D.B. Collins, M. C. Feller, K. Klinka,[1] Forest Sciences Department, 2424 Main Mall, University of British Columbia, Vancouver BC V6T 1Z4

and

L. de Montigny, Research Branch, BC Ministry of Forests, PO Box 9519 Stn. Prov. Govt., 712 Yates Street, Victoria BC V8W 9C2

Forest Floor Nutrient Properties in Single- and Mixed-Species, Second Growth Stands of Western Hemlock and Western Redcedar

Abstract

Forest floors in single- and mixed-species stands of western hemlock and western redcedar in the coastal forest of southern British Columbia were examined with respect to acidity (pH), and concentrations of total C, total N, mineralizable-N, and total Ca, Mg, K, P, and S. Using four properties (pH and total C, N, and Ca), canonical discriminant analysis separated forest floors of hemlock and redcedar stands, with mixed-species stands overlapping those of each single-species stand. Despite interactions between stand type and location, several properties were significantly different or showed clear trends between stand types. Forest floor pH, and concentrations of mineralizable-N, total Ca, and total K increased, while concentrations of total C and S decreased in the order from hemlock to hemlock-redcedar to redcedar stands. These results are consistent with other studies and suggest that forest floor decomposition and nutrient availability increase with increasing presence of redcedar.

Introduction

The influence of tree species on forest soils has been the subject of study for at least a century (Binkley 1995). Studies on the processes and properties of forest soils in western North America have been ongoing since the 1950's (Tarrant et al. 1951, Alban 1969). Of particular interest has been the influence of western hemlock (*Tsuga heterophylla*) and western redcedar (*Thuja plicata*), two of the most common tree species in southern coastal British Columbia, but each with a different nutrient amplitude (Krajina 1969). Interest in hemlock and redcedar is due, in part, to the fact that both species grow together in unmanaged stands, and both species appear to exert very different influences on the properties and processes in forest floors (Ovington and Madgewick 1957, Alban 1969). It has generally been found that acid, mycogeneous Mor humus forms develop in hemlock stands, while less-acid and more-zoogenous Mormoder, Moder, or even Mull humus forms develop in redcedar stands (Krajina 1969, Green et al. 1993). Previous studies have shown variable, and sometimes contradictory, results for the relative influence of species on N availability (Binkley and Hart 1989, Prescott and Preston 1994, Prescott et al. 1995; Cindy Prescott, University of British Columbia, personal communication). In addition to these variable findings, the detection of significant site by species interaction effects suggests that the influence of hemlock and redcedar on N availability may be site-specific (Cincy Prescott, University of British Columbia, personal communication).

This study is a component of a larger study investigating the productivity of single- and mixed-species stands of hemlock and redcedar on intermediate sites (Green and Klinka 1994) in the Coastal Western Hemlock zone (Krajina 1969) of southern British Columbia. The objective of this study was to determine the influence of hemlock and redcedar, growing separately and together, on forest floor nutrient properties. The questions addressed were: (1) Does each stand type have unique forest floor nutrient properties? and (2) Do any forest floor nutrient properties discriminate between stand types? Based on previous studies, we predicted that the forest floors in redcedar stands would be richer in nutrients than those in hemlock stands, and that mixed-species stands would have properties intermediate between those of single-species stands. Determining whether or not any unique forest floor properties can discriminate between the stand types will help reveal whether or not potential mechanisms of competitive reduction and/or facilitation exist in hemlock–redcedar mixtures (Vandermeer 1989, Kelty 1992). Competitive reduction and facilitation are positive plant interactions that result in mixed-species stands achieving higher relative productivity than

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[1] Author to whom correspondence should be addressed. Email: klinka@interchange.ubc.ca

pure stands of either component species (Harper 1977; Callaway 1995).

Materials and Methods

Study Sites

Study stands were located in three areas: Capilano River (Capilano), at 49°28' N latitude, 123°08' W longitude, and 310 m elevation, University of British Columbia Malcolm Knapp Research Forest (Malcolm Knapp), at 47°17' N latitude, 122°36' W longitude, and 360 m elevation, and Mission Tree Farm No. 26 (Mission), at 49°21' N latitude, 122°21' W longitude, and 370 m elevation. Within each area (location), nine stands were initially selected on intermediate sites: three hemlock stands, three redcedar stands, and three hemlock-redcedar mixtures (= three stand types) of approximately equal proportion, on a basal area basis, for a total of 27 study stands. Final assignment of each stand to a stand type was based on basal area calculations. Those stands with greater than 66% basal area contribution of either species were assigned accordingly to the hemlock or redcedar stand types. Those stands with less than 16% difference in basal area contributions by hemlock and redcedar were assigned into the hemlock-redcedar stand type (Table 1). These stand type selection criteria resulted in retention of seven hemlock stands, seven hemlock-redcedar stands, and four redcedar stands for study, for a total of 18 stands.

