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Plant derived tissue and soil nutrient concentration for plantations of four conifer species growing under different site and vegetation management conditions

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ABSTRACT

This study investigates the long-term effects of vegetation management on nutrient concentration of various tissues and ecosystem components of 16 to 18 year-old Douglas-fir (DF), western hemlock (WH), western red-cedar (WRC), and grand fir (GF) stands growing in Oregon's central Coast Range (CR) and DF and WRC growing in Oregon's Cascade mountain foothills (CF) under two contrasting vegetation management (VM) treatments. The treatments consist of: Control, which received no herbicide application post planting, and VM, which received five years of spring release herbicide application. Both treatments include a fall site preparation herbicide application. The ecosystem was broken down into crop trees (separated into foliage, live branches, bark, and stemwood), midstory species (separated into foliage and stem), understory, forest floor, fine roots, and mineral soil (with depth increments 0.0–0.2 m, 0.2–0.4 m, 0.4–0.6 m, and 0.6–1.0 m). All samples were analyzed for concentration of total carbon, nitrogen, phosphorus, potassium, calcium, magnesium, sulfur, boron, copper, iron, manganese, sodium, and zinc. This study design resulted in 1,740 unique nutrient concentration results being reported. The effect of VM (treatment) on tissue concentration varied by nutrient, overstory crop species (species), ecosystem component, and site. Forest floor and crop tree bark, followed by fine roots, were the ecosystem component nutrient concentrations that showed the greatest number of treatment effects across all species. Soil concentrations showed large variation across sites but were generally unaffected by treatment and species. At the CR site, magnesium and calcium soil concentrations were higher in VM plots across species, while zinc concentrations were lower. There were no other effects of treatment on soil nutrient concentrations, but there were some significant treatment × crop species interactions. Most notably, at the CF site, the concentration of C and N were higher in VM plots than control plots of DF, while the opposite was true for WRC. While total soil concentrations were generally unaffected by treatment and are unlikely to be adversely affected in the long term, it is possible that VM can reduce soil nitrogen for slow growing species like WRC.

1. Introduction

Tissue and soil nutrient concentrations are useful measures in order to determine the nutrient status of a stand as well as potential for nutrient deficiencies or soil nutrient depletion (Turner et al., 1977; Stone, 1990; Slesak et al., 2016; DeBruler et al., 2019). They are the basis for various nutrient management guidelines such as Diagnosis and Integrated Recommendation system (DRIS) and the Kinsey regime which allow development of site-specific fertilization prescriptions (Beaufils, 1973; Mainwaring et al., 2014). Nutrient concentrations are useful in this respect because they indicate how much of a resource is available in the exploitable soil as well as whether plant foliage is optimally equipped to meet a plant's physiological needs. If a plant is lacking a particular nutrient or set of nutrients such that its physiological processes are limited, it will have a suboptimal concentration of nutrients in its foliage. The lowest foliar concentration where nutrients do not significantly limit growth is known as the critical concentration (Ulrich, 1952).

Plants distribute nutrients throughout their tissues in order to satisfy their physiological needs. These nutrients are often divided into two categories, macronutrients and micronutrients, based on the relative requirements of plants. The following are considered macronutrients

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and are required in larger amounts: carbon (C), nitrogen (N), phosphorous (P), potassium (K), calcium (Ca), magnesium (Mg), and sulfur (S). The following are considered micronutrients and are required in much smaller amounts: boron (B), copper (Cu), iron (Fe), manganese (Mn), sodium (Na), and zinc (Zn).

Foliage is generally the tissue type that contains the greatest concentration of nutrients with the exception of Ca which may be higher in the branches, trunk and phloem (Cole and Gessel, 1992; Augusto et al., 2008; Marschner and Marschner, 2012). While foliage comprises approximately 4% of aboveground biomass in a 40-year-old Douglas-fir stand, it contains roughly 70% of the total aboveground nitrogen (Turner and Long, 1975; Turner, 1981; Cole and Gessel, 1992).

Silvicultural treatments, such as vegetation management (VM), during the establishment phase set the trajectory for stand development. These treatments may affect plants by altering the concentration of nutrients in a tissue or in soil (Burger and Pritchett, 1988; Powers and Reynolds, 1999; Powers et al., 2005). Looking at the content of a tissue may not reveal physiologically important changes and may only show trends in biomass if concentrations remain the same. A decrease in tissue nutrient concentration may mean that an organism is having difficulty meeting its physiological needs for that nutrient, whereas a decrease in content can be the result of a number of factors such as reduced biomass or changes in allocation.

The effects of VM on plant nutrient concentrations has been studied, although generally in younger tree seedlings. VM allows trees greater access to site resources and commonly affects nutrient content as the treatments often produce significantly more biomass in most tissues (Petersen et al., 2008; Devine et al., 2011), whereas its effects on nutrient concentration vary by study and tree age. Five-year-old Douglas-fir seedlings have shown increased foliar N content and concentration with vegetation control (Slesak et al., 2010; Devine et al., 2011). These trends varied between sites and concentration effects were only significant at the study level and not at the site level (Devine et al., 2011). A study in the Oregon Coast Range showed N was higher in VM treated Douglas-fir seedlings after the first year of growth but not the second (Rose and Ketchum, 2002). In contrast, B showed a significant decrease in VM treated plots but only after the second year of growth (Rose and Ketchum, 2002). Differences in concentrations are not always observed, as Petersen et al. found that there were no differences in foliar N, P, K, S, Ca and Mg in five-year-old Douglas-fir seedlings (Petersen et al., 2008). A recent study at the Long Term Soil Productivity (LTSP) sites in the Pacific Northwest found that effects on plant nutrition in 15- and 20-year-old Douglas-fir stands varied by site and soil properties (Littke et al., 2020a). One site with historically low base cations showed reduced foliar Ca with sustained VM. Another site with historically higher cations and lower N displayed increased foliar Al and Mg and lower foliar N at a second site with sustained VM, and no detectable differences in foliar nutrients at a third site (Littke et al., 2020a).

The effects of VM on foliar nutrients change over time. Across a gradient of site conditions, foliar N and P concentrations were greater for treated plots early in stand development. These differences disappeared at ages 7 and 9 for all sites, except for N concentrations at the site that had lowest N levels and untreated trees displayed signs of N deficiency (Powers and Reynolds, 1999). One study of loblolly pine conducted at mid-rotation found that eradication of herbaceous vegetation during stand establishment resulted in a decrease in foliar N and K (Miller et al., 2006). They found that all available soil nutrients declined over time but this decline was greater for C, N and Ca.

The effect of silvicultural management on soil concentration has also been studied, with most studies focusing on different forms of N or P. The LTSP study has investigated the effects of different intensive management practices across the US, including sites in the PNW (Powers et al., 2005). Sites in Oregon show that after planting, soil nutrients (exchangeable Ca, Mg, K, and total N) tend to increase after 10 years in the top 0.3 m of soil, although the increase is greater when there is no vegetation control after planting (Slesak et al., 2016). Total soil P is more variable, tending to decrease 10 years after planting in the top 0.3 m. At one site the decrease was less when harvest residues were left on site and there was no vegetation control after planting, while at the other site the decrease was less with annual vegetation control after planting (Slesak et al., 2016). A follow up study looked at total P and different pools of labile to less labile P 10 years after planting which all showed roughly the same result: at one site, when there was a detectable difference in P concentrations of any pool, concentrations were higher with no annual vegetation control while the other site showed the opposite trend (DeBruler et al., 2019). A similar study from the Fall River LTSP site in Washington showed that total soil N concentrations in the top 0.15 m of soil decreased 10 years after planting (Knight et al., 2014). A recent study at the same sites showed a general decrease in soil base cations and reduced simulated nitrate uptake at 15 or 20 years with annual VM, with forest floor samples showing similar trends (Littke et al., 2020a, 2020b).

