dr. Maja Krzic, Assistant Professor**
External Examiner
Agroecology, Faculty of Land and Food Systems
University of British Columbia

**Date Defended/Approved:** November 30, 2006

# ABSTRACT

The overall objective of this research was to detect the influence of bigleaf maple (*Acer macrophyllum* Pursh) on soils in a conifer forest of southwest British Columbia. Forest floor properties were measured beneath bigleaf maple along six transects and on two 36 m x 36 m plots. Wavelet analysis, kriging, spatial autocorrelation analysis, local indicators of spatial association, and parametric statistics were used to explore and confirm bigleaf maple patterns of influence on surrounding soils. Results indicated that forest floor in close proximity (approximately 2.5 m) to bigleaf maple stems had increased pH, exchangeable cations, and mineralizable N as compared to soils further away from bigleaf maple stems. A buried bag technique and a bioassay with Douglas-fir [*Pseudotsuga menziesii* (Mirb.) Franco] seedlings were used to assess the influence of bigleaf maple on nutrient availability and conifer growth. Bigleaf maple plots had significantly higher net nitrification than Douglas-fir plots.



**Keywords:** bigleaf maple; forest floor; wavelet analysis; kriging; autocorrelation; nitrogen mineralization

**Subject Terms:** *Acer macrophyllum* -- British Columbia; Forest management -- British Columbia; call number SD 397 M3 B53 1999

*To my grandparents*

*Margaret and Donald Forsyth*
*and*
*Mary and George Chandler*

*Thank-you for your playful and adventurous spirits*

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# TABLE OF CONTENTS

# LIST OF FIGURES

# LIST OF TABLES

# CHAPTER 1: INTRODUCTION

## 1.1 Introduction

The nutrient dynamics of deciduous species within Pacific Northwest forests is a question of importance because of their influence on commercially valuable conifer stands. As these forests are generally nutrient poor (Meidinger and Pojar, 1991), understanding the impact of deciduous species on the nutrient cycling and site fertility of conifer forests could be beneficial. While bigleaf maple (*Acer macrophyllum* Pursh) (BLM) is a common and large tree species with potential commercial value (B.C. Ministry of Forests, 1999), little is known about the degree and spatial extent of its impact on the surrounding forest floor. The goal of this research was to detect BLM influence on soils in a conifer forest of southwest British Columbia (BC). This subject was approached by partitioning the goal into three objectives organized in this thesis as chapters, with unique sample design and data analysis techniques. The spatial extent of BLM influence on forest floor properties was assessed in this study and the use of different methodologies to understand and interpret these spatial patterns was investigated.

Currently, only a single study on the influence of BLM on soils in the Pacific Northwest has been reported in the literature (Fried et al. 1990). Fried's study took place in Oregon and compared the physical and chemical properties

of forest floor and mineral soil beneath five BLM plots paired with five Douglas-fir [*Pseudotsuga menziesii* (Mirb.) Franco] plots. Differences between the site types were found with litterfall macronutrient content and annual litterfall weights significantly higher in soils beneath BLM. Turnover rates of forest floor nutrients were found to be significantly faster beneath BLM than beneath Douglas-fir. However, no significant differences in forest floor biomass or nutrients were found between site types.

## 1.2 Research Objectives

The goal of this research was to detect bigleaf maple influence on soils in a conifer forest of southwest BC. The objectives of chapter two were to:

*(i)* determine the spatial extent to which BLM canopy and tree stem influence forest floor pH and depth; and

*(ii)* investigate the influence of slope and microtopography on the spatial variability of forest floor pH under BLM influence.

The research objectives of chapter three were to:

*(i)* observe spatial patterns of forest floor properties and litterfall amounts under the influence of individual BLM stems; and

*(ii)* determine statistical significance in the observed spatial patterns in forest floor properties and litterfall amounts under the influence of BLM.

The objective of chapter four was to investigate the influence of BLM on forest floor nutrient availability in conifer forest.

## 1.3 Study Area

The study area is located within University of British Columbia's Malcolm Knapp Research Forest, Maple Ridge, BC (Fig. 1.2). It is in the Coastal Western Hemlock biogeoclimatic zone, dry maritime subzone (CWHdm). The study area has a temperate climate. The mean annual precipitation is 1827 mm ranging from 53 mm in the driest summer month to 292 mm in the wettest winter month. 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 Expert Committee on Soil Survey, 1998). The area has a history of natural fire events occurring every 200 years with a large fire sweeping across the western portion of the forest in 1868. Between 1920 and 1931, old growth stands were harvested from the eastern portion of the forest until a fire was started by logging equipment in 1931. The forest has been left to naturally regenerate since this time.

The stands in this study are approximately 140 and 70 years old. The 140-year-old stands are dominated by Douglas-fir, western red cedar (*Thuja plicata* Donn), and western hemlock [*Tsuga heterophylla* (Raf.) Sarg.]. Although conifers dominate the canopy, there are areas along streams, roadsides and steep embankments where conifers are co-dominant with BLM and red alder (*Alnus rubra*). There is a mix of native 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 70-year-old stands are dominated by western hemlock and western red cedar, with few Douglas-fir and generally less understory vegetation.

## 1.4 Background - *Bigleaf maple characteristics and ecology*

BLM can grow up to 30 m in height with a diameter at breast height of up to 2.5 m (Haeussler et al., 1990). BLM leaves can grow up to 30 cm in diameter (Hosie, 1969). BLM trees mature between 150 and 300 years of age and are generally found at the base of colluvial slopes and along stream edges (Haeussler et al., 1990). This is a low elevation species which rarely occurs at elevations that exceed 300 m. BLM is found in southwest BC, with its northern limit at approximately 52° N, reaching from Vancouver Island across to the adjacent mainland and stretching up the Fraser Canyon as far as Lytton (Haeussler et al., 1990) (Fig. 1.1).

Asymmetrical lateral growth of individual branches of sugar maple (*Acer saccharum* Marsh.) has been found to be a response to neighbourhood competition as a means to minimize the negative effects of competing trees (Brisson, 2001). BLM can grow freely towards canopy gaps and a single tree can consist of multiple stems. BLM can thus expand its canopy and increase the extent to which it influences the soils beneath via litterfall and throughfall. Furthermore, this branching architecture combined with bark water storage capacity affects the stemflow yield and solute flux of forest soils (Levia and Herwitz, 2005). BLM bark has shallow, wide scaly ridges that retain water well

and it can also be covered in mosses, ferns, and liverworts on its trunk and branches (Hosie, 1969).

BLM seeds are encased in fruit consisting of large double samara with wings up to 40 mm long (B.C. Ministry of Forests, 1999). The seeds germinate early (as early as late February) with all emergence occurring by July. Despite early emergence, only 4 % of BLM seeds may emerge on unprotected plots due to high rates of seed predation (Tappeiner and Zasada, 1993). BLM seeds provide a high quality food source to small mammals and dead trees provide habitat for cavity nesting birds. A recent study found that pileated woodpecker *(Dryocopus pileatus)* cavity trees are more likely to be surrounded by patches containing BLM (Hartwig et al., 2004). BLM presence was also found to be the best predictor of deer mice (*P. maniculatus)* and explained up to 42 % of the abundance in American shrew moles (*N. gibbsii)* (Carey and Harrington, 2001).

BLM is thought to (*i*) absorb high amounts of nutrients, specifically Ca, Mg, K, P and N (Krajina et al., 1982), which are believed to be distributed about a site via litter deposition; (*ii*) have rapid litter decomposition rates resulting in an increase of nutrients available to tree roots (Fried, 1990); and (*iii*) be associated with mull humus form development (Krajina et al., 1982). Thus, BLM may be beneficial to surrounding conifers. Furthermore, BLM has recently been considered to have economic potential, particularly for value-added specialty products (B.C. Ministry of Forests, 1999). Despite the ecological and economic benefit of BLM, it has been considered a competitor of Douglas-fir stands and this species is often managed to control its presence (Hauessler, 1990).

In areas that have been clearcut, up to 40 % of all seedling mortality may occur over the winter without known cause. Browsing by deer can limit growth of BLM seedlings to < 1 m in up to 90 % of BLM between 15 and 20 years old (Fried, 1988). In areas that had been thinned, a subsequent study (Maas-Hebner et al., 2005) found that low survival (61 %), poor growth rates (only 4 % in good condition) and severe browsing (93 % of trees) had deteriorated the presence and general condition of BLM seedlings by the eighth growing season. BLM was the only tree among 5 conifer and 2 deciduous species to not successfully establish within the first 2 years This was explained by frequent and persistent elk browsing. This is consistent with Fried (1988) where a large drop in survival occurred in the 2$^{nd}$ year, however, Fried hypothesized the mortalities were due to an invasion of herbaceous vegetation.

Current management strategies view broadleaf species as serious competitors to conifer crop species and employ several methods to control its presence, including mechanical site preparation, uprooting of maple stumps, or overstory removal. It has been found that BLM competition with Douglas-fir may be reduced by cutting stumps to a height < 30 cm (Tappeiner et al., 1996). Other methods of BLM control include manual sprout cutting, and prescribed burning as well as chemical treatment with herbicides although this treatment has shown the capacity to damage adjacent trees through networked root systems (B.C. Ministry of Forests, 1999). On southern Vancouver Island, BC, biological control with silverleaf fungus (*Chondrostereum purpureum*) has also been studied as a viable method of broadleaf suppression (De Jong et al., 1995).

These measures to control broadleaf species have reduced patch sizes and increased fragmentation of remaining hardwood stands (Kennedy and Spies, 2005). Forests managed to extirpate BLM may create isolates of populations and eliminate food sources and habitat complexity required by interdependent floral and faunal communities of healthy forest ecosystems. The effect of this would be a loss in species diversity and impaired resilience to natural disturbances including fire, pest infestation and extreme climatic conditions. Moreover, BLM is a species that retains high amounts of base cations and acts as a nutrient sink, which may positively influence the surrounding soils and vegetation that may in turn influence economic potential of crop species via yield and quality.

## 1.5 Thesis Overview

This thesis is composed of five chapters. The first chapter introduces the thesis; it provides the research objectives, a description of the study area and background information about bigleaf maple characteristics and ecology. Chapter two describes a study that used measurements of forest floor pH along 6 transects, each 40 m long and extending from a single dominant BLM. Wavelet analysis and *t*-tests using site types were used to detect the spatial extent of bigleaf maple on forest floor pH. Chapter three describes spatial and aspatial analytical techniques used to detect the pattern of influence of BLM on the surrounding soils.

Measurements of soil properties were made on two 36 m x 36 m plots to detect spatial regimes in forest floor pH; cation exchange capacity; exchangeable cations (Ca, K, Mg, Al, Na, Fe, Mn); mineralizable N; forest floor horizon depths and weights per unit area; water content of forest floor and mineral soil; and litterfall mass. An exploratory approach was used that included kriging, spatial autocorrelation analysis, local indicators of spatial association, and parametric statistics. Chapter four describes a nitrogen mineralization buried bag study and a pot trial used to measure differences in forest floor nutrient availability between BLM and Douglas-fir paired plots. Chapter five is the concluding chapter to this thesis; it summarizes results and provides suggestions for future studies.

## 1.6 References


**Agriculture Canada Expert Committee on Soil Survey. 1998.** The Canadian System of Soil Classification, 3rd Edition. Canada Department of Agriculture Publication No. 1646, Ottawa, ON.

**B.C. Ministry of Forests. 1999.** Bigleaf Maple Managers' Handbook. Government of Canada, British Columbia. 105 pp.

**Brisson, J. 2001.** Neighbourhood competition and crown asymmetry in *Acer saccharum*. Can. J. For. Res. **31:** 2151-2159.

**Carey, A. B. and C. A. Harrington. 2001.** Small mammals in young forests: implications for management for sustainability." Forest Ecology and Management **154:** 289-309.

**Fried, J. S., Tappeiner, J. C., and Hibbs, D. E. 1988.** Bigleaf maple establishment and early growth in Douglas-fir forests. Can. J. For. Res. **18:** 1226-1233.

**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, B.C. 272 pp.

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

**Hosie, R. C. 1969.** Native Trees of Canada. Authority of the Minister of Fisheries and Forestry. Ottawa, Ontario. 380 pp.

**De Jong, M., E. Sela, Shamoon, S., and Wall, R. 1996.** Natural Occurrence of Chondrostereum purpureum in Relation to Its Use as a Biological Control Agent in Canadian Forests. Biological Control **6:** 347-352.

**Kennedy, R. S. H. and T. A. Spies. 2005.** Dynamics of hardwood patches in a conifer matrix: 54 years of change in a forested landscape in Coastal Oregon, USA. Biological Conservation **122:** 363-374.

**Krajina, V. J., Klinka, K., and Worrall, J., 1982.** Distribution and ecological characteristics of trees and shrubs of British Columbia. Univ. B.C. Fac. Forestry, Vancouver, B.C. 131 pp.

**Levia, D. F. and S. R. Herwitz 2005.** Interspecific variation of bark water storage capacity of three deciduous tree species in relation to stemflow yield and solute flux to forest soils. Catena **64:** 117-137.

**Maas-Hebner, K. G., Emmingham, W. H., Larson, D. J. and Chan, S. S. 2005.** Establishment and growth of native hardwood and conifer seedlings underplanted in thinned Douglas-fir stands. Forest Ecology and Management **208:** 331-345.

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

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

**Tappeiner, J. C. II and Zasada, J. C. 1993.** Establishment of salmonberry, salal, vine maple, and bigleaf maple seedlings in the coastal forests of Oregon. Can. J. For. Res. **23:** 1775-1780.

**Tappeiner, J. C. II, Zasada, J. C., Huffman, D., and Maxwell, B.D. 1996.** Effects of cutting time, stump height, parent tree characteristics, and harvest cariables on development of bigleaf maple sprout clumps. West. J. Appl. For. **11:** 120-124.

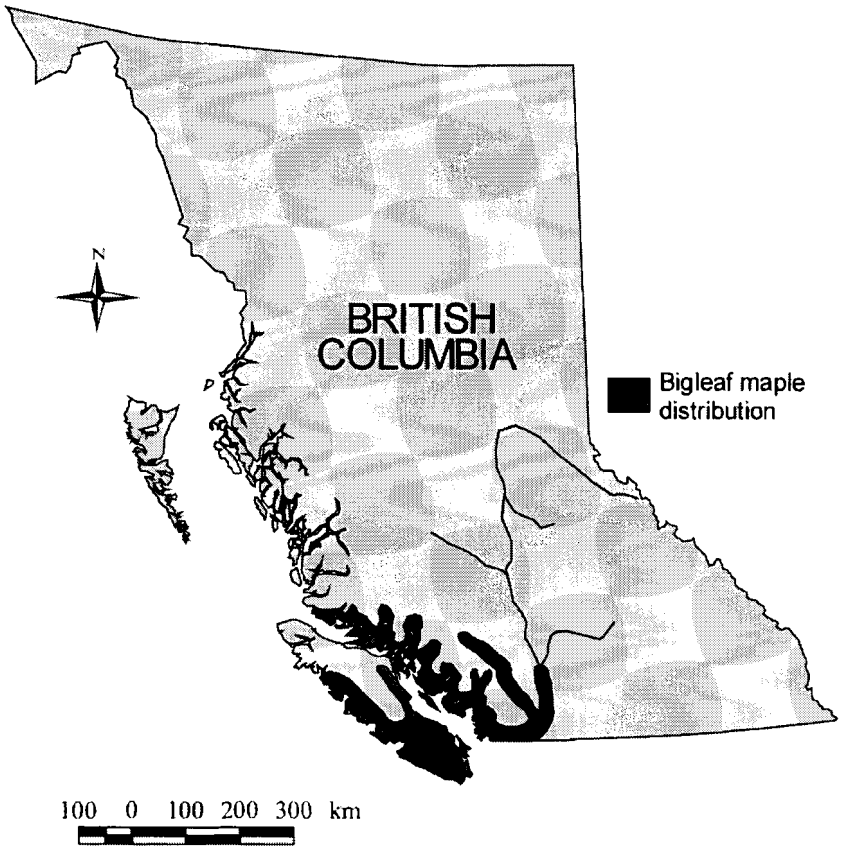


**Figure 1.1. Canadian distribution of bigleaf maple (*Acer macrophyllum* Pursh) in southwestern British Columbia (modified from Haeussler et al. 1990).**

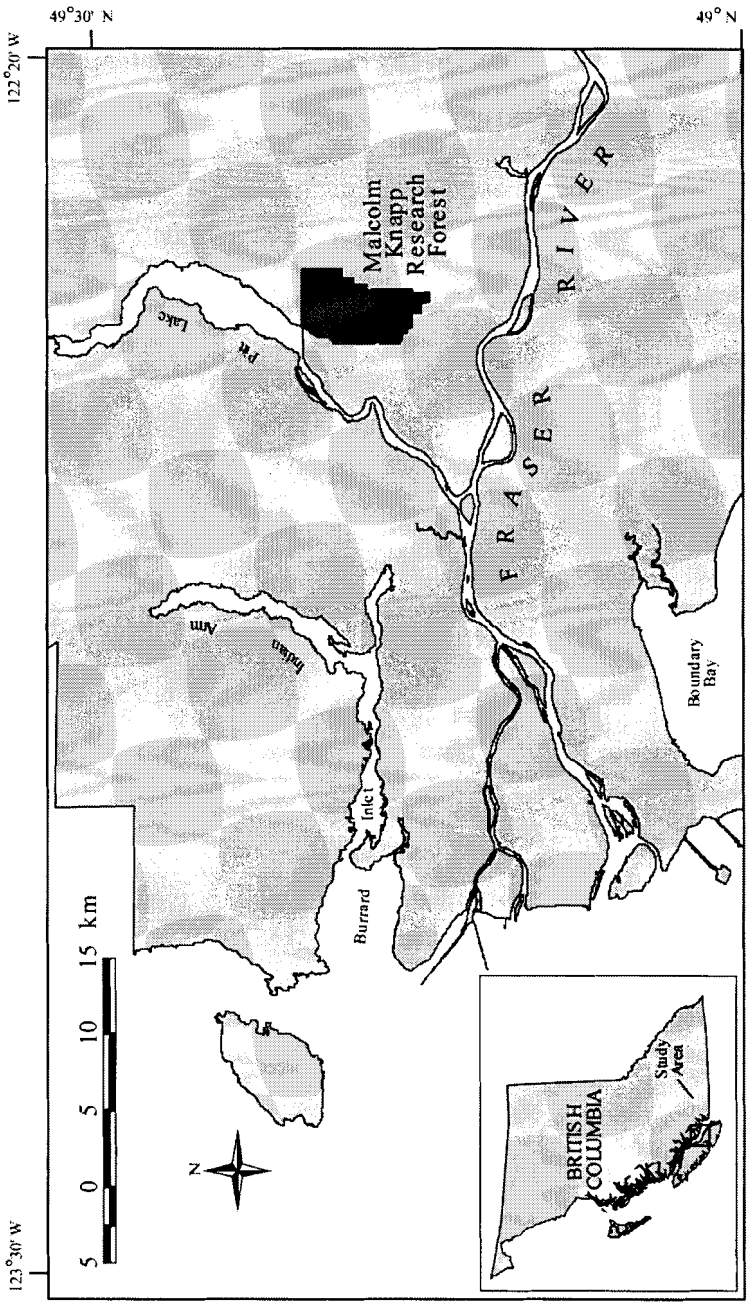


**Figure 1.2. Location of study area, the UBC Malcolm Knapp Research Forest, Maple Ridge, British Columbia, Canada.**

# CHAPTER 2: BIGLEAF MAPLE INFLUENCE ON FOREST FLOOR ACIDITY AND DEPTH IN COASTAL CONIFER FORESTS OF SOUTHWEST BC

## 2.1 Abstract

The research objective was to determine the spatial extent to which bigleaf maple (*Acer macrophyllum* Pursh) canopy and tree stem influence forest floor pH and depth. Forest floor pH in response to slope and microtopography was also investigated. Forest floor samples were collected at 1 m intervals along 6 transects 40 m in length extending upslope and downslope from beneath individual bigleaf maple trees. The fresh forest floor samples were tested for pH. Wavelet analysis, student t-tests and Analysis of variance (ANOVA) were used to detect patterns in the data. When all transects were tested at once with *t*-tests, the forest floor pH was found to be significantly higher ($P < 0.001$) up to a distance of 3 m from the bigleaf maple stems and directly beneath the crown projection than in the surrounding forest floor. Slope position (up or down slope of the stem) and microtopographic position (pit or mound) were not found to significantly influence forest floor pH. ANOVA detected significant differences ($P < 0.05$) in pH and forest floor thickness between three site types; stem, canopy and beyond the canopy extent. Results of this study indicate that bigleaf maple positively influences forest floor pH and thickness at a scale relative to an individual tree's stem and canopy.

## 2.2 Introduction

While bigleaf maple (*Acer macrophyllum* Pursh) (BLM) is a common and large tree species with potential commercial value (B.C. Ministry of Forests, 1999), little is known about the degree and spatial extent of its impact on the surrounding forest floor. BLM may act as a nutrient sink by locking nutrients (that may otherwise be leached through the soil profile and out of the ecosystem) in its biomass (Minore, 1979). BLM may also input its nutrients into the surrounding soil, thereby improving site fertility, via throughfall, litterfall, stemflow, root dispersal, bark water retention, and biotic consumption, relocation and waste (Hosie, 1969; Fried et al. 1990).

As the largest maple in western Canada, BLM has a complex and majestic physical structure that provides for the needs of many organisms including habitat and food sources from its seeds, stems and litter (Fried et al. 1988; Hartwig et al., 2004). Despite the ecological and economic benefit of BLM, it has been considered a competitor of Douglas-fir stands and is often removed from stands and managed to control its presence (Hauessler, 1990).

The influence of deciduous species on soil properties in conifer forests has been the focus of several studies (Prescott, 2002; Tashe and Schmidt, 2003; Washburn and Arthur, 2003), yet to date there have been no studies to determine the influence of BLM on forest floor properties at plot-scale in British Columbia's coastal forests. One of the few studies on BLM was conducted in western Oregon and compared the physical and chemical properties of forest floor and mineral soil beneath 5 paired plots of BLM and Douglas-fir

[*Pseudotsuga menziesii* (Mirb.) Franco] (Fried et al. 1990). No significant differences were found in the biomass and nutrient content of forest floor, however, litterfall nutrient content and annual litterfall weight were significantly higher and turnover rates of forest floor nutrients were significantly faster beneath BLM.

The variable chosen in my study, soil pH, is important because it controls the availability of elements both required and toxic to plants and organisms (Brady and Weil, 2002). It plays a role in the weathering of minerals, it is critical to the soil's cation exchange complex and it influences chemical reactions, particularly hydrolysis and redox reactions (Fisher and Binkley, 2000). The foliage, wood, bark and leaf litter of BLM have relatively high levels of bases compared to other northwestern trees (Minore, 1979). BLM may release its base cations into the surrounding soil matrix, thereby increasing the pH of generally nutrient poor soils.

Areas within conifer forest occupied by vine maple (*Acer circinatum* Pursh) have been found to have higher pH, and concentrations of Ca, Mg, and K, in the forest floor as well as thinner forest floors than conifer areas not occupied by vine maple in southwest BC (Ogden and Schmidt, 1997). Forest floor properties may also be influenced by abiotic factors such as slope and microtopography. A study conducted in a coastal western hemlock [*Tsuga heterophylla* (Raf.) Sarg.] forest located in southwest BC compared soil temperature and soil water in pits and mounds under paired plots of vine maple gaps and conifer canopies (Schmidt et al., 1998). Results indicate that pits were wetter than mounds in all seasons and

pits were cooler in the summer period and warmer in the winter period. It was found that the variability of soil climate was closely related to microtopography, overriding the influence of vine maple.

Another study on the spatial extent of influence of red alder (*Alnus rubra* Bong.) on soil chemistry was conducted at two sites, one infertile and one fertile (as determined by site index) in western Washington (Rhoades and Binkley, 1992). This study found an increase in N availability in a mixed conifer stand that extended 8 - 12 m downslope into a pure conifer stand at the infertile site. This trend differed at the relatively fertile site where there was an increase in pH at the conifer stand that extended 5 m into the mixed conifer forest downslope and upslope. This indicates that soil properties may be more closely related to tree species composition and/or other factors than slope.

Soils are considered to be the product of five variables; climate, relief, organisms, parent material, and time (Jenny, 1941). In the current study, one biotic factor, BLM, and one abiotic factor, relief, are under consideration while the other three factors (climate, parent material, and time) are considered constant. The objectives of this study were to *(i)* determine the spatial extent to which BLM canopy and tree stem influence forest floor pH and depth; and *(ii)* investigate the influence of slope and microtopography on the spatial variability of forest floor pH under BLM influence.

## 2.3 Methodology

### 2.3.1 Study Site

The study area is described in section 1.3. The study site (Fig. 2.1) is 1 ha (100 m x 100 m) with a westerly aspect and with slopes ranging on average from 15 – 37 %. It is located between a forestry road along the eastern edge and a stream along the western edge. There is a gradual rolling pattern creating small, flat benches across the slope, with large stump mounds and rocks, up to 3 m in diameter, dispersed across the site. The landscape is also highly heterogeneous on a microtopographic scale with several pit/mound undulations occurring within a 1 m distance and with the pits/mounds averaging from 30 - 50 cm each in size. The undulations generally occurred in an upslope/downslope orientation, but the study site was relatively level across the slope.

The predominant soil types of the study site are Humo-Ferric Podzols derived from ablation till overlaying basal till. These are generally coarse-textured soils of nutrient poor and acidic parent materials such as granodiorites (Meidinger and Pojar, 1991). These soils characteristically have a low nutrient holding capacity and enable considerable leaching, resulting in overall low soil fertility (Tashe and Schmidt, 2001).

### 2.3.2 Sampling

Within the study site, six BLM plots were selected using the following criteria: (1) a BLM that is dominant within the stand; (2) the bole of the BLM is no

less than 15 m from any other dominant BLM or deciduous tree species; (3) the bole of the BLM is no less than 25 m from roads, skid trails, and recently deforested sites and (4) the plot is undisturbed by other research studies, debris flow, water courses or other influences which may significantly reduce the quality of the study. DBH of the BLM stems on transects 1 to 5 are as follows: 0.50, 0.96, 0.44, 0.40, and 1.05 m. Transect 6 had two stems with DBH of 0.78 m and 0.40 m. Location of the tree stem and canopy edges along the transect were recorded.

At each plot, forest floor was sampled at 1 m intervals along transects that extended from the BLM stem and into the conifer forest. The six transects (Fig. 2.2) were 40 m in length and began (0 m) 10 m upslope of the upslope canopy extent and continued downslope another 30 m. Forest floor samples were collected by carefully removing the fresh litter and with a trowel the F and H layers of the forest floor were removed and placed in a labelled sample bag. The following measurements were made at each sample location; forest floor depths (L, F, H); presence of Ah that is greater than 2cm in depth (yes/no) and type of F horizon (Fm or Fz); canopy type directly above sample location; and microtopographic position (pit, mound, slope or flat). Humus forms were classified (Green et al., 1993). Overall slope was measured by selecting segments of 10 m (or nearer where there was an abrupt change in slope) along the transect beginning at 0 m. All trees within 7 m of either side of each transect were mapped and the diameter at breast height of all trees greater than 30 mm was recorded.

A total of 283 forest floor samples were collected between June 21 and August 10, 2005. Samples were collected every 1 m along each transect except in the cases of transect 4 (points 36, 37 and 38), transect 5 (point 21) and transect 6 (point 21.5) which are missing data due to the presence of large rocks. The transects were also sampled more intensively about the stem (every 0.5 m) beginning at the center of the stem and continuing 3 m upslope and 5 m downslope. The fresh forest floor samples were analyzed for pH at Simon Fraser University with a glass electrode pH meter using a 1:4 soil-to-solution ratio with 0.01 *M* $CaCl_2$ as the suspension solution (Kalra and Maynard, 1991).

### 2.3.3 Descriptive Statistics

Mean, minimum, maximum, range and standard deviation were calculated (McGrew and Monroe, 2000) for each transect. The pH and microtopographic profile were plotted with the location of the stem and the projection of BLM canopy in order to visualize the variables collectively. Humus forms were also plotted with canopy and stem locations.

### 2.3.4 Wavelet Analysis

Wavelet analysis has been used to determine ecological boundaries (Dale and Mah, 1998; Fagan et al. 2003) and has been applied in soil science to determine abrupt changes in N mineralization over space (Redding et al., 2003). This procedure is a scalable windowing function and is very similar to local quadrat variance methods (Rosenberg, 2001). The variance at each point within

its scaled window (in this case 4 m) relative to the entire transect was calculated and peaks in variance were determined as single abrupt increases in variance (Redding et al., 2003). This function outputs the wavelet analysis in three ways; there is a variance x position graph, a variance x scale graph, and a position x scale graph which also includes variance by way of a colour ramp (the latter two are not reported in the current study).

