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The influence of bigleaf maple on forest floor and mineral soil properties in a coniferous forest in coastal British Columbia

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Abstract

Bigleaf maple (*Acer macrophyllum* Pursh) is a common tree species in coastal forests of the Pacific Northwest. We studied the influence of bigleaf maple on forest floor and mineral soil properties in a forest dominated by Douglas-fir [*Pseudotsuga menziessi* (Mirb.) Franco] and western hemlock [*Tsuga heterophylla* (Raf.) Sarg.]. Twelve plots containing bigleaf maple were compared to paired plots without the influence of bigleaf maple. Compared to conifer plots, forest floors at bigleaf maple plots were significantly thinner, but the total contents of C in both forest floor and surface mineral soils did not differ between bigleaf maple and conifer plots. This suggests that the bigleaf maple litter may not be fully decomposing; rather a portion of the decomposing litter may be transforming into recalcitrant soil organic matter. Bigleaf maple plots had significantly higher pH, NO_3-N concentrations and contents and mineralizable N contents in the forest floor as well as significantly higher cation exchange capacity and concentrations of N (total, mineralizable and NO_3-N) and exchangeable K, Ca and Mg in the mineral soil. The changes in soil chemical properties suggest that the presence of bigleaf maple in conifer forests may cause a modest improvement in soil fertility.

Keywords: Bigleaf maple; *Acer macrophyllum*; Nutrient cycling; Forest floor properties; Mineral soil properties; Humus form

1. Introduction

Nutrient cycling is crucial to soils in the Pacific Northwest, which are typically acidic and deficient in nitrogen (N) and phosphorus (P) (Tarrant et al., 1951; Fisher and Binkley, 2000). Although mineral weathering and understory vegetation play an important role in nutrient flux, the forest canopy produces most of the litter reaching the forest floor and, therefore, has the largest influence on the development of the forest floor and its properties. Forest nutrition may be improved in mixed-wood stands, especially if mixed foliage results in higher elemental inputs, faster decay, or if the present species are limiting in different nutrients (Rothe and Binkley, 2001). Litterfall measurements comparing European beech (*Fagus sylvatica* L.) and Norway spruce (*Picea abies* (L.) H. Karst.) showed significantly higher contents of calcium (Ca), potassium (K) and magnesium (Mg) in European beech litter, and little difference for N and P (Rothe and Binkley, 2001).

Vine maple (*Acer circinatum* Pursh) is an understory shrub or tree native to British Columbia (BC) and the northwestern United States, and like other hardwoods is managed to minimize its competitive influence in conifer forests. Research in BC conifer forests reported that vine maple litter is nutrient-rich and fast decomposing, suggesting its presence positively influences site fertility (Ogden and Schmidt, 1997; Wardman and Schmidt, 1998; Tashe and Schmidt, 2001). Plots with vine maple had a higher pH in the upper mineral soil and greater concentrations of Ca, K and Mg in the forest floor relative to conifer-dominated plots (Ogden and Schmidt, 1997). In the same study area, Wardman and Schmidt (1998) observed greater site index and tree height of Douglas-fir [*Pseudotsuga menziessi* (Mirb.) Franco] when adjacent to vine maple. The positive influence of vine maple on productivity in coastal forests suggests bigleaf maple (*Acer macrophyllum* Pursh), a substantially larger tree, may have a similar and possibly greater impact on conifer productivity.

Bigleaf maple is abundant in western North America. Its native range extends from northern Vancouver Island (British Columbia Ministry of Forests, 1989), south into California, and always within 300 km of the Pacific Ocean (Fig. 1) (Peterson et al., 1999; United States Department of Agriculture Forest

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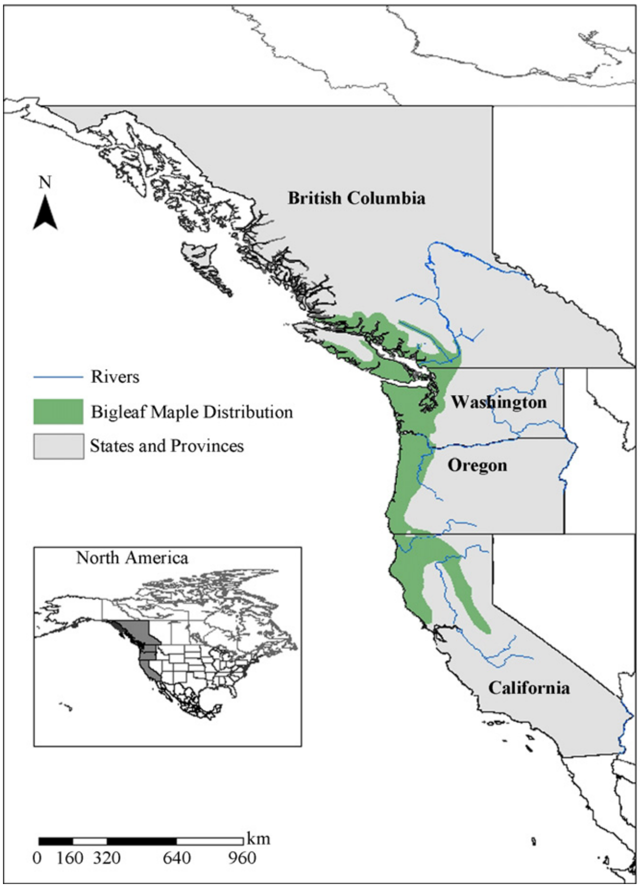

Fig. 1. Geographic distribution of bigleaf maple in southwestern British Columbia (modified from Haeussler et al., 1990 and USDAFS, 2004).