Most studies look at only a few nutrients and tend to focus on younger trees and only one or two crop species (typically Douglas-fir and ponderosa pine in Oregon). In this study we investigated how vegetation management affected various nutrients (7 macro, including C, and 6 micro) on multiple conifer species (Douglas-fir, western hemlock, western redcedar, and grand fir) in two important timber producing ecoregions in Oregon (the Oregon Cascade foothills and the Oregon Coast Range). The specific objectives of this study were: to quantify nutrient concentrations of all ecosystem components, explore how these varied by overstory species, site, and VM treatment, and explore whether crop tree foliar concentrations were correlated with soil concentrations.

2. Materials and methods

2.1. Description of sites

Two contrasting study sites were selected for this study. The Coastal Range (CR) site is located at 44.616°N, 123.574°W near Summit, OR, approximately 40 km from the coast. The site was planted in the year 2000 and experiences a mean annual temperature of 11.1°C and average annual rainfall of 1,707 mm. The CR site was planted with coast Douglas-fir (DF, *Pseudotsuga menziesii* var. *menziesii* (Mirbel) Franco) and western hemlock (WH, *Tsuga heterophylla* (Raf.) Sarg.) (four replicates each, eight plots per species), and western redcedar (WRC, *Thuja plicata* Donn ex D. Don) and grand fir (GF, *Abies grandis* (Dougl. ex D. Don) Lindl.). (three replicates each, six plots per species). Soils at the CR site are part of the Preacher-Bohannon complex which is derived from siltstone and sandstone, and has a fine and loamy texture (Flamenco et al. 2019). This soil complex is classified as an Andic Dystrudept, meaning that while it is not an Andosol, it has high aluminum and iron activity (Soil Survey Staff, 2015). This site sits near the western edge of the Tyee formation, a sedimentary rock formation that is composed largely of marine micaceous sandstone and siltstone.

The Cascade Foothills (CF) site is located at 44.476°N, 122.726°W near Sweet Home, OR, and was planted in the year 2001 only with DF and WRC (four replicates each). The site has a mean annual temperature of 12.4°C and an average annual rainfall of 1,179 mm. Soils at the CF site are from the Bellpine series which is derived from sedimentary rock, and have a fine and loamy texture (Flamenco, et al. 2019; Soil Survey Staff, 2015; Ulrich, 1952). Soils of this series are classified as Xeric Haplohumults, indicating an Ultisol with high organic matter content that experiences seasonal drought. These soils are well drained and characterized by a more xeric moisture regime than the CR site. The bedrock is a mixture of basalt, sedimentary rocks, and tuff. Similar to the CR site, these soils are derived from sedimentary bedrock, however tuff and mafic intrusions will lend different chemical characteristics to these soils. Mafic rocks tend to be higher in iron and magnesium than sandstone. This site was formerly agricultural land that was not sufficiently productive.

Table 1
P values for the effect of crop species (SPP), treatment (TRT), and their interaction (SPP*TRT) on the concentration of C, N, P, K, Mg, Ca, S, B, Cu, Fe, Mn, Na, and Zn in plant derived and soil ecosystem components of 16–18 year-old Douglas-fir (DF), western hemlock (WH), western redcedar (WRC), and grand fir (GF) stands growing on a site located in the central Coast Range (CR) of western Oregon. P values only included when P $<$ 0.1 and values below 0.05 are presented in bold.

Component	Effect	C	N	P	K	Mg	Ca	S	B	Cu	Fe	Mn	Na	Zn
Foliage*	SPP			**0.004**	**0.035**		**0.004**	**0.041**	**0.020**			**0.003**	**0.012**	**0.007**
	TRT					**0.014**								
	SPP*TRT				**0.005**									0.089
Branch*	SPP	**<0.001**		**0.001**	**0.005**		**<0.001**	**0.003**	**0.015**			**0.018**	0.053	**<0.001**
	TRT	**0.044**												
	SPP*TRT				**0.046**			0.081						
Bark*	SPP	**0.025**	**0.020**	**<0.001**	**0.020**	**0.008**	**<0.001**		**0.034**	0.052		**0.003**		**0.001**
	TRT			**0.005**	**0.090**	**0.001**	**0.014**	**0.041**		**0.037**				**0.027**
	SPP*TRT						**0.030**			0.063				
Wood*	SPP	**0.004**	**0.008**	**0.001**		**0.002**	**0.071**		**0.015**	**0.011**		**0.004**		**0.043**
	TRT													
	SPP*TRT											**0.040**		
Root*	SPP	**0.042**												
	TRT	0.076									**0.006**			
	SPP*TRT													
Understory*	SPP	**0.044**			0.052	**0.005**	**<0.001**					**0.004**	**0.037**	0.062
	TRT		**0.038**		**0.015**	**<0.001**				**0.014**		**0.005**	0.058	
	SPP*TRT		0.079			**0.013**			**0.050**	0.092		**0.035**		
Forest floor*	SPP					**0.017**								
	TRT						**0.026**		0.063	**0.033**				
	SPP*TRT													
Soil 0.0–0.2 m*	SPP	0.059	0.085	0.057		**0.014**			0.054			0.098	**0.027**	
	TRT					0.072						**0.025**	**0.099**	**0.032**
	SPP*TRT											**0.043**		
Soil 0.2–0.4 m**	SPP					**0.002**			0.092		**0.032**	**0.007**	**0.011**	0.093
	TRT					0.090								
	SPP*TRT										**0.039**			
Soil 0.4–0.6 m**	SPP					**0.042**						0.089	**0.008**	
	TRT					0.091	**0.020**							
	SPP*TRT	**0.023**	0.060										0.063	
Soil 0.6–1.0 m**	SPP					0.052								
	TRT					**0.045**								
	SPP*TRT													

2.2. Study design

A randomized complete block design with eight VM regimes (treatments) was implemented at each of the two sites. The eight different VM treatments consisted of spring release applications that differed in the number and timing of herbicide treatments applied during the first 5 years after planting, see Chen 2004 for more details (Chen, 2004). Similar to Flamenco et al. (2019), for this study we used only the control (Control; only pre-planting vegetation control) and the 5 consecutive years of spring release vegetation management treatments (VM). Each treatment plot was 24.4 m × 24.4 m (0.06 ha) in size and was planted with 64 seedlings (8 rows of 8 trees) with 3 m × 3 m spacing, resulting in a planting density of 1,111 trees ha^{-1}. Measurement plots consisted of the internal six rows of six trees allowing for a one tree buffer on all sides. All plots were planted with a single tree species, and the experimental unit was the plot. All DF plots received pre-commercial thinning at age 12 years to reduce stocking by 25% and thinning residues were left on site. A summary of stand attributes at age 18-years is provided in Table A1.