This study applied wavelet transformation with PASSAGE (Rosenberg, 2001) to explore the variance of forest floor pH along 40 m transects hypothesized to be under the influence of BLM. The Mexican hat wavelet function (Fig. 2.3) was used, as it is a continuous function, with the parameters set to a maximum scale of 10 % (4 m). As wavelet analysis requires data points located at regular spatial intervals the pH data set was modified by removing the 0.5 m observations located about the stem of each transect. Locations along the transect with single dominant peaks in wavelet variance were visually compared with the pH graph to determine whether the variation was due to an increase or a decrease in pH and if this was in relation to stem or canopy presence.

### 2.3.5 Student *t*-tests and Analysis of Variance (ANOVA)

The high degree of variance (indicating an abrupt increase in pH) about the stem detected with the wavelet transformation led to the determination of the treatment classes with which to carry out two-sample difference of means *t*-tests (Student, 1908). It was hypothesized that the pH of the forest floor *(i)* less than 3 m from the tree stem was higher than that of the surrounding forest floor; *(ii)*

beneath the canopy but greater than 3 m from the stem was higher than that of the surrounding forest floor; and *(iii)* beneath the canopy (therefore including the stem) was higher than the surrounding forest floor (Fig. 2.4).

It was also hypothesized that the pH of the forest floor *(i)* downslope from the tree stem was higher than the pH of forest floor upslope from the tree stem; *(ii)* downslope from the downslope canopy extent was higher than the pH of forest floor upslope from the upslope canopy extent; and *(iii)* in pits was higher than the pH of forest floor on mounds. A significance level ($\alpha$) of 0.05 was used for all *t*-test data analysis. ANOVA with Tukey multiple comparison tests (Steele and Torrie, 1980) was applied to detect significant differences ($P$ = 0.05) in pH and forest floor thickness between three site types; within the stem's area of influence (< 3 m from the stem), beneath the canopy extent and outside the canopy extent. All statistical analyses were carried out with SPlus (Insightful Corp., 2005).

## 2.4 Results

### 2.4.1 Descriptive Statistics

pH values along the 6 transects as well as BLM stem, BLM, canopy, and microtopography along slope are illustrated (Fig. 2.5). Mean values of forest floor pH ranged from 4.23 to 4.77, while the minimum pH value varied from 3.01 to 3.87 and the maximum varied from 5.04 to 5.89 (Table 2.1). The range for each transect was relatively consistent between 2.02 and 2.29 pH units with standard deviations from 0.42 to 0.50 pH units. Sample points < 3 m from the tree stem

had 24 % mull, 64 % moder and 12 % mor humus forms (Fig. 2.6). Sample points under the BLM canopy but > 3 m from the stem had 42 % mull and 58 % moder humus forms. Sample points not beneath the BLM canopy had 42 % mull, 52 % moder and 6 % mor humus forms (Fig. 2.7).

### 2.4.2 Wavelet Analysis

Wavelet analysis was carried out (Fig. 2.8) and exceptionally high variance values occurred near the edges of transects. To reduce the edge effect of this method and to detect variance associated with the tree, the first and last 5 observations of each transect were removed. The remaining highest three values of each transect were ranked as first, second, or third and their locations on the transects were recorded (Table 2.2). Wavelet analysis of the pH data resulted in multiple peaks on transects 1, 5, and 6 at locations 13 m, 18 m, and 19 m and single dominant peaks on transects 2, 3, and 4 at 12 m, 14 m and 6 m.

The distance of the wavelet peak on each transect to a tree feature is reported for the highest three variance values (Table 2.3). The shortest distance per rank indicated stem influence with an extent of 0 - 1.5 m upslope and 0 - 2.5 m downslope. Two of the highest three ranked variance values on transects 1 and 2 occur at the upslope side of the stem and extended downslope, 2 m past the stem. On transects 4 and 5, two of the highest three ranked values are 1.5 m upslope of the stem, but 1 m downslope past the stem on transect 4 and 2.5 m downslope past the stem on transect 5. Transects 3 and 6 had the highest ranked value at 0 m on the upslope side of the stem, and both had only one value that could possibly be attributable to stem influence. Transect 6 also

indicated in the second and third highest rank values canopy influence 1 m downslope of the upslope canopy, extending until 3 m before the downslope canopy extent.

### 2.4.3 Student *t*-tests - *Bigleaf maple influence on forest floor pH*

Three student *t*-tests were used to detect tree stem and canopy influence. Results found that the tree's physical structures, stem and canopy, influence the forest floor pH on separate spatial scales. When all transects were tested together, the pH of the forest floor less than 3 m from the tree stem was significantly higher ($P < 0.001$) than the surrounding forest floor (Table 2.4). Forest floor pH beneath the canopy (but greater than 3 m from the stem) was significantly higher ($P < 0.001$) than the surrounding forest floor (Table 2.5). Forest floor pH beneath the canopy (therefore including the stem) was significantly higher ($P < 0.001$) than the surrounding forest floor (Table 2.6). Transect 1 did not follow the trend in all tests and transects 3 ($P = 0.30$) and 5 ($P = 0.076$) did not show significant differences in pH when the canopy influence without the stem was tested.

### 2.4.4 Student *t*-tests - *Slope and microtopography influence on forest floor pH*

The pH of the forest floor downslope of the tree stem was found to be significantly higher than the pH of forest floor upslope of the stem on 2 of the 6 transects; transect 1 ($P = 0.008$) and transect 6 ($P < 0.001$) (Table 2.7). When all transects were tested together the test indicated that an overall trend ($P = 0.064$) may exist. When the slope was considered from the canopy extent for each

transect (Table 2.8), no overall trend was detected ($P = 0.89$). The analysis of the microtopography data did not detect a significant trend in forest floor acidity. When each transect was tested for significant difference independently, the pH of forest floor on only transect 3 was significantly higher ($P = 0.004$) on the mounds than in pits (Table 2.9) and when all transects were tested together no significant trend was detected ($P = 0.31$).

### 2.4.5 ANOVA - *Bigleaf maple influence on forest floor pH and depth*

ANOVA detected significant differences in pH on transects 2 through 6 and all transects between the 3 site types; stem, canopy and outside the canopy extent (Table 2.10). Tukey multiple comparison tests of those 5 transects found that in all 5 cases, the forest floor < 3 m from the stem was significantly ($P < 0.05$) higher than the forest floor beyond the canopy extent. Furthermore, multiple comparisons of pH on transect 4 and all transects combined indicated that the forest floor pH directly beneath the canopy was significantly ($P < 0.05$) higher than the forest floor beyond the canopy extent.

The forest floor beneath the canopy extent was found to be significantly thinner ($P < 0.05$) than forest floor within area of stem influence on transects 2, 4 and on all transects as a group (Table 2.11). On transect 2, the forest floor beneath the canopy extent was found to be significantly thinner ($P < 0.05$) than forest floor outside canopy and on all transects as a group, the forest floor outside the canopy extent was found to be significantly thinner ($P < 0.05$) than forest floor within the area of stem influence.

## 2.5 Discussion

With the pH data, it was important to consider the variance in both spatial structure and magnitude. The current study detected significant differences in forest floor pH in relation to proximity from individual trees. Wavelet output indicated the highest magnitude in variance at locations relative to individual tree structures, particularly the stems. Results found that BLM stems significantly increased forest floor pH up to a distance of 1.5 m upslope of the stem and this pattern of influence extended as far as 2.5 m downslope of the stem. This approximate 2.5 m area of influence about the stem was tested and confirmed with *t*-tests and five out of the six transects indicated a local influence of 2.5 m. This could be a response to the heavy flow of water, carrying base cations from the tree foliage and tree bark, down the tree branches and stem into the surrounding forest floor.

Wavelet analysis results indicated that canopy influence may also be present, however, it was only detected on transect 6, within the canopy extent, and with only second and third ranked variance values. Although canopy influence was not detected quantitatively with wavelet analysis in all transects, the tree canopy was predicted and found with *t*-tests to be influencing the forest floor directly beneath its crown projection. The influence of the canopy is likely due to the input of nutrients to the forest floor via litterfall, and via throughfall. The combined influence of the crown projection and the stem was pronounced and had the lowest *P*-values of all six treatment class *t*-tests, supporting Fried's (1990) findings that the tree as a whole increases forest floor pH.

The difficulty in detecting BLM canopy influence with wavelet analysis could be caused by the relatively low magnitude of influence of BLM canopy compared to the stem. Its influence may not be strong enough to emit a discernable signal amid *(i)* the high degree of variation in soil properties; *(ii)* the concentrated influence of the BLM stem (which can be located anywhere beneath the canopy); or *(iii)* the influence of canopies and stems of other trees along the transect. Furthermore, there may be other factors not included in this study related to the morphological properties of individual tree canopies (such as branching structure or canopy thickness and therefore the quantity of forest floor throughfall and sunlight interception or litter deposition and decomposition rates) that are moderating or dominating the pattern of canopy influence. Lastly, the wavelet function is not an optimum form of analysis as it is unable to transform data not sampled at equal intervals along transects. This can be problematic with highly variable soils data (often < 1 m) which often consists of missing data values due to the presence of other standing or fallen trees and large rocks (at times > 2 m in diameter).

Transects 1 and 6 had significantly different pH downslope than upslope from the stem, however transects 2, 3, 4 and 5 did not support this finding. The upslope section of transect 3 had on average a higher rather than lower pH than the downslope section, unlike transects 1, 2, 5 and 6. When all transects were tested together, a weak anisotropic pattern in forest floor pH in response to slope was detected. When testing for BLM patterns of influence upslope and downslope outside the canopy extent (thereby excluding stem influence), no

patterns were detected. This follows closely with the findings of Rhoades and Binkley (1992) suggesting that forest floor pH may be more influenced by tree species presence than slope.

Data analysis with student *t*-tests found no significant differences between the pH in pits and mounds except for in transect 3 which had significantly higher pH on mound sample locations. This is inverse to the expected trend since temperatures in pits are moderated with cooler conditions in the summer and warmer conditions in the winter. Schmidt et al. (1998) found pits to be wetter than mounds year-round. It is therefore conceivable that the nutrients deposited as leaf litter by the canopy directly above, and that may be found in pits, are leached by the excess of surface water that flows into the local depressions from the surrounding mounds. Furthermore, the few occurrences of pits and mounds relative to positions on the slope created small sample sizes of each microtopographic type (pit/mound) and may have reduced the opportunity of finding significant differences.

This study found that on all transects, the forest floor pH within stem influence and beneath the canopy extent was significantly higher ($P < 0.05$) than outside the canopy extent. No significant differences in forest floor pH were found between the stem area of influence and the canopy extent, although on every transect, the average pH under stem influence was higher than the pH of forest floor not under stem influence but beneath the canopy extent.

The forest floor was found to be thickest within the stem area of influence, but thinnest beneath the canopy extent, with the area outside of the canopy

extent having a comparatively moderate thickness. This supports the findings of Ogden and Schmidt (1997) who found thinner forest floors in relation to vine maple canopy extent.

## 2.6 Conclusion

Results of hypothesis testing indicated a pattern of influence on the spatial variation of forest floor pH that was closely associated with BLM canopy extent regardless of its shape, breadth (in this case 7 to 20 m) or its location in relation to the tree stem. Moreover, wavelet analysis results suggested that stemflow influences forest floor pH to a greater degree than crown projection area via throughfall and litterfall although it is on a finer spatial scale of approximately 2.5 m from the stem. This study also found that abiotic factors, such as relief may be influencing the pattern of soil pH found beneath BLM, although slope may have a stronger influence than microtopography. Forest floor thickness was also found to be influenced by individual tree structure with the thickest forest floors occurring within 3 m of individual tree stems and the thinnest forest floors situated directly beneath the canopy. Therefore, the spatial variability of forest floor pH and depth in response to BLM could arise from a combination of factors relying on individual tree morphology including canopy shape and stem location as well as abiotic factors such as slope and micro-scale relief.

It must also be noted that this study is only a snapshot in time and the influence of BLM on the structural complexity (including pit/mound micro-relief) created by treefall is not observed. Furthermore, species influence likely varies throughout the season, for example during the fall when litterfall is prominent or

during the winter when coastal rainfall is at its peak. The spatial structure of forest floor chemistry is also of interest in terms of spatial dependency of chemical properties to themselves and in relation to each other. Future research on species influence on forest floor properties could investigate the spatial structure of forest floor chemistry in relation to BLM in more than a single dimension, whether that added dimension be time or space.

## 2.7 Acknowledgements

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## 2.8 References

**B.C. Ministry of Forests. 1999.** Bigleaf Maple Managers' Handbook. Government of Canada, British Columbia. 105 pp.

**Brady, N. C., and Weil, R. R. 2002.** The Nature and Properties of Soils. Prentice Hall, New Jersey. 960 pp.

**Dale, M. and Mah, M. 1998.** The use of wavelets for spatial pattern analysis in ecology. J. Veg. Sci. **9:** 805-814.

**Fagan, W., Fortin, M.-J., and Soykan, C. 2003.** Integrating edge detection and dynamic modeling in quantitative analyses of ecological boundaries. Bioscience **53:** 730-738.

**Fisher, R. F., and Binkley, D. 2000.** Ecology and Management of Forest Soils. John Wiley & Sons, New York. 489 pp.

**Fried, J. S., Tappeiner, J. C., and Hibbs, D. E. 1988.** Bigleaf maple establishment and early growth in Douglas-fir forests. Can. J. For. Res. **18:** 1226-1233.

**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.

**Green, R. N., Trowbridge, R. L., Klinka, K. 1993.** Towards a taxonomic classification of humus forms. For. Sci. Monogr. **29:** 1-49.

**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, B.C. 272 pp.

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

**Hosie, R. C. 1969.** Native Trees of Canada. Authority of the Minister of Fisheries and Forestry. Ottawa, Ontario. 380 pp.

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

**Jenny, H. 1941.** Factors of Soil Formation. McGraw, New York. 281 pp.

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

**McGrew, J. C., and Monroe, C. B. 2000.** An Introduction to Statistical Problem Solving in Geography, second edition. McGraw-Hill, USA. 254 pp.

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

**Minore, D. 1979.** Comparative autecological characteristics of northwestern tree species - a literature review. U.S. Dep. Agric. For. Serv., Gen. Tech. Rep. PNW-87. 72 pp.

**Ogden, A. E. and Schmidt, M. G. 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.

**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.

**Prescott, C. 2002.** The influence of the forest canopy on nutrient cycling. Tree Physiology **22:** 1193-1200.

**Rhodes, C. C. and Binkley, D. 1992.** Spatial extent of impact of red alder on soil chemistry of adjacent conifer stands. Can. J. For. Res. **22:** 1434-1437.

**Rosenberg, M. R. 2001.** PASSAGE: Pattern Analysis, Spatial Statistics, and GeographicExigesis. Version 1.1 Release 3.4. Department of Biology, Arizona J.W.

**Schmidt, M., Ogden, A., and Lertzman, K. 1998.** Seasonal comparison of soil temperature and moisture in pits and mounds under vine maple gaps and conifer canopy in a coastal western hemlock forest. Can. J. Soil Sci. **78:** 291-300.

**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. pp. 633.

**Student** (William Gosset). 1908. The Probable Error of a Mean. Biometrika **6**: 1-25.

**Tashe, N. and M. Schmidt, M. 2001.** The impact of vine maple on site fertility of coastal temperate forests. Forest Ecology and Management **147:** 263-279.

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

**Washburn, C. S. M. and Arthur, M. A. 2003.** Spatial variability in soil nutrient availability in an oak-pine forest: potential effects of tree species. Can. J. For. Res. **33:** 2321-2330.

**Table 2.1. Mean (standard deviation in parentheses), minimum, maximum, and range for pH data, and aspect and slope of each transect.**

| | pH Data | | | | | | Aspect | Slope | |
|---|---|---|---|---|---|---|---|---|---|
| Transect | Mean | Standard Dev. | Min. | Max. | Range | *n* | | Distance (m) | % |
| 1 | 4.25 | (0.45) | 3.27 | 5.54 | 2.27 | 48 | 105° | 0 - 10 | 35 |
| | | | | | | | | 10 - 20 | 26 |
| | | | | | | | | 20 - 40 | 21 |
| 2 | 4.60 | (0.50) | 3.12 | 5.41 | 2.29 | 48 | 125° | 0 - 10 | 15 |
| | | | | | | | | 10 - 22 | 24 |
| | | | | | | | | 22 - 40 | 21 |
| 3 | 4.23 | (0.45) | 3.13 | 5.28 | 2.15 | 48 | 60° | 0 - 10 | 25 |
| | | | | | | | | 10 - 20 | 16 |
| | | | | | | | | 20 - 40 | 15 |
| 4 | 4.27 | (0.48) | 3.01 | 5.04 | 2.03 | 45 | 120° | 0 - 10 | 21 |
| | | | | | | | | 10 - 36 | 22 |
| 5 | 4.68 | (0.42) | 3.87 | 5.89 | 2.02 | 47 | 85° | 0 - 10 | 25 |
| | | | | | | | | 10 - 20 | 23 |
| | | | | | | | | 20 - 26 | 19 |
| | | | | | | | | 26 - 40 | 37 |
| 6 | 4.77 | (0.48) | 3.76 | 5.81 | 2.05 | 47 | 85° | 0 - 10 | 19 |
| | | | | | | | | 10 - 30 | 33 |
| | | | | | | | | 30 - 40 | 21 |

**Table 2.2. Results of wavelet analysis for forest floor pH. Values are the location on the transect, in meters, of the stem, canopy, and highest three ranked values of wavelet variance.**

| | Distance along transect (m) | | | | |
|---|---|---|---|---|---|
| | Bigleaf Maple | | Rank | | |
| Transect | Stem | Canopy | 1 | 2 | 3 |
| 1 | 10 - 11 | 10 - 25 | 13 - 14 | 34 | 10 |
| 2 | 12 - 14 | 10 - 26 | 12 | 16 - 17 | 33 |
| 3 | 12 - 14 | 10 - 17 | 14 | 33 | 30 |
| 4 | 15.5 - 16 | 10 - 19 | 6 | 14 | 17 |
| 5 | 13.5 - 14.5 | 10 - 22 | 17 - 18 | 12 | 27 |
| 6 | 16 - 18 | 10 - 30 | 18 - 19 | 27 | 11 |

Underlined values indicate dominant peak of multiple peaks, single values denote single dominant peaks.

**Table 2.3. Wavelet transform peaks for forest floor pH. Values are the distance (meters) of the highest three ranked values of wavelet variance in relation to upper (U) and lower (L) edge of the tree stem and tree canopy extent.**

| | Distance along transect (m) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Rank 1 | | | | Rank 2 | | | | Rank 3 | | | |
| | Stem | | Canopy | | Stem | | Canopy | | Stem | | Canopy | |
| Transect | U | L | U | L | U | L | U | L | U | L | U | L |
| 1 | $3^b$ | $2^b$ | $3^b$ | $11^a$ | $24^b$ | $23^b$ | $24^b$ | $9^b$ | 0 | $1^a$ | 0 | $15^a$ |
| 2 | 0 | $2^b$ | $2^b$ | $14^a$ | $4^b$ | $2^b$ | $6^b$ | $9^a$ | $21^b$ | $19^b$ | $23^b$ | $7^b$ |
| 3 | $2^b$ | 0 | $4^b$ | $3^a$ | $21^b$ | $19^b$ | $23^b$ | $16^b$ | $18^b$ | $16^b$ | $20^b$ | $13^b$ |
| 4 | $9.5^a$ | $10^a$ | $4^a$ | $13^a$ | $1.5^a$ | $2^a$ | $4^b$ | $5^a$ | $1.5^b$ | $1^b$ | $7^b$ | $2^a$ |
| 5 | $3.5^b$ | $2.5^b$ | $7^b$ | $4^a$ | $1.5^a$ | $2.5^a$ | $2^b$ | $10^a$ | $13.5^b$ | $12.5^b$ | $17^b$ | $5^b$ |
| 6 | $2^b$ | 0 | $8^b$ | $11^a$ | $11^b$ | $9^b$ | $17^b$ | $3^a$ | $5^a$ | $7^a$ | $1^b$ | $19^a$ |

Underlined values indicate the distance of nearest peak to tree feature in each rank.

[a] Wavelet variance peaks located upslope of tree feature edge.

[b] Wavelet variance peaks located downslope of tree feature edge.

**Table 2.4. pH of forest floor on transects 1 - 6 at distances less than 3 m from bigleaf maple stem and greater than 3 m from bigleaf maple stem.**

| | Stem | | | | | | |
|---|---|---|---|---|---|---|---|
| Transect | Stem + 2.5 m | | *n* | > 2.5 m from stem | | *n* | *P* (*t*-test) |
| 1 | 4.28 | (0.69) | 11 | 4.24 | (0.36) | 37 | 0.80 |
| 2 | 4.95 | (0.36) | 13 | 4.47 | (0.48) | 35 | 0.0021 |
| 3 | 4.65 | (0.35) | 11 | 4.11 | (0.40) | 37 | < 0.001 |
| 4 | 4.68 | (0.20) | 11 | 4.14 | (0.47) | 34 | < 0.001 |
| 5 | 5.05 | (0.50) | 11 | 4.57 | (0.32) | 36 | < 0.001 |
| 6 | 4.99 | (0.66) | 13 | 4.68 | (0.37) | 34 | 0.045 |
| All | 4.78 | (0.54) | 70 | 4.36 | (0.45) | 213 | < 0.001 |

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

**Table 2.5. pH of forest floor on transects 1 - 6 beneath bigleaf maple canopy and beneath bigleaf maple canopy gaps (not including areas of stem influence).**

| | Canopy (not including Stem) | | | | | | *P* |
|---|---|---|---|---|---|---|---|
| Transect | Canopy | | *n* | No Canopy | | *n* | (*t*-test) |
| 1 | 4.27 | (0.20) | 14 | 4.18 | (0.44) | 23 | 0.48 |
| 2 | 4.71 | (0.29) | 12 | 4.35 | (0.52) | 23 | 0.033 |
| 3 | 4.31 | (0.13) | 4 | 4.08 | (0.42) | 33 | 0.30 |
| 4 | 4.69 | (0.23) | 7 | 4.00 | (0.41) | 27 | < 0.001 |
| 5 | 4.73 | (0.42) | 9 | 4.51 | (0.27) | 27 | 0.076 |
| 6 | 4.91 | (0.42) | 15 | 4.52 | (0.24) | 19 | 0.0017 |
| All | 4.63 | (0.39) | 61 | 4.25 | (0.44) | 152 | < 0.001 |

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

**Table 2.6. pH of forest floor on transects 1 - 6 beneath bigleaf maple canopy and beneath bigleaf maple canopy gaps.**

| | Canopy (including Stem) | | | | | | *P* |
|---|---|---|---|---|---|---|---|
| Transect | Canopy | | *n* | No Canopy | | *n* | (*t*-test) |
| 1 | 4.28 | (0.47) | 25 | 4.18 | (0.44) | 23 | 0.70 |
| 2 | 4.84 | (0.34) | 25 | 4.35 | (0.52) | 23 | < 0.001 |
| 3 | 4.56 | (0.34) | 15 | 4.08 | (0.42) | 33 | < 0.001 |
| 4 | 4.68 | (0.20) | 18 | 4.00 | (0.41) | 27 | < 0.001 |
| 5 | 4.90 | (0.48) | 20 | 4.51 | (0.26) | 27 | < 0.001 |
| 6 | 4.95 | (0.54) | 28 | 4.52 | (0.24) | 19 | 0.0020 |
| All | 4.74 | (0.47) | 131 | 4.26 | (0.44) | 152 | < 0.001 |

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

**Table 2.7. pH of forest floor on transects 1 - 6 downslope from the bigleaf maple stem and upslope from the bigleaf maple stem.**

| | Slope (from Bigleaf Maple Stem) | | | | | | *P* |
|---|---|---|---|---|---|---|---|
| Transect | Downslope | | *n* | Upslope | | *n* | (*t*-test) |
| 1 | 4.35 | (0.43) | 34 | 3.98 | (0.40) | 14 | 0.0081 |
| 2 | 4.62 | (0.52) | 31 | 4.59 | (0.47) | 17 | 0.83 |
| 3 | 4.15 | (0.47) | 32 | 4.38 | (0.32) | 16 | 0.083 |
| 4 | 4.21 | (0.49) | 26 | 4.38 | (0.48) | 19 | 0.25 |
| 5 | 4.70 | (0.43) | 32 | 4.63 | (0.41) | 15 | 0.55 |
| 6 | 5.08 | (0.40) | 27 | 4.36 | (0.28) | 20 | < 0.001 |
| All | 4.51 | (0.54) | 182 | 4.40 | (0.44) | 101 | 0.064 |

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

**Table 2.8. pH of forest floor on transects 1 - 6 downslope from the bigleaf maple canopy and upslope from the bigleaf maple canopy.**

| | Slope (from Bigleaf Maple Canopy Edge) | | | | | | *P* |
|---|---|---|---|---|---|---|---|
| Transect | Downslope | | *n* | Upslope | | *n* | (*t*-test) |
| 1 | 4.35 | (0.43) | 14 | 4.01 | (0.40) | 13 | 0.042 |
| 2 | 4.37 | (0.57) | 14 | 4.35 | (0.44) | 10 | 0.94 |
| 3 | 4.00 | (0.43) | 23 | 4.28 | (0.34) | 10 | 0.076 |
| 4 | 3.93 | (0.33) | 17 | 4.12 | (0.51) | 10 | 0.24 |
| 5 | 4.53 | (0.21) | 19 | 4.46 | (0.34) | 10 | 0.48 |
| 6 | 4.69 | (0.16) | 9 | 4.37 | (0.20) | 10 | 0.001 |
| All | 4.26 | (0.46) | 96 | 4.25 | (0.40) | 63 | 0.89 |

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

**Table 2.9. pH of forest floor on transects 1 - 6 located in pits and on mounds.**

| | Microtopography | | | | | | *P* |
|---|---|---|---|---|---|---|---|
| Transect | Pit | | *n* | Mound | | *n* | (*t*-test) |
| 1 | 4.38 | (0.19) | 3 | 4.43 | (0.39) | 7 | 0.85 |
| 2 | 4.58 | (0.49) | 6 | 3.98 | (0.74) | 5 | 0.14 |
| 3 | 4.02 | (0.32) | 9 | 4.71 | (0.51) | 8 | 0.0039 |
| 4 | 4.15 | (0.31) | 4 | 4.30 | (0.40) | 4 | 0.59 |
| 5 | 4.81 | (0.47) | 6 | 4.78 | (0.62) | 9 | 0.92 |
| 6 | 4.79 | (0.21) | 5 | 4.95 | (0.27) | 4 | 0.36 |
| All | 4.43 | (0.47) | 33 | 4.56 | (0.58) | 37 | 0.31 |

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

**Table 2.10. ANOVA (with Tukey multiple comparison test) of forest floor pH on transects 1 - 6 at 3 site types in relation to of individual bigleaf maple; within 2.5 m from the stem; 2.5 m from the stem to the canopy edge; and not under bigleaf maple canopy.**

| Transect | Stem + 2.5m | *n* | Stem +2.5m to Canopy Edge | *n* | Not under Canopy | *n* | *Prob. (F)* |
|---|---|---|---|---|---|---|---|
| 1 | 4.28 | 11 | 4.27 | 14 | 4.18 | 23 | 0.93 |
| 2 | 4.95*a* | 13 | 4.71*ab* | 12 | 4.35*b* | 23 | < 0.001 |
| 3 | 4.65*a* | 11 | 4.31*ab* | 4 | 4.08*b* | 33 | < 0.001 |
| 4 | 4.68*a* | 11 | 4.69*a* | 7 | 4.00*b* | 27 | < 0.001 |
| 5 | 4.97*a* | 11 | 4.91*ab* | 9 | 4.51*b* | 27 | < 0.001 |
| 6 | 4.99 | 13 | 4.91 | 15 | 4.52 | 19 | 0.010 |
| All | 4.78*a* | 70 | 4.64*a* | 60 | 4.26*b* | 153 | < 0.001 |

Underlined values indicate significant differences at $P < 0.05$.

Values with different letters in the same row are significantly different ($P < 0.05$).

**Table 2.11. ANOVA (with Tukey multiple comparison test) of forest floor depth on transects 1 - 6 at 3 site types in relation to of individual bigleaf maple; within 2.5 m from the stem; 2.5 m from the stem to the canopy edge; and not under bigleaf maple canopy.**

| Transect | Stem + 2.5m | *n* | Stem +2.5m to Canopy Edge | *n* | Not under Canopy | *n* | *Prob. (F)* |
|---|---|---|---|---|---|---|---|
| 1 | 2.23 | 11 | 1.57 | 14 | 1.78 | 23 | 0.077 |
| 2 | 3.19*a* | 13 | 1.83*b* | 12 | 2.76*a* | 23 | 0.0085 |
| 3 | 2.55 | 11 | 3.00 | 4 | 2.58 | 33 | 0.54 |
| 4 | 2.55*a* | 11 | 1.36*b* | 7 | 2.09*ab* | 27 | 0.012 |
| 5 | 2.27 | 11 | 1.94 | 9 | 2.19 | 27 | 0.75 |
| 6 | 3.00 | 13 | 3.00 | 15 | 2.63 | 19 | 0.33 |
| All | 2.66*a* | 70 | 2.10*b* | 60 | 2.34*b* | 153 | 0.0031 |

Underlined values indicate significant differences at $P < 0.05$.