The study stands were naturally regenerated after clearcutting and slashburning, were unmanaged, fully stocked, and even-aged (50-70 yr at breast height), and represented the stem exclusion stage of stand development (Oliver and Larson 1996). This stand age allowed sufficient time for the overstory to influence forest floor nutrient properties, but preceded the understory reinitiation stage (Oliver and Larson 1996) and the influence this understory vegetation may have on forest floor nutrient properties. All stands were within the Submontane Very Wet Maritime Coastal Western Hemlock variant, and were located on fresh, nutrient-medium, oval-leaf huckleberry (*Vaccinium ovalifolium*) sites (Green and Klinka 1994); i.e., the study sites were edaphically-equivalent. Major climatic influences such as temperature and precipitation are expected to be roughly

TABLE 1. Means and standard errors (in parentheses) of selected study stand attributes, stratified according to study stand type; Hw = western hemlock, Cw = western redcedar, HwCw ≈ 1:1 mixture of western hemlock and western redcedar on a basal area basis. Actual stand attributes are provided for the Malcolm Knapp and Mission Cw stand types, as each consisted of only one study stand.

Stand type	Study area	Stems per hectare	Stand volume ($m^3 ha^{-1}$)	Quadratic mean diameter @ 1.3 m (cm)	Forest floor thickness (cm)	Basal area (m^2ha^{-1})		
						Hw	Cw	Total
Hw	Capilano	919	1021.1	29.3	25.8	70.6	12.7	83.3
		(133)	(34.5)	(2.80)	(13.40	(5.7)	(5.7)	(2.5)
	Malcolm Knapp	889	1040.7	33.2	10.0	70.6	2.6	73.2
		(204)	(46.0)	(3.5)	(4.8)	(0.7)	(0.7)	(0.7)
	Mission	661	1362.2	50.6	16.5	114.5	6.5	121.0
		(228)	(363.1)	(18.2)	(11.9)	(5.3)	(9.3)	(52.7)
Cw	Capilano	1289	748.1	26.0	11.9	17.2	64.3	81.5
		(318)	(68.1)	(6.1)	(7.4)	(7.3)	(7.3)	(7.8)
	Malcolm Knapp	767	762.7	41.2	5.0	22.9	71.8	94.7
					(2.1)			
	Mission	967	786.6	33.9	8.6	25.8	57.4	83.2
					(6.9)			
HwCw	Capilano	961	892.9	28.7	17.5	47.7	37.5	85.2
		(24)	(59.6)	(2.4)	(8.4)	(1.3)	(1.3)	(7.9)
	Malcolm Knapp	1089	780.1	31.5	6.6	35.7	40.0	75.7
		(377)	(70.7)	(4.6)	(4.7)	(2.3)	(2.3)	(0.5)
	Mission	978	776.5	32.2	9.3	32.8	41.5	74.3
		(29)	(138.4)	(1.9)	(8.5)	(5.9)	(5.9)	(8.4)

equivalent, although length of growing season may be truncated with easterly progression through the study areas from Capilano, to Malcolm Knapp, and finally to Mission. Since all stands were within a 63 m elevation range, orographically induced precipitation should vary between stands by no more than approximately 63 mm yr^{-1} (100 mm precipitation increase for every 100 m increase in elevation) (Schaefer and Nikleva 1973), or approximately 3% of the approximate 2000 mm annual precipitation (Oke and Hay 1994).