Service [USDAFS], 2004). It is a low-elevation species, typically occurring below 300 m (Haeussler et al., 1990). Bigleaf maple is found in pure stands or in combination with conifer (Douglas-fir, western hemlock [*Tsuga heterophylla* (Raf.) Sarg.], and western redcedar [*Thuja plicata* Donn ex D. Don.]) and deciduous (red alder [*Alnus rubra* Bong.] and black cottonwood [*Populus trichocarpa* (Torr. & A. Gray)]) tree species. Conventionally, the presence of bigleaf maple has been deemed competitive and even detrimental to conifer survival (Haeussler et al., 1990).

Several aspects of bigleaf maple suggest that its presence can contribute a rich supply of nutrients to the forest nutrient cycle (Krajina et al., 1982). Bigleaf maple litterfall is high in N, Ca and K compared to other tree species of western North America (Haeussler et al., 1990), and contains higher levels of most nutrients than conifer litter (Fried et al., 1990; Tarrant et al., 1951; Turk, 2006). Observations from a study comparing the soil properties beneath Douglas-fir with those beneath bigleaf maple (Fried et al., 1990) support this idea. Fried et al. (1990) found that concentrations of Ca, K, Mg, molybdenum (Mo), and zinc (Zn) in Douglas-fir litter were significantly greater beneath bigleaf maple than under Douglas-fir at all sites. In addition, faster decomposition of bigleaf maple litter than of Douglas-fir needles was observed, which Fried et al. (1990) suggested resulted from high base concentrations of maple litter.

Epiphytes supported by bigleaf maple are another potential source of nutrient input. In coastal old-growth forests of the Olympic Peninsula, large epiphyte populations on the bark of bigleaf maples contributed nearly four times the foliar biomass of the host tree, demonstrating the crucial role epiphytes may play in nutrient cycling (Nadkarni, 1984). The combined effect of relatively high litter nutrient content and fast litter decomposition as well as potential nutrient input from associated epiphytic populations suggests that bigleaf maple has the potential to contribute a significant amount of nutrients to the forest floor and soil.

Considerable research has been carried out concerning species influence on soils, but results are not consistent and generalizations are not possible (Binkley and Giardina, 1998). Although previous studies involving bigleaf maple and vine maple show promising results, evidence does not consistently support the idea that nutrient availability is better under broad-leaved than needle-leaved trees (Prescott, 2002). The influence of vegetation types on soil and forest productivity requires a number of studies encompassing a variety of species.

The present study investigates the influence of bigleaf maple on site fertility in a coastal Douglas-fir forest through an examination of forest floor and mineral soil properties in paired plots with and without bigleaf maple present. The objectives of this study were to determine the influence of big leaf maple on: (1) forest floor depths and humus form type, (2) forest floor chemical properties and (3) mineral soil properties.

2. Materials and methods

2.1. Study area and sampling design

This study was conducted at the Malcolm Knapp Research Forest (MKRF), located in Haney, BC (49°16′40″N, 122°34′20″W) approximately 40 km east of Vancouver (Fig. 2). The study area is located in the coastal western hemlock (CWH) biogeoclimatic zone. Mean annual precipitation is 2140 mm and mean monthly temperatures range from 1.4 to 16.8 °C (Pojar and Meidinger, 1991). The forest mainly consists of a mixture of Douglas-fir, western hemlock and western redcedar. Bigleaf maple, black cottonwood and red alder are also common. Understory vegetation includes vine maple, western sword fern (*Polystichum munitum* (Kaulfuss) K. Presl), salal (*Gaultheria shallon* Pursh), and trailing blackberry (*Rubus ursinus* Cham. & Schlecht.). Two 1 m deep soil pits revealed that the soil in the study area is a Gleyed Dystric Brunisol (Tashe, 1998). Soil textures throughout the profile were identified as sandy loam and loamy sand (Tashe, 1998). Parent materials have been identified as colluvial and morainal deposits (Klinka, 1976).

Four conifer-dominated stands with a component of bigleaf maple were located using forest cover maps (British Columbia Ministry of Forests, 1989) and local knowledge supplied by MKRF personnel. Of the four stands chosen, two were aged 125 years and two 65 years. The two older stands regenerated naturally following wildfire, and the two younger stands were planted after an accidental fire.