Values with different letters in the same row are significantly different ($P < 0.05$).

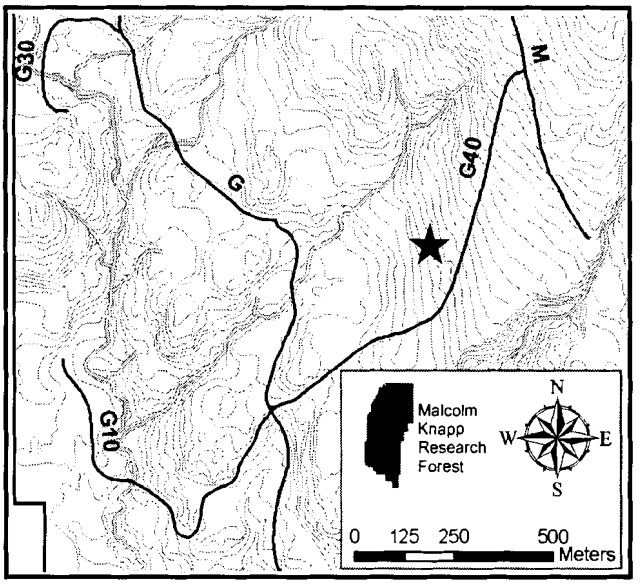


**Figure 2.1. Study site. UBC Malcolm Knapp Research Forest, southwest British Columbia, Canada.**

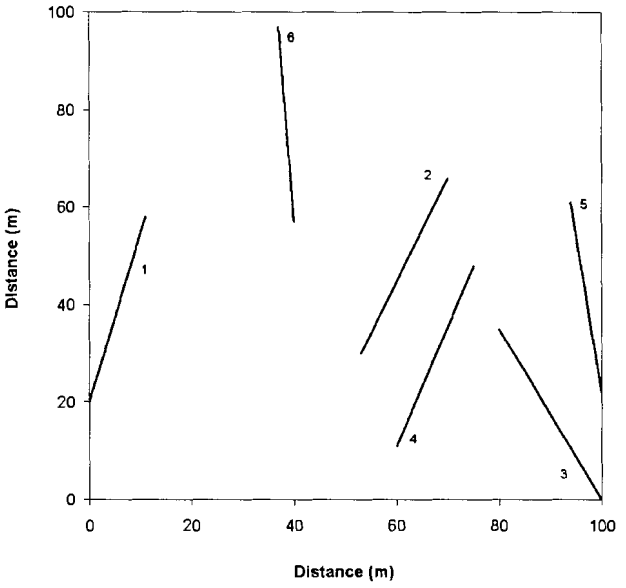


**Figure 2.2. Study site (100 m x 100 m) with 6 transects, each 40 m in length.**

$$g(x) = \frac{2}{\sqrt{3}} \pi^{-\frac{1}{4}} \left(1 - 4x^2\right) e^{-2x^2}$$

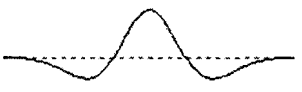

**Figure 2.3. The Mexican Hat wavelet function.**

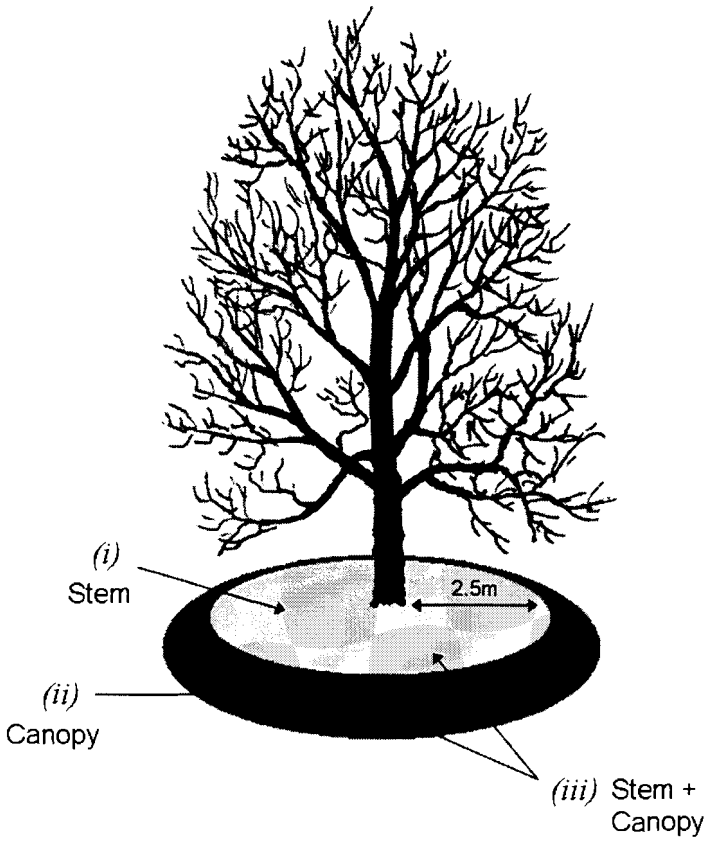


**Figure 2.4. Site types used to test bigleaf maple areas of influence on forest floor pH.**

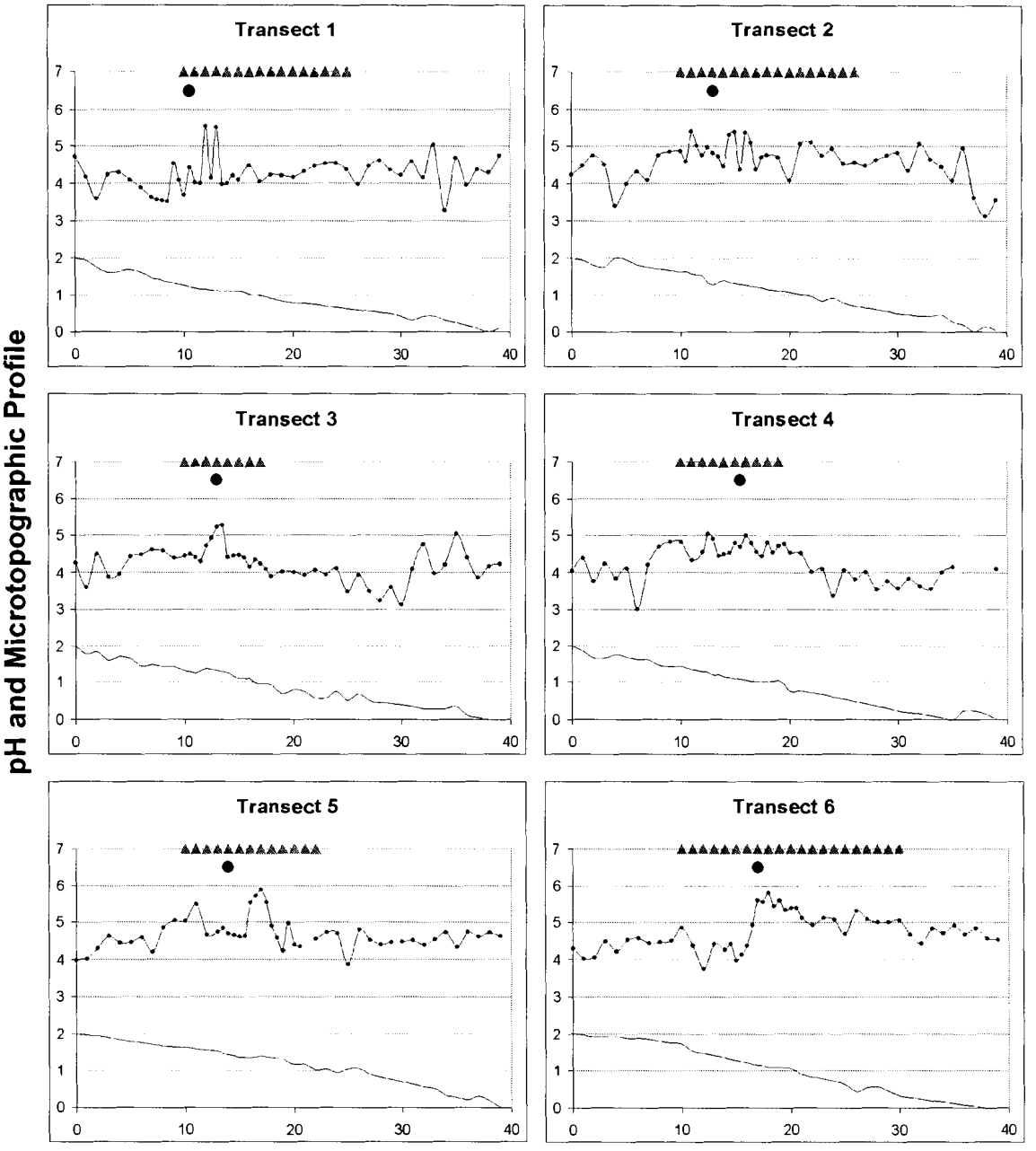


**Figure 2.5.** Tree stem location, canopy extent, pH, and topographic profile (0 m top of slope and 40 m bottom of slope) along 6 transects, each 40 m transects. Tree structural properties are indicated (● = stem location; ▲= canopy extent).

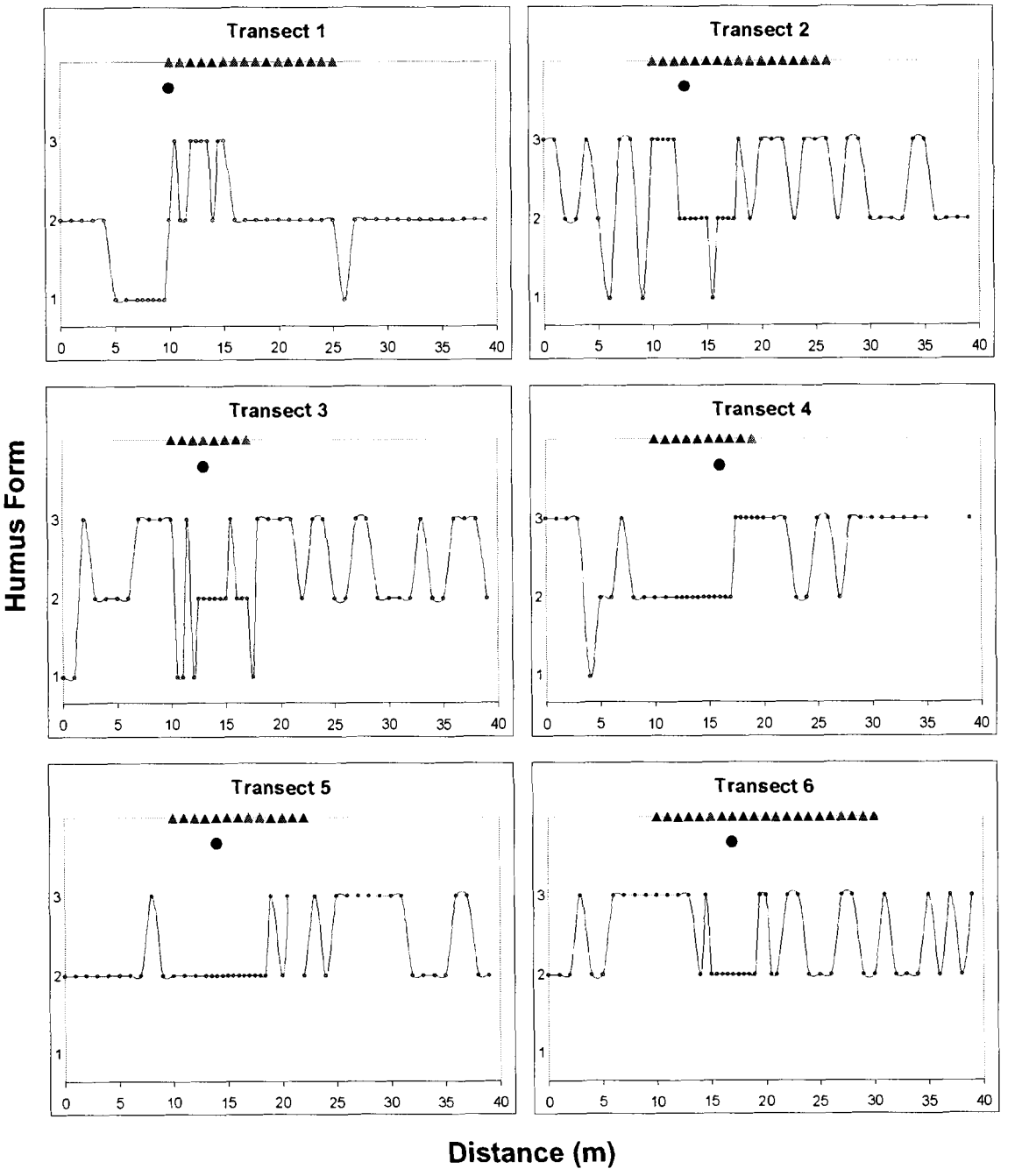


**Figure 2.6.** Humus form (mor = 1, moder = 2, mull = 3) along 6 transects, each 40 m in length. Tree structural properties are indicated (● = stem location; ▲ = canopy extent).

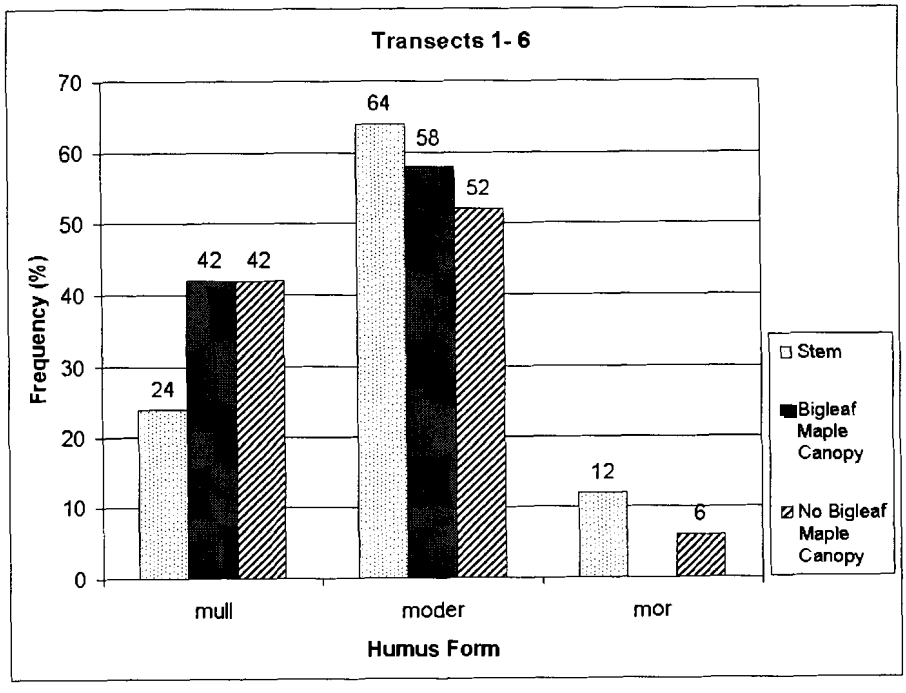


**Figure 2.7. Frequency (%) of humus forms on 6 transects of 40 m within the following treatment classes; stem (up to a distance of 3 m from the stem); canopy (not including locations of stem); and bigleaf maple canopy gap.**

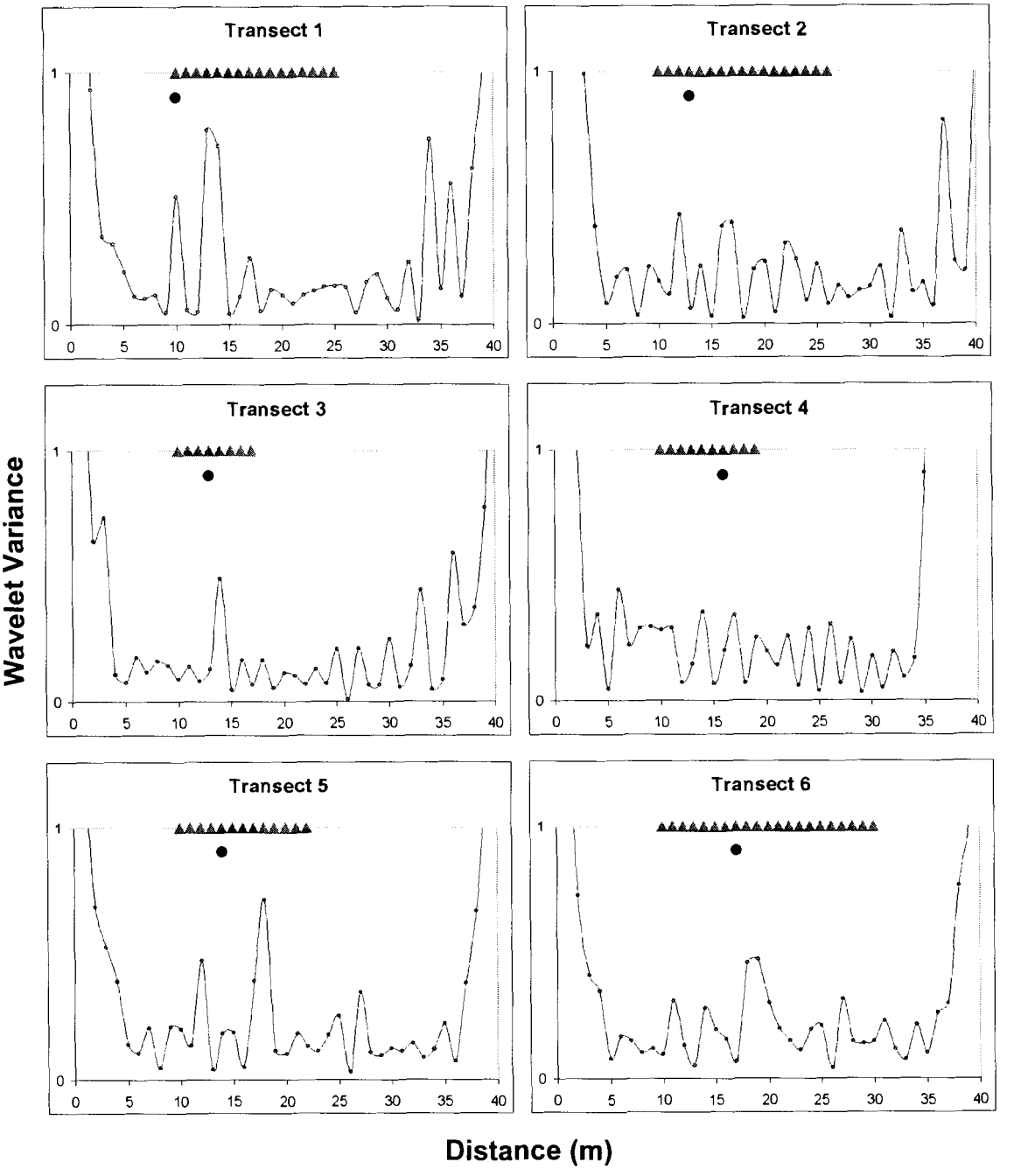


**Figure 2.8.** **Wavelet transforms of pH data along 6 transects, each 40 m in length. Tree structural properties are indicated (• = stem location; ▲ = canopy extent).**

# CHAPTER 3: ANALYTICAL METHODS FOR DEFINING SPATIAL PATTERNS OF FOREST FLOOR PROPERTIES AND LITTERFALL AMOUNTS ASSOCIATED WITH BIGLEAF MAPLE IN CONIFER FOREST

## 3.1 Abstract

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 x 36 m plots, centered on individual dominant bigleaf maple stems were sampled at systematic locations and tested for forest floor pH, cation exchange capacity, exchangeable cations (Ca, K, Mg, Al, Na, Fe, Mn) and mineralizable N. Tree stem location, canopy cover type, depths of forest floor horizons, forest floor weights per unit area, water content of forest floor and mineral soil, and litterfall mass (over a fall season of 16 weeks) were also measured. Spatial and aspatial analytical techniques were used to explore the pattern of influence of bigleaf maple on the surrounding soils. The kriging approach was used to illustrate the overall spatial patterns, SAA provided information about the behaviour and realm of influence of a property, and LISA statistics located points of statistical significance. Most soil chemical properties had higher concentrations in locations adjacent to the bigleaf maple stem on both study plots. All exchangeable cations on both plots were positively spatially

autocorrelated ($P < 0.05$) up to distances of 4 m. Tukey tests found significantly greater bigleaf maple leaf litter amounts ($P < 0.05$) beneath bigleaf maple canopy compared to conifer canopy on both plots. Plot 2 had significantly higher forest floor ($P < 0.01$) and mineral soil ($P < 0.04$) water contents beneath the canopy than beyond the canopy extent.

## 3.2 Introduction

### 3.2.1 Background Information

In the earlier part of the 20$^{th}$ century, Hans Jenny stated that there are five primary factors to soil formation; climate, organisms, relief, parent materials, and time (Jenny, 1941). This idea initiated many studies on the influence of trees on the chemistry of surrounding forest soils (Gast, 1937; Zinke, 1962; Mina, 1967; Gersper and Holowaychuck, 1971; Crampton, 1982; Boettcher and Kalisz, 1990; Escudero et al., 1991; Binkley, 1995; Binkley and Menyailo, 2005, as well as many others). The role of deciduous species within forest ecosystems has become an important topic to land managers interested in quantifying how these trees influence nutrient cycling and soil nutrient availability (Chen et al., 2004; Fried et al., 1990; Ogden and Schmidt, 1997; Wardman and Schmidt, 1998; and Washburn and Arthur, 2003). This is an area of study that includes researchers interested in optimal forest productivity (B.C. Ministry of Forests, 1999; Maas-Hebner et al., 2005; Mottonen et al., 1999) as well as ecologists and those not only interested in commercial timber values (Barker et al., 2002; Carrey and Harrington, 2001; Finzi et al., 1998; Hartwig et al., 2004).

### 3.2.2 Research Rationale

Few studies have been conducted to determine the influence of bigleaf maple (*Acer macrophyllum* Pursh) (BLM) on the surrounding soils within conifer forests of the Pacific northwest. The only current published study was conducted in western Oregon using a paired plot sample design with five BLM plots paired with five Douglas-fir [*Pseudotsuga menziesii* (Mirb.) Franco] plots (Fried, 1990). Fried's study found that all sites with BLM had higher annual litterfall weights and mineral soil nutrient contents for N, P, K, Ca, S, and Mg than Douglas-fir sites. However, no significant differences in forest floor biomass and nutrient content were found between the two site types.

The hypothesis that spatial patterns of soil properties are at least in part influenced by individual trees has in the past been addressed using sample designs that have incorporated paired plots (Fried, 1990; Ogden and Schmidt, 1997; Wardman and Schmidt, 1998; Tashe and Schmidt, 2003), transects (Zinke, 1962) and systematic sample locations in relation to individual trees (i.e. at the tree stem, and below canopy periphery) (Crampton, 1984; Escudero et al., 1991). However, there have been no studies to date that have resulted in a description of soil properties under the influence of BLM throughout a 2 dimensional space This study provides an example of a plot-scale study, contributing new knowledge concerning the impact of deciduous species growing in conifer forest on soil properties and demonstrates the use of analytical techniques to assess the spatial extent of this influence.

### 3.2.3 Research Objectives

The objective of this study was to detect the spatial characteristics of forest floor properties and litterfall amounts related to BLM within conifer forest. The specific objectives of this study were to *(i)* explore spatial patterns of forest floor properties and litterfall amounts under the influence of individual BLM stems with kriging and spatial autocorrelation analysis and; *(ii)* determine statistical significance in the observed spatial patterns in forest floor properties and litterfall amounts under the influence of BLM using local indicators of spatial association and parametric statistics.

## 3.3 Methodology

### 3.3.1 Plot Selection

The study area is described in section 1.3. Two BLM plots (Fig. 3.1) were selected based on the following criteria: (1) a BLM dominant within the stand; (2) the bole of the BLM no less than 15 m from any other dominant BLM or deciduous trees; (3) the bole of the BLM no less than 25 m from roads, skid trails, and recently deforested sites; and (4) a plot undisturbed by other research studies, debris flow, water courses or other influences which could significantly reduce the quality of the study. Each plot was 36 m x 36 m in size and centered about a single BLM stem. Plot 1 is in a 140-year-old stand of a mixture of Douglas-fir, western red cedar (*Thuja plicata* Donn) and western hemlock [*Tsuga heterophylla* (Raf.) Sarg.] naturally regenerated from a fire that occurred in 1868.

Plot 2 is in a 70-year-old stand and is a natural regeneration from a fire that occurred in 1931 consisting primarily of western hemlock and western red cedar.

All trees within each plot and up to 7 m from the edge of the plots, with a diameter at breast height > 3 cm, were mapped. For each tree the following was recorded: x, y coordinates of stem, species, and diameter at breast height. The canopy extent of each conifer was determined by the radius from the stem to the outer edge of the canopy. The canopy extent of the central BLM was recorded as the radius from the stem to the edge of the tree canopy at 16 points around the tree (every 22.5 degrees).

### 3.3.2 Sampling Design

Two sampling designs were used within each 36 m x 36 m plot. Both designs were centered about the BLM stem selected for each of the two plots (Fig. 3.2). The first design (A) consisted of two grids with upslope at the top of the grid and downslope at the bottom of the grid. For the first grid, flags were placed at each 4 m x 4 m node and samples were collected from the center of four surrounding nodes ($n$ = 81). Within this larger grid was a smaller (8 m x 8 m) grid also centered on the BLM, with flags placed at each 1 m node and samples collected from the center of four surrounding nodes ($n$ = 49). Both grids shared only the central sample point, located at the tree stem and both grids of each plot were sampled on the same day. At the 129 sample locations, forest floor samples were collected for analysis of chemical properties and forest floor depths were measured.

The second sampling design (B) consisted of a single grid with 25 points forming the shape of a diamond 36 m long and 36 m wide. Design B was a subset of design A; all points on design B were shared with 25 of the points on the larger grid (with 4 m spacing) of Design A. Sample locations were 5.65 m apart at right angles and 8 m apart horizontally. This design was used for the following measurements; (*i*) forest floor sampling to measure water content and weight per unit area; (*ii*) mineral core extraction to measure water content and bulk density of mineral soil directly beneath the forest floor samples; and (*iii*) litterfall collection.

### 3.3.3 Forest Floor and Mineral Soil Sampling

At each of the two plots, forest floor samples were collected at 129 sampling points (including both the 4 m and 1 m sample grids) for sample design A. Plot 1 was sampled on August 26, 2005 and plot 2 was sampled on September 2, 2005. The samples were collected with a trowel by removing a section of the forest floor down to the mineral soil, measuring forest floor horizon depths, and then carefully removing F and H forest floor material and placing it into a labelled sample bag for transport to the Soils Laboratory at Simon Fraser University. At each sample location, the tree canopy type (BLM, Douglas-fir, western hemlock, western red cedar, red alder (*Alnus rubra* Bong.), and vine maple (*Acer circinatum* Pursh)) directly above the sample location was recorded.

At each plot for sample design B, 15 cm x 15 cm intact forest floor samples were collected to the depth of mineral soil at the 25 sample locations.

Plot 1 was sampled on August 28, 2005 and plot 2 was sampled September 3, 2005. Once the intact forest floor samples were removed, mineral soil lying directly beneath was collected using a bulk density hammer and cylinder (7.5 cm high x 7.2 cm in inner diameter).

### 3.3.4 Litterfall Collection

Litterfall was collected using 25 cm x 50 cm greenhouse trays with holes in the bottom to allow drainage and lined with 1 mm nylon mesh. On September 1, 2005, greenhouse trays were placed at 25 sampling locations (Sampling Design B) on the 36 m x 36 m grids. Litterfall that had accumulated in the trays was collected biweekly over 4 months (from September 14 until December 22, 2005). The litter samples were oven dried at 70° C overnight and then sorted into the following 5 categories; BLM leaves; BLM samara; cedar bough or scales; Douglas-fir or hemlock needles; and other. The 'other' geneally consisted of small twigs, fern or moss, and insect frass. Each of the five litter types for all 25 sample locations on both grids for each of 8 collection periods was weighed.

### 3.3.5 Laboratory Analysis

For the 129 forest floor samples per plot from sample design A, pH was measured on field-moist forest floor samples the same day as collection. The pH testing was conducted at Simon Fraser University and followed standard procedures with a 1:4 soil-to-solution ratio with 0.01 *M* $CaCl_2$ as the suspension solution (Kalra and Maynard, 1991). The suspension was stirred every 5 minutes

for 30 minutes and left to settle for the following 30 minutes. The pH was measured by immersing a glass electrode pH meter into the supernatant solution. The pH value was recorded after the reading on the pH meter stabilized (usually within 1 minute).