The ecosystem was divided into soil layers and plant derived tissues. The plant derived components were broken down into overstory (planted crop trees), midstory (hardwoods and natural conifer regeneration), understory (shrubs, grasses, forbs, ferns and moss) and forest floor (including coarse woody debris). The overstory was divided into foliage, live branches, stemwood, bark, and fine roots. The midstory was broken down into foliage and bole (stemwood and bark). The soil was divided into four layers (0–0.2 m, 0.2–0.4 m, 0.4–0.6 m, and 0.6–1 m).

Tissue samples were collected from both overstory crop trees and midstory hardwood species. The crop tree canopy was above that of the midstory species and tree sizes are reported in Flamenco et al. (2019). Overstory tissue for nutrient analysis were obtained from samples collected by Flamenco et al. (2019), who destructively sampled 4 trees for each crop species and treatment at each site (48 trees total). Sampled trees were chosen to represent the range of stem diameters present at both sites. Stemwood samples were collected by removing a stem section (or cookie) at DBH. Stem bark samples were obtained by removing the bark from the cookie taken at DBH. Branch and foliage samples were collected from the middle of the living crown (see Flamenco et al., 2019) for further details on crop tree sampling).

As dominant midstory species are the same across sites, samples for nutritional analysis were taken only at the CR site without respect to treatment (only few midstory individuals were found in the VM plots). Midstory tissue samples for nutrient analysis (foliage and stemwood) were collected from midstory trees during July 2019. Only the four most prevalent species were sampled: red alder (*Alnus rubra* Bong.), bigleaf maple (*Acer macrophyllum* Pursh), Oregon cherry (*Prunus emarginata* (Douglas ex Hook.) D. Dietr.), and cascara buckthorn (*Frangula purshiana* DC.). These four species account for 98% of the midstory biomass (Flamenco et al., 2019). Stemwood samples were collected at DBH using a 12-mm increment borer from four different individuals from each species. Foliage samples were also taken from four different individuals from each species.

Understory, forest floor and fine roots were collected from 6 subplots (0.6 m × 0.6 m) per plot. All vegetation in or hanging over these plots

Table 2
P values for the effect of crop species (SPP), treatment (TRT), and their interaction (SPP*TRT) on the concentration of C, N, P, K, Mg, Ca, S, B, Cu, Fe, Mn, Na, and Zn in plant derived and soil ecosystem components of 16–18 year-old Douglas-fir (DF) and western redcedar (WRC) stands growing on a site located in Cascade foothills (CF) of western Oregon. P values only included when P $<$ 0.1 and values below 0.05 are presented in bold.

Component	Effect	C	N	P	K	Mg	Ca	S	B	Cu	Fe	Mn	Na	Zn
Foliage*	SPP	**0.005**	**0.012**	**<0.001**	**<0.001**		**<0.001**	**<0.001**	**0.013**			**<0.001**		
	TRT													
	SPP*TRT				0.064	**0.013**				0.097				
Branch*	SPP			**0.033**			**0.004**	**0.039**		**0.002**		**<0.001**		0.067
	TRT		**0.016**				0.056	0.058				0.080		
	SPP*TRT		**0.015**			0.055	0.067	**0.004**			0.093			
Bark*	SPP	**0.003**				**<0.001**	**<0.001**		**0.002**			**0.025**	**0.040**	**0.009**
	TRT													
	SPP*TRT													
Wood*	SPP		**0.001**			**0.000**	**<0.001**	**0.016**				**0.000**		**0.021**
	TRT			0.099		0.077	**0.006**							
	SPP*TRT													
Root*	SPP							**0.011**						
	TRT	0.083	0.093											**0.033**
	SPP*TRT													
Understory*	SPP		**0.001**					**0.001**		0.094			**0.003**	
	TRT						**0.032**							
	SPP*TRT						**0.036**							
Forest floor*	SPP					0.100				**0.015**		**0.028**		
	TRT			**0.021**	**0.049**				0.083	**0.045**			0.053	
	SPP*TRT													
Soil 0.0–0.2 m*	SPP								**0.042**			0.084		
	TRT				**0.024**									
	SPP*TRT								0.070					
Soil 0.2–0.4 m**	SPP													
	TRT													
	SPP*TRT						**0.040**							
Soil 0.4–0.6 m**	SPP											0.098		
	TRT													
	SPP*TRT	**0.007**	**0.031**									**0.030**		
Soil 0.6–1.0 m**	SPP													
	TRT													
	SPP*TRT	**0.012**	**0.004**							**0.016**				

was collected. The forest floor was manually removed down to the organic horizon and included woody debris, duff, and litter. Researchers then collected a core of the top 0.2 m of mineral soil and used a 2 mm sieve to collect fine roots (Flamenco et al., 2019). Within a plot, all six subsamples were combined for nutrient analysis. One sample from each of the lower soil layers (from 0.2 m to 1.0 m depth) was collected in the spring 2019 from each plot using 50 mm × 50 mm soil cores (AMS, bulk density soil sampling kit). Fine roots were collected from these soil samples using a 2 mm sieve.

2.3. Nutrient analysis

All plant samples were oven-dried at 65 °C until reaching constant weight and ground to pass a 0.425 mm sieve. These tissues were then prepared for nutrient extraction by overnight combustion in quartz tubes at 580 °C. Samples were extracted in 20% v/v HCl for 15 min and then diluted 1:1 with distilled water. These extracts were filtered and stored at 4 °C until analysis. Total soil nutrients were extracted by microwave digestion. Samples were heated to 175 °C in an Anton-Paar MicrowaveGO and held at that temperature for 4.5 min in a solution of 70% HNO3. Digested samples were diluted 1:1 with distilled water, filtered, and stored at 4 °C until analysis. Concentrations of C, N and S were determined by dry combustion using an Elementar vario MACRO cube. All other nutrients (P, K, Mg, Ca, B, Cu, Fe, Mn, Na, and Zn), were determined by analyzing extracts with an Agilent ICP-OES 5110. All analyses were carried out at the Central Analytical Laboratory at Oregon State University.

2.4. Statistical analysis

The Statistical Analysis Software version 9.4 (SAS Institute Inc. Cary, NC) was used for all statistical analysis. Analysis of variance, including Tukey multiple comparisons tests, was used to test the effects of site, species and treatments on all soil and plant derived concentrations (PROC MIXED, SAS Institute Inc. Cary, NC), where block was included as a random effect. Significance was determined using $\alpha = 0.05$. As not all species were planted at each site- site, site × species, site × treatment, and site × species × treatment effects were calculated using a reduced dataset including only Douglas-fir and western redcedar. Pearson correlation coefficients between plant nutrient concentrations and soil nutrient concentrations were determined across treatments, species and sites (PROC CORR, SAS Institute. Cary, NC). SigmaPlot version 14 (Systat Software, Inc. San Jose, CA) was used to create all figures.