Sampling

Within each stand a 30 x 30 m (0.09 ha) sample plot uniform in topography and soil was established. Forest floors were sampled at 12 random locations in each study stand. The samples collected were composited into three samples, i.e., each composite sample consisted of four randomly chosen samples from the total of 12 samples. All samples were air-dried to constant mass and ground on a Wiley mill to pass a 2-mm sieve. Each of the 81 samples was analyzed for pH, mineralizable nitrogen (min-N), and concentrations (%) of total nitrogen (N), carbon (C), calcium (Ca), magnesium (Mg), potassium (K), phosphorus (P), and sulfur (S). Acidity was determined with a pH meter and glass and reference electrodes using a 1:5 forest floor:distilled water suspension. C concentration was determined by the loss on ignition method. Concentrations of N, Ca, Mg, K, and P were determined after a Parkinson and Allen digestion (Parkinson and Allen 1975) followed by analysis of Ca, Mg, and K by atomic absorption spectrophotometry using a Varian Spectra AA 10 instrument, and N and P using standard colorimetric methods on a Technicon TRAACS 800 continuous flow analyzer. S concentration was determined by a Leco SC32 Sulfur Determinator. Min-N was determined following anaerobic incubation (Powers 1980), followed by analysis of NH_4 using the Technicon TRAACS 800 continuous flow analyzer.

Statistical Analysis

All nutrient properties were subjected to normality and variance homogeneity tests, via probability plots (Neter et al. 1996) and Bartlett's test (Zar 1984) at $P = 0.05$. Tests for outliers were conducted with studentized residual analysis (Neter et al. 1996). The variances of each of pH, Ca, and min-N were found to be significantly non-homogenous, and model coefficients were fitted via iteratively re-weighted least squares procedures to compensate for the heteroscedasticity. Mean values of forest floor nutrient properties among the three stand types were compared with a one-way analysis of variance (ANOVA), utilizing a general linear regression model (Neter et al. 1996). The model used for testing the stand type, location, and their interaction with nutrient properties was:

$$[1] \quad Y_i = b_0 + b_1\mathrm{STAND} + b_2\mathrm{LOC} + b_3\,\mathrm{STAND*LOC} + \varepsilon_i$$

where Y_i is a nutrient property, b_0 is an overall mean, STAND is stand type, LOC is location or replicate, STAND*LOC is stand type*location interaction effect, and ε_i is model error.

Stand types and locations were incorporated into the model as dummy variables to determine interaction effects. Significant differences in mean nutrient properties among stand types were detected with a Bonferroni multiple range test (Zar 1984).

Those forest floor nutrient properties found to be significantly different among stand types were subjected to correlation analysis, to assist in finding significantly correlated properties that enhanced discrimination between stand types. Forward, backward, and stepwise discriminant function analysis was performed to determine those forest floor nutrient properties that significantly discriminated among stand types. These discriminating forest floor properties were then subjected to canonical discriminant analysis to determine the degree of discrimination among stand types. Within group covariance matrices were found to be homogenous ($P = 0.05$), allowing the pooled covariance matrix to be used in discriminant analyses (Neter et al. 1996). Accepted levels of significance were set at $P \leq 0.05$ for all analyses unless otherwise stated. SAS release 6.12 TS level 0020 was used for all analyses (SAS Institute 1989).

Results

ANOVA by model [1] indicated that: (i) total C, C:N ratio, and total S were significantly related to stand type but not to location, (ii) min-N was significantly related to both stand type and location, (iii) a significant stand type*location interaction existed for pH, total Ca, and K, and (iv) total N, Mg, and P were not significantly related to stand type or location (Table 2).

TABLE 2. Means and standard errors (in parentheses) of forest floor nutrient properties of study stands, stratified according to stand type and location. For a given chemical property, values in the same row with the same superscript are not significantly different; an absence of superscripts indicates no significant differences ($P \leq 0.05$).