The forest floor samples from plots 1 and 2 were air-dried and further chemical analysis was conducted by the Ministry of Forests and Range, Research Branch Laboratory, Victoria, BC. The 129 samples from each plot were analyzed for cation exchange capacity, exchangeable cations, and mineralizable nitrogen. Cation exchange capacity and exchangeable cations (Ca, K, Mg, Al, Na, Fe, Mn) were measured using a standard displacement method ($BaCl_2$) (Hendershot and Duquette, 1986) with ICAP spectrometry to measure the solution. The sum of cations indicated the cation exchange capacity. To determine mineralizable nitrogen, organic and inorganic forms of nitrogen were converted into mineralized forms with an incubation method (Bremner, 1965, 1996; Kenney and Bremner 1966; Waring and Bremner 1964*a*; Waring and Bremner 1964*b*). The forest floor samples were incubated under anaerobic conditions for two weeks at 30° C. These conditions permitted soil anaerobes to break down the available forms of nitrogen to ammonium. The ammonium was then displaced from the soil with 1N KCl extractant and measured colorimetrically with a Technicon Auto-analyzer II.

The 15 cm x 15 cm intact forest floor samples (25) and mineral cores (25) were carefully transported to the soils laboratory at Simon Fraser University. They were weighed within 12 hours of collection, oven dried at 70° C (forest floor)

and at 105° C (mineral core samples) for 24 hours, and then reweighed. For the intact forest floor and mineral soil core samples the water content and weight per unit area (forest floor samples) or bulk density (mineral core samples) were calculated.

### 3.3.6 Exploratory Spatial Data Analysis

In this study, exploratory spatial data analysis (ESDA) (Tukey, 1977; Haining et al., 1998; Dragicevic et al., 2004) was used to explore spatial patterns of soil properties under the influence of BLM. ESDA was carried out with kriging and spatial autocorrelation analysis (SAA). ESDA encompasses a set of analytical approaches used to explore, synthesize and interpret spatial data. It allows for the flexibility of choices in methods to suit the requirements of the study as they might change throughout the study. As discoveries occur during data analysis, new questions or information might initiate the use of alternative tools that best investigate the data and test unforeseen hypotheses.

#### *3.3.6.1 Kriging*

Maps for each of the two plots were created with ArcMap (ESRI, 1999) to assist visual detection of spatial patterns indicating species influence. Universal kriging (Matheron, 1970; Oliver, 1990; Mottonen et al. 1999; Mueller et al., 2004) was used to interpolate the values of 129 points (sample design A) for the following forest floor properties; pH, CEC, Ca, K, mineralizable N, and horizon depths of the F, LFH, and Ah layers. Soil properties of samples collected at only

the 25 points (sample design B) (i.e. litterfall, mineral soil cores and intact forest floor samples) were not interpolated as the spatial lag between points was greater than the variability resulting in gradual but relatively homogeneous surfaces.

Kriging is an interpolation method that originated from geostatistics. It models the spatial structure of sampled data and enables the prediction of values at unsampled locations. With this technique, spatially continuous maps of the properties over the study region were constructed based on the spatial variance (estimated spatial structure) of each property. pH values on each plot were presented as a continuous surface with stretched symbology where the highest value = white; and lowest value = black to provide an example of the continuous surface prior to discretization. The surface values of all the kriging output surfaces were classified and presented in five discrete classes and each kriging surface was then overlaid with BLM canopy extent.

*3.3.6.2 Spatial Autocorrelation Analysis*

SAA was performed to construct correlograms of the forest floor chemical properties (pH, CEC, Ca, K, and mineralizable N) and horizon depths (F, LFH, and Ah) using the values of 129 points (1 m and 4 m resolution sample grids), 49 sample points (1 m resolution sample grid), and 81 sample points (4 m resolution sample grid). Correlograms chart the resulting Moran *I* values over distance classes and were constructed with PASSAGE (Rosenberg, 1998). The 25 points of design B (litterfall, mineral soil cores and intact forest floor samples) were not

tested with SAA because of the small sample size, and minimum distance of 5.65 m between points.

SAA is the estimation of spatial autocorrelation using correlograms (Cliff and Ord, 1973). Spatial autocorrelation occurs where the state of a property at one sampling location can be dependent on the surrounding sampled points (non-random) and this relationship of dependency can vary over space. This relationship can be positive with similar spatial regimes or negative, with dissimilar spatial regimes. The strength of the relationship is translated as a value, the Moran *I* (Moran, 1950; Bailey and Gatrell, 1995) which can have a value between -1 (strong negative spatial autocorrelation) and 1 (strong positive spatial autocorrelation), and can also have a value of 0 indicating lack of spatial association.

### 3.3.7 Confirmatory Data Analysis

Confirmatory data analysis (CDA) (Tukey, 1977, 1980) usually follows ESDA; in this study, it was used to test the hypotheses and validate the patterns detected with ESDA. Confirmatory techniques included local indicators of spatial association (LISA; used to locate spatial regimes detected visually) and parametric statistics (ANOVA and t-tests; to determine significant differences between three site types). The three site types were BLM stem (the spatial extent of 2.5 m was determined by the Moran *I* correlograms of the 7 m x 7 m grid sampled at 1 m resolution); BLM canopy; and conifer canopy.

*3.3.7.1 Local Indicators of Spatial Association*

LISA was used to confirm the observed spatial patterns of forest floor chemical properties (pH, CEC, Ca, K, and mineralizable N) and horizon depths (F, LFH, and Ah) using the values of 129 sample points as well as litterfall and forest floor water content from the 25 points of sample design B on both plots. LISA cluster maps were created with GeoDa (Anselin, 1998, 2006) and a significance level of $\alpha = 0.05$ was used for all LISA analyses. LISA indicators decompose the global indicator of spatial association into the contribution of each observation (Anselin, 1995) and provide four outputs. The first is a significance map with a filter for $\alpha = 0.1$, $\alpha = 0.05$ and $\alpha = 0.01$. The second is a corresponding LISA cluster map that indicates the nature of the clusters; whether the clusters are of high values or low values and if the clusters are surrounded by points of high values or low values. A box plot and a Moran scatterplot are also produced.

*3.3.7.2 Parametric Statistics (ANOVA and t-tests)*

ANOVA with Tukey multiple comparison tests (Steele and Torrie, 1980) were used to detect significant differences ($P = 0.05$) in forest floor chemistry and forest floor horizon depths among site types. Data from sample design A ($n = 129$) were classified into three site types: BLM stem (0 m to 2.5 m from the stem); BLM canopy (2.5 m from the stem to the edge of the BLM canopy); and conifer (beyond the BLM canopy extent). Data collected with sample design B ($n = 25$) were tested with *t*-tests for significant differences ($P = 0.05$) between two

site types (BLM canopy and conifer canopy). This included litterfall amounts, forest floor and mineral soil water contents, and bulk density of mineral soil. All parametric statistical analyses were carried out with SPlus (Insightful Corp., 2005).

### 3.3.8 Litterfall

Litterfall was collected with sampling design B ($n$ = 25) for plots 1 and 2 over the collection period from September 1, 2005 to December 22, 2005. Total BLM litterfall (kg $ha^{-1}$) and total litterfall (kg $ha^{-1}$) were mapped with ArcMap (ESRI, 1999) and represented using graduated symbols overlaid with BLM canopy extent. Total litterfall (kg $ha^{-1}$) was presented with bar graphs using SPlus (Insightful Corp., 2005). The bar graphs indicate litter deposition amounts under the 2 canopy types (BLM and conifer) and over the 112 day collection period.

## 3.4 Results

### 3.4.1 Plot Characteristics

Stem locations and canopy extents of all trees on plots 1 and 2 were mapped (Fig. 3.3). Plot 1 was located along the west side of road G40 between the road and a stream. Mean elevation above sea level of plot 1 ranged from 150 m - 155 m. On plot 1, BLM basal area was 2 $m^2$ $ha^{-1}$, cedar was 38 $m^2$ $ha^{-1}$, Douglas-fir was 32 $m^2$ $ha^{-1}$ and western hemlock was 2 $m^2$ $ha^{-1}$. The diameter at breast height of the BLM on plot 1 was 861 mm with a canopy that extends 792

cm (standard deviation = 178 cm) from its trunk. Plot 2 was located on the east side of road F30, where the mean elevation above sea level ranged from 180 - 185 m. On plot 2, BLM basal area was 1 $m^2$ $ha^{-1}$, cedar was 64 $m^2$ $ha^{-1}$, Douglas-fir was absent and western hemlock was 6 $m^2$ $ha^{-1}$. The diameter at breast height of the BLM on plot 2 was 550 mm with a canopy that extends 715 cm (standard deviation = 199 cm) from its trunk.

### 3.4.2 Exploratory Spatial Data Analysis

#### *3.4.2.1 Kriging*

Universal kriging was used to produce gradual surfaces and detect the spatial patterns of the forest floor properties under study (pH, CEC, Ca, K, mineralizable N, and F, LFH, and Ah horizon depths). Forest floor pH was interpolated with the kriging approach and overlaid with BLM and conifer tree canopy extents (Fig. 3.4) to produce output maps for visual inspection and analysis. Higher pH values were located near the stem. Plot 1 ranged in pH from 2.8 - 6.0 and plot 2 pH ranged from 3.0 - 4.8.

Results of the interpolation of these properties on plots 1 and 2 are presented in 5 discrete classes (Figs. 3.5 and 3.6). Both plots had higher values near the BLM stem in the center of the map, particularly for pH and K in plot 1. Although pH and K in 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 BLM stem at the center of the plot. Plot 1 pH (5.9) was slightly higher than that of plot 2 (5.6), and plot 1 K (9.0 cmol $kg^{-1}$) was almost 3 times

that of plot 2 (3.3 cmol $kg^{-1}$). Conversely, plot 2 had higher amounts of Ca (105.8 cmol $kg^{-1}$) than plot 1 (77.2 cmol $kg^{-1}$). Forest floor depths of plot 1, particularly the F and LFH horizons, were spatially related to the location of the BLM, with thicker forest floor beneath the canopy. However, the inverse trend was produced for plot 2 where a concentric pattern of thinner Ah, F, and total LFH horizons were visually detected nearest to the BLM stem.

*3.4.2.2 Spatial Autocorrelation Analysis*

SAA was conducted to determine the furthest distance in which the chemical properties (pH, CEC, Ca, K and mineralizable N) and other properties (F, LFH, and Ah forest floor horizon depths) were spatially related to each other. Moran *I* correlograms (Figs. 3.7, 3.8, 3.9, and 3.10) were constructed of all data points ($n$ = 129) for each plot. Independent correlograms for the larger 36 m x 36 m grid ($n$ = 81) and the smaller 7 m x 7 m grid ($n$ = 49) were also created (the latter two are presented on the same graph). Moran *I* values range from positive 1 (similar spatial regime) to negative 1 (dissimilar spatial regime) while values of 0 indicate that no spatial pattern was detected.

Differences in Moran *I* values were found between the three types of correlograms. For the individual 7 m x 7 m grids sampled every 1 m, positive spatial autocorrelation ($P$ = 0.05) was detected at both plots up to 2 m from the stem in all chemical properties (pH, CEC, Ca, K) except for mineralizable N. However, significant negative autocorrelation occurred at 4 m for plot 1 pH, CEC and K and 5 m for plot 1 Ca. Plot 2 had significant negative autocorrelation at 4

m for pH, CEC, and Ca. Mineralizable N was found to be positively spatially autocorrelated at distances of 7 m and 8 m on plot 1 and not at all on plot 2, with both plots indicating no pattern of negative spatial autocorrelation. For all chemical properties on both plots, no significant (positive or negative) spatial autocorrelation was detected at a distance of 3 m. Plot 1 F and plot 2 Ah horizon depths were significantly positively autocorrelated up to a distance of 2 m while plot 1 Ah, plot 2 F and total LFH horizon depths of both plots indicated no positive spatial regimes.

This fine scale pattern was not detected in either of the other two grid designs ($n$ = 81 and $n$ = 129) on both plots even though the latter ($n$ = 129) contained all points including those sampled at 1 m. The sample design containing only the 4 m sample resolution ($n$ = 81) detected variation of Moran $I$ values with the shortest distance of 4 m (K and mineralizable N) and longest of 12 m (pH, CEC, Ca) on plot 1. Conversely, plot 2 had the shortest distance of 8 m (pH, CEC, Ca and mineralizable N) and longest of 12 m (K). Plot 1 F horizon was found to be positively autocorrelated up to a distance of 12 m and total (L, F, H) forest floor depth only at 12 m. Both plots resulted in significant positive spatial autocorrelation up to distances of 8 m for Ah, while no spatial patterns for F and total (LFH) forest floor depths were found for plot 2.

With all sample points included ($n$ = 129), the Moran $I$ of all chemical properties (pH, CEC, Ca, K, and mineralizable N) on both grids indicated positive spatial autocorrelation at 4 m with Ca up to a distance of 6 m on plot 1 and K and mineralizable N up to a distance of 6 m on plot 2. Forest floor depth of the F

horizon on plot 1 was found to be positively autocorrelated up to 4 m, however plot 2 indicated no such significant trend. On both plots, the total forest floor depth (LFH) was found to be spatially dependent up to 6 m and the Ah horizon at a shorter distance of 4 m.

### 3.4.3 Confirmatory Data Analysis

#### *3.4.3.1 Local Indicators of Spatial Association*

LISA results for the chemical properties (Figs. 3.11 and 3.12) indicated statistically significant ($P = 0.05$) LISA indices associated with BLM on both plots. Black squares indicate clusters of high values 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. All points indicated by squares and crosses are reported at a significance level of $P < 0.05$.

Spatial regimes in the forest floor chemistry were detected with clusters of high values surrounded by high values of pH, CEC, exchangeable Ca and K, and mineralizable N about the stem of the BLM. Outside these clusters of high values, there were significant clusters of low values surrounded by low values. The average distances of high value contiguous points in eight directions (at 45° angles) from the central point (the tree stem location) was calculated.

From plots 1 and 2 respectively, the furthest distance to which the cluster of each chemical property extended from the BLM stem are as follows; pH 1.4 m and 1.6 m; Ca 2 m and 1.5 m; CEC 2 m and 1.8 m; K 2.4 m and 2.5 m; and

mineralizable N 1.6 m and 1.8 m. Exchangeable Al illustrated an inverse trend to the rest of the chemical properties studied. The cluster was of low values at the tree stem with plot 1 resulting in a cluster with an average distance of 2.6 m from the tree stem in plot 1 with plot 2 containing no significant spatial pattern at the base of the stem.

No significant spatial patterns in weight of forest floor per unit area or bulk density of the mineral soil were found. However, LISA statistics detected spatial patterns in litterfall (kg $ha^{-1}$) and water content (%) on both plots (Figs. 3.13 and 3.14). Clusters of large amounts of BLM litterfall occurred in 4 (plot 1) and 3 (plot 2) sample locations beneath or adjacent to BLM canopy. A single sample location with significantly high water content outside but adjacent to the BLM canopy extent was found for plot 2 and at the same sample location as that of high amounts of litterfall. LISA maps of forest floor depths (F, LFH, and Ah) on plot 1 indicated significantly high values surrounded by high values only beneath the BLM canopy extent while on plot 2, these high values occurred outside the canopy extent as well.

*3.4.3.2 Parametric Statistics (ANOVA and t-tests)*

ANOVA found for both plots, 6 of the 10 chemical properties (pH, CEC, exchangeable Ca, K, and Mg and mineralizable N) were significantly higher within 2.5 m from the BLM stem than under the BLM canopy or beyond the BLM canopy extent (Tables 1 and 2). On both plots, exchangeable Mg was higher beneath the BLM canopy than not under the BLM canopy. For plot 1,

exchangeable Al and Mn were found to have significant differences but with an inverse trend from the other properties with the lowest values near the BLM stem and the highest values beyond the BLM canopy extent. For plot 2 (Table 2), no significant differences were found for exchangeable Fe, Na, Al or Mn.

ANOVA results for forest floor depths were different for the two plots; however, significant trends were detected on both (Tables 3 and 4). Significant differences in L, F and total depths for both plots were found beneath the canopy and beyond the canopy extent. Thickest horizons were found beneath the canopy and the thinnest beyond the canopy extent except the F and total forest floor depths on plots 2 were thinner beneath the canopy than beyond the canopy extent.

The *t*-tests of litterfall and forest floor and mineral soil properties (Tables 5 and 6) found significantly higher ($P < 0.05$) amounts of BLM leaf litter beneath the BLM canopy extent than beyond the BLM canopy extent on both plots. Plot 2 also had significantly higher forest floor ($P < 0.01$) and mineral soil ($P < 0.04$) water contents beneath BLM canopy than beyond the canopy extent.

### 3.4.4 Litterfall

The spatial distribution of total litterfall (kg $ha^{-1}$) and total BLM leaf litterfall (kg $ha^{-1}$) from September 1 2005 to December 22, 2005 was overlaid with BLM canopy extent to visualize its relationship with locations of high amounts of litterfall (Figs. 3.15 and 3.16). On plot 1, 169 kg $ha^{-1}$ (17 %) of BLM litterfall occurred outside the canopy extent while beneath the canopy litterfall deposition

was generally concentrated at two sample locations; at the tree stem (1560 kg $ha^{-1}$) and the other at an adjacent sample location (2338 kg $ha^{-1}$). Plot 2 had a maximum of 65 kg $ha^{-1}$ (8 %) BLM litterfall beyond the canopy extent and it too had two primary sample locations for litter deposition, at the stem (1343 kg $ha^{-1}$) and an adjacent location (1002 kg $ha^{-1}$).

On plot 1, 31 % of total litterfall deposited beneath BLM canopy originated from BLM leaves (26 %) and samara (5 %) (Fig. 3.17). In contrast, only 11 % of the litterfall outside of the BLM canopy extent originated from BLM leaves (7 %) and samara (4 %). Beneath the BLM canopy the weight of BLM leaf litter was more than 5 times that of the samara; however beyond the canopy extent more than half of the total BLM litter consisted of samara. On plot 2, 25 % of the total litterfall deposited beneath the BLM canopy originated from BLM leaves. In contrast, only 2 % of the litterfall deposited outside of the BLM canopy extent originated from BLM leaves and 0 % from samara. Beneath the canopy, the BLM leaf litter amounts were more than 11 times higher than those outside the BLM canopy extent. On plot 2, very few samara were generated with only 1 kg $ha^{-1}$ deposited outside the canopy extent and 0 kg $ha^{-1}$ deposited beneath the canopy.

The majority of litter deposition on both plots for all litter types occurred during the $4^{th}$ week of the collection period, October 13th to October $26^{th}$, 2005 (Fig. 3.18). Plot 1 followed this trend in all litter classes but plot 2 did not. Plot 2 had a maximum deposition of BLM litter during the $3^{rd}$ week of litter collection, September $29^{th}$ to October $12^{th}$, 2005.

## 3.5 Discussion

The present study found that ESDA was useful for visualization and detection of spatial patterns in the data. Kriging provided smooth surfaces for the visualization and detection of local patterns in forest floor chemistry centred on the BLM stem at both plots. SAA with global Moran *I* indicated the distance that spatial dependency between individual points became significantly less pronounced; between 2 m and 3 m on the 7 m x 7m grid ($n$ = 49) and between 4 m and 6 m on the 36 m x 36 m grid depending on the property and plot ($n$ = 129). Confirmatory data analysis with LISA and parametric statistics supported and confirmed these findings. LISA statistics indicated that the influence of an individual stem on forest floor chemical properties extends between 1.4 m (pH, plot 1) to 2.5 m (K, plot 2) from an individual tree stem.

Tukey tests indicated that on both plots, pH, CEC, Ca, Mg, K and mineralizable N had significantly higher concentrations within 2.5 m from the BLM stem than at the other two site types (BLM canopy and conifer canopy). Student *t*-tests found that the total forest floor depth (LFH) and depth of Ah on plot 1 were significantly higher beneath the canopy extent while plot 2 exhibited an inverse trend with the F horizon found to be significantly lower beneath the BLM canopy extent than outside the canopy extent. Student *t*-tests also found that beneath BLM canopy, there was significantly greater BLM litter deposition on both plots as well as significantly higher % water contents of the forest floor and mineral soil on plot 2 compared to outside BLM canopy extent.

Forest floor depth beneath the canopy extent was significantly different from beneath conifer canopy. However, plot 1 BLM canopy had thicker forest floor while on plot 2 it was thinner. This may be explained by the difference in conifer species presence between the two grids (basal area of cedar in plot 1 is nearly half that of plot 2) and the associated contribution of individual conifers to the physical structure (i.e. cedar boughs and scales versus conifer needles) and chemical characteristics of the forest floor via litter deposition.

Kriging methods interpolated the actual data values and provided continuous surfaces for visual interpretation, however, the patterns observed in the continuous surface lack statistical significance. SAA provided a description of how properties (for example, pH) can influence the occurrence of that property over space (generally with positive relationships up to 4 m or 6 m). LISA statistics were effective at confirming the hypotheses derived from the kriging technique and SAA by locating where on the 36 m x 36 m plot statistically significant local trends of both positive and negative spatial association occurred. Because the average distance from the central location within a cluster can be calculated, the spatial extent can be determined at a scale finer than the 1 m, despite the 1 m sample resolution.

One sample, two-tailed, Kolmogorov-Smirnov tests of composite normality found that pH, CEC, Ca, and mineralizable N were normally distributed; they satisfy the first assumption for parametric analysis. However, SAA has determined that these properties are spatially autocorrelated; LISA statistics have found clusters of spatial association and the results of the parametric tests

indicate nonstationarity across site types. Non-parametric measures should be considered for future related studies because the soil properties studied do not meet the criteria of independence over space as required for robust parametric significance testing.

Due to the heterogeneous nature of soil properties, identifying spatial patterns at plot scale should incorporate sampling designs with no less than 1 m sampling resolution. A number of other environmental factors other than species may be influencing spatial variation of soil properties in conifer forest, such as slope (Rhoades and Binkley, 1992), microtopography (Schmidt et al., 1998), and edge effects (Redding et al., 2003) to name a few. Future studies should consider multivariate methods, for example variance partitioning (partial redundancy analysis) (Borcard et al., 1992; Redding et al., 2003) to quantify the percentage of variation induced by individual factors. Further methods of map creation for visual exploration of tree influence might include the self-organizing map (SOM; though more data is needed for SOM) (Openshaw et al.,1995; Openshaw and Wymer, 1995; Vesanto and Alhoniemi, 2000) and more particularly for soils data, researchers should consider the Geo-SOM (Bacao et al., 2005) which accounts for spatial dependency in geo-referenced data.

Previous studies (Zinke, 1962; Crampton, 1984; Escudero, 1991) found that the variation in soil chemistry creates circular patterns in relation to the distance from the stem and in relation to the canopy of individual trees. Therefore, the morphological properties of trees account for the different patterns in variation of soil properties beneath the tree canopy. The current study supports

the findings of these previous studies as results indicated that BLM tree canopy stem influences the surrounding forest floor in different ways for different properties. The spatial pattern of tree stem influence on forest floor chemistry was generally concentric about the BLM stem; however, there is fine scale variation within this area of influence as shown with LISA.

Fried (1990) found that all sites with BLM had higher annual litterfall weights and mineral soil nutrient contents for N, P, K, Ca, S, and Mg than Douglas-fir sites but found no significant differences in forest floor biomass or nutrient content. The current study found that BLM litter was deposited directly beneath and oriented with the canopy extent and that the total litterfall on plot 1 had significantly higher total litterfall beneath BLM. This trend did not occur on plot 2 although this could be due to the difference in stature between the BLM trees on plots 1 and 2. Although Fried (1990) did not detect variation in forest floor properties due to BLM influence, the current study found significantly higher concentrations of pH, CEC, Ca, Mg, K and mineralizable N in forest floor within 2.5 m from the BLM stem on both plots.

## 3.6 Conclusion

The question of spatial influence of an individual tree can be asked in several different ways. Kriging is capable of impressing upon the researcher how a variable may appear as a continuous surface over space by calculating and predicting the values of a property at unsampled locations. SAA can answer the question of how far the state at a location can influence the state at other

locations. LISA indices can map where these regimes of spatially associated clusters occur throughout a plot whereas parametric statistics evaluate the variance of a property between site types. These four techniques were successful in answering the various questions surrounding BLM influence on forest floor within the scope of this study by providing exploratory tools and confirmatory methods of analysis.

This study found that BLM influences the surrounding forest floor and these changes may have a positive influence on soil nutrient availability within conifer forests. A strong influence is associated with the BLM stem and may not extend very far (less than 3 m from the stem of an individual tree) while a less pronounced influence may exist due to BLM canopy. This work provides information for forest managers interested in retaining key deciduous species for the benefit of conifer crop species in southwest BC and a methodological foundation for future research on the influence of individual trees on soil properties.

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## 3.8 References


**Anselin, L. 1995.** Local Indicators of Spatial Association. Geographical Analysis **27:** 93-115.

**Anselin, L. 1998.** GeoDa Version 0.9.5-i. Copyright 1998-2004. Luc Anselin and the Regents of the University of Illinois.

**Anselin, L. 2006.** GeoDa: An Introduction to Spatial Data Analysis. Geographical Analysis **38:** 5-22.

**B.C. Ministry of Forests. 1999.** Bigleaf Maple Managers' Handbook. Government of Canada, British Columbia. pp. 105.

**Bacao, F., Lobo, V., Painho, M. 2005.** The self-organizing map, the Geo-SOM, and relevant variants for geosciences. Computers and Geosciences **31:** 155-163.

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

**Barker, J. R., Ringold, P. L., and Bollman, M. 2002.** Patterns of tree dominance in coniferous riparian forests. Forest Ecology and Management **166:** 311-329.

**Binkley, D. 1995.** The influence of trees on forest soils - processes and patterns. *In* Proceedings of the Trees and Soil Workshop. Eds. D. J. Mead and Conforth, I. S. Agronomy Society of New Zealand Special Publication #10. Lincoln University Press, Canterbury. pp. 1-33.

**Binkley, D. and Menyailo, O. 2005.** Tree Species Effects on Soils: Implications for Global Change. NATO Science Series, Kluwer Academic Publishers, Dordrecht. pp. 1-16.

**Borcard, D., Legendre, P., and Drapeau, P. 1992.** Partialling out the spatial component of ecological variation. Ecology **73:** 1045-1055.

**Boettcher, S. E. and Kalisz, P. J. 1990.** Single-tree influence on soil properties in the mountains of eastern Kentucky. Ecology **71:** 1365-1372.

**Bremmer, J.M. 1965.** Inorganic forms of nitrogen. In: C.A. Black (ed). Methods of Soil Analysis. Part 2. Agronomy **9:**1179-1237.

**Bremner, J. M. 1996.** Nitrogen Availability Indexes. In Methods of Soil Analysis, Part 2, Agronomy 9, C.A. Black editor. American Society of Agronomy (Wisconsin) Pub., pp 1324-1345.

**Carey, A. and Harrington, C. 2001.** Small mammals in young forests: implications for management for sustainability. Forest Ecology and Management, **154:** 289-309.

**Chen, H. Y. H., Légaré, S., and Bergeron, Y. 2004.** Variation of the understory composition and diversity along a gradient of productivity in Populus tremuloides stands of northern British Columbia, Canada. Canadian Journal of Botany **82:** 1314-1323.

**Cliff, A.D. and Ord, J. K. 1973.** Spatial Autocorrelation. London: Pion Press.

**Crampton, C. B. 1982.** Podzoilzation 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.

**Dragicevic, S., Schuurman, N. and Fitzgerald, J. M. 2004.** The Utility of Exploratory Spatial Data Analysis in the Study of Tuberculosis Incidences in an Urban Canadian Population." Cartographica **39:** 29-39.

**Escudero, A., M. Hernandez, ad Arco, J. 1991.** Spatial patterns of soil composition around isolated trees. Developments in Geochemistry **6:** 507-517.

**ESRI. 1999.** ArcMap Version 9.0. Copyright 1999-2004 ESRI Inc.

**Finzi, A., Canham, C., and Breemen, N. V. 1998.** Canopy tree-soil interactions within temperate forests: species effects on pH and cations. Ecological Applications **8:** 447-454.

**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.

**Gast, P.R. 1937.** Contrasts between the soil profiles developed under pines and hardwoods. J. For. **35:** 11-16.

**Gersper, P.L. and Holowaychuck, N. 1971**. Some effects of stem flow from forest canopy trees on chemical properties of soils. Ecology **52:** 691-702.

**Haining, R. S., Wise, S. and Ma, J. 1998.** Exploratory Spatial Data Analysis in a Geographic Information System Environment. The Statistician **47:** 457-469.

**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. Forest Ecology and Management **187:** 225-234.

**Hendershot, W.H. and Duquette, M. 1986.** A simple barium chloride method for determining cation exchange capacity and exchangeable cations. Soil Science Society of American Journal **50:** 605-608.

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

**Jenny, H. 1941.** Factors of Soil Formation. McGraw, New York. pp. 281.

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

**Kenney, D.R. and J.M. Bremner, J. M. 1966.** Comparison and evaluation of laboratory methods of obtaining air index of soil nitrogen availability. Agronomy Journal **58:**498-503.

**Maas-Hebner, K. G., Emmingham, W. H., Larson, D. J. and Chan, S. S. 2005.** Establishment and growth of native hardwood and conifer seedlings underplanted in thinned Douglas-fir stands. Forest Ecology and Management **208:** 331-345.