3. Results

The results from this study are extensive, with results of 13 different nutrient concentrations for 11 ecosystem components of conifer plantations of four different crop species growing under two contrasting VM treatments at two sites. The second site only contained two of the four species, two nutrients (K and Na) were below detectable levels in stemwood, and S was not measured for soil components- resulting in 1,644 unique nutrient concentration results. Nutrient concentrations for the foliage and stem of four midstory species growing at the CR site are also reported for an additional 96 unique results. We focused on

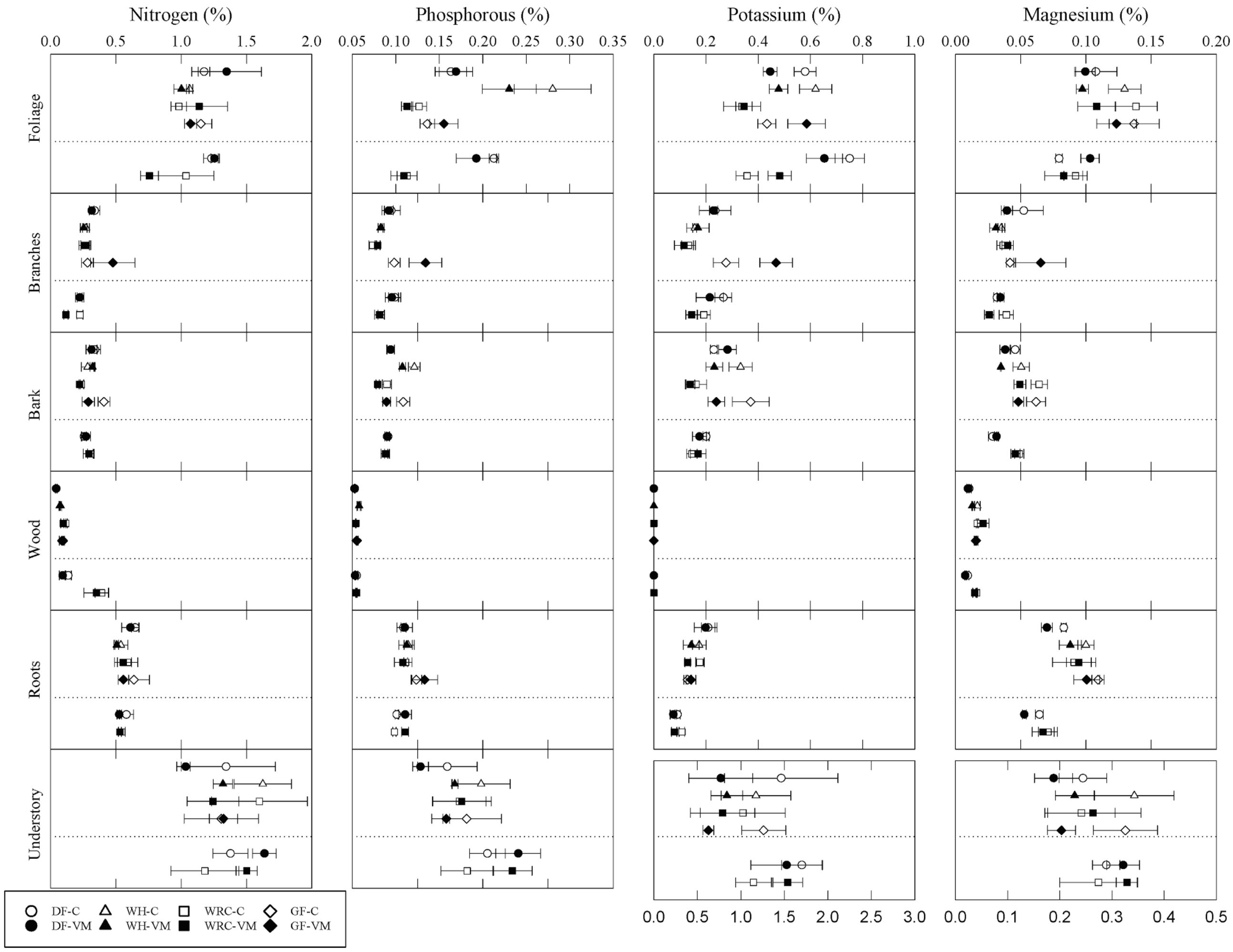

Fig. 1. Concentrations of N, P, K, and Mg for foliage, branches, bark, stemwood, fine roots and understory of 16–18 year-old stands of Douglas-fir (DF), western hemlock (WH), western redcedar (WRC), and grand fir (GF) at sites in the central Coast Range (CR, shown above dotted line) and Cascade foothills (CF, shown below dotted line) of Western Oregon. Concentrations of control plots are shown with a white symbol and treatment plots are shown with a filled symbol.

treatment, site, and species effects of N, P, K, Mg, B, Mn, Zn, and Cu as well as correlations between soil nutrients and plant derived nutrients. Results for each of the 1,740 unique ecosystem component nutrient concentrations can be found in the appendix. Tables A2-A14 provide values for each of the 13 nutrients for all ecosystem components, crop species, VM treatments, and sites. Tables A15 and A16 provide values for the midstory and understory.

3.1. Crop species and vegetation management effects

A summary of ANOVA results for the effects of crop species, treatment, and crop species × treatment interaction on nutrient concentrations are provided in Table 1 for the CR site and Table 2 for the CF site. We considered P-values$<$0.05 to be significant but have also included values between 0.05 and 0.1 for reader's consideration. In general, crop species had a larger effect on nutrient concentrations than treatment or crop species × treatment interaction. At the CR site, 30%, 12%, and 7% of nutrient concentrations ($n = 137$) were affected by crop species, treatment, and crop species × treatment interaction, respectively, while 51% were unaffected by these factors (Table 1). For the CF site, 23%, 5%, and 8% of nutrient concentrations were affected by crop species, treatment, and crop species × treatment interaction, respectively, while 64% were unaffected by these factors (Table 2).

At both sites, plant derived nutrient concentrations (crop trees, understory, and forest floor, $n = 89$) were more affected by crop species and treatment than the soil components ($n = 48$). At CR, 61% of plant derived nutrient concentrations and 27% of soil nutrient concentrations were affected by crop species, treatment, or their interaction. At CF, 46% of plant derived nutrient concentrations and 19% of soil nutrient concentrations were affected. The understory was largely unaffected by crop species and treatment, only showing significant effects for C and Fe at the CR site and S and Zn at the CF site. Mg, Mn, and C were the nutrients most effected by treatments at CR and N, Ca, and Mn were the most affected nutrients at CF.

Within crop tree tissues, fine roots showed the lowest C concentration, ranging between 27.4 and 33.9% (indicating that the fine root sample likely included dead roots), while all other crop tree tissues ranged from 46% to 50% (standard for living plant tissue (Ågren, 2008)). The concentration of C in crop tree branches, bark, stemwood, and roots varied by species at the CR site and was generally higher for DF