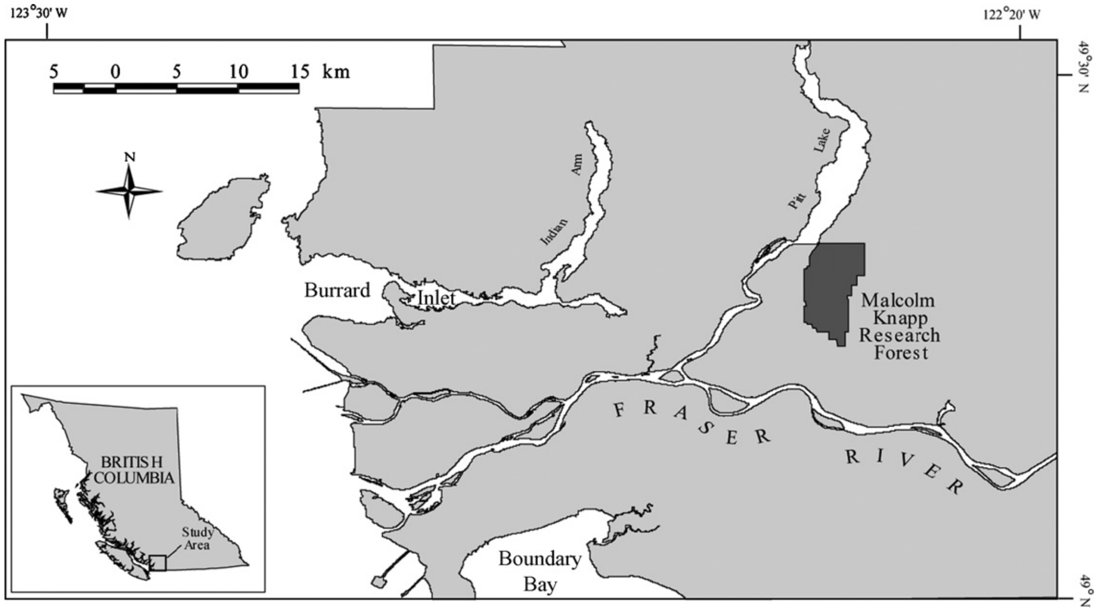

Fig. 2. Location of Malcolm Knapp Research Forest in southwest British Columbia.

Soil properties were compared between vegetation types (bigleaf maple and conifer) using a paired-plot methodology. Three sets of paired plots were selected within each stand, yielding a total of 12 pairs (24 plots). Each bigleaf maple plot contained one bigleaf maple tree, and was paired with a conifer plot exhibiting similar site characteristics (slope, aspect, elevation and understory vegetation). This allowed for comparison between sites with and without bigleaf maple. Plots had a radius of 5 m (0.0079 ha in size) and were centred on the bole of a dominant or co-dominant tree. All plots met two further criteria: (1) they showed no signs of recent disturbance, and (2) they were at least 15 m away from other deciduous trees.

Despite the latter precaution, a considerable amount of black cottonwood litter accumulated in one plot during the observation period. Data from this plot were, therefore, excluded from further analysis of forest floor and mineral soil. Where possible, conifer plots were centred on the boles of dominant Douglas-fir trees. A western hemlock bole was used as the centre of one plot because no suitable Douglas-fir stem was present. The characteristics of this plot were similar to its pair. Selected conifer plots were between 30 and 65 m from their established paired bigleaf maple pair.

2.2. *Forest floor sampling and analysis*

Humus form sampling and classification occurred during November and December 2003, and January, March and November 2004. Three forest floor samples were extracted from each plot using randomly selected bearings and distances (between 1.5 and 4.0 m) from the plot centre. The same sets of bearings and distances were used for all plots. Sampling at woody, rocky, or disturbed locations was avoided. If sampling at a randomly selected location was not suitable, sampling was conducted 0.5 m in each of the cardinal directions (in the order north, south, east, west) until a suitable sampling location was encountered. Samples extracted were approximately 20 cm × 20 cm and extended to the depth of the organic–mineral soil interface.

To reduce errors in depth estimation due to disturbance, depths of horizons affecting humus form classifications (e.g., L, F, H, Ah, and Ae) were recorded in the field. Where differentiation between organic and mineral material (typically H versus Ah material) was uncertain, sub-samples were removed from excavation sides for determination of organic matter content following the loss-on-ignition (LOI) method, described by Kalra and Maynard (1991).

At each plot, three additional forest floor samples were collected for quantitative measurement in July 2005 and followed the methods used for humus form sampling. Moist forest floor samples were weighed, and then subsamples of the forest floor were weighed, oven-dried at 105 °C for 48 h, and re-weighed (Kalra and Maynard, 1991) to calculate the mass per unit area. An additional subsample of equivalent mass was removed from each sample, oven-dried for 24 h at 70 °C, weighed, ground and composited per plot (Ogden, 1996; Tashe, 1998). After thorough mixing, composite samples from each plot were sent to the Ministry of Forests and Range Analytical Laboratory in Victoria, BC where pH, total N, C and sulphur (S), mineralizable N, exchangeable K, Ca, Mg, Fe and Al, available P, NO_3-N and NH_4-N were determined.

Forest floor pH was measured by using a pH meter with a combination electrode and data acquisition system in a 1:1 forest floor to water solution (Kalra and Maynard, 1991). Total C, N, and S were measured on a Fisons NA-1500 Elemental Analyser. The calculated concentrations of C and N were used to calculate the C:N ratio of the forest floor. Exchangeable K, Ca, Mg, Fe and Al were determined using an ARL 3560 inductively coupled argon plasma (ICAP) spectrometer. The sum of cations included in this method was used to measure effective cation exchange capacity (CEC) (Carter, 1993; Hendershot and Duquette, 1986). Available P was extracted using the Bray P1 method. Afterwards, the phosphate in the extracting solution was complexed with ammonium molybdate and antimony potassium tartrate to form a stable antimony-phospho-molybdenum blue complex (Kalra and Maynard, 1991; John, 1970). Nitrate N and NH_4-N were measured colorimetrically using an Alpkem Flow System IV analyzer (Carter, 1993; Bremner, 1965).