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

**Mina, V. N. 1967.** Influence of stemflow on soil. Sov. Soil Sci. **7:** 1321-1329.

**Moran, P.A.P. 1950.** Notes on Continuous Stochastic Phenomena. Biometrika **37:** 17-23.

**Mottonen, M., Jarvinen, E., Hokkanen, T. J. Kuuluvainen, T. and Ohtonen, R. 1999.** Spatial distribution of soil ergosterol in the organic layer of a mature Scots pine (Pinus sylvestris L.) forest. Soil Biology and Biochemistry **31:** 503-516.

**Mueller, T. G., Pusuluri, N. B., Mathias, K. K., Cornelius, P. L., Barnhisel, R. I. and Shearer, S. A. 2004.** Map Quality for Ordinary Kriging and Inverse Distance Weighted Interpolation. Soil Science Society of America Journal **68:** 2042-2047.

**Ogden, A. and Schmidt, M. 1997.** Litterfall and soil characteristics in canopy gaps occupied by vine maple in a coastal western hemlock forest. Canadian Journal of Soil Science **77:** 703-711.

**Oliver, M. A. 1990.** Kriging: a method of interpolation for geographical information systems. Int. J. Geographical Information Systems, **4:** 313-332.

**Openshaw,S., Blake, M.,Wymer, C., 1995.** Using neurocomputing methods to classify Britain's residential areas. In: Fisher, P. (Ed.), Innovations in GIS,vol. 2. Taylor & Francis, London, pp. 97-111.

**Openshaw,S.,Wymer,C.,1995.** Classifying and regionalizing census data. In: Openshaw,S. (Ed.), Census Users Handbook. GeoInformation International, Cambrige,UK, pp. 239-268.

**Rhodes, C. C. and Binkley, D. 1992.** Spatial extent of impact of red alder on soil chemistry of adjacent conifer stands. Can. J. For. Res. **22:** 1434-1437.

**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.

**Rosenberg, M. S. 1998.** Pattern Analysis Spatial Statistics and Geographic Exegis (PASSAGE) Version 1.1. Copyright 1998-2004.

**Schmidt, M., Ogden, A., and Lertzman, K. 1998.** Seasonal comparison of soil temperature and moisture in pits and mounds under vine maple gaps and conifer canopy in a coastal western hemlock forest. Can. J. Soil Sci. **78:** 291-300.

**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. pp. 633.

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

**Tukey, J. W. 1977.** Exploratory Data Analysis. Addison-Wesley, MA. pp. 688.

**Tukey, J. W. 1980.** We need both exploratory and confirmatory. American Statistician **34:** 23-25.

**Vesanto, J. and Alhoniemi, E. 2000.** Clustering of the self-organizing map. IEEE Transactions on Neural Networks **11:** 586-600.

**Wardman, C. and M. Schmidt, M.** 1998. Growth and form of Douglas-fir adjacent to persistent vine maple gaps in southwestern British Columbia. Forest Ecology and Management **106:** 223-233.

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

**Waring, S.A. and Bremner, J. M. 1964b.** Effect of soil mesh-size on the estimation of mineralizable nitrogen in soils. Nature **202:** 1141.

**Washburn, C. S. M. and Arthur M. A. 2003.** Spatial variability in soil nutrient availability in an oak-pine forest: potential effects of tree species. Canadian Journal of Forest Research **33:** 2321-2330.

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

**Table 3.1. Plot 1 mean values and ANOVA (with Tukey multiple comparison test) of forest floor chemical properties beneath an individual bigleaf maple at 3 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) | 4.23*b* | (0.32) | 4.07*b* | (0.50) | < 0.001 |
| CEC (Ba) ($cmol_c\ kg^{-1}$) | 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 Mg ($cmol_c\ kg^{-1}$) | 7.86*a* | (2.33) | 4.71*b* | (1.16) | 3.48*c* | (0.91) | < 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 Mn ($cmol_c\ kg^{-1}$) | 0.41*a* | (0.12) | 0.53*b* | (0.15) | 0.58*b* | (0.25) | 0.0049 |
| Exch Fe ($cmol_c\ kg^{-1}$) | 0.002*a* | (0.0052) | 0.0076*a* | (0.017) | 0.021*a* | (0.046) | 0.034 |
| Exch Al ($cmol_c\ kg^{-1}$) | 0.070*a* | (0.049) | 0.29*a* | (0.37) | 0.69*b* | (1.11) | 0.0029 |
| Exch Na ($cmol_c\ kg^{-1}$) | 0.14 | (0.052) | 0.12 | (0.044) | 0.10 | (0.083) | 0.088 |
| Mineral N ($g\ kg^{-1}$) | 105.468*a* | (269.48) | 84.057*b* | 198.65) | 80.182*b* | (229.49) | < 0.001 |

Underlined values indicate significant differences ($P < 0.05$).

Values with different letters in the same row are significantly different ($P < 0.05$).

Values in parentheses are standard deviations.

**Table 3.2. Plot 2 mean values and ANOVA (with Tukey multiple comparison test) of forest floor chemical properties beneath an individual bigleaf maple at 3 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) | 3.59*b* | (0.38) | 3.59*b* | (0.39) | < 0.001 |
| CEC (Ba) ($cmol_c\ kg^{-1}$) | 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 Mg ($cmol_c\ kg^{-1}$) | 7.34*a* | (1.97) | 5.57*b* | (1.12) | 4.42*c* | (0.95) | < 0.001 |
| Exch K ($cmol_c\ kg^{-1}$) | 2.13*a* | (0.42) | 1.79*b* | (0.29) | 1.56*c* | (0.36) | < 0.001 |
| Exch Mn ($cmol_c\ kg^{-1}$) | 0.87 | (0.29) | 0.94 | (0.26) | 1.06 | (0.42) | 0.071 |
| Exch Fe ($cmol_c\ kg^{-1}$) | 0.0080 | (0.0090) | 0.013 | (0.018) | 0.0080 | (0.014) | 0.26 |
| Exch Al ($cmol_c\ kg^{-1}$) | 0.12 | (0.17) | 0.25 | (0.34) | 0.20 | (0.23) | 0.19 |
| Exch Na ($cmol_c\ kg^{-1}$) | 0.19 | (0.037) | 0.16 | (0.037) | 0.19 | (0.088) | 0.12 |
| Mineral N ($g\ kg^{-1}$) | 99.82*a* | (193.74) | 86.88*b* | (175.67) | 75.08*c* | (166.77) | < 0.001 |

Underlined values indicate significant differences ($P < 0.05$).

Values with different letters in the same row are significantly different ($P < 0.05$).

Values in parentheses are standard deviations.

**Table 3.3. Plot 1 mean values and ANOVA (with Tukey multiple comparison test) of forest floor depth (cm) beneath an individual bigleaf maple at 3 site types; within 2.5 m from the stem (*n* = 21); 2.5 m from the stem to the canopy edge (*n* = 50); and not under bigleaf maple canopy (*n* = 58).**

| Forest Floor Horizon | Bigleaf Maple Stem | | Bigleaf Maple Canopy | | Conifer | | *Prob.* (*F*) |
|---|---|---|---|---|---|---|---|
| L | 1.17*a* | (0.83) | 0.74*b* | (0.72) | 0.39*c* | (0.46) | < 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 |
| Ah | 4.86*a* | (3.19) | 4.50*a* | (2.60) | 3.26*b* | (2.18) | 0.011 |
| L, F and H | 3.17*a* | (1.97) | 2.95*a* | (1.57) | 1.93*b* | (0.95) | < 0.001 |

Underlined values indicate significant differences ($P < 0.05$).

Different letters in the same row are significantly different ($P < 0.05$).

Values in parentheses are standard deviations.

**Table 3.4. Plot 2 mean values and ANOVA (with Tukey multiple comparison test) of forest floor depth (cm) beneath an individual bigleaf maple at 3 site types; within 2.5 m from the stem (*n* = 21); 2.5 m from the stem to the canopy edge (*n* = 40); and not under bigleaf maple canopy (*n* = 68).**

| Forest Floor Horizon | Bigleaf Maple Stem | | Bigleaf Maple Canopy | | Conifer | | *Prob.* (*F*) |
|---|---|---|---|---|---|---|---|
| L | 0.64*ab* | (0.32) | 0.64*a* | (0.39) | 0.47*b* | (0.31) | 0.021 |
| 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 |
| Ah | 1.98*a* | (0.83) | 2.91*b* | (1.32) | 2.56*ab* | (1.50) | 0.04 |
| L, F and H | 3.05*ab* | (1.18) | 3.09*a* | (0.83) | 3.68*b* | (1.25) | 0.011 |

Underlined values indicate significant differences ($P < 0.05$).

Different letters in the same row are significantly different ($P < 0.05$).

Values in parentheses are standard deviations.

**Table 3.5. 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) |
|---|---|---|---|---|---|
| FF weight/unit area (g $cm^{-3}$) | 1.91 | (0.85) | 1.99 | (0.77) | 0.81 |
| FF water content (g $g^{-1}$) | 44.46 | (15.04) | 39.61 | (19.67) | 0.53 |
| MS bulk density (g $cm^{-3}$) | 0.55 | (0.23) | 0.67 | (0.21) | 0.19 |
| MS water content (g $g^{-1}$) | 50.93 | (44.78) | 30.74 | (31.11) | 0.20 |
| Bigleaf Maple Leaf (kg $ha^{-1}$) | 899.47 | (666.11) | 166.35 | (211.74) | < 0.01 |
| 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 |
| Other (kg $ha^{-1}$) | 429.42 | (195.62) | 342.45 | (264.57) | 0.40 |
| Total Conifer Litterfall (kg $ha^{-1}$) | 1731.92 | (754.02) | 1805.60 | (648.57) | 0.80 |
| Total Litterfall (kg $ha^{-1}$) | 3101.68 | (799.63) | 2416.75 | (762.48) | 0.04 |

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

**Table 3.6. 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) |
|---|---|---|---|---|---|
| FF weight/unit area (g $cm^{-3}$) | 0.79 | (0.15) | 0.68 | (0.36) | 0.49 |
| FF water content (g $g^{-1}$) | 144.31 | (29.52) | 107.71 | (27.40) | 0.010 |
| MS bulk density (g $cm^{-3}$) | 0.51 | (0.24) | 0.66 | (0.24) | 0.20 |
| MS water content (g $g^{-1}$) | 50.67 | (47.48) | 25.88 | (12.64) | 0.04 |
| Bigleaf Maple Leaf (kg $ha^{-1}$) | 747.20 | (362.16) | 64.67 | (102.85) | 0.00 |
| 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 |
| Other (kg $ha^{-1}$) | 179.60 | (49.46) | 327.58 | (326.84) | 0.29 |
| Total Conifer Litterfall (kg $ha^{-1}$) | 2007.87 | (485.78) | 2482.27 | (681.23) | 0.13 |
| Total Litterfall (kg $ha^{-1}$) | 2934.67 | (442.78) | 2875.45 | (814.91) | 0.87 |

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

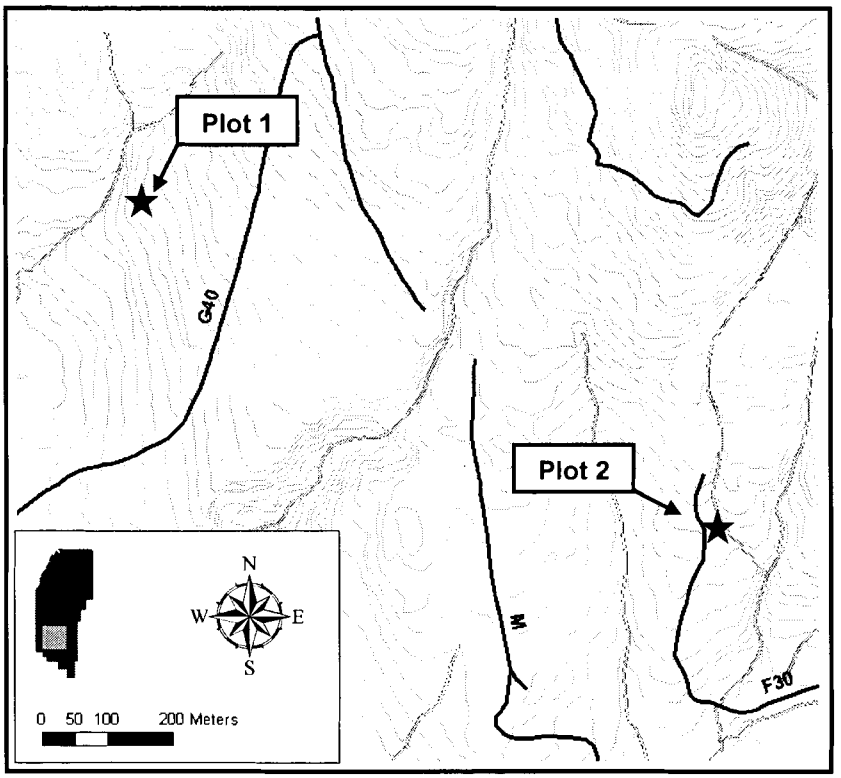
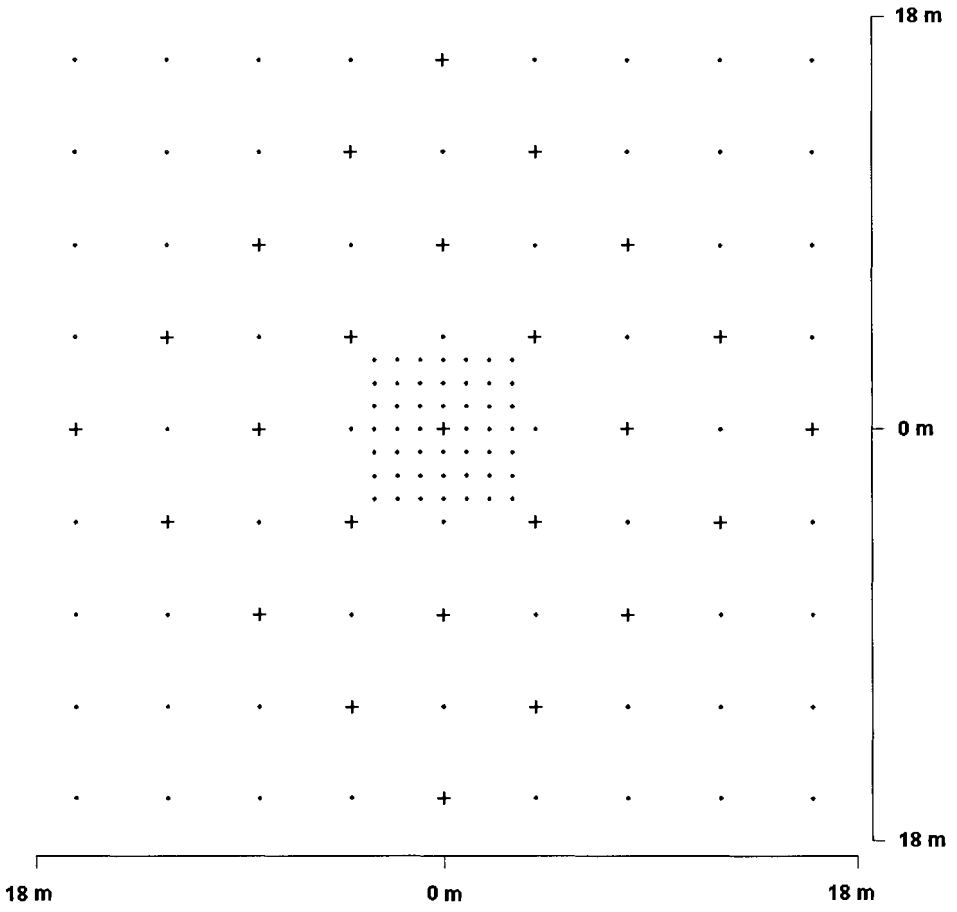



**Figure 3.1. Bigleaf maple plot locations (2) within the study site, the University of British Columbia Malcolm Knapp Research Forest, British Columbia, Canada.**




Sample Design A · and +

Sample Design B +

Figure 3.2. Sample design A for forest floor sample collection includes all sample locations on the sample grid centered on a dominant bigleaf maple. The 36 m x 36 m grid is sampled every 4 m ($n$ = 81) and includes a 7 m x 7 m grid sampled every 1m ($n$ = 49) at the tree stem for a total of $n$ = 129. Sample design B (denoted by +) was used for intact forest floor sampling and litterfall collection ($n$ = 25).

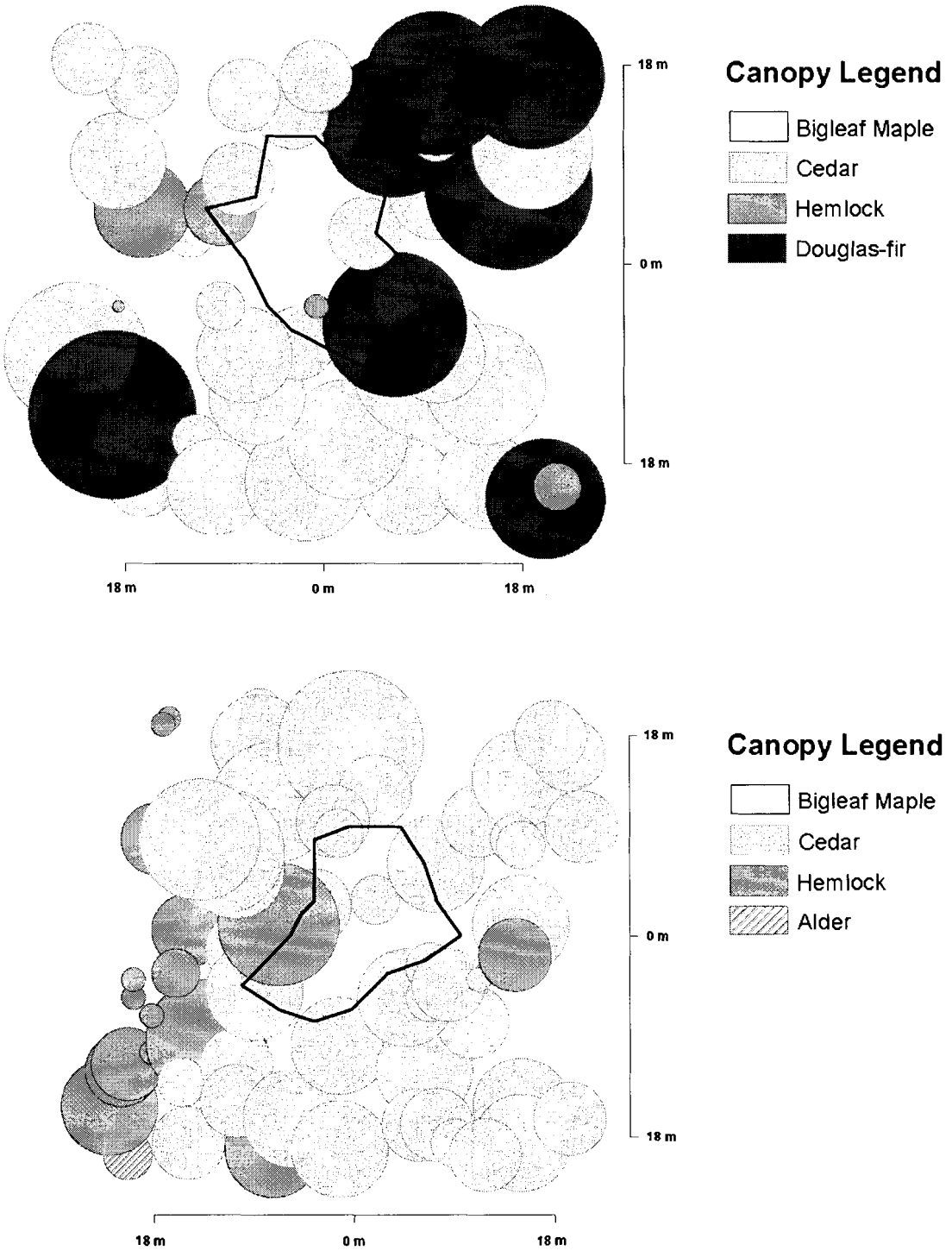



**Figure 3.3. Canopy extent of trees on plot 1 (above) and plot 2 (below). A single dominant bigleaf maple is located at the center of each 36 m x 36 m plot (canopy outlined by a solid black line).**

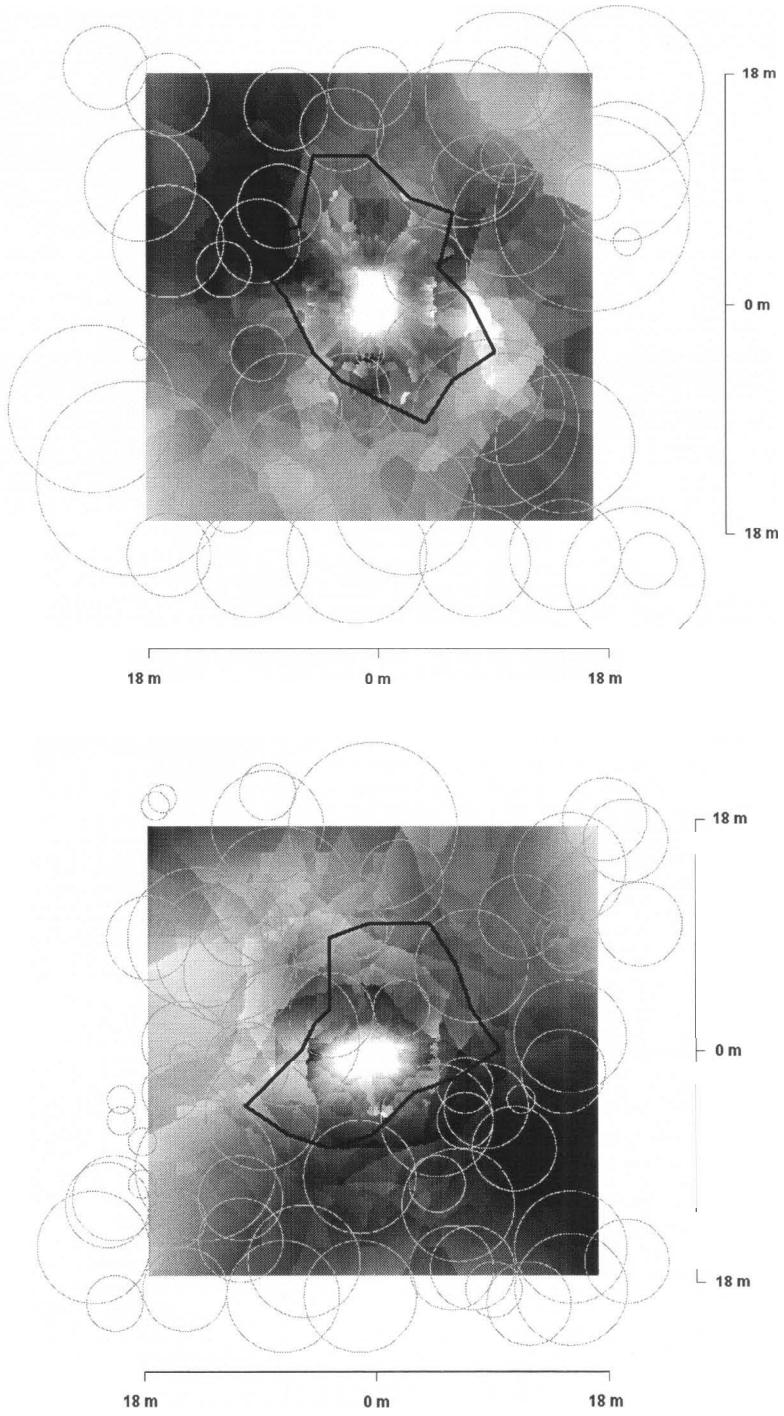



**Figure 3.4.** Plots 1 (above) and 2 (below) with forest floor pH values interpolated with Universal Kriging (stretched symbology where highest value = white; and lowest value = black). Surface ranges in pH value of 2.8-6.0 (plot 1) and 3.0-4.8 (plot 2) and overlaid with tree canopy extents. Each plot is a 36 m x 36 m grid centered on a dominant bigleaf maple.

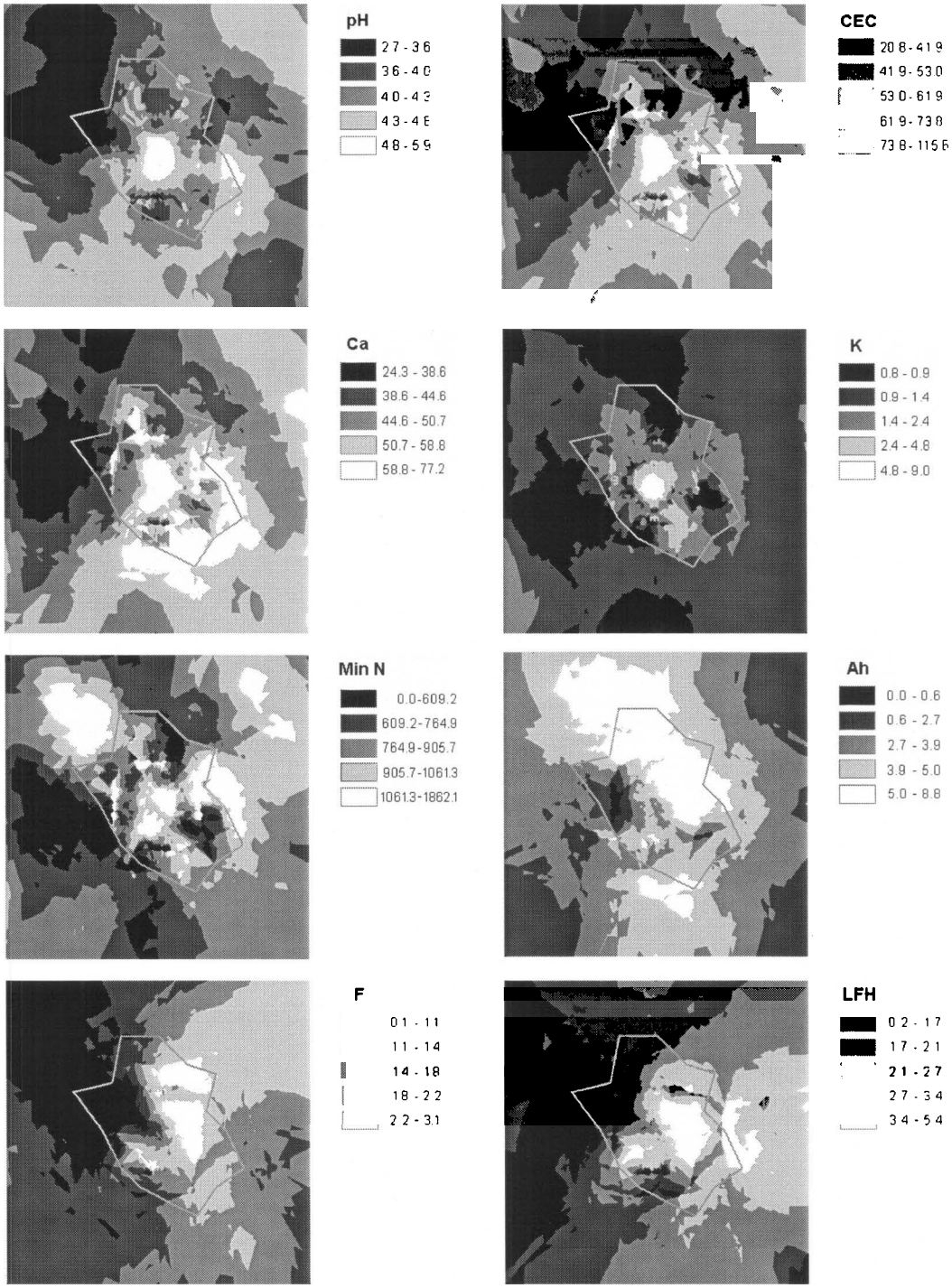



**Figure 3.5.** Plot 1 forest floor pH, CEC (cmolc $kg^{-1}$), Ca (cmolc $kg^{-1}$), K (cmolc $kg^{-1}$) and mineralizable N (g $kg^{-1}$) with depths (cm) of the Ah and F layers and the total forest floor depth (L, F, H). Values are interpolated with Universal Kriging and classified into 5 classes. Each kriging map is overlaid with a polygon indicating the canopy extent of a dominant bigleaf maple centered on the 36 m x 36 m plot.