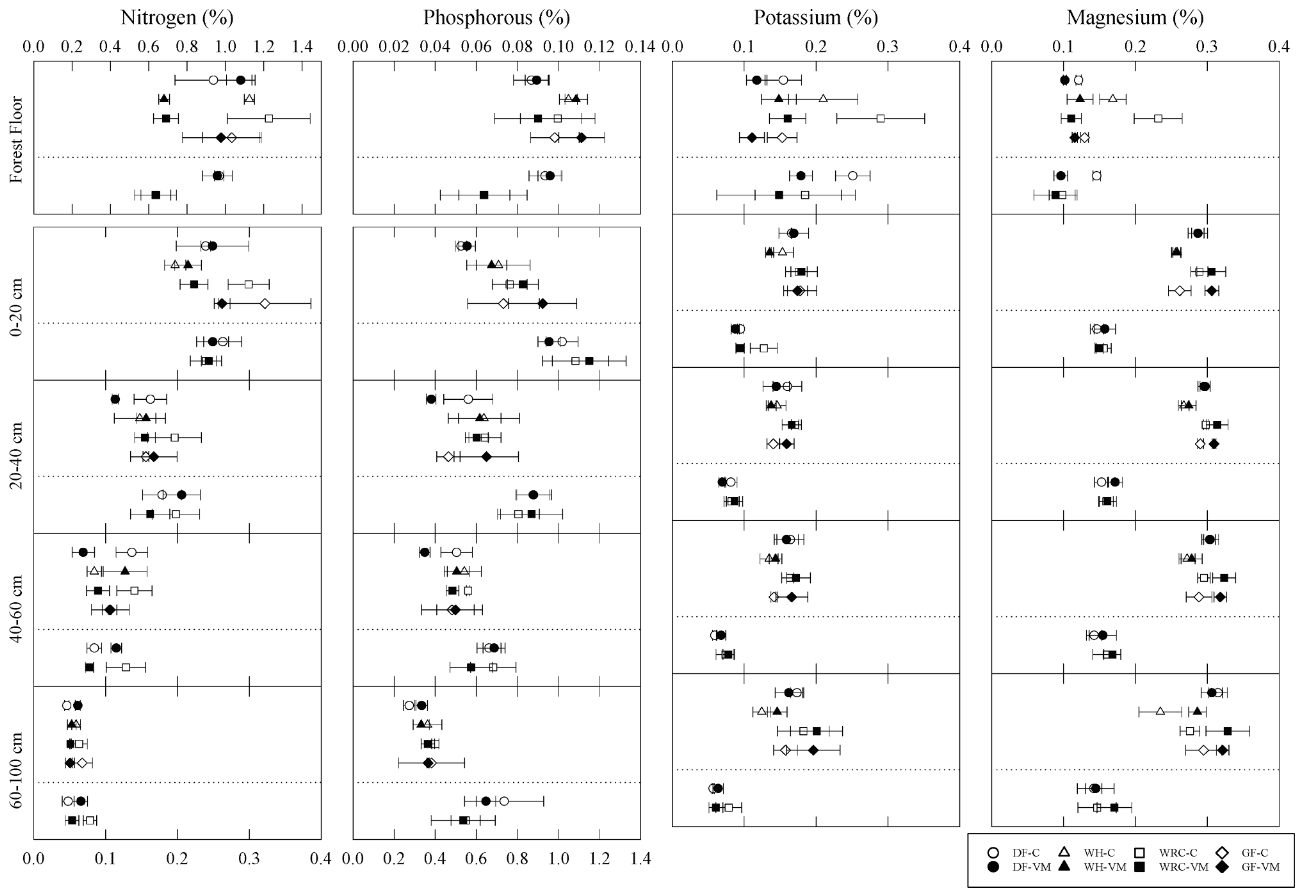

Fig. 2. Concentrations of N, P, K, and Mg for forest floor and the 0–20 cm, 20–40 cm, 40–60 cm and 60–100 cm soil layers of 16–18 year-old stands of Douglas-fir (DF), western hemlock (WH), western redcedar (WRC), and grand fir (GF) at sites in the central Coast Range (CR, shown above dotted line) and Cascade foothills (CF, shown below dotted line) of Western Oregon. Concentrations of control plots are shown with a white symbol and treatment plots are shown with a filled symbol.

than the other species, except for roots (Table 1). The only effect of treatment on crop tree C concentration at CR was VM plots having higher branch C than control plots ($P = 0.044$). VM treatment did not affect crop tree C at CF, but DF had higher bark and foliage C than WRC (Table 2, $P < 0.003$).

For all species, the largest N, P and K concentrations were observed in foliage, ranging between 0.978 and 1.252% N, 0.116 to 0.255% P, and 0.381 to 0.607% K (Fig. 1). At the CF site, DF has higher foliar concentrations of N, P, and K than WRC ($P < 0.012$). Foliar N was not affected by crop species or treatment at the CR site, however foliar P was significantly higher in WH than all other species ($P < 0.031$). There was a significant crop species × treatment interaction for foliar K at the CR site ($P = 0.005$) such that WH growing in the control had higher foliar K than WRC growing under either treatment ($P < 0.047$). Foliar Mg was not affected by crop species at CR but was significantly higher in control plots ($P = 0.014$). At CF, foliar Mg of DF was higher in VM plots than control plots ($P = 0.027$), while WRC was unaffected by treatment (Fig. 1). The concentration of N, P, K and Mg were lower in branches, bark, stemwood, and roots than foliage and often varied by species, and to a lesser extent treatment, except for K at the CF site (Tables 1 and 2). Bark was to most sensitive to crop species and treatment followed by branches and stemwood.

The concentration of B, Cu, Mn, and Zn in crop tree tissues were not affected by treatment at either site except for fine root Cu at both sites and bark Cu and Zn at CR (Tables 1 and 2). In each of these cases, nutrient concentrations were higher in control plots than VM plots (Fig. 3). The effect of crop species was more pronounced than that of treatment. At the CR site, foliar, branch, bark, and stemwood B, Mn, and Zn all varied by species except for stemwood Mn. For example, WH foliar B was higher than DF and WRC while GF foliar Zn was higher than DF and WH. Crop tree Cu concentrations were generally unaffected by species with the exception of DF having higher stemwood Cu than WH and GF. When the effect of crop species was significant for crop tree tissue B, Cu, Mn, and Zn at CF (Table 2), concentrations tended to be higher in DF than WRC except for bark B and fine root Cu.

Soil nutrient concentrations were mostly unaffected by crop species or treatment (Tables 1 and 2). At both sites, six of the thirteen nutrients did not show any crop species, treatment, or crop species × treatment interaction for any soil depth. Additionally, three nutrients only showed an effect for one of the four soil layers at CR while this was true for five nutrients at CF. Soil Mg was the most impacted nutrient at CR with WH having lower soil Mg than WRC in all three of the upper soil layers and all other species in the 0.2–0.4 m layer ($P < 0.050$). Soil Mg in the 0.6–1.0 m layer was not affected by species but was higher in VM plots than control plots at CR ($P = 0.046$). It should be noted that there were no detectable species differences in the deepest layer (0.6–1.0 m) for any nutrient at CR. There was a treatment × crop species interaction for soil C and N at CF such that the concentration of these elements in the