Mineralizable N was measured for forest floor samples using an anaerobic incubation method, in which a soil sample is incubated under anaearobic, water-logged conditions for 2 weeks at 30 °C and measured colorimetrically using a Technicon Auto-analyzer II (Waring and Bremner, 1964a,b; Bremner, 1965). Total contents were converted to kg ha^{-1} by multiplying total concentrations by the forest floor mass per unit area.

2.3. Mineral soil sampling and analysis

Three randomly selected mineral soil samples per plot were collected in July 2005 using a bulk density corer (radius 5.0 cm, height 7.0 cm, total volume 549.8 cm^3). Bulk density cores were taken from directly beneath forest floor sampling locations. The total moist mass of soil cores was measured. Subsamples from soil cores were weighed, oven dried at 105 °C for 48 h, and weighed again (Kalra and Maynard, 1991) to calculate bulk density.

Coarse (>2 mm) fragment content was determined by dry sieving each sample. Equal portions from each of the soil samples were air-dried, composited by plot, thoroughly mixed and sent to the Ministry of Forests and Range Analytical Laboratory in Victoria, BC for analysis of pH, total N and C, mineralizable N, exchangeable K, Ca, Mg, Fe and Al, available P, NO_3-N and NH_4-N. Mineral soil samples were analysed using the same methods as described for forest floor samples.

2.4. Statistical analysis

All quantitative data were statistically analyzed using S-Plus 7.0 software. Plots were considered as individual sample units each representing the mean of three sub-samples. All data sets were plotted on a Quantile-Quantile (QQ) graph for visual inspection of normal to near-normal distribution. A significance level of $P = 0.10$ was used for all data analyses. Data appearing normal were analysed using paired *t*-tests to test for statistically significant differences between vegetation types. Not normal or not near-normal data were log-transformed prior to statistical analyses to achieve normality. Data that could not be corrected with log transformations were analysed using the Wilcoxin signed rank test, which is the nonparametric analogue to the *t*-test (Zolman, 1993).

The probability of committing a Type II (β) error, failure to reject the null hypothesis when the alternative hypothesis is true (Kleinbaum et al., 1998), was calculated when paired *t*-tests yielded non-statistically significant results on normally distributed data. Power ($1 - \beta$) was determined using a computer program created by Borenstein and Cohen (1988).

3. Results

3.1. Forest floor horizon depths and humus form classification

All depths of the forest floor and upper mineral horizons, with the exception of the H horizon, showed statistical differences between bigleaf maple and conifer plots (Table 1; Fig. 3). The Ah horizon was significantly thicker at bigleaf maple plots, when examined both alone and in combination with the H horizon. Total forest floor plus Ah horizon was thicker at bigleaf maple plots. Conifer plots had significantly thicker L, F, F + H, Ae, and total forest floor horizons (L + F + H) relative to bigleaf maple plots (Fig. 3).

Six humus form types were identified: humimor, hemimor, mormoder, leptomoder, mullmoder, and vermimull. Lignic humus forms (lignomor and lignomoder) were not observed because sampling of woody forest floors was avoided. Similarly, charcic and clastic humus forms were absent at all subplots due to avoidance of charcoal- and coarse fragment-rich locations, respectively. All subplots were well drained; at no location was the water table at or near the soil surface for a significant portion of the frost-free season.

Humus forms at bigleaf maple plots were not as variable as at conifer plots (Fig. 4). Over 50% of humus forms at bigleaf maple plots were classified as vermimull; the remaining humus

Table 1
Mean depth (cm) of the forest floor and upper mineral horizons for bigleaf maple and conifer plots ($n = 11$)

	Bigleaf maple plots		Conifer plots		*P* (*t*-test)	*P* (*Z* stat.)
Litter horizon (L)	0.88	(0.60)	1.25	(1.00)	0.069	
Fibric horizon (F)	2.98	(2.18)	3.85	(1.84)	0.048[a]	
Humic horizon (H)	0.75	(1.00)	1.47	(1.11)		0.13
Ah	6.18	(2.68)	2.80	(1.59)	0.005	
Ae	0.19	(0.26)	0.54	(0.44)		0.05
Total forest floor	4.61	(2.07)	6.57	(2.40)	0.015[a]	
Ah plus H	6.93	(2.76)	4.27	(1.54)	0.005	
Forest floor and Ah	10.79	(1.83)	9.37	(2.22)	0.055	

Values in parentheses represent standard deviations. Single and double underlined values indicate significant differences at $P < 0.1$ and $P < 0.05$.

[a] Data were log transformed to meet underlying statistical assumptions.

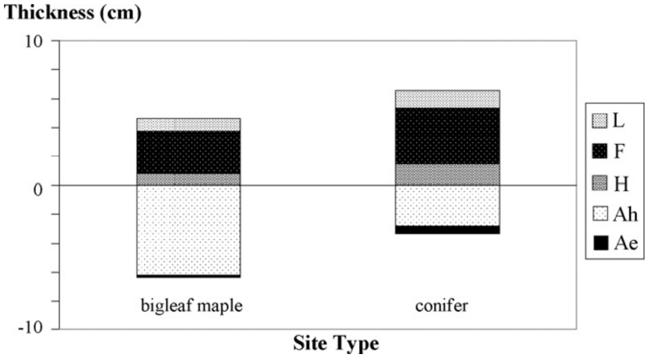

Fig. 3. Mean thickness of forest floor and A horizons for bigleaf maple and conifer plots ($n = 11$).