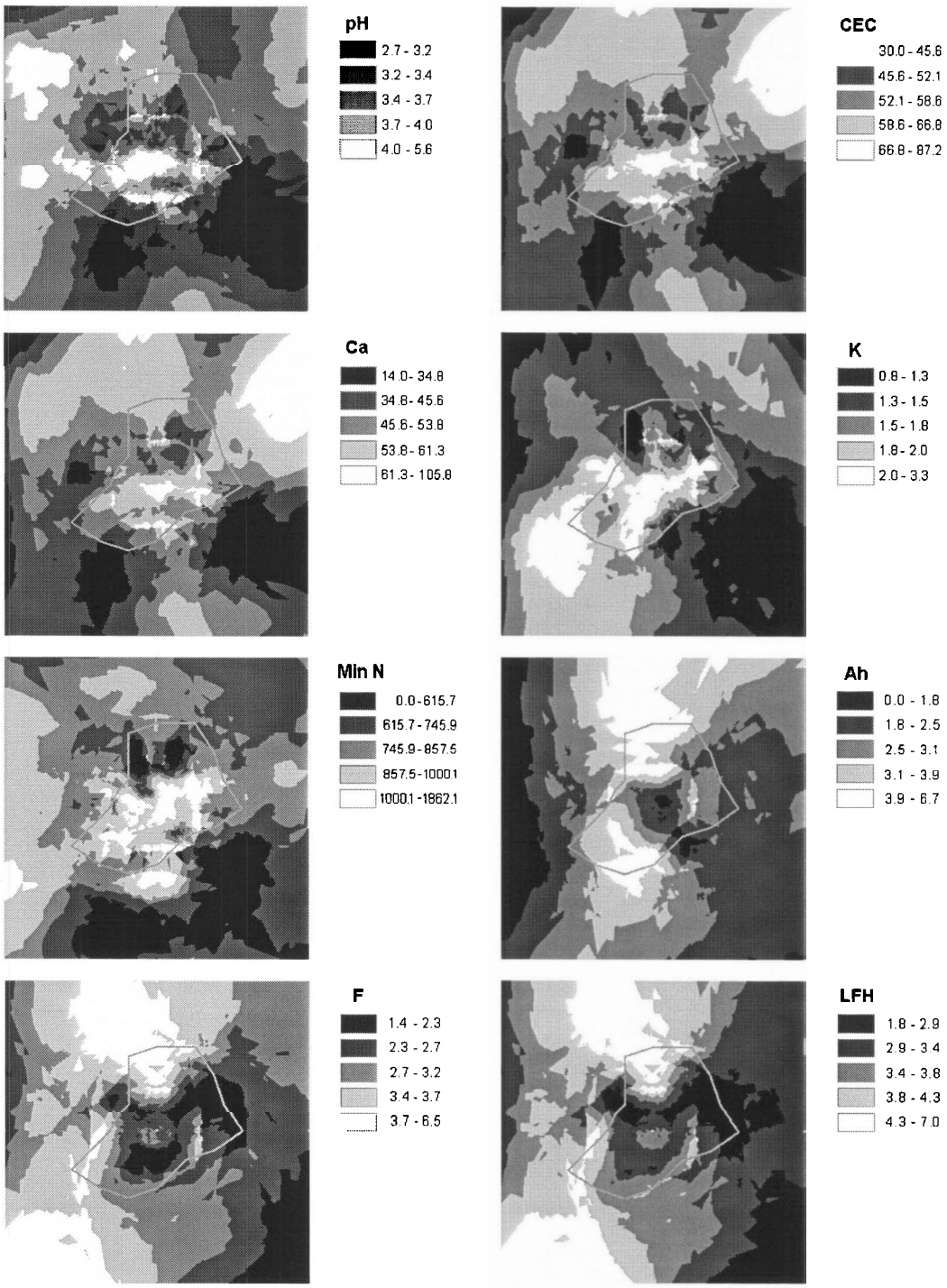



**Figure 3.6.** Plot 2 forest floor pH, CEC (cmolc $kg^{-1}$), Ca (cmolc $kg^{-1}$), K (cmolc $kg^{-1}$) and mineralizable N (g $kg^{-1}$) with depths (cm) of the Ah and F layers and the total forest floor depth (L, F, H). Values are interpolated with Universal Kriging and classified into 5 classes. Each kriging map is overlaid with a polygon indicating the canopy extent of a dominant bigleaf maple centered on the 36 m x 36 m plot.

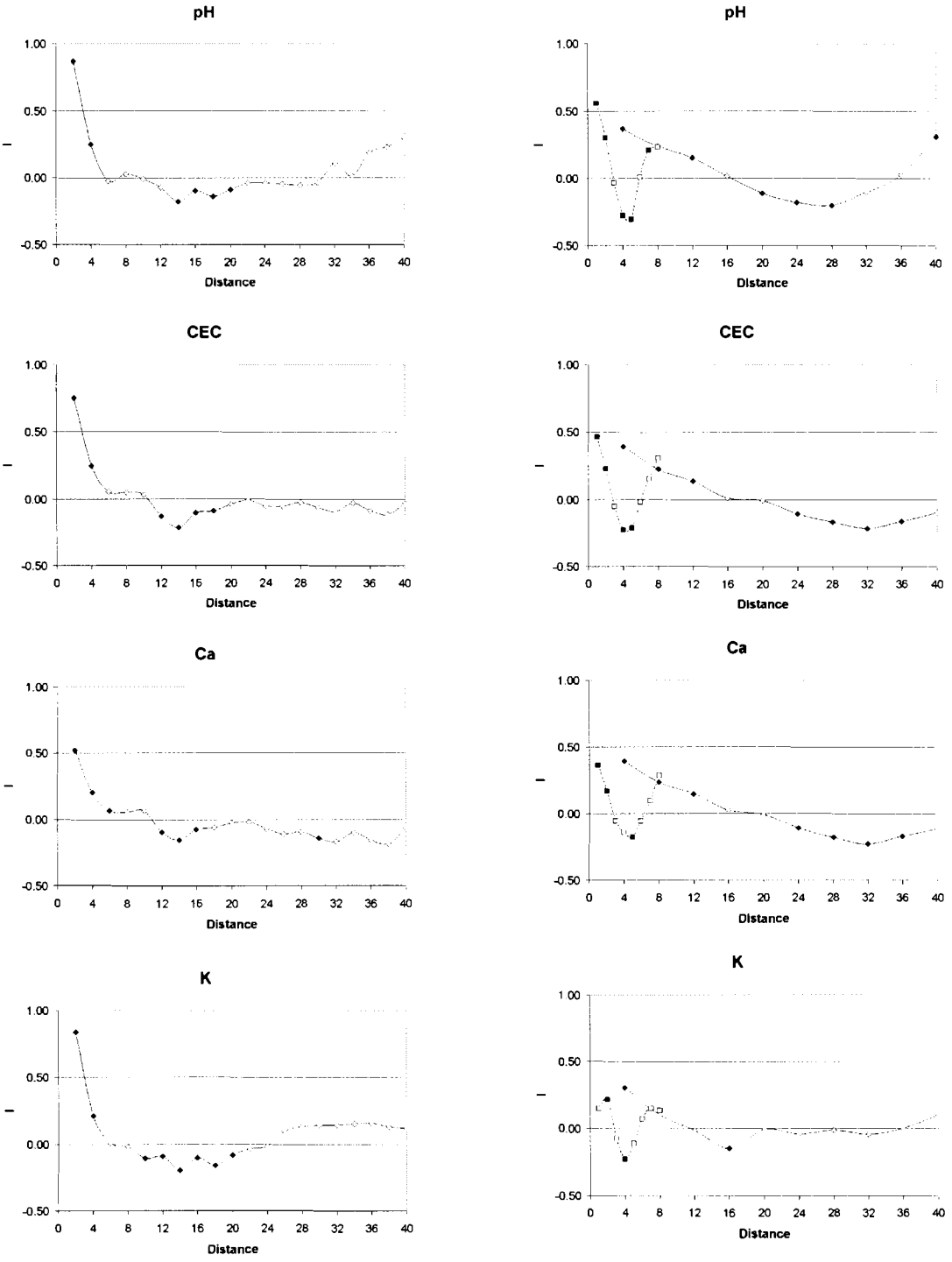



**Figure 3.7. Plot 1 correlograms of forest floor acidity and chemical properties ($cmol_c\ kg^{-1}$) sampled on a 36 m x 36 m grid at 1 m and 4 m resolution ($n$ = 129) (left) and decomposed into the 2 sample grid resolutions (1m and 4 m) (right). Bold points indicate significant Moran $I$ values ($P < 0.05$).**

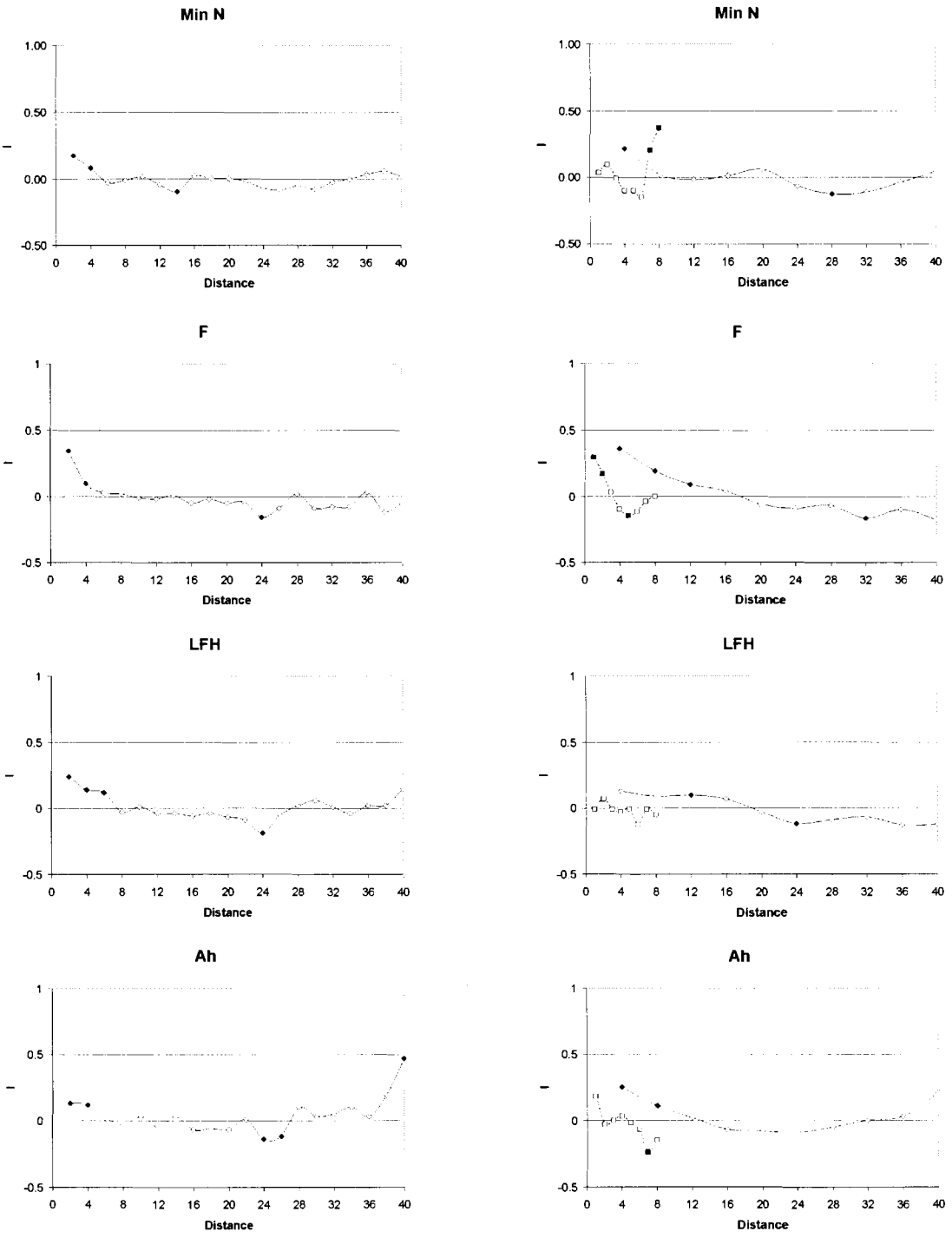



**Figure 3.8. Plot 1 correlograms of mineralizable N (g $kg^{-1}$) and forest floor (F, total L,F,H and Ah) depths (cm) sampled on a 36 m x 36 m grid at 1 m and 4 m resolution ($n$ = 129) (left) and decomposed into the 2 sample grid resolutions (1m and 4 m) (right). Bold points indicate significant Moran I values ($P$ < 0.05).**

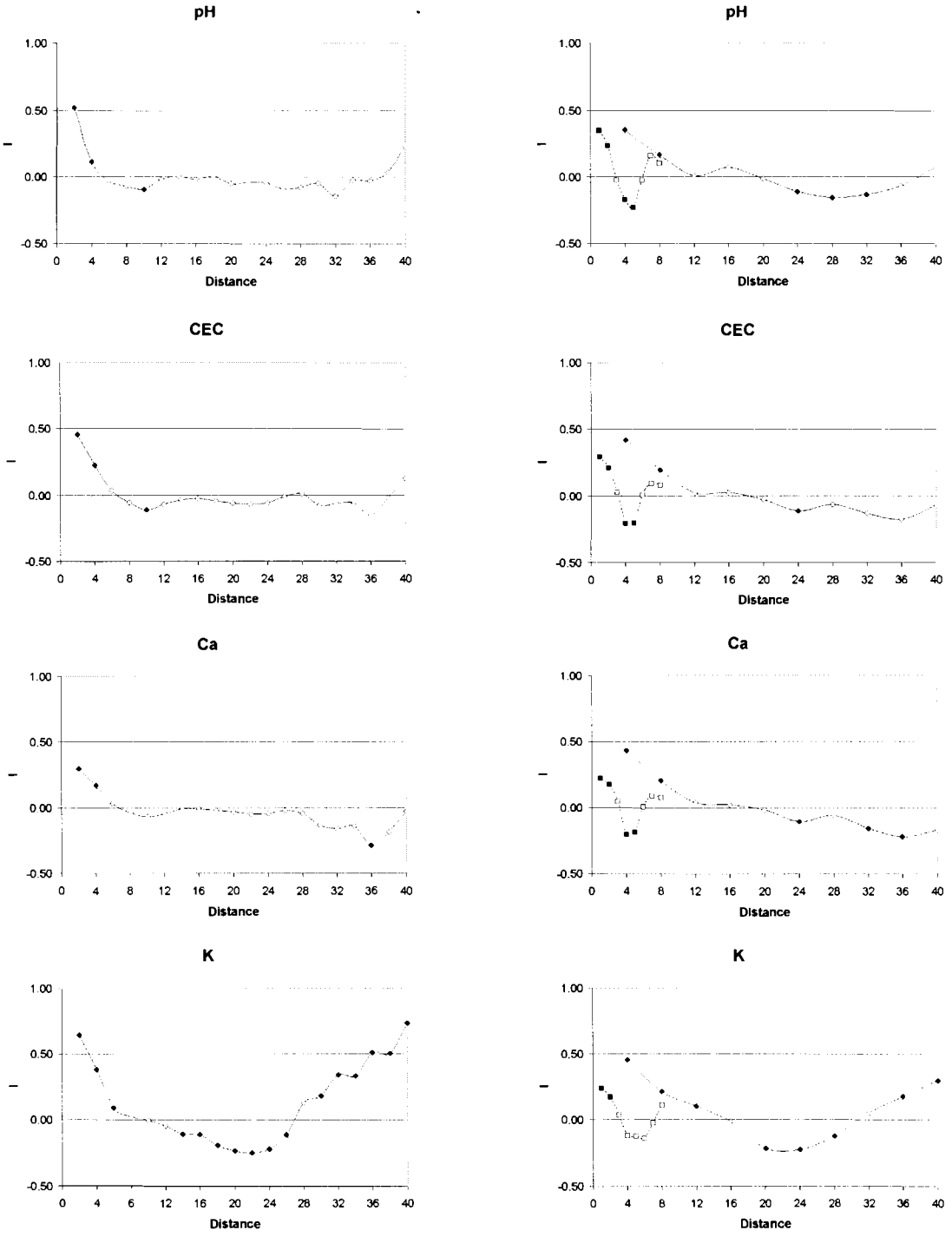



**Figure 3.9. Plot 2 correlograms of forest floor acidity and chemical properties (cmolc $kg^{-1}$) sampled on a 36 m x 36 m grid at 1 m and 4 m resolution ($n$ = 129) (left) and decomposed into the 2 sample grid resolutions (1m and 4 m) on the (right). Bold points indicate significant Moran I values ($P < 0.05$).**

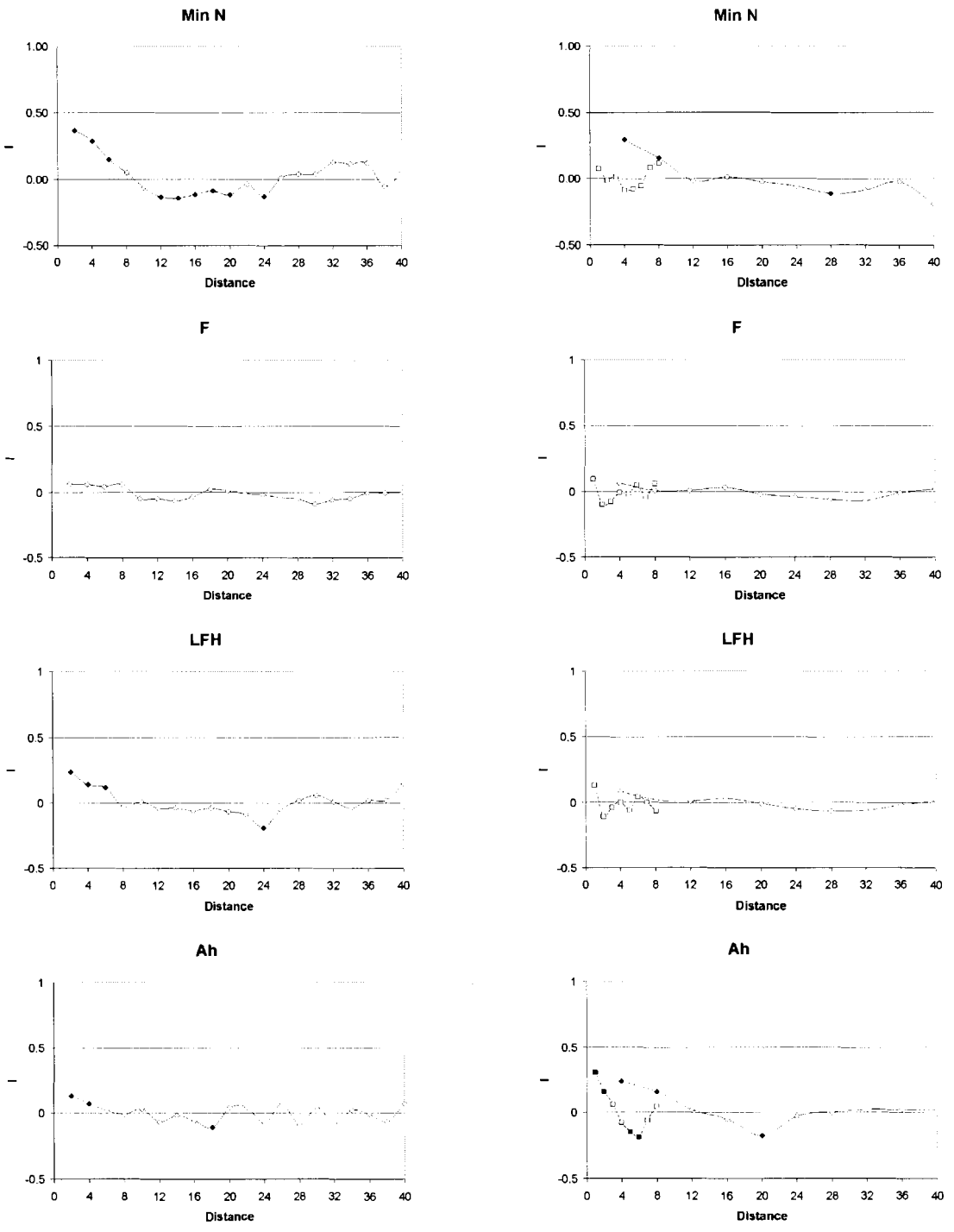



**Figure 3.10. Plot 2 correlograms of mineralizable N (g $kg^{-1}$) and forest floor (F, total L,F,H and Ah) depths (cm) sampled on a 36 m x 36 m grid at 1 m and 4 m resolution ($n$ = 129) (left) and decomposed into the 2 sample grid resolutions (1m and 4 m) (right). Bold points indicate significant Moran I values ($P < 0.05$).**

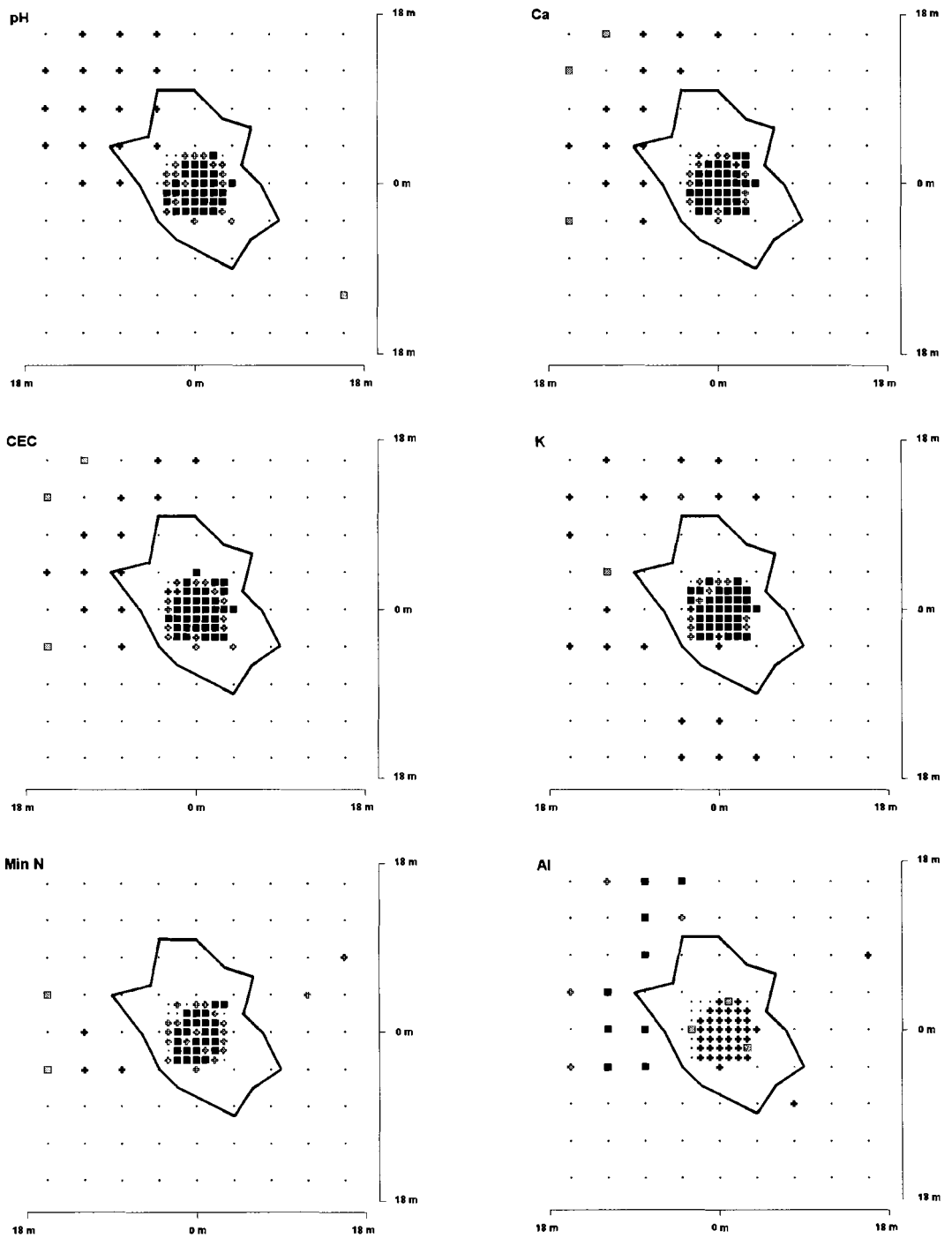



Figure 3.11. Plot 1 LISA maps overlaid over the sample grid (black points) and a polygon indicating the bigleaf maple canopy extent. Maps indicate clusters of spatially associated forest floor chemical properties (pH, cation exchange capacity, mineralizable N and exchangeable Ca, K and Al). Black squares 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 ($P < 0.05$).

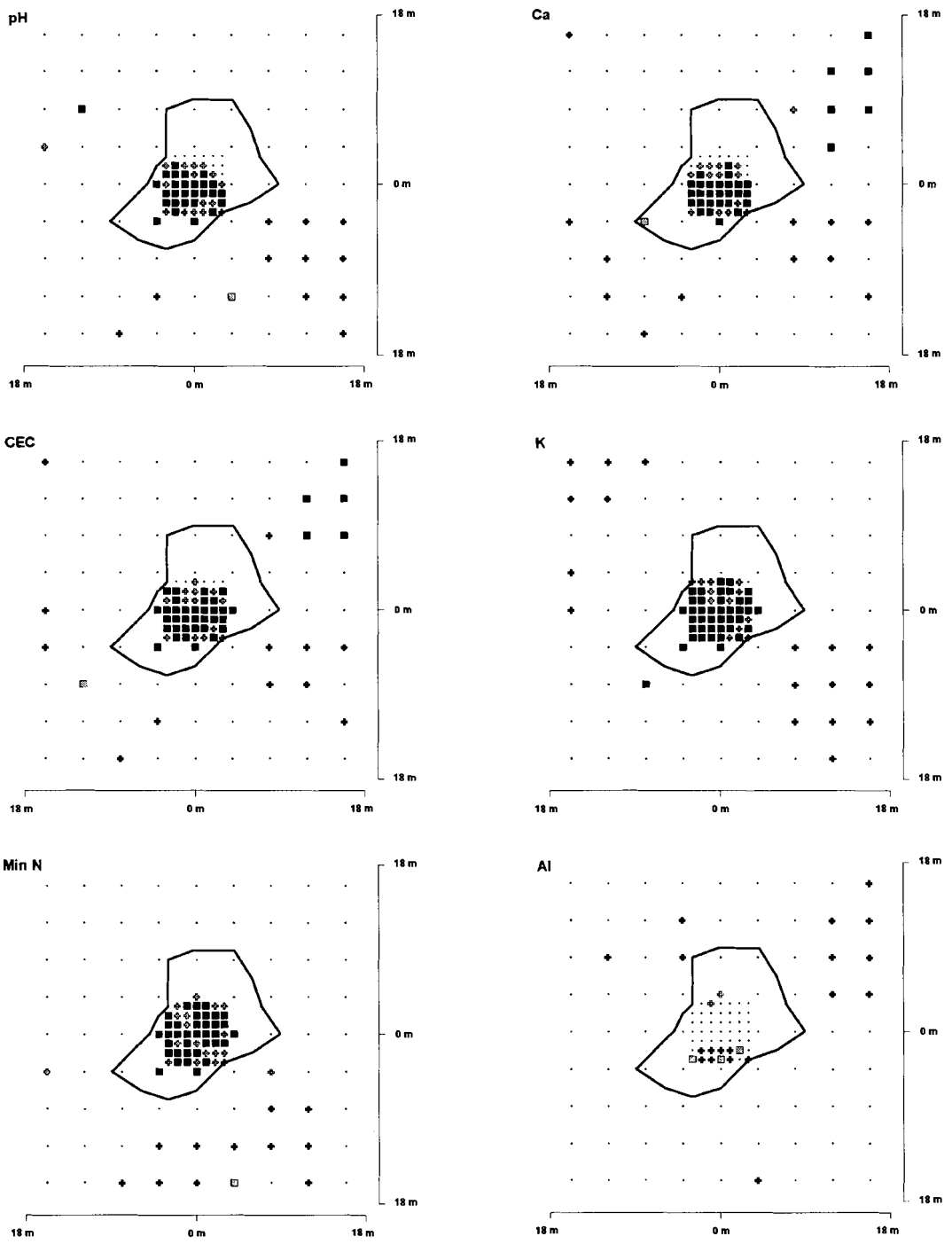



**Figure 3.12.** Plot 2 LISA maps overlaid over the sample grid (black points) and a polygon indicating the bigleaf maple canopy extent. Maps indicate clusters of spatially associated forest floor chemical properties (pH, cation exchange capacity, mineralizable N and exchangeable Ca, K and Al). Black 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 ($P < 0.05$).