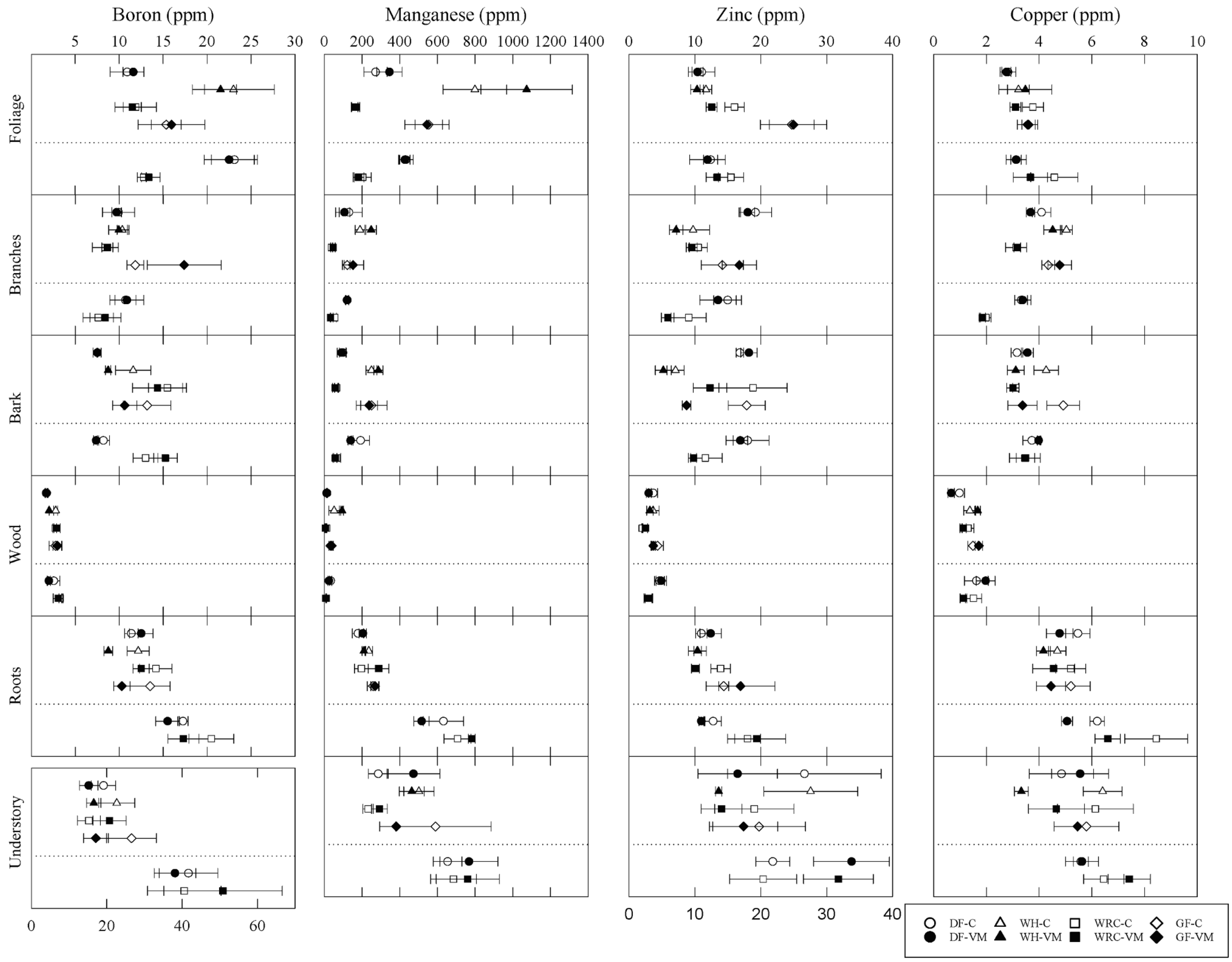

Fig. 3. Concentrations of B, Mn, Zn, and Cu for foliage, branches, bark, stemwood, fine roots and understory of 16–18 year-old stands of Douglas-fir (DF), western hemlock (WH), western redcedar (WRC), and grand fir (GF) at sites in the central Coast Range (CR, shown above dotted line) and Cascade foothills (CF, shown below dotted line) of Western Oregon. Concentrations of control plots are shown with a white symbol and treatment plots are shown with a filled symbol.

0.4–0.6 m and 0.6–1.0 m layers was higher in VM plots than control plots for DF while the opposite was true for WRC (Fig. 2).

There were a few significant site × crop species × treatment interactions. Notably, there were two depths (0.2–0.4 m and 0.4–0.6 m) for WRC at the CF site where there was significantly lower soil N in treated plots than Control plots ($P < 0.05$) and one layer (0.6–1.0 m) for which this trend was marginally significant ($P = 0.07$). For DF at the CF site soil N concentrations were higher in treated plots than Control plots for the 0.6–1.0 m depth ($P < 0.05$). Soil C concentrations were higher in the 0.4–0.6 m depth for VM plots of DF at the CR site ($P < 0.05$).

A more general review of the results showed some interesting trends. Nutrient concentration in mineral soil decreased with depth for C, N, P and Ca, but no clear trend was observed for K and Mg (Fig. 2). Micronutrient concentrations of soils decreased with increasing depth for Mn and Zn while other micronutrients showed no pattern. For Na, the top layer of soil contained the lowest concentration across all species (Fig. 4). Concentrations of Mg, Ca and S in forest floor were relatively high, ranging between 0.116 and 0.146% Mg, 0.754 to 1.600% Ca and 0.090 to 0.111% S. Both, Cu and Fe, had the highest concentrations in fine roots ranging between 4.8 and 6.4 ppm Cu and 1209 and 1554 ppm Fe. The forest floor also contained a notably high concentration of Fe ranging from 914 to 1281 ppm. The concentrations of Mn were highest in the forest floor for all species except WRC, with concentrations ranging from 449 to 833 ppm. The concentration of B was highest in foliage for all species except for WRC, with concentrations averaging between 22.3 and 12.4 ppm. Each species had highest Zn concentrations in a different tissue. The concentration of Na was highest in fine roots and forest floor, averaging between 118 and 162 ppm. In WRC, concentrations of Zn, B, and Mn were highest in fine roots.

3.2. Site effects

The effect of site on nutrient concentrations (averaged across VM treatments) is provided in Table 3. The effect of site was more pronounced in DF plots than WRC plots. 39% of plant derived nutrient concentrations (crop trees, understory, and forest floor, $n = 89$) in DF plots were significantly affected by site compared to 29% in WRC plots. 73% and 46% of soil nutrient concentrations ($n = 48$) were affected by site in DF and WRC plots, respectively. Soil nutrient concentrations were highly site dependent for all depths, with the exception of C, N and Zn. 57% of the 119 significant site effects indicated that the nutrient concentration was higher at the CF site than the CR site.

Concentrations of N were lower at the CR site for the understory in DF plots and the bark and stemwood of WRC, but the concentration was higher for the branches of DF (Table 3). Concentrations of B were lower at the CR site in the forest floor, foliage, roots, and understory of DF. Concentrations of C at the CR site were lower in the forest floor and understory of DF, but higher for roots of both DF and WRC. For Ca, concentrations were lower at the CR site for roots and understory of both DF and WRC, but higher in the bark of WRC. Concentrations of Fe were