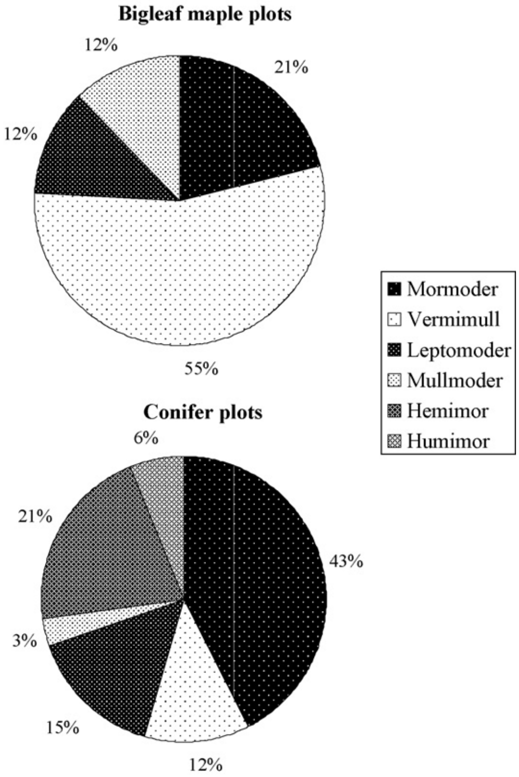

Fig. 4. Frequency of humus forms at bigleaf maple and conifer plots ($n = 11$).

forms were mormoder (21%), mullmoder and leptomoder (12% each). Conifer plots were represented by six groups of humus forms, and were dominated by mormoder (43%) and hemimor (21%).

3.2. *Forest floor chemical properties*

Forest floor mass per unit area, pH, mineralizable N contents, and NO_3-N concentrations and contents were significantly higher for bigleaf maple plots than for conifer plots (Table 2). Total C concentration and NH_4-N contents were higher ($P = 0.12$ for both; not significant) at bigleaf maple plots. Exchangeable Fe and Al concentrations were significantly higher at conifer plots.

Table 2
Forest floor chemical properties for bigleaf maple and conifer plots ($n = 11$)

	Bigleaf maple plots		Conifer plots		P (t-test)	Power ($1 - \beta$)
Forest floor (kg ha^{-1})	13,602	(3672)	10,027	(2562)	0.042	
pH (1:1 H_2O)	4.59	(0.50)	4.17	(0.33)	0.019	
Total C (g kg^{-1})	356	(83.4)	403	(71.0)	0.12	0.26
Total C (kg ha^{-1})	4,931	(2123)	4,032	(1265)	0.28	0.21
Total N (g kg^{-1})	12.9	(2.79)	14.1	(2.42)	0.25	0.19
Total N (kg ha^{-1})	178	(71.3)	142	(45.9)	0.21	0.27
C:N ratio	27.9	(4.40)	28.6	(2.35)	0.69	0.07
Mineral N (mg kg^{-1})	345	(77.7)	312	(77.3)	0.29	0.15
Mineral N (kg ha^{-1})	4.74	(1.79)	3.06	(0.81)	0.015	
NO_3-N (mg kg^{-1})	43.2	(39.1)	14.2	(17.4)	0.017[a]	
NO_3-N (kg ha^{-1})	0.59	(0.60)	0.15	(0.21)	0.005[a]	
NH_4-N (mg kg^{-1})	64.0	(24.5)	64.2	(29.4)	0.98	0.03
NH_4-N (kg ha^{-1})	0.87	(0.43)	0.63	(0.31)	0.12	0.30
Available P (mg kg^{-1})	54.5	(27.3)	50.5	(27.9)	0.75[a]	0.05
Available P (kg ha^{-1})	0.76	(0.52)	0.54	(0.41)	0.12[a]	0.18
Total S (g kg^{-1})	0.93	(0.44)	0.95	(0.57)	0.95	0.03
Total S (kg ha^{-1})	12.8	(7.63)	10.3	(7.76)	0.49	0.11
Exch K (cmol kg^{-1})	0.80	(0.27)	0.83	(0.29)	0.76	0.04
Exch Ca (cmol kg^{-1})	29.1	(7.77)	24.1	(7.51)	0.15[b]	
Exch Mg (cmol kg^{-1})	3.17	(0.79)	2.87	(1.27)	0.44	0.09
Exch Fe (cmol kg^{-1})	0.048	(0.066)	0.11	(0.68)	0.011[a]	
Exch Al (cmol kg^{-1})	1.22	(0.98)	2.79	(1.43)	0.021	
CEC (Ba) (cmol kg^{-1})	34.8	(9.01)	31.3	(8.70)	0.30	0.14

Values in parentheses represent standard deviations. Single and double underlined values indicate significant differences at $P < 0.1$ and $P < 0.05$.

[a] Data were log transformed to meet underlying statistical assumptions.

[b] Wilcoxin Signed-Rank Test was used to determine probability value.