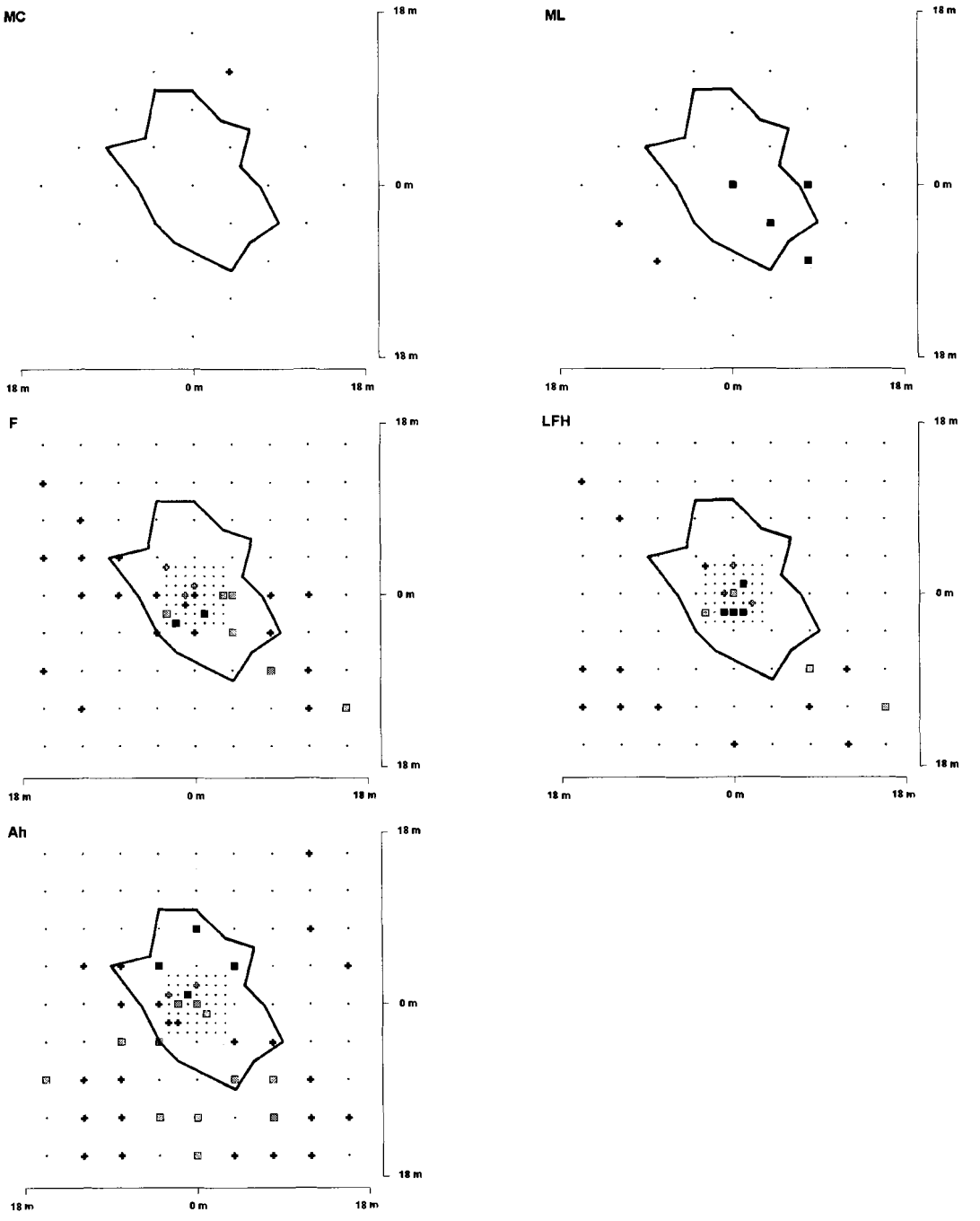



Figure 3.13. Plot 1 LISA maps overlaid over the sample grid (black points) and a polygon indicating bigleaf maple canopy extent. Maps indicate clusters of spatially associated bigleaf maple litterfall (ML) (kg $ha^{-1}$) ($n$ = 25) and forest floor water content (MC) (g $g^{-1}$) ($n$ = 25) and F, LFH and Ah forest floor depths (cm) ($n$ = 129). Black squares indicate clusters of high values 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 ($P < 0.05$).

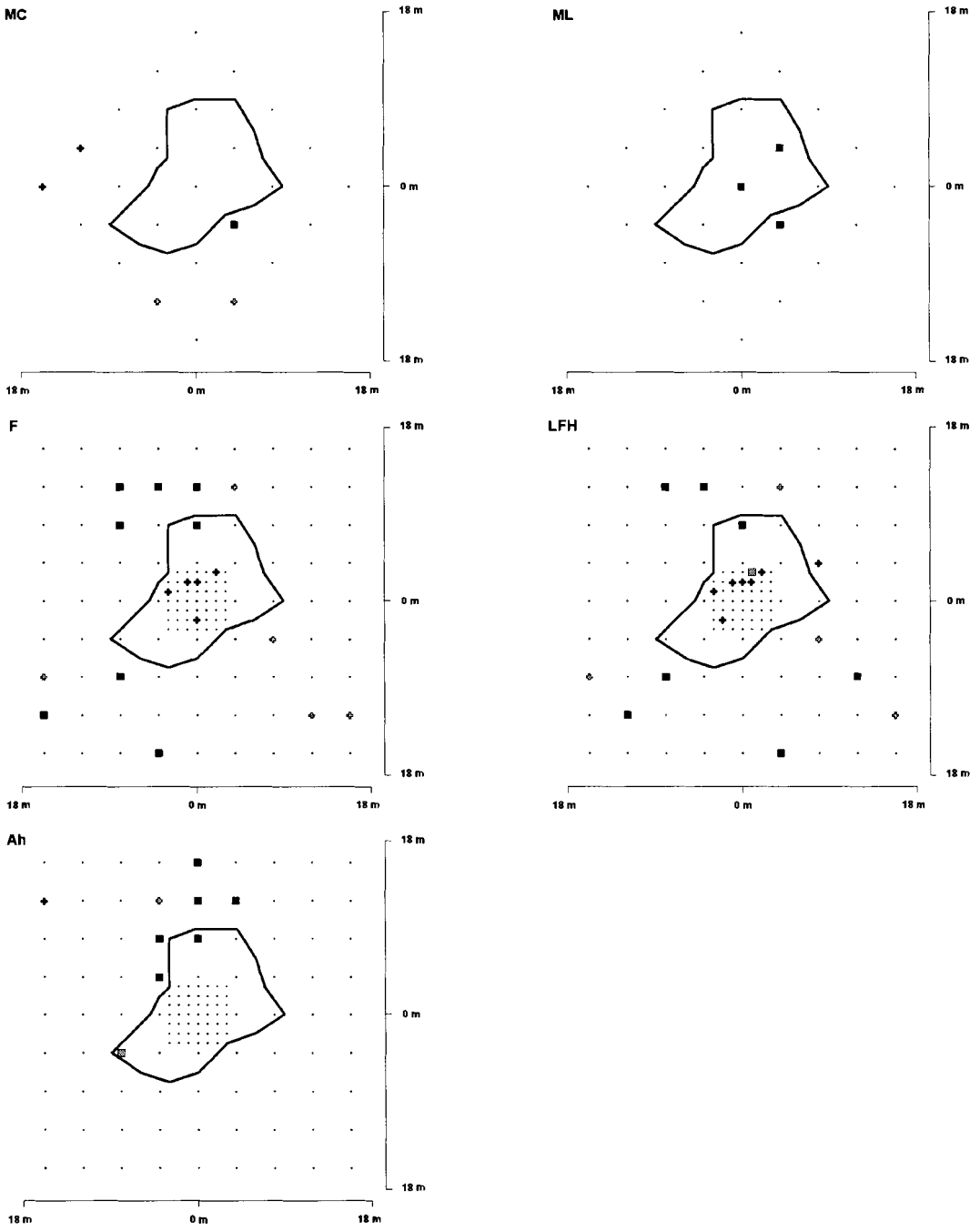



**Figure 3.14.** Plot 2 LISA maps overlaid over the sample grid (black points) and a polygon indicating bigleaf maple canopy extent. Maps indicate clusters of spatially associated bigleaf maple litterfall (ML) (kg $ha^{-1}$) ($n$ = 25) and forest floor water content (MC) (g $g^{-1}$) ($n$ = 25) and F, LFH and Ah forest floor depths (cm) ($n$ = 129). Black squares indicate clusters of high values 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 ($P < 0.05$).

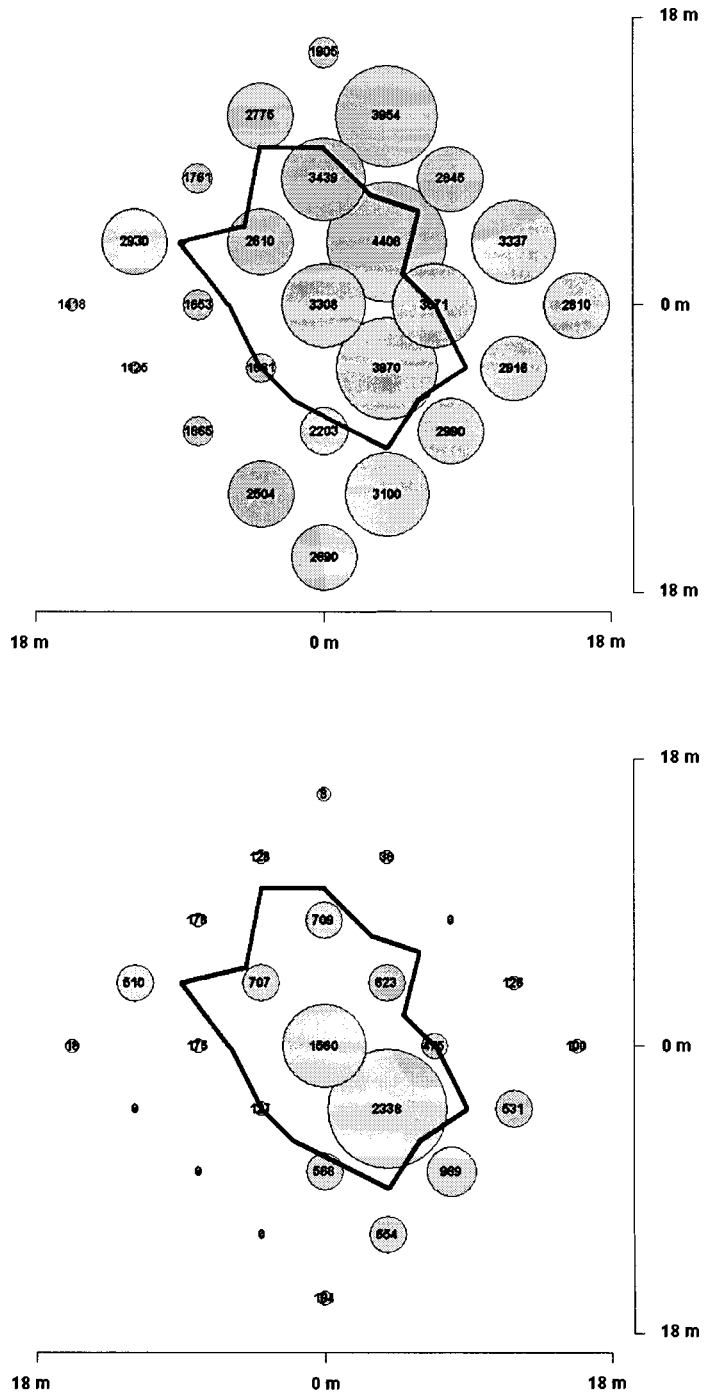



Figure 3.15. Plot 1 total litterfall (kg $ha^{-1}$) (above) and total bigleaf maple litterfall (kg $ha^{-1}$) (below) collected between September 1 to December 22, 2005 ($n$ = 25). Each plot was a 36 m x 36 m grid centered on a dominant bigleaf maple stem. Bigleaf maple canopy extent is indicated by a black polygon and litterfall amounts are presented as graduated circles.

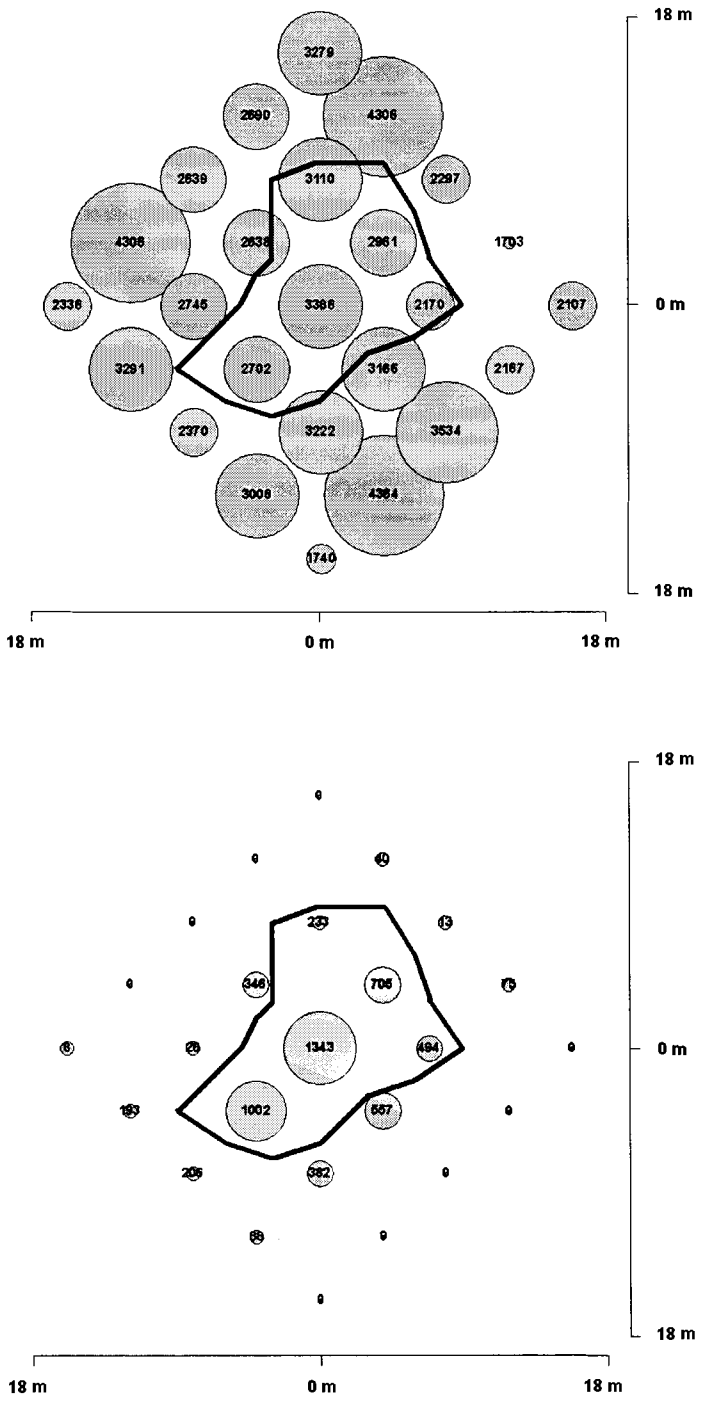



Figure 3.16. Plot 2 total litterfall (kg $ha^{-1}$) (above) and total bigleaf maple litterfall (kg $ha^{-1}$) (below) collected between September 1 to December 22, 2005 ($n$ = 25). Each plot was a 36 m x 36 m grid centered on a dominant bigleaf maple stem. Bigleaf maple canopy extent is indicated by a black polygon and litterfall amounts are presented as graduated circles.

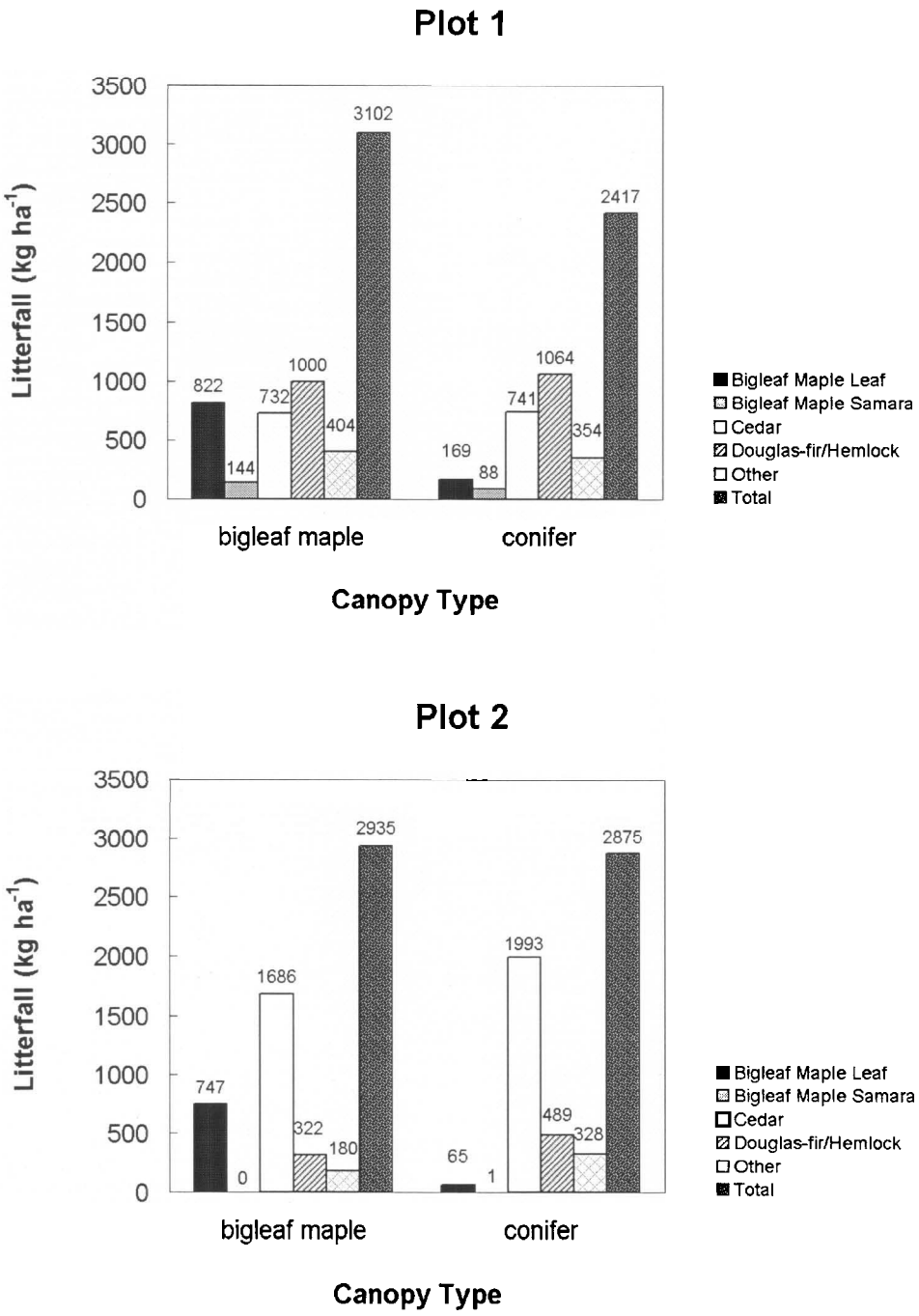



**Figure 3.17.** Litterfall (kg $ha^{-1}$) beneath bigleaf maple canopy (plot 1 *n* = 10; plot 2 *n* = 6) and beneath conifer canopy (plot 1 *n* = 15; plot 2 *n* = 19). Each grid is 36 m x 36 m and centered on a dominant bigleaf maple. Litter was collected biweekly from September 1 to December 22.

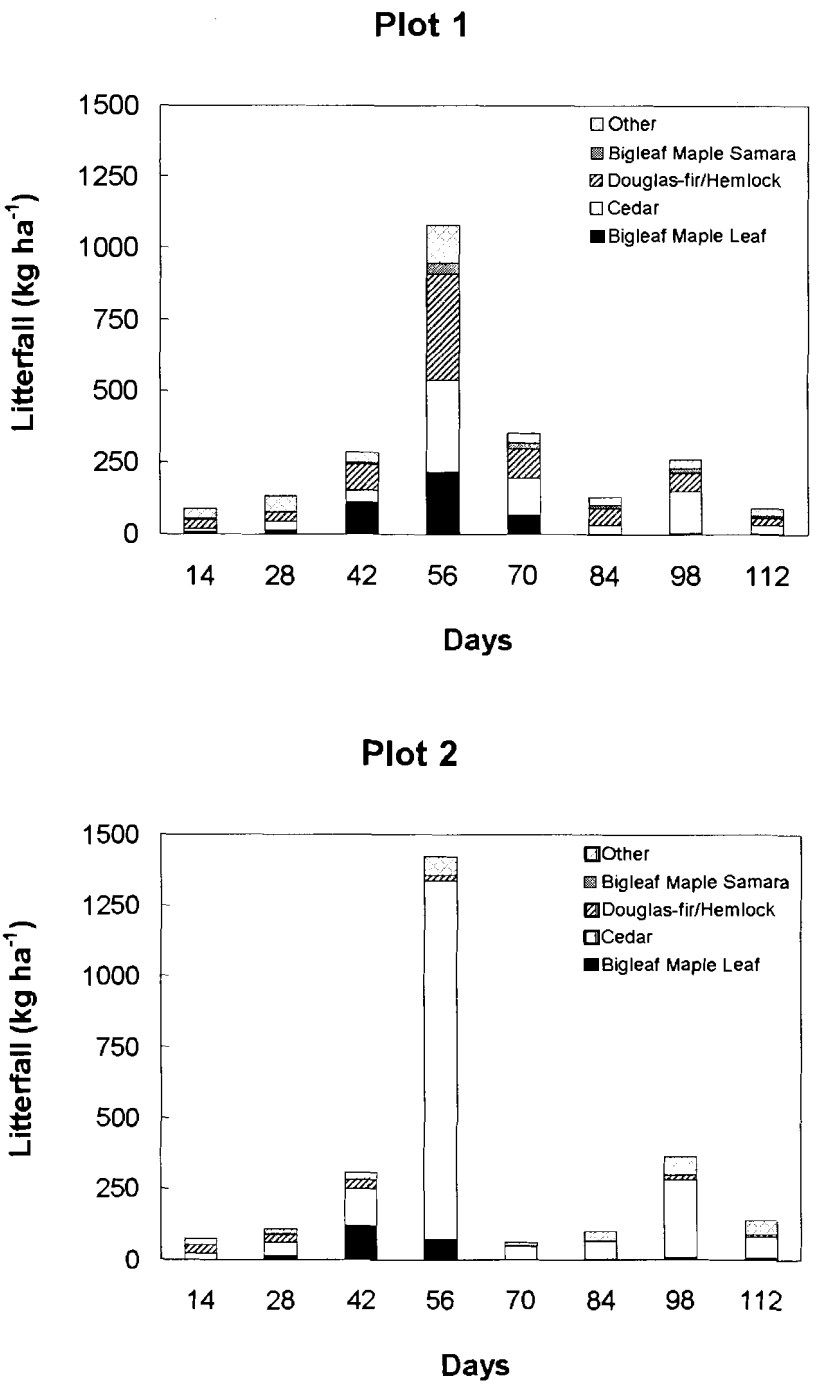



**Figure 3.18. Litterfall (kg $ha^{-1}$) collected on plot 1 (above) and plot 2 (below) over 112 days (from September 1 to December 22, 2005). Each plot was a 36 m x 36 m grid centered on a dominant bigleaf maple. Litter traps were laid at 25 systematic sample locations (Figure 3.2) on each plot and litter was collected biweekly ($n$ = 400). Litter was sorted into the following classes: bigleaf maple leaf, cedar, Douglas-fir or hemlock needles, bigleaf maple samara and other.**

# CHAPTER 4: BIGLEAF MAPLE INFLUENCE ON NITROGEN MINERALIZATION AND NUTRIENT AVAILABILITY FOR DOUGLAS-FIR UPTAKE

## 4.1 Abstract

This study investigated the influence of bigleaf maple (*Acer macrophyllum* Pursh) on nitrogen mineralization and nutrient availability in a conifer forest of southwest BC. A buried bag techniques was used to detect differences in nitrogen mineralization in forest floor from 12 bigleaf maple-Douglas-fir [*Pseudotsuga menziesii* (Mirb.) Franco] paired plots. A pot trial was also used to detect differences in growth and foliar nutrient concentrations of Douglas-fir seedlings planted in forest floor and mineral soil that was removed from each of the 24 plots. Bigleaf maple plots had significantly higher $NO_3^-$ ($P$ = 0.0016), net nitrification ($P$ = 0.002), and total $NO_3^-$ and $NH_4^+$ ($P$ = 0.047). Douglas-fir plots had significantly higher $NH_4^+$ ($P$ = 0.047) and net ammonification ($P$ = 0.023). Douglas-fir grown in soil from bigleaf maple plots had significantly longer needles ($P$ = 0.03) and had a weak tendency for greater stem height ($P$ = 0.11 after 7 weeks of growth) and basal diameter ($P$ = 0.078 after 15 weeks of growth) than Douglas-fir grown in soil from beneath Douglas-fir.

## 4.2 Introduction

While bigleaf maple (*Acer macrophyllum* Pursh) (BLM) is a common and large tree species with potential commercial value (B.C. Ministry of Forests, 1999), little is known about the degree and spatial extent of its impact on the surrounding forest floor. BLM may act as a nutrient sink by locking nutrients (that may otherwise be leached through the soil profile and out of the ecosystem) in its biomass (Minore, 1979). BLM may also input its nutrients into the surrounding soil, thereby improving site fertility, via throughfall, litterfall, stemflow, root dispersal, bark water retention, and biotic consumption, relocation and waste (Hosie, 1969; Fried et al. 1990).

As the largest maple in western Canada, BLM has a complex and majestic physical structure that provides for the needs of many organisms including habitat and food sources from its seeds, stems and litter (Fried et al. 1988; Hartwig et al., 2004). Despite the ecological and economic benefit of BLM, it has been considered a competitor of Douglas-fir stands and is often removed from stands and managed to control its presence (Hauessler, 1990).

The influence of deciduous species on soil properties in conifer forests has been the focus of several studies (Prescott, 2002; Tashe and Schmidt, 2003; Washburn and Arthur, 2003), yet to date there have been no studies to determine the influence of BLM on forest floor properties at plot-scale in British Columbia's coastal forests. One of the few studies on BLM was conducted in western Oregon and compared the physical and chemical properties of forest

floor and mineral soil beneath 5 paired plots of BLM and Douglas-fir [*Pseudotsuga menziesii* (Mirb.) Franco] (Fried et al. 1990). No significant differences were found in the biomass and nutrient content of forest floor, however, litterfall nutrient content and annual litterfall weight were significantly higher and turnover rates of forest floor nutrients were significantly faster beneath BLM.

Nitrogen is the most limiting nutrient for plant growth in most temperate forests, particularly for the Pacific Northwest (Gessel et al., 1973; Swanston and Myrold, 1997; Fisher and Binkley, 2000). The forest floor of conifer forests typically develops from decaying woody debris, which is generally acidic and low in available nitrogen (Klinka et al. 1995). However, the quality and quantity of foliar litter deposited onto the forest floor and recycled into nutrient forms available to plants may alter site fertility (Prescott, 2002) and the microbial communities present (Grayston and Prescott, 2005). Microbial populations found in the soil can immobilize nitrogen (Hart et al. 1994) and it is possible for competition for labile forms of nitrogen to occur between soil microorganisms and plant species when N is limited (Kaye and Hart, 1997).

BLM foliage, litter, wood, and bark has high levels of N, K, and Ca and contains relatively low amounts of P and Mg compared to other tree species of the northwest (Minore, 1979). The decomposition rate of litter material on the forest floor is primarily a function of climate, the nature and abundance of soil organisms, and litter quality (Swift et al., 1979; Couteaux et al., 1995). It is believed that forest floor has a higher level of microbial activity than mineral soil

(Gordon, 1987) and that N-mineralization rates vary seasonally, with faster rates in the spring and summer (Binkley, 1989).

Washburn and Arthur (2003) found that the litter of red maple (*Acer rubrum L.*) reduced surface soil N turnover but increased the soil cation availability. Wardman and Schmidt (1998) found that vine maple (*Acer circinatum* Pursh) may positively influence site productivity as Douglas-fir [*Pseudotsuga menziesii* (Mirb.) Franco] located adjacent to vine maple gaps had 182 % larger crowns and 46 % larger boles than Douglas-fir in the surrounding forest matrix. Miller et. al, (2006) examined the influence of individual reserve trees of 2 broadleaf species, northern red oak *(Quercus rubra L.)* and yellow-poplar *(Liriodendron tulipifera L.)* distributed evenly throughout clearcut areas of a hardwood forest in eastern United States. Their results indicated that the reserve trees influenced not only the growth rate but also the species composition of the surrounding regeneration within their immediate vicinity.

The current study used a buried bag mineralization study and a pot trial to investigate the influence of BLM on forest floor nutrient availability within conifer forest.

## 4.3 Methodology

### 4.3.1 Study Site

Within the Malcolm Knapp Research Forest, 12 BLM plots and 12 conifer plots from 4 stands (Fig. 4.1) were selected based on the following criteria: (1) a tree that is dominant within the stand; (2) the stem of the tree is no less than 15

m from any other dominant deciduous tree species; (3) the bole of the tree is no less than 25 m from roads, skid trails, and recently deforested sites and (4) a plot undisturbed by other research studies, debris flow, water courses or other influences which could significantly reduce the quality of the study. Both the N-mineralization and greenhouse studies used the forest floor from these 24 plots.

### 4.3.2 Buried Bag Study

The buried bag technique (Hart et al., 1994) was used to detect differences in N mineralization between BLM and conifer site types. At each of the 24 plots, a central point was located within 2 m of the tree stem and 6 samples were taken within 30 cm from this central point (Fig. 4.2). Of the 6 samples, 3 were reburied in polyethylene bags and left to incubate in situ, while the other 3 were removed from the plot and transported to Pacific Soils Analysis Inc., Richmond, B.C. for chemical analysis. Each intact forest floor sample was collected by inserting a cylinder (5 cm inner diameter, 15 cm height) into the forest floor then removing it from the ground by excavating the soils adjacent to the cylinder while avoiding disturbance of forest floor at other sample locations.