	Stand type				Location		
Chemical property	Western hemlock n = 21	Western hemlock-western redcedar n = 21	Western redcedar n = 21	Significant STAND* LOCATION interaction	Capilano n = 18	Malcolm Knapp n = 15	Mission n = 15
pH	3.8 (0.1)	4.2 (0.2)	4.3 (0.2)	*	3.9 (0.1)	4.0 (0.1)	4.2 (0.2)
C (%)	49.8^{a} (6.0)	47.2^{a,b} (6.7)	44.1^{b} (5.6)		49.5 (5.4)	47.8 (5.8)	45.0 (7.5)
N (%)	0.750 (0.120)	0.739 (0.099)	0.682 (0.093)		0.724 (0.117)	0.727 (0.102)	0.712 (0.112)
C:N Ratio	67.2^{a,b} (8.5)	70.3^{a} (12.7)	60.3^{b} (8.9)		69.8 (12.2)	66.5 (10.3)	63.7 (9.3)
Mineralizable N (mg kg^{-1})	54.79^{b} (8.03)	60.75^{a,b} (9.20)	70.60^{a} (15.14)		54.12^{b} (7.26)	67.13^{a} (13.97)	64.10^{a,b} (10.08)
Ca (%)	0.232^{b} (0.072)	0.324^{b} (0.080)	0.571^{a} (0.107)	*	0.284 (0.082)	0.312 (0.086)	0.338 (0.082)
Mg (%)	0.032 (0.016)	0.027 (0.014)	0.027 (0.007)		0.032 (0.016)	0.025 (0.007)	0.028 (0.014)
K (%)	0.071 (0.021)	0.076 (0.026)	0.096 (0.019)	*	0.073 (0.025)	0.070 (0.021)	0.092 (0.021)
P (%)	0.020 (0.004)	0.020 (0.003)	0.019 (0.002)		0.019 (0.004)	0.021 (0.003)	0.020 (0.003)
S (%)	0.192^{a} (0.040)	0.161^{a,b} (0.039)	0.148^{b} (0.040)		0.175 (0.032)	0.169 (0.045)	0.165 (0.053)

N.B.: Significant differences listed for Ca (%) detected at $\alpha = 0.10$, at $\alpha = 0.05$ significant stand type x location interaction effect negates significance testing.

Does Each Stand Type Have Unique Forest Floor Nutrient Properties?

The forest floors in the hemlock stands had significantly higher total C and S concentrations than those found in the redcedar stands (Table 2). Although non-significant, total Mg and N concentrations appeared to be slightly higher in the hemlock stands, than in the hemlock-redcedar or redcedar stands.

The forest floors in the redcedar stands had significantly higher min-N concentrations than the forest floors within the hemlock stands (Table 2). The significant stand type*location interactions found for pH, total Ca, and total K precluded multiple range testing of these forest floor properties between stand type means. However, plots of these interactions revealed that the forest floors of the redcedar stands had higher pH and total Ca concentration than the hemlock stands, while no trend was observed for total K concentrations (Figures 1 and 2). When P increased from 0.05 to 0.10, no significant stand type*location interaction was detected for total Ca, and the redcedar stands had significantly higher total Ca concentrations than the hemlock or hemlock-redcedar stands (Table 2).

The forest floors of the hemlock-redcedar stands had nutrient properties intermediate between that of the hemlock and redcedar stands, except in C:N ratio. The forest floors in the hemlock-redcedar stands had significantly greater C:N ratios than the forest floors within the redcedar stands.

Do Any Forest Floor Nutrient Properties Discriminate Between Stand Types?

The hemlock stands had significantly higher mean total C and S concentrations, which were significantly positively correlated with each other, and with concentrations of total N (Table 3). Total C was significantly negatively correlated with total K, and positively correlated to C:N ratio. Total S was significantly negatively correlated with pH and total Ca.

The redcedar stands had significantly higher mean min-N, and the highest pH and total Ca concentrations, which were all significantly positively correlated with each other (Table 3). Both pH and total Ca were significantly positively correlated with total K, and significantly negatively correlated with total S. pH was also significantly negatively correlated with total C, total N, and C:N ratio.

The hemlock-redcedar stands had significantly higher mean C:N ratios, which were significantly negatively correlated with pH, and concentrations of total N and K (Table 3).

The forest floor properties used in the canonical discriminant analysis were identified through stepwise, backward elimination and forward selection procedures. All resulted in the selection