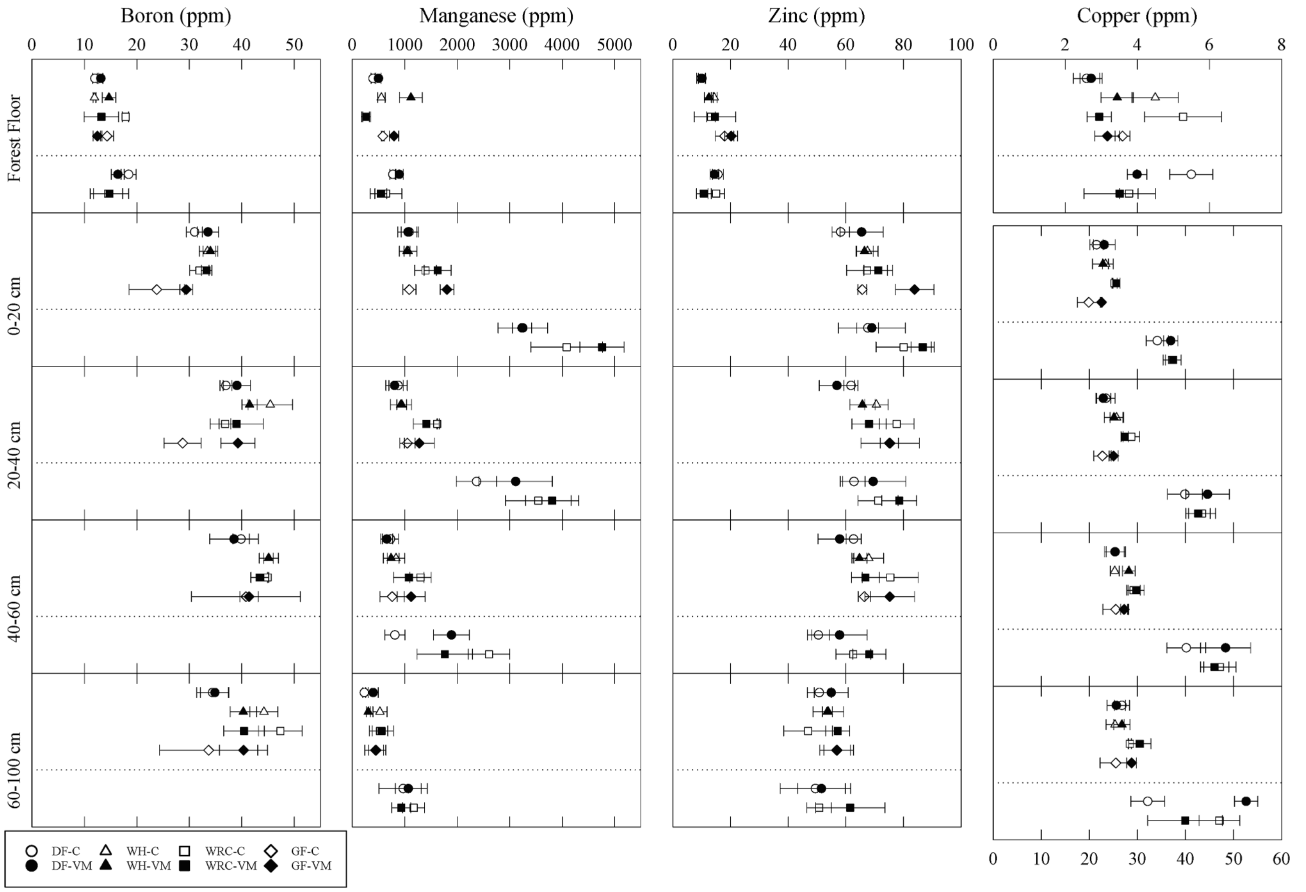

Fig. 4. Concentrations of B, Mn, Zn, and Cu for forest floor and the 0–20 cm, 20–40 cm, 40–60 cm and 60–100 cm soil layers of 16–18 year-old stands of Douglas-fir (DF), western hemlock (WH), western redcedar (WRC), and grand fir (GF) at sites in the central Coast Range (CR, shown above dotted line) and Cascade foothills (CF, shown below dotted line) of Western Oregon. Concentrations of control plots are shown with a white symbol and treatment plots are shown with a filled symbol.

Table 3
P values of site effect for concentration of C, N, P, K, Mg, Ca, S, B, Cu, Fe, Mn, Na, and Zn for each nutrient tissue type and soil layer for 16–18 year-old Douglas-fir (DF) and western redcedar (WRC) stands growing on sites located in the central Coast Range (CR) and the Cascade foothills (CF) of western Oregon (data averaged between Control and VM treatments). Green cells indicate that the concentration was higher at the CR site and white cells indicate the concentration was higher at the CF site. Blank cells indicate no significant differences across sites.

Spp	Tissue	C	N	P	K	Mg	Ca	S	B	Cu	Fe	Mn	Na	Zn
DF	Foliage*				0.005				0.009		0.039		0.002	
	Branch*		0.032					0.028					0.020	
	Bark*					0.004					0.003		0.042	
	Wood*									0.040	0.001	0.002		0.040
	Root*	0.014			<0.001	0.001	<0.001		0.001		0.002	0.001	0.022	
	Understory*	0.011	0.013	0.033			0.034		0.015					
	Forest floor*	0.033			0.029		0.006		0.004	0.006		<0.001	0.022	0.018
	Soil 0.0–0.2 *m**			<0.001	0.001	<0.001	<0.001		<0.001	0.001	<0.001	<0.001	<0.001	
	Soil 0.2–0.4 *m***			<0.001	0.002	<0.001	0.002		<0.001	0.004	<0.001	0.004		
	Soil 0.4–0.6 *m***			0.001	0.001	<0.001	0.016		<0.001	0.008	<0.001	0.038	<0.001	
	Soil 0.6–1.0 *m***			0.001	<0.001	<0.001	0.047		<0.001	0.003	<0.001	0.013	0.001	
WRC	Foliage*					0.024								
	Branch*									<0.001				
	Bark*		0.010		0.002		0.001						<0.001	
	Wood*		<0.001											
	Root*	0.033			0.009	0.029	0.017			0.012	0.019	<0.001		
	Understory*						0.009		0.022			0.036		
	Forest floor*					0.036		0.049					<0.001	
	Soil 0.0–0.2 *m**				0.002	<0.001	0.008		0.002	0.002	<0.001	0.006		
	Soil 0.2–0.4 *m***				0.001	<0.001	0.014		0.001	<0.001	<0.001	0.019		
	Soil 0.4–0.6 *m***					<0.001	<0.001		0.007	<0.001	<0.001	0.038	<0.001	
	Soil 0.6–1.0 *m***				0.001	<0.001	0.021		0.016	0.018	0.001	0.020	<0.001	

* sampled at age 16 years.
** sampled at age 18 years.