A glass plug was inserted into the cylinder at the end with the top layer of forest floor and used to push the sample out of the cylinder until the mineral soil-forest floor interface could be seen at the bottom. The mineral soil was carefully removed from the bottom of the sample and the intact forest floor core was then carefully placed in a polyethylene bag and sealed with a twist tie. For the 3 samples remaining on site, the bag above the twist tie was cut off and the

bagged sample was reburied in its place with as little disturbance as possible to prevent disturbing the N-transformation rate (Hart et al., 1994).

Forest floor was placed on the reburied bags to prevent penetration of solar radiation and left to incubate for 40 days (from July 20$^{th}$ and 21$^{st}$ to August 29$^{th}$ and 30$^{th}$, 2005). Prior to chemical analysis, each of the three samples per plot were composited ($n$ = 24). All samples removed from the study site were kept cool at 4° C in a cooler or refrigerator until delivered (within 48 hours) to Pacific Soils Analysis, Richmond, British Columbia for chemical analysis.

*4.3.2.1 Chemical Analysis*

The composite samples ($n$ = 24) were tested for pH at the Simon Fraser University Soils Laboratory and followed standard procedures with a 1:4 soil-to-solution ratio with 0.01 *M* $CaCl_2$ as the suspension solution (Kalra and Maynard, 1991). The suspension was stirred every 5 minutes for 30 minutes and left to settle for the following 30 minutes. A glass electrode pH meter was immersed into the supernatant solution and the pH value was recorded after the reading on the pH meter stabilized (usually within 1 minute). "Pacific Soils Analysis" laboratory carried out the chemical laboratory analysis to determine available nitrogen (ammonium and nitrate) on the 12 forest floor samples from each plot type, before and after incubation. Available $NH_4^+$ and $NO_3^-$ were determined using a 0.5 *M* $K_2SO_4$ extract. $NH_4^+$ was measyred colorimetrically on a Technicon Autoanalyser, and $NO_3^-$ was measured by the CTA color development method and measured on a Turner colorimeter (Lavkulich, 1977, 1978; Carter, 1993).

### 4.3.3 Greenhouse Experiment

At each of the 12 BLM and 12 Douglas-fir plots, soil was removed from a location < 2.5 m from the tree stem on May 5$^{th}$ and 6$^{th}$, 2005. A measuring tape was used to measure a location within 2.5 m from the tree stem that had not already been sampled in previous experiments, and that was free from coarse woody debris and large rocks. A section of forest floor with mineral soil was carefully excavated, removed and placed into a greenhouse pot 21 cm high x 19 cm in diameter, and transported to the greenhouse at Simon Fraser University. On May 10$^{th}$, 2005, Douglas-fir seedlings were planted into the 24 pots, half with soil from beneath a dominant BLM and half with soil from beneath a dominant conifer.

Coastal Douglas-fir seedlings were acquired from Pelton Reforestation Ltd., Maple Ridge, B.C., May 9, 2005. Seedlings were from a single seedlot (60303), and had been grown for approximately 16 months prior to replanting for the purpose of this experiment. All seedlings were carefully washed to completely remove the growing medium prior to planting into the pots. The seedlings were grown in a greenhouse at Simon Fraser University and rotated with randomized procedure bimonthly to reduce the effects of different light intensities. The seedlings were watered weekly and then twice a week during the hottest summer period from July 14$^{th}$ to August 24$^{th}$ to avoid desiccation. Height and basal diameter were recorded biweekly. Seedlings were harvested November 12, 2005, 182 days after planting.

The seedlings were oven-dried at 70° C for 24 hours, separated into roots, stem, and needles, weighed, and stored in labelled bags. Prior to oven-drying the seedlings, 3 samples of new needle growth from each seedling was removed, measured and an average needle length for each seedling was calculated. The Ministry of Forests and Range, Research Branch Laboratory in Victoria, BC, carried out foliar analysis. A subsample of 2 grams of needles from each seedling were delivered to the laboratory in Victoria to determine foliar concentrations of N, P, K, Ca, Mg, S, Fe, Mn, B, Zn, Cu, and Al. Tissue samples were ground and added to a strong acid bath in closed microwave digestion vessels and heated to 130° C in 2 minutes (pressure limit 275 psi, power limit 650 watts). Samples were then held for 1 minute at 130° C and reheated to 180° C in 5 minutes (pressure limit 375 psi, power limit 650 watts) and held again at 180° C for 20 minutes. An ICP spectrometer was used to determine the elemental concentrations in the samples after cooling, swirling and rinsing (Kalra and Maynard, 1991).

### 4.3.4 Statistical Analysis

Statistical analysis included two-sample difference of means *t*-tests (Student, 1908) to find significant differences ($P = 0.05$) in measured properties between BLM and Douglas-fir site types for the buried bag study and for the greenhouse experiment. The buried bag study compared mineralization of N between the site types while the greenhouse experiment compared Douglas-fir

seedling growth and foliar elemental concentrations. All statistical analyses were carried out with SPlus (Insightful Corp., 2005).

## 4.4 Results

### 4.4.1 N-Mineralization

Results indicated that the pH of forest floor from BLM plots was significantly higher ($P$ = 0.016) than forest floor from Douglas-fir plots, however, no significant differences in initial $NH_4^+$ and $NO_3^-$ were detected between the two site types (Table 4.1). After incubation, significant differences in $NH_4^+$ and $NO_3^-$ as well as net ammonification and net nitrification were detected between the two site types. BLM plots had significantly higher $NO_3^-$ ($P$ = 0.0016) and higher net nitrification ($P$ = 0.002) while Douglas-fir plots had higher $NH_4^+$ ($P$ = 0.047) and higher net ammonification ($P$ = 0.023).

### 4.4.2 Greenhouse Experiment

At the time of harvest all Douglas-fir seedlings had become pot bound and no significant differences in stem height or basal diameter were detected for Douglas-fir seedlings grown in soil medium from BLM and Douglas-fir plots (Tables 4.2 and 4.3). Douglas-fir seedlings grown in the soil medium that was collected from beneath BLM indicated a possible weak trend of increased stem height growth ($P$ = 0.11) for the first 7 weeks of growth. For the Douglas-fir seedlings grown in the soil from the BLM site there was also a weak trend of increased basal diameter growth at each measurement date ($P$ = 0.24, 0.078 and

0.095 for the 3 measurement dates). The needles of the Douglas-fir seedlings grown in the soil from the BLM plot were significantly longer ($P$ = 0.03) than those grown in the soil from beneath Douglas-fir (Table 4.4).

The foliage of the Douglas-fir seedlings grown in soil from BLM plots had significantly lower concentrations of Al ($P$ = 0.0079) and significantly higher concentrations of Ca ($P$ = 0.02) and N ($P$ = 0.04) compared to Douglas-fir plots (Table 4.5). Concentrations and contents of all other measured elements were not significantly different in foliage of Douglas-fir seedlings grown in soil collected beneath BLM and soil collected beneath Douglas-fir.

## 4.5 Discussion

BLM presence positively influenced the mineralization of nitrogen into forms available to plants. Prior to incubation, there were no significant differences in ammonium or nitrate levels between the two sites. Although net ammonification was significantly higher at Douglas-fir sites, net nitrification, ammonium, and nitrate concentrations were significantly higher at the BLM sites. The BLM site type also had significantly higher pH, which could indicate increased cation availability. This may provide an environment favourable to particular microbial (Fraterrigo, 2006) and invertebrate (Carcamo, 2000; Forge, 2000; Marhan, 2006; Postma-Blaauwa, 2006) communities responsible for N mineralization.

Douglas-fir seedling growth was not significantly different between the site types indicating that although the seedlings may have different nutrient uptake,

the soils from beneath both Douglas-fir and BLM contained enough nutrient for seedling growth. Foliar samples indicated that for both BLM and Douglas-fir site types, all macronutrients (N, P, K, Ca, Mg) and micronutrients (Mn, Fe, Zn, Cu, B) were adequate for Douglas-fir growth (Ballard and Carter, 1986). Tashe and Schmidt (2001) found that N, P and K were severely deficient, slightly deficient and moderately deficient (respectively) in both vine maple and conifer plots in a 130-year-old stand in southwest BC. In addition, significantly higher N concentrations were found in Douglas-fir foliage from trees in plots with a component of vine maple compared to plots without vine maple in a 130-year-old stand.

The pot trial found significantly lower concentrations of Al and significantly higher concentrations of Ca and N were found in the foliage of Douglas-fir grown in soil from the BLM plots. Al may inhibit N nitrification (Gilliam et al., 2005), the cycling of nitrogen into the form of nitrogen preferred by deciduous species. This study found high concentrations of Al associated with Douglas-fir plots, which may potentially act as an allelopathic inhibitor for cycling of nitrogen into labile forms preferred by deciduous species.

The buried bag technique has its limitations; it is difficult to avoid the disturbance of the incubated samples due to soil organisms and rodents. Moreover, the nature of the polyethylene bag itself likely influences measurements made with this technique. The forest floor sample in the bag is segregated from air movement, soil colloid mobility, leaching, and other processes that might otherwise occur in forest floor. This may either reduce or

increase the presence of various forms of nitrogen. This aside, the technique provided a controlled measure of N mineralisation by which differences between site types were detected.

Pot trials may not accurately evaluate nutrient cycling within forest conditions. The greenhouse controls climatic variations that would otherwise occur across a forested landscape and in response to microtopographic variation (Schmidt et al., 1998). The watering schedule limits the intensity, frequency and type of water seedlings receive and time may also play a role in the tree's requirement for and ability to acquire nutrients from their environment (Cole and Gessel, 1992). Disturbance caused by soil collection for the pot trial could have altered mineralization rates; however, this would have occurred at both plot types. This study found that within the growing period, seedling roots can became confined to the pot and not able to grow into areas where soil chemical and physical properties are best for root growth, as would be expected in field conditions. Therefore, measurements taken at earlier stages of the pot trial (i.e. before the roots became confined to the pot) may better represent differences in plot types without the confinement of seedling roots.

## 4.6 Conclusion

Forest floor influenced by BLM exhibited an increased rate of N mineralization and there was a weak trend for growth of Douglas-fir seedlings to be improved. Deciduous species such as BLM may enrich the surrounding forest

floor and this may positively influence the nutrient uptake and growth of commercial forest species, such as Douglas-fir.

## 4.7 Acknowledgements

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## 4.8 References

**B.C. Ministry of Forests. 1999.** Bigleaf Maple Managers' Handbook. Government of Canada, British Columbia. 105 pp.

**Binkley, D. and S. Hart, S. C. 1989.** The components of nitrogen availability assessments in forest soils. Adv. Soil Sci. **10:** 57-112.

**Ballard, T.M. and Carter, R. E. 1986.** Evaluating forest stand nutrient status. Land Management Report 20. Ministry of Forests, Victoria, Canada. pp. 60.

**Cárcamo, H. A., Abe, T. A., Prescott, C. E., Holl, F. B., and Chanway, C. P. 2000.** Influence of millipedes on litter decomposition, N mineralization, and microbial communities in a coastal forest in British Columbia, Canada. Can. J. For. Res. **30:** 817-826.

**Carter, M. R. 1993.** Soil Sampling and Methods of Analysis. Canadian Society of Soil Science. Lewis Publishers. pp. 823.

**Cole, D.W. and Gessel, S. P. 1992.** Fundamentals of Tree Nutrition. In Chappell, H.N., Weetman, G. F., and R.E. Miller, R. E. Forest Fertilization: Sustaining and improving nutrition and growth of western forests. Institute of Forest Resources Contrib. 73. College of Forest Resources, Univ. of Washington, Seattle, WA.

**Couteaux M.-M., Bottner, P., Berg, B. 1995.** Litter decomposition, climate and litter quality. 1995. Trends in Ecology & Evolution **10:** 63-66.

**Fraterrigo, J. M., Balser, T. C., and Turner, M. G. 2006.** Microbial community variation and its relationship with nitrogen mineralization in historically altered forests. Ecology **3:** 570-579.

**Fried, J. S., Tappeiner, J. C., and Hibbs, D. E. 1988.** Bigleaf maple establishment and early growth in Douglas-fir forests. Can. J. For. Res. **18:** 1226-1233.

**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.

**Fisher, R. F. and Binkley, D. 2000.** Ecology and Management of Forest Soils. John Wiley and Sons. pp. 489.

**Forge, T. A. and Simard, S. W. 2000.** Trophic structure of nematode communities, microbial biomass, and nitrogen mineralization in soils of forests and clearcuts in the southern interior of British Columbia. Canadian Journal of Soil Science **80:** 401-410.

**Gessel, S.P. and Atkinson, W.A. 1973.** Forest fertilization practices. In Forest soils of the Douglas-fir region. Washington State University, Cooperative Extension Service, Pullman, Wash. pp. 293–298.

**Gilliam, F. S., Lyttle, N. L., Thomas, A., and Adams, M. B. 2005.** Soil Variability along a Nitrogen Mineralization and Nitrification Gradient in a Nitrogen-Saturated Hardwood Forest. Soil Science Society of America Journal **69:** 247-256.

**Gordon, A. M., Tallas, M., Van Cleve, K. 1987.** Soil Incubations in Polyethylene Bags: Effect of Bag Thickness and temperature on nitrogen transformations and CO2 permeability. Can J. Soil Sci. **67:** 65-75.

**Grayston, S. J. and Prescott, C. E. 2005.** Microbial communities in forest floors under four tree species in coastal British Columbia. Soil Biology & Biochemistry **37:** 1157-1167.

**Hart, S. C., Stark, J. M., Davidson, E. A., and Firestone, M. K. 1994b.** Nitrogen mineralization, immobilization and nitrification. In Methods of soil analysis. Part 2: Microbial and biochemical properties. Edited by R. F. Weaver, J. S. Angle, and P. S. Bottomley. Soil Science Society of America, Madison, Wis., Book Series No. 5. pp. 985-1018.

**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, B.C. 272 pp.

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

**Hosie, R. C. 1969.** Native Trees of Canada. Authority of the Minister of Fisheries and Forestry. Ottawa, Ontario. 380 pp.

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

**Kaye, J. P. and Hart, S. C. 1997.** Competition for nitrogen between plants and soil microorganisms. Trends in Ecology and Evolution **12:** 139-143.

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

**Klinka, K, Lavkulich, L. M., Wang, Q. and Feller, M. C. 1995**. Influence of decaying wood on chemical properties of forest floors and surface mineral soils. Annales des Sciences Forestieres **52:** 523-533.

**Lavkulich, L. M. 1977.** Methods Manual, Pedology Laboratory. Dept. of Soil Science, University of British Columbia.

**Lavkulich, L. M. 1978.** Methods Manual, Pedology Laboratory. Dept. of Soil Science, University of British Columbia.

**Marhan, S. and Scheu, S. 2006.** Mixing of different mineral soil layers by endogeic earthworms affects carbon and nitrogen mineralization. Biol Fertil Soils **42:** 308-314.

**Miller, G. W., Kochenderfer, J. N., and Fekedulegn, D. B. 2006.** Influence of individual reserve trees on nearby reproduction in two-aged Appalachian hardwood stands. Forest Ecology and Management **224:** 241-251.

**Minore, D. 1979.** Comparative autecological characteristics of northwestern tree species - a literature review. U.S. Dep. Agric. For. Serv., Gen. Tech. Rep. PNW-87. 72 pp.

**Postma-Blaauwa, M. B., Bloemb, J., Faberb, J. H., van Groenigenb, J. W., de Goedea, R. G. M., and Brussaard, L. 2006.** Earthworm species composition affects the soil bacterial community and net nitrogen mineralization. Pedobiologia **50:** 243-256.

**Prescott, C. 2002.** The influence of the forest canopy on nutrient cycling. Tree Physiology **22:** 1193-1200.

**Student (William Gosset). 1908.** The Probable Error of a Mean. Biometrika **6:** 1-25.

**Schmidt, M., Ogden, A., and Lertzman, K. 1998.** Seasonal comparison of soil temperature and moisture in pits and mounds under vine maple gaps and conifer canopy in a coastal western hemlock forest. Can. J. Soil Sci. **78:** 291-300.

**Swanston, C.W. and Myrold, D.D. 1997.** Incorporation of nitrogen from decomposing red alder leaves into plants and soil of a recent clearcut in Oregon. Canadian Journal of Forest Research **27:** 1496-1502.

**Swift, M. J., Heal, O. W., and Anderson, M.J. 1979.** Decompositionin Terrestrial Ecosystems. Univ. of California Press, Berkeley. pp. 372.

**Tashe, N. and Schmidt, M. G. 2001.** The impact of vine maple on site fertility of coastal temperate forests. Forest Ecology and Management **147:** 263-279.

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

**Wardman, C. and Schmidt, M. G. 1998.** Growth and form of Douglas-fir adjacent to persistent vine maple gaps in southwestern British Columbia. Forest Ecology and Management **106:** 223-233.

**Washburn, C. S. M. and Arthur, M. A. 2003.** Spatial variability in soil nutrient availability in an oak-pine forest: potential effects of tree species. Canadian Journal of Forest Research **33:** 2321-2330.

**Table 4.1. Nitrogen mineralization results for buried bag study (incubation period of 40 days).**

| | Bigleaf Maple Plot ($n$ = 12) | | Douglas-fir Plot ($n$ = 12) | | $P$ ($t$-test) |
|---|---|---|---|---|---|
| | Before Incubation | | | | |
| PH | 4.17 | (0.58) | 3.58 | (0.51) | 0.016 |
| *Concentrations* (mg $kg^{-1}$) | | | | | |
| $NH_4^+$ | 23.83 | (6.51) | 18.67 | (6.47) | 0.064 |
| $NO_3^-$ | 17.92 | (8.64) | 14.17 | (5.06) | 0.21 |
| | After Incubation | | | | |
| *Concentrations* (mg $kg^{-1}$) | | | | | |
| $NH_4^+$ | 35.75 | (24.58) | 77.17 | (63.64) | 0.047 |
| $NO_3^-$ | 176.92 | (85.15) | 70.92 | (56.38) | 0.0016 |
| $NH_4^+$ and $NO_3^-$ | 212.67 | (77.81) | 148.08 | (72.37) | 0.047 |
| Net Ammonification | 11.92 | (26.82) | 58.50 | (60.19) | 0.023 |
| Net Nitrification | 159.00 | (84.99) | 56.75 | (54.41) | 0.0020 |

Underlined values indicate significant differences at $P < 0.05$.

Values in parentheses are standard deviations.

**Table 4.2. Mean stem height (mm) of Douglas-fir seedlings grown in soil collected beneath bigleaf maple and soil collected beneath Douglas-fir.**

| | Stem Height Growth (mm) | | | | |
|---|---|---|---|---|---|
| Growth Period (2005) | Bigleaf Maple Soil ($n$ = 12) | | Douglas-fir Soil ($n$ = 12) | | $P$ ($t$-test) |
| May 17 - July 5 | 117.92 | (38.18) | 97.42 | (20.18) | 0.11 |
| May 17 - August 30 | 167.92 | (78.85) | 176.83 | (93.84) | 0.80 |
| May 17 - November 12 | 164.00 | (81.10) | 173.17 | (95.92) | 0.80 |

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

**Table 4.3. Mean basal diameter (mm) of Douglas-fir seedlings grown in soil collected beneath bigleaf maple and soil collected beneath Douglas-fir.**

| | Basal Diameter Growth (mm) | | | | |
|---|---|---|---|---|---|
| Growth Period (2005) | Bigleaf Maple Soil ($n$ = 12) | | Douglas-fir Soil ($n$ = 12) | | $P$ ($t$-test) |
| May 17 - July 5 | 1.16 | (0.38) | 0.55 | (0.50) | 0.24 |
| May 17 - August 30 | 3.05 | (0.96) | 2.40 | (0.75) | 0.078 |
| May 17 - November 12 | 3.71 | (1.13) | 2.99 | (0.89) | 0.095 |

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

**Table 4.4. Mean dry biomass (g) and mean needle length (mm) of Douglas-fir seedlings grown in soil collected beneath bigleaf maple and soil collected beneath Douglas-fir.**

| | Bigleaf Maple Soil ($n$ = 12) | | Douglas-fir Soil ($n$ = 12) | | $P$ ($t$-test) |
|---|---|---|---|---|---|
| *Biomass (g)* | | | | | |
| Stem (without needles) | 5.30 | (1.86) | 4.42 | (1.48) | 0.22 |
| Shoot (includes needles) | 9.35 | (3.55) | 8.74 | (3.19) | 0.67 |
| Root | 11.25 | (4.51) | 10.87 | (2.90) | 0.81 |
| Needles | 4.01 | (1.65) | 4.33 | (1.84) | 0.66 |
| Whole tree | 20.59 | (7.98) | 19.62 | (5.81) | 0.74 |
| *Length (mm)* | | | | | |
| Needles | 24.58 | (6.86) | 18.92 | (4.93) | 0.030 |

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

**Table 4.5. Mean concentrations of elements in foliage of Douglas-fir seedlings grown in soil collected beneath bigleaf maple and soil collected beneath Douglas-fir.**

| | Bigleaf Maple Soil ($n$ = 12) | | Douglas-fir Soil ($n$ = 12) | | $P$ ($t$-test) |
|---|---|---|---|---|---|
| N (g $kg^{-1}$) | 29.76 | (4.24) | 25.76 | (4.74) | 0.040 |
| P (g $kg^{-1}$) | 2.09 | (0.59) | 1.89 | (0.75) | 0.47 |
| K (g $kg^{-1}$) | 9.16 | (1.52) | 9.01 | (2.06) | 0.85 |
| Ca (g $kg^{-1}$) | 5.80 | (1.21) | 4.60 | (1.13) | 0.020 |
| Mg (g $kg^{-1}$) | 2.03 | (0.53) | 1.78 | (0.49) | 0.24 |
| S (g $kg^{-1}$) | 1.93 | (0.66) | 1.96 | (0.47) | 0.88 |
| Fe (mg $kg^{-1}$) | 138.71 | (40.17) | 133.24 | (27.89) | 0.70 |
| Mn (mg $kg^{-1}$) | 842.78 | (802.41) | 566.86 | (294.58) | 0.28 |
| B (mg $kg^{-1}$) | 39.62 | (18.05) | 40.76 | (18.86) | 0.88 |
| Zn (mg $kg^{-1}$) | 102.78 | (32.82) | 99.83 | (34.76) | 0.83 |
| Cu (mg $kg^{-1}$) | 9.70 | (3.39) | 9.23 | (4.54) | 0.78 |
| Al (mg $kg^{-1}$) | 88.49 | (22.28) | 142.91 | (60.49) | 0.0079 |

Underlined values indicate significant differences at $P < 0.05$.

Values in parentheses are standard deviations.

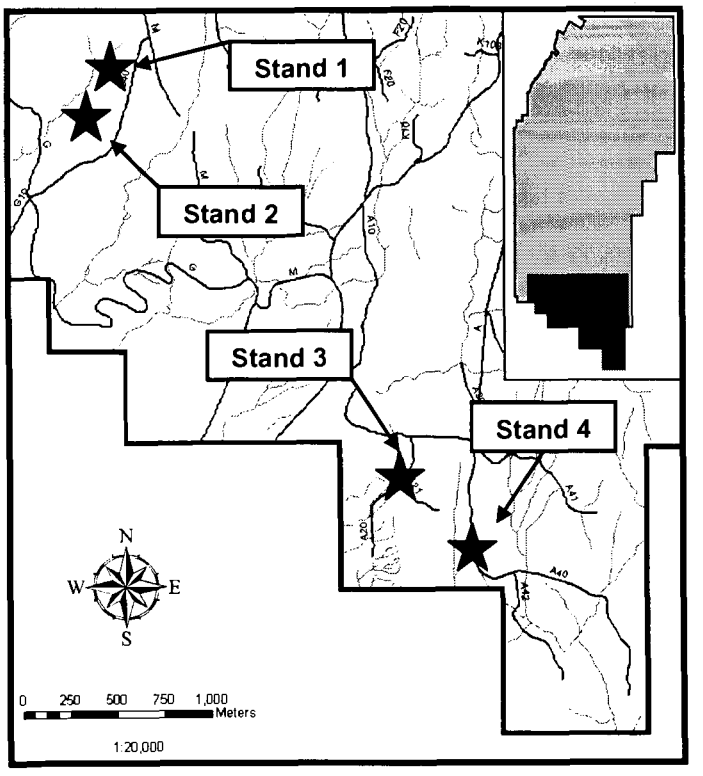


Figure 4.1. The study site contains 4 stands each with 3 Bigleaf maple and Douglas-fir plots. Stands 1 and 2 are 140 years old and stands 3 and 4 are 80 years old.

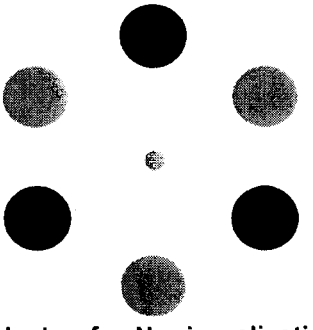

Figure 4.2. Sample design for N-mineralization buried bag study. At 12 bigleaf maple plots and 12 Douglas-fir plots, 3 forest floor samples were removed for chemical analysis and 3 were incubated in place for 40 days. The central point was < 2 m from the tree stem and each of the 6 samples were taken within 30 cm of the central point. Every second sample (black) was removed for chemical analysis and the remaining 3 samples were placed in polyethylene bags and reburied for incubation. The 3 samples at each plot, before and after incubation, were composited ($n$ = 24).

# CHAPTER 5: CONCLUSION

## 5.1 Conclusion

The overall goal of this study was to detect bigleaf maple influence on soils in a conifer forest of southwest BC and was addressed by its three components. In the first part of the research BLM was found to influence forest floor pH. Significant increases in forest floor pH within 2.5 m of individual BLM stems and beneath the canopy extent were found and the pH data indicated a high degree of variability over space. This pattern of influence was not found to be anisotropic on slopes ranging from 15 - 37 %. This information was useful in developing a two dimensional plot-scale sample design that incorporated a nested design to capture variability of forest floor properties in relation to both tree stem and canopy.

The nested plot-scale sample design developed for the second component of this study provided insight regarding the finer scale patterns about the individual tree stem. Forest floor in close proximity (approximately 2.5 m) from BLM stems exhibited increased exchangeable cation concentrations and cation exchange capacity, higher pH, and increased concentrations of mineralized N than areas greater than 2.5 m from the tree stem. Spatial patterns of litter deposition resembled the irregular shape of the tree's canopy and collected on the forest floor in an area concentrated about its respective tree stem.

The last component of this research used BLM-Douglas-fir paired plots to investigate how BLM influences N mineralization and nutrient availability. Locations within 2 m of bigleaf maple stems mineralize nitrogen faster than areas within 2 m of conifer stems. Ca and N derived from the bigleaf maple leaves decompose into forms readily available for assimilation by young Douglas-fir in soils that are otherwise generally coarse and nutrient poor. This study found that Douglas-fir seedlings grown in soil from bigleaf maple plots had higher concentrations of Ca and N in their foliage than Douglas-fir seedlings grown in soils from conifer plots.

Area of influence cannot be predicted from only DBH data in the case of BLM; plots often have multiple stems that may not grow perpendicular to the ground. Although plot 1 had a larger BLM stem than plot 2, the area over which the tree canopy influence occurred was similar between the two plots. Irregularities in the shape of BLM canopy called for an innovative combination of analytical tools for describing the influence of the tree as a whole. For example, linear data analysis does not accurately describe spatial patterns of forest floor data, due to strong relationships between the data points that may or may not be stationary.

Wavelet transformations of the transect data detected breaks in pH data at locations adjacent to the tree stem on several transects. Kriging constructed continuous maps for visualization of soil properties over 36 m x 36 m plots centered on a dominant BLM stem while SAA correlograms offered insight on the relationship of spatial dependency between points and provided an example of

fine-scale spatial pattern detection of properties within a broader spatial pattern. LISA statistics, were able to detect patterns of spatial dependency, provided locality of these patterns with LISA maps and provided *P*-values attributed to each observation with significance maps.

This work provides a methodological foundation for future research on deciduous tree influence on soil properties in conifer forest. The overall findings of this study are that BLM influence is limited to the spatial extent of the physical structures of the tree with the greatest impact at the tree stem. This suggests that a single BLM tree may not be able to enrich soils away from the tree, even on sloped landscapes, but it does influence the soils in close proximity to it.

## 5.2 Future Directions

Spatial scale played a major role throughout this study. Transect data provided the basis for the dimensions and nesting of the plot-scale sample design. Without evidence of slope as a significant factor generating anisotropic behaviour, the sample plots were centered on individual BLM stems and this plot-scale data began to unfold the nature of BLM influence on the forest floor properties through space. Future studies should consider investigating the influence of BLM on a broader spatial scale, for example, a 200 m x 300 m study site with a 2 m sample resolution. Non-linear multivariate methods, for example variance partitioning analysis (partial redundancy analysis) should also be considered as an analytical tool. Another possibility of exploring deciduous species influence could involve modeling changes of physical characteristics influencing soil properties and their response over time.