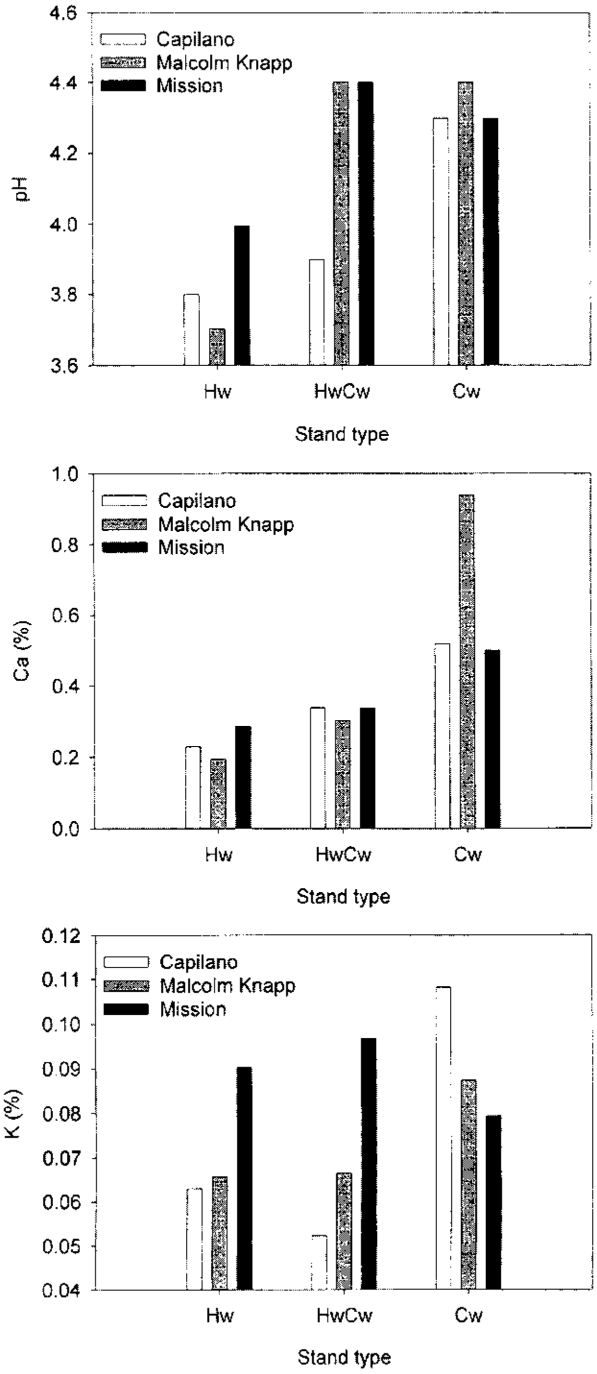

Figure 1. Mean values of the forest floor nutrient properties (pH, total Ca, and total K) with observed, significant ($P<0.05$) stand type*location interaction effects, according to stand type.

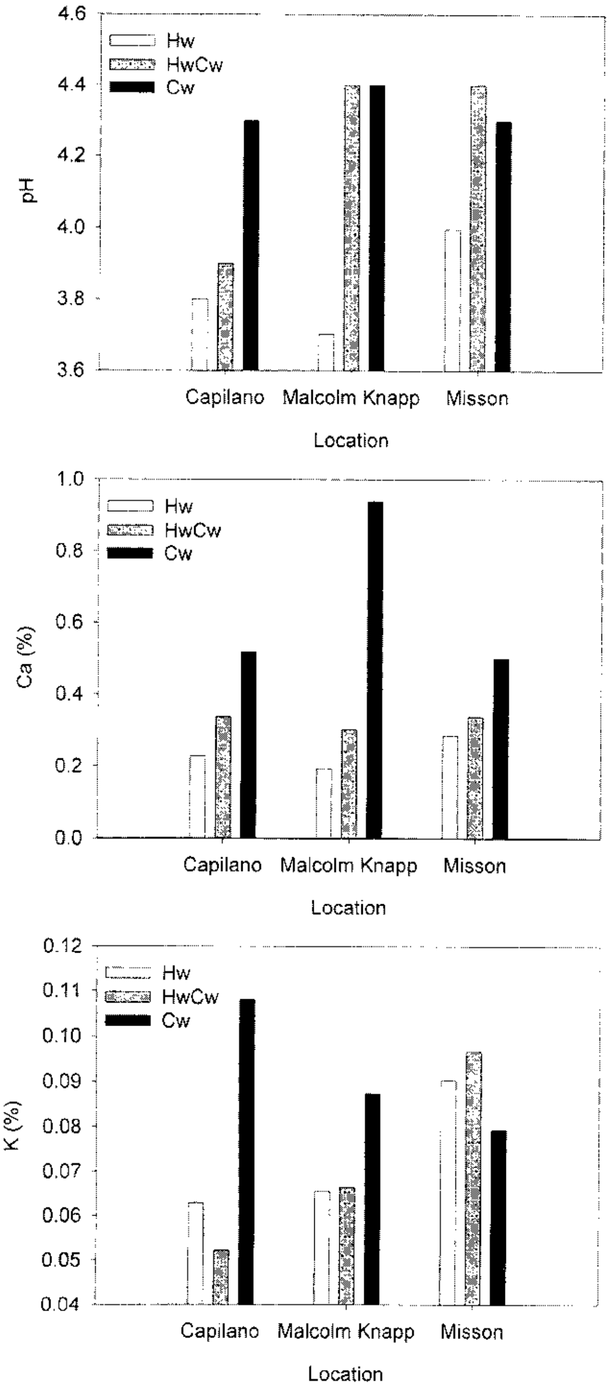

Figure 2. Mean values of the forest floor nutrient properties (pH, total Ca, and total K) with observed, significant ($P<0.05$) stand type*location interaction effects, according to location.