Table 3
Mineral soil properties for bigleaf maple and conifer plots at 0–7 cm depth ($n = 11$)

	Bigleaf maple plots		Conifer plots		P (t-test)	Power $(1-\beta)$
Bulk density (g cm^{-3})	0.67	(0.15)	0.77	(0.09)	$\underline{0.05}$	
Gravel content (%)	55.9	(8.93)	56.1	(8.18)	0.94	
pH (1:1 H_2O)	4.94	(0.41)	4.80	(0.21)	0.35	0.16
Total C (g kg^{-1})	81.8	(20.4)	68.1	(21.3)	0.20	0.31
Total C (kg ha^{-1})	39,484	(8,373)	38,967	(13,226)	0.70^{a}	0.03
Total N (g kg^{-1})	3.60	(0.83)	2.88	(0.90)	$\underline{0.09}$	
Total N (kg ha^{-1})	1,734	(320)	1637	(519)	0.44	0.07
C:N ratio	22.7	(1.97)	23.8	(2.48)	0.30	0.18
Mineral N (mg kg^{-1})	78.4	(28.1)	53.4	(17.2)	$\underline{\underline{0.04}}$	
Mineral N (kg ha^{-1})	37.3	(10.0)	29.9	(8.10)	$\underline{0.07}$	
NO_3-N (mg kg^{-1})	6.50	(3.75)	3.44	(4.14)	$\underline{\underline{0.04}}^{b}$	
NO_3-N (kg ha^{-1})	3.05	(1.73)	1.92	(2.27)	$\underline{0.07}^{b}$	
NH_4-N (mg kg^{-1})	13.1	(5.12)	11.1	(3.04)	0.40	0.19
NH_4-N (kg ha^{-1})	6.22	(1.94)	6.23	(1.97)	0.99	0.03
Available P (mg kg^{-1})	14.1	(12.9)	25.5	(30.9)	0.43^{a}	0.19
Available P (kg ha^{-1})	7.29	(7.88)	15.8	(20.1)	0.26^{a}	0.23
Exch K (cmol kg^{-1})	0.095	(0.054)	0.060	(0.026)	$\underline{\underline{0.04}}$	
Exch Ca (cmol kg^{-1})	3.85	(2.54)	1.68	(1.01)	$\underline{\underline{0.02}}$	
Exch Mg (cmol kg^{-1})	0.36	(0.26)	0.19	(0.16)	$\underline{0.09}^{b}$	
Exch Fe (cmol kg^{-1})	0.014	(0.012)	0.033	(0.032)	$\underline{\underline{0.01}}^{a}$	
Exch Al (cmol kg^{-1})	1.79	(1.60)	2.00	(1.18)	0.34^{a}	0.05
CEC (Ba) (cmol kg^{-1})	6.20	(3.03)	4.03	(2.06)	$\underline{0.08}$	

Values in parentheses represent standard deviations. Single underlined values indicate significant differences at $P < 0.1$. Double underlined values indicate significant differences at $P < 0.05$.

[a] Data were log transformed to meet underlying statistical assumptions.

[b] Wilcoxin Signed-Rank Test was used to determine probability value.

Exchangeable Ca concentrations were higher ($P = 0.15$; not significant) at bigleaf maple plots compared to conifer plots.

3.3. Mineral soil properties

Percent gravel content in the surface mineral soil was similar between site types (approximately 56%), but bulk density was significantly higher at conifer plots relative to bigleaf maple plots (Table 3). Total N concentrations, mineralizable N concentrations and contents, NO_3-N concentrations and contents, exchangeable Ca, K and Mg concentrations and CEC were all significantly higher at bigleaf maple plots. Exchangeable Fe was significantly higher at conifer plots.

4. Discussion

4.1. Forest floor and Ah horizon depths

Harmon et al. (1990) found Douglas-fir and bigleaf maple to have the slowest and second fastest decay rates, respectively, of 11 Pacific Northwest tree species of the Pacific Northwest. Thinner forest floor beneath bigleaf maple as compared to beneath conifers could be explained by the rapid decomposition of bigleaf maple litter relative to conifer litter. However, Ah horizons were thicker at bigleaf maple plots compared to conifer plots. This suggests that bigleaf maple litter may decay rapidly in the initial stages of decomposition, but a portion of the litter may be converted to recalcitrant soil organic matter. Part of the soil organic matter may remain in the forest floor and part may be incorporated into the mineral soil. This results in thinner forest floor horizons and thicker Ah horizons. The thicker Ah horizons may also be due to more active biotic communities being supported under bigleaf maple. More active biotic communities could increase rates of organic matter incorporation into the mineral soil. Our results are in agreement with investigations of vine maple in the Pacific Northwest. Ogden and Schmidt (1997) found that vine maple plots had significantly thinner forest floors than conifer plots. Tashe and Schmidt (2003) found vine maple plots to have significantly thicker Ah horizons than conifer plots, although no statistical differences were observed for the L, F or H horizons.

Ae horizons were thinner at bigleaf maple plots. In addition, the percentage of plots with Ae horizons was lower for bigleaf maple as compared to conifer plots. This is likely related to the lower content of base-forming cations of conifer litter relative to bigleaf maple litter. Valachovic et al. (2004) found higher concentrations of Ca, K and Mg in bigleaf maple as compared to Douglas-fir litter. We found lower pH in forest floors beneath conifers as compared to bigleaf maple. The greater acidity beneath conifers likely results in greater eluviation. Although there may have been significant eluviation during the lifespan of these trees, we suspect that conifers and maples were in similar locations in the previous stand.