TABLE 3. Correlation coefficients for forest floor nutrient properties and their significance.

	pH	C	N	C:N	min-N	Ca	Mg	K	P	S	STB
pH	-1.00	-0.75*	-0.30*	-0.35*	-0.31*	-0.44*	-0.02	-0.56*	-0.05	-0.63*	-0.48*
C		-1.00	-0.39*	-0.47*	-0.16	-0.30	-0.08	-0.34*	-0.03	-0.74*	-0.33
N			-1.00	-0.62*	-0.21	-0.05	0.08	0.09	-0.20	-0.47*	-0.05
C:N				-1.00	-0.30	-0.30	-0.16	-0.38*	-0.16	-0.17	-0.32
min-N					-1.00	-0.65*	-0.16	0.03	-0.08	-0.03	-0.63*
Ca						-1.00	-0.14	-0.34*	-0.00	-0.24*	-0.99*
Mg							-1.00	-0.08	-0.06	-0.11	-0.07
K								-1.00	-0.17	-0.19	-0.44*
P									-1.00	-0.06	-0.02
S										-1.00	-0.26
STB											-1.00

*Significant correlation at $P<0.015$.

STB = Sum of bases (total Ca, Mg, and K).

of the same properties: pH, C:N ratio, and total Ca. The computed equations for the two canonical variables were:

$$[2] \quad CAN_1 = 2.844\,(pH) + 0.023\,(C{:}N) + 5.025\,(Ca) \qquad R^2 = 0.60 \quad SEE = 0.055$$

$$[3] \quad CAN_2 = 3.389\,(pH) + 0.071\,(C{:}N) - 3.860\,(Ca) \qquad R^2 = 0.31 \quad SEE = 0.095$$

Ordination of the data shows a gradual progression of samples from the left to the right region of ordination, i.e., from hemlock to hemlock-redcedar to redcedar stands (Figure 3). Cross-validation procedures resulted in a low predicted overall misclassification error rate ($P\leq0.111$), indicating good discrimination among stand types by the three forest floor nutrient properties selected.

Discussion

Does Each Stand Type Have Unique Forest Floor Nutrient Properties?

The hemlock stands had significantly higher mean total C and N concentrations and forest floor thicknesses than the other stand types, indicating that hemlock stands produce greater amounts of litter. This may be due to hemlock carrying more foliage, or perhaps due to greater rates of growth in hemlock stands, relative to redcedar stands. The hemlock stands also had significantly higher mean total S concentrations than the redcedar stands (Table 2). The decreasing trend of total S with progression from hemlock to hemlock-redcedar to redcedar stands is probably related to pH, given the negative correlation between pH and total S (Table 3), and the established acidification of forest floors by hemlock litter (Tarrant et al. 1951, Daubenmire 1953). The link between soil acidity, nitrogen dynamics, and exchangeable bases (most notably Ca) is well documented. High soil acidity is normally associated with low concentrations of Ca ions (or other base cations), and high NH_4-N:NO_3-N ratios (Runge and Rode 1991). The findings of these studies are consistent with the lowest pH levels and total Ca concentrations in the hemlock stand type.

Total Mg concentrations did not differ significantly between stand types, although the hemlock stands appeared to have slightly higher Mg than the hemlock-redcedar or redcedar stands (Table 2). Mg concentrations differed among locations, decreasing from Capilano to Mission to Malcolm Knapp, perhaps due to differences in parent material mineralogy.

An increase in pH with increasing redcedar presence was evident, despite the interaction effect (Figure 1). pH was expected to be a discriminating property of forest floors among stand types, but the interaction effect necessitated closer examination of pH and correlated data. The interaction plots (Figures 1 and 2), and examination of those properties unaffected by interactions, but correlated with pH (Tables 2 and 3), allow inferences to be drawn on the pH observations. Total C, N, and S concentrations and C:N ratio, which are negatively correlated with pH, all decrease with increasing redcedar presence. At the same time min-N concentrations, which are positively correlated with pH, increased with increasing redcedar presence (Tables 2 and 3).