4.2. Humus form classification

It was expected that bigleaf maple plots would be dominated by Mulls, because Mulls are most common beneath species with rapidly decomposing litter (Green et al., 1993). Mor humus was expected under conifer plots as it forms in acidic conditions often associated with conifer forests. Moders are intermediate between Mors and Mulls, and often have an accumulation of the F horizon (dominated by fungi relative to bacteria) similar to Mors, but are also biologically active and have an abundance of faunal droppings similar to Mulls (Green et al., 1993). Moders were expected at both bigleaf maple and conifer plots. More than half of humus forms examined at bigleaf maple plots were classified as belonging to the Mull order (vermimull). The remaining humus forms were groups of the Moder order (mormoder, mullmoder and leptomoder). Humus forms of the Mor order were absent at bigleaf maple plots. At conifer plots, the dominant humus form orders were Moder and Mor, with a greater variety of groups than at maple plots.

Results suggest bigleaf maple can influence humus forms within mixedwood stands. Bigleaf maple likely influences the formation of humus form types through its nutrient-rich litter, which rapidly decays and transforms into soil organic matter. Consequently, the abundance and diversity of microbes in the organic horizons and the rate at which nutrients are made available for plant uptake change. If the type of humus form in the forest floor is an indicator of site productivity as was suggested by Green et al. (1993), then our results suggest that bigleaf maple can benefit the growth of surrounding vegetation. The observed differences in humus form agree with other studies of maple species of the Pacific Northwest. Krajina et al. (1982) suggested Mulls are typical of bigleaf maple litter. Tashe and Schmidt (2003) observed Mulls beneath vine maple and abundant Mors and Moders beneath conifer plots. Occasionally Mors were also observed under vine maple (Tashe and Schmidt, 2003). Similar to the results of Tashe and Schmidt (2003) our results suggest that Mulls can form under conifers, although in the absence of bigleaf maple this is not common. Unlike Tashe and Schmidt (2003), however, Mors were not observed under bigleaf maple. This may be due to the difference in size between the two species (vine maple is an understory shrub or tree species). Similarly, the lack of Mors beneath bigleaf maple may be related to the more significant effect of bigleaf maple on forest floor characteristics relative to vine maple.

4.3. *Forest floor mass and mineral soil bulk density*

We had anticipated a lower oven-dry mass for forest floors beneath bigleaf maple due to faster decay rates of bigleaf maple relative to conifer litter and incorporation of organic matter into surface mineral soils. However, forest floors beneath bigleaf maple had greater mass per unit area compared to conifer plots. The greater total forest floor mass at bigleaf maple plots suggests that bigleaf maple litter may rapidly transform into possibly recalcitrant soil organic matter, rather than fully decomposing. This also suggests that the degree of incorporation of humus into the surface mineral soil is less than expected. Although the litter is transforming into humus, it appears to be recalcitrant and stable in the forest floor horizons. Fried et al. (1990) did not find any significant differences in forest floor mass in a study of five paired bigleaf maple/Douglas-fir plots. Results were highly variable with three paired plots having no difference in forest floor mass, one having greater mass beneath bigleaf maple and one having greater mass beneath Douglas-fir. Tashe and Schmidt (2003) found no significant difference in forest floor mass between vine maple and conifer plots. On the other hand, Ogden and Schmidt (1997) found a weak trend for lower forest floor mass beneath vine maple relative to conifers.

Bulk density of the surface mineral soil was lower at bigleaf maple plots compared to conifer plots. It was expected that bigleaf maple plots would have lower mineral soil bulk density because of the greater amount of organic matter being produced and mixed into the mineral soil compared to conifer plots. Fried et al. (1990) similarly observed lower bulk densities in the top 10 cm of mineral soil beneath bigleaf maple in two of five measured paired plots. Lower mineral soil bulk densities suggest that soils surrounding bigleaf maple experience greater mixing by fauna, are higher in organic matter and are better aerated, encouraging microbial survival and water infiltration.

4.4. *Carbon, nitrogen and phosphorus*

We expected the addition of base-rich litter from bigleaf maple (Valachovic et al., 2004) would be reflected in higher organic matter concentrations in the surface mineral soil at bigleaf maple plots. However, we did not find significantly higher concentrations of C in the surface mineral soil beneath bigleaf maple, ($P = 0.20$) suggesting that bigleaf maple litter is not fully decomposing and the litter is partially recalcitrant and remaining in the forest floor layers.

Fried et al. (1990) found significantly greater total C concentrations beneath bigleaf maple than beneath Douglas-fir. In the case of vine maple, Tashe and Schmidt (2003) found greater C concentrations in the mineral soil beneath vine maple than conifers at one of two stands. On the other hand, Ogden and Schmidt (1997) did not find a significant difference in total C concentrations in mineral soil beneath vine maple and conifers.

We found evidence that bigleaf maple may have a positive influence on N availability. Mineralizable N contents, and NO_3-N concentration and contents in the forest floor and mineral soil as well as mineralizable N concentrations in the forest floor were all higher at bigleaf maple plots. Greater N availability beneath bigleaf maple may be due to relatively high N concentrations in bigleaf maple litter (Valachovic et al., 2004). The trend for greater N availability at bigleaf maple plots found in our study is similar to the findings of previous researchers. Fried et al. (1990) showed that total soil N concentration in the surface mineral soil was significantly greater under bigleaf maple than under Douglas-fir. Tashe and Schmidt (2003) found mineralizable N concentrations, measured by laboratory anaerobic incubation, were greater under vine maple than under conifers in the mineral soil at two stands and in the forest floor at one of two stands. Total N concentration and content were also greater in the mineral soil beneath vine maple than beneath conifers at one of the two stands (Tashe and Schmidt, 2003).