Concentrations of forest floor min-N increased with increasing presence of redcedar, although min-N was also significantly related to location (Table 2). When measured by anaerobic incubation procedures, min-N is representative of N liberated from microbial biomass (Myrold 1987). This is consistent with the increase in both pH and min-N concentrations with increasing influence of redcedar, as the low acidity of redcedar forest floors has been associated with increased microbial populations, decreased fungal biomass, and increased rates of decomposition in the forest floor, relative to that of hemlock (Turner and Franz 1985, Prescott and Preston 1994). These findings support the proposition that both species of trees have differential influences on the microbial populations, fauna, and properties of the underlying forest floor and soil (Alban 1969), and that these influences affect min-N concentrations. However, the significant differences in pH and min-N and total K concentrations among locations suggest that the influence of the tree species on N availability not only associated with changes in pH, but is also site-specific.

Forest floor concentrations of total Ca, Mg, and K were expected to increase with increasing presence of redcedar, in agreement with the findings of other studies (Daubenmire 1953, Alban 1969, Turner and Franz 1985, Prescott and Preston 1994). Despite the interaction effect, Ca was observed to increase with increasing presence of redcedar, while the same cannot be said of Mg or K (Figure 1). The data from this study suggest that the effect of increasing hemlock or redcedar presence on total Mg concentrations is weakly expressed. The erratic interaction effects observed in the K data suggest that stand type probably does affect forest floor K concentrations, but that this effect is masked by some other source of variability. The source of this variability is unclear, but may be due to measurement error, an unidentified environmental phenomena, or insufficient sample size.

Mean forest floor C:N ratios significantly decreased with progression from the hemlock-redcedar to the hemlock to the redcedar stands. This trend is neither strengthened nor weakened by the findings of other studies. Prescott and Preston (1994) found that C:N ratios in redcedar stands are lower than in hemlock stands. These findings are supported by Hendrickson (1985), who found that the addition of a weak base to forest floor material, analogous to the influence of redcedar on forest floors relative to hemlock, has been found to increase N mineralization more than C mineralization, thus decreasing the C:N ratio of the substrate mineralized. However, a more recent study found higher C:N ratios in hemlock stands (Cindy Prescott, University of British Columbia, personal communication). These findings indicate site specificity with respect to C:N ratios in hemlock and redcedar stands.

Do Any Forest Floor Nutrient Properties Discriminate Between Stand Types?

No significant differences in total N, Mg, and P concentrations were associated with stand type. Significant differences between stand types were detected in four (C, C:N, min-N, S) of the 10 forest floor nutrient properties assayed, while two additional properties (pH, Ca) showed strong trends with respect to stand type.

The inability of N, Mg, and P to differentiate among hemlock and redcedar stands has been recorded in other studies. Alban (1969) found no difference in forest floor total N, Mg, or K concentrations between stand types. Prescott and Preston (1994) similarly found no significant difference in forest floor total N concentrations among hemlock and redcedar stands. Turner and Franz (1985) reported significantly higher total N concentrations in hemlock forest floor material, but significantly higher total N concentrations in the mineral soil of redcedar stands. Higher total P concentrations have been associated with either redcedar (Tarrant et al. 1951) or hemlock (Prescott and Preston 1994). These findings suggest that forest floor total N, Mg, and P concentrations are affected not only by tree species, but by other site-specific factors as well.

The total variation in pH, C:N ratio, and total Ca concentrations between stand types is summarized by canonical discriminant analysis. The hemlock and redcedar stand means are well separated with the hemlock-redcedar stand mean intermediate between the two (Figure 3). Similar horizontal and vertical spread of the canonical variables indicates that both have similar power of differentiation. Variability in individual samples is indicated by their dispersion around the mean for each stand type, and the distance between the means indicates the uniqueness of the forest floor nutrient properties of each stand type. The well