We had expected that in comparison to conifer sites, bigleaf maple sites would have lower total C and N contents in the combined forest floor and mineral soil. However, we found greater total C and N contents in the combined forest floor and mineral soil beneath bigleaf maple, but this difference was not significant. The lack of significant differences in total C and N contents between bigleaf maple and conifer sites suggests that bigleaf maple litter may not be not fully decomposing at a faster rate than conifer litter, but rather it is being converted into soil organic matter. We also noted that the forest floor accounts for a relatively small proportion of the total C and N in the combined forest floor and mineral soil (11.0% for C and 9.3% for N at bigleaf maple sites; 9.4% for C and 8.0% for N at conifer sites) indicating the relative importance of the C and N contents in the mineral soil.

Carbon:nitrogen ratios can provide an indication of nitrogen availability to plants (Brady and Weil, 2002). We expected to find significantly lower C:N ratios for bigleaf maple plots compared to conifer plots. Contrary to expectations, the forest floor and surface mineral soil C:N ratios were not significantly different between vegetation types. Fried et al. (1990) found no significant difference in C:N ratios for mineral soils beneath vine maple and Douglas-fir. Tashe and Schmidt (2003) found lower C:N ratios of the surface mineral soil for vine maple plots relative to conifer plots at one stand. They did not, however, find significantly lower C:N ratios in the forest floor.

The finding that bigleaf maple had no significant influence on P availability differs from results of a study of vine maple (Tashe and Schmidt, 2003) where available P concentrations in the forest floor were lower beneath vine maple than beneath conifers. Vine maple thus has a potential negative impact on P availability whereas we found no evidence for bigleaf maple to have a negative impact.

4.5. Exchangeable bases, pH and CEC

Bigleaf maple litter is base-rich (Valachovic et al., 2004; Turk, 2006). Greater values for exchangeable Ca, K and Mg concentrations and pH and CEC were, therefore, expected in the forest floor and mineral soil beneath bigleaf maple. Under bigleaf maple, concentrations of exchangeable Ca, K and Mg in the mineral soil were significantly higher. Similar to our results, Fried et al. (1990) found bigleaf maple sites to have significantly higher concentrations of Ca, K and Mg in surface mineral soils at three, two and one of five sites, respectively. Our findings are also in agreement with studies of vine maple. Compared to conifer sites Tashe and Schmidt (2003) found significantly higher total exchangeable bases in forest floors at vine maple sites, and Ogden and Schmidt (1997) found significantly higher concentrations of Ca, K and Mg in forest floors beneath vine maple.

Forest floor pH was found to be significantly higher at bigleaf maple plots, but mineral soil pH was not significantly different between the two vegetation types. Fried et al. (1990) did not measure forest floor pH, but found significantly higher pH in mineral soil beneath bigleaf maple for only two of five paired bigleaf maple/Douglas-fir plots. In the presence of vine maple, Tashe and Schmidt (2003) found higher forest floor pH in one of two stands and higher mineral soil pH in the other of the two stands. Ogden and Schmidt (1997) found higher pH in the forest floor under vine maple. It appears that bigleaf maple and vine maple both tend to have higher pH in forest floor and mineral soil beneath their canopies as compared to beneath surrounding conifers. However, this tendency is inconsistent across substrates (forest floor and mineral soil) and study sites.

The CEC of the mineral soil was significantly higher for bigleaf maple relative to conifer plots. Higher CEC may be related to greater concentrations of organic colloids in surface mineral soils from decomposing litter at bigleaf maple plots. Fried et al. (1990) found higher CEC in the mineral soil beneath bigleaf maple in two of five paired bigleaf maple plots.

5. Conclusion

Our study indicates that bigleaf maple litter may not fully decompose in a short period of time, but rather may be rapidly processed by soil organisms into faecal matter that then decomposes slowly into soil organic matter. The organic matter from bigleaf maple litter appears to be redistributed from the forest floor to the mineral soil more rapidly than that from Douglas-fir. Evidence to support this conclusion includes thinner forest floors with a greater mass in the presence of bigleaf maple and a lack of difference in total C contents between vegetation types in both forest floor and mineral soil. If bigleaf maple litter were to decompose rapidly and completely, we would expect less total carbon in the forest floor and mineral soil where bigleaf maple is present. Future work should investigate the conversion of bigleaf maple litter into soil organic matter, the apparent redistribution and accumulation of organic matter, and the change in composition of the organic matter as it decomposes.

Our results suggest that bigleaf maple can modestly improve soil fertility within conifer forests. Bigleaf maple sites had higher pH and concentrations of mineralizable N and NO_3-N in the forest floor, and higher CEC and concentrations of total N, mineralizable N, and NO_3-N in the surface mineral soil. Bigleaf maple did not appear to have any negative impacts on soil fertility as all other measured parameters were not significantly different between the vegetation types. Bigleaf maple had no impact on concentrations of NH_4-N or available P in either the forest floor or the mineral soil. The modest improvement in soil fertility beneath bigleaf maple may lead to increased availability of nutrients to surrounding conifers and potentially improved conifer growth. In this context, bigleaf maple may be a desirable species for forest management, despite its competitive role in younger stands. Further research should compare growth and foliar nutrients of conifers surrounding bigleaf maple with those lacking influence of bigleaf maple to investigate whether improved soil fertility leads to improved conifer productivity.

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