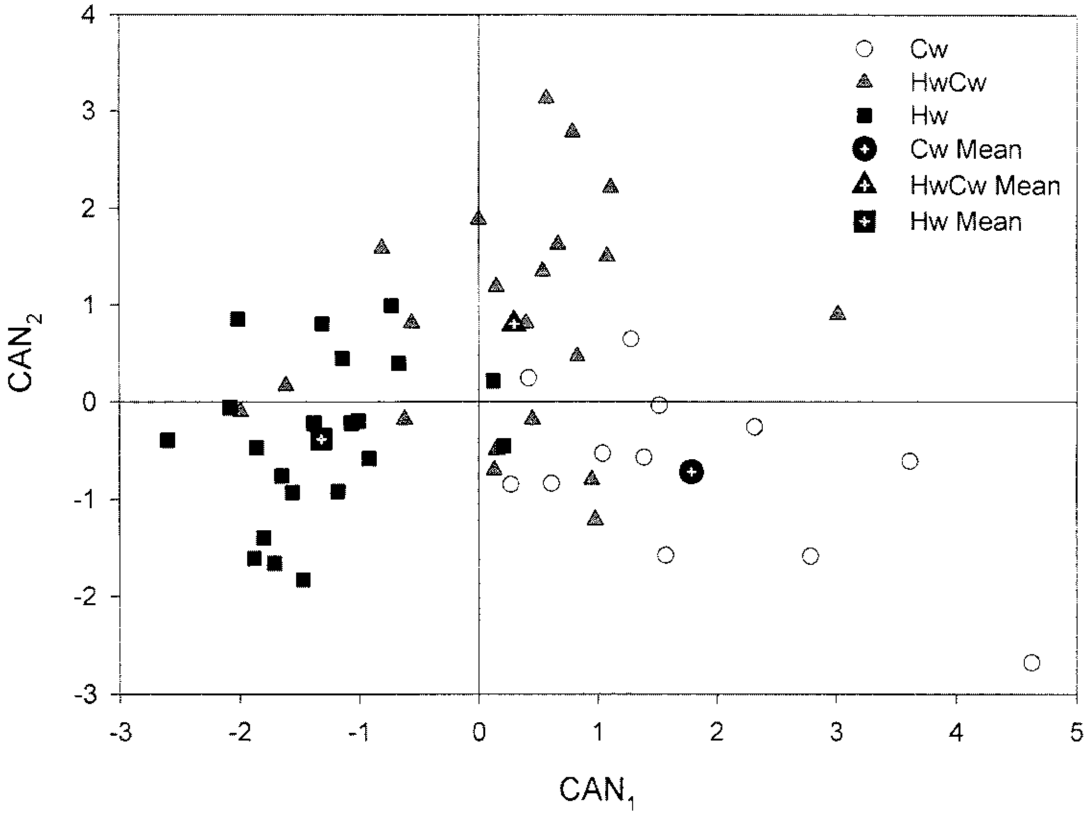

Figure 3. Ordination of 27 forest floor samples and means for each stand type as functions of the first and second canonical variables, based on forest floor nutrient properties significantly discriminating amongst stand types (pH, C:N ratio, total Ca, and total Mg) ($P<0.10$). Abbreviations for stand types are: Hw – western hemlock stand, Cw—western redcedar stand, HwCw—western hemlock-western redcedar stand.

defined separation of hemlock and redcedar stand means, with the hemlock-redcedar stand mean intermediate, indicates that the forest floors in hemlock and redcedar stands have distinctly different nutrient properties, while the hemlock-redcedar stands have intermediate nutrient properties. Forest floor pH, C:N ratio, and Ca concentration successfully discriminate between hemlock, redcedar and hemlock-redcedar stands.

Several forest floor nutrient properties differed significantly between hemlock and redcedar stands, with hemlock-redcedar stands having intermediate properties. It appears that each tree species influenced stand forest floor nutrient properties in a different way, and that this influence is site-specific. Hemlock stands had significantly greater total C and S concentrations than redcedar stands, while redcedar stands had significantly greater min-N concentrations. Although significant stand type*location interactions were found for pH and total Ca, interaction plots showed increases in pH and Ca were associated with increasing redcedar presence. Most forest floor nutrient properties in the hemlock-redcedar stands were intermediate between the hemlock and redcedar stand types, although the hemlock-redcedar stands did have significantly higher C:N ratios than the redcedar stands. Overall, the forest floors under hemlock, and redcedar stands had distinct nutrient properties, while hemlock-redcedar stands had intermediate forest floor nutrient properties. Forest floor nutrient status generally improved with increasing presence of redcedar. Forest floor pH, C:N ratio, and total Ca concentrations effectively discriminate between stands of hemlock, redcedar, and their mixtures.

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