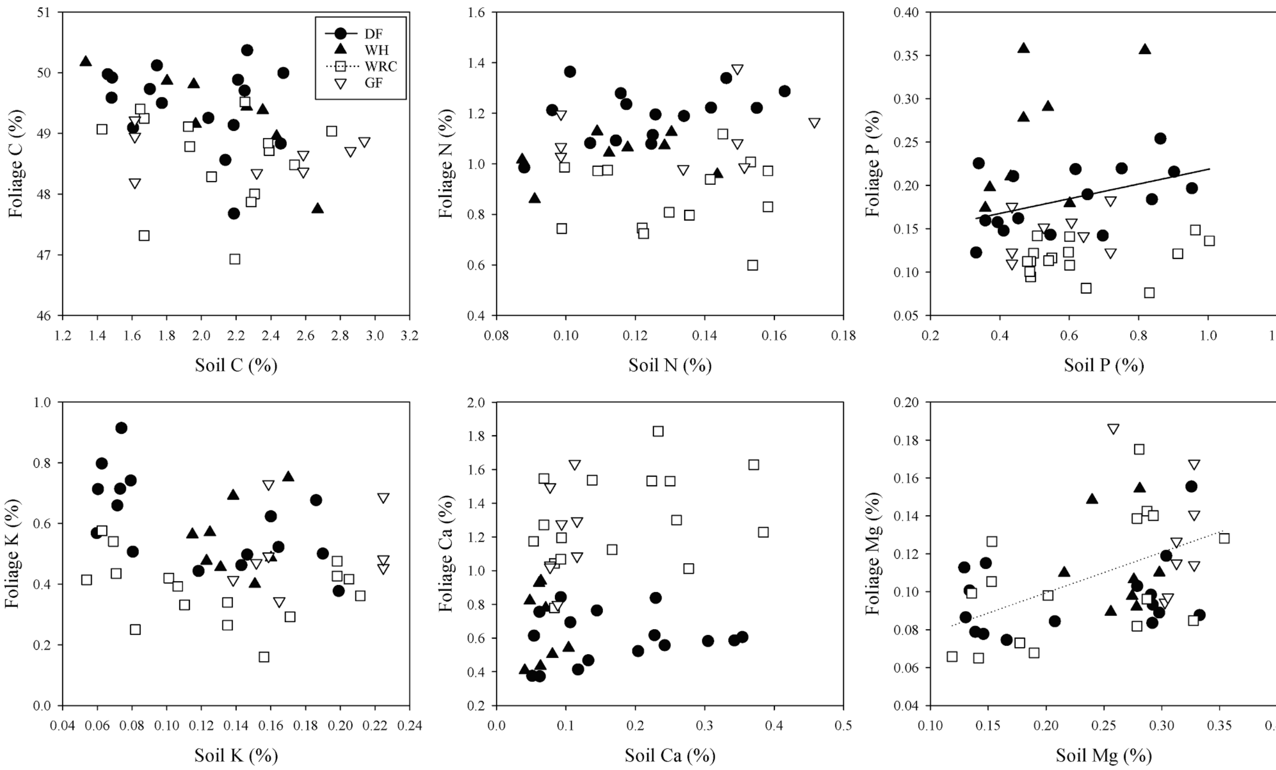

Fig. 5. Plots of foliar vs soil concentrations of C, N, P, K, Ca, and Mg of 16–18 year-old stands of Douglas-fir (DF), western hemlock (WH), western redcedar (WRC), and grand fir (GF) at sites in the central Coast Range (CR) and Cascade foothills (CF) of Western Oregon. Correlations are shown when the model is significant across both sites ($P < 0.1$). Correlations for DF are shown with a solid line and the correlations for WRC are shown with a dotted line. Soil nutrient concentrations represent a weighted average for the top 1 m of soil.

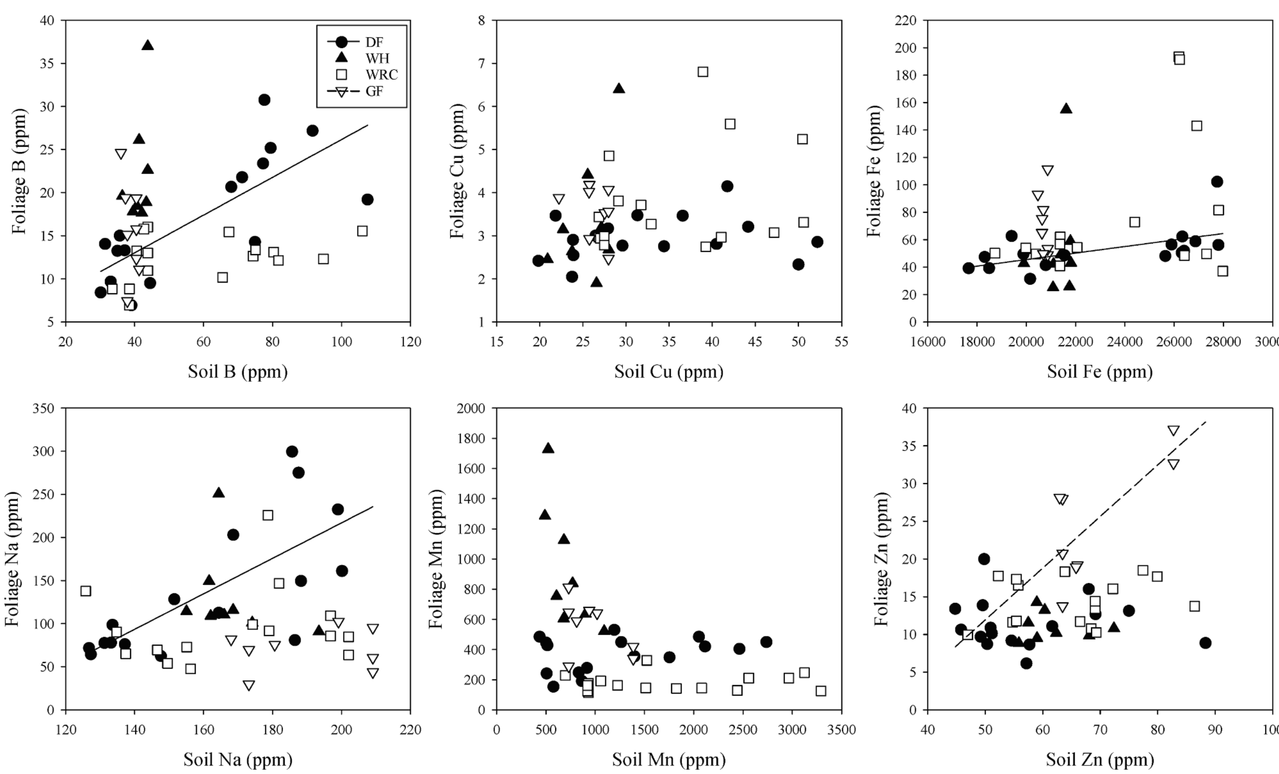

Fig. 6. Plots of foliar vs soil concentrations of B, Cu, Fe, Na, Mn, and Zn of 16–18 year-old stands of Douglas-fir (DF), western hemlock (WH), western redcedar (WRC), and grand fir (GF) at sites in the central Coast Range (CR) and Cascade foothills (CF) of Western Oregon. Correlations are shown when the model is significant across both sites ($P < 0.1$). Correlations for DF are shown with a solid line and the correlation for GF is shown with a dashed line.

lower at the CR site for the bark, foliage, and stemwood of DF and lower in the fine roots of both DF and WRC. For K, concentrations were lower at the CR site for the forest floor and foliage of DF, but higher for the bark of WRC and the fine roots of both DF and WRC. Concentrations of Mg were higher at the CR site for the bark and roots of DF and the forest floor, foliage and roots of WRC. Concentrations of Mn were lower at the CR site for the forest floor, roots, and stemwood of DF and for the roots and understory of WRC. Concentrations of Na were higher at the CR site for the bark, branches, forest floor, foliage, and fine roots of DF and for the bark and forest floor of WRC.

Generally, soil nutrient concentrations of Ca, B, Cu, Fe, and Mn were higher at the CF site and soil nutrient concentrations of K, Mg and Na were higher at the CR site for both species (Table 3). Soil nutrient concentrations tended to show similar patterns for all depths, with all layers being significantly higher at one site or displaying no significant difference. Na and K were the only nutrient concentrations that were significantly different between sites in some layers but not others. Phosphorous was the only nutrient that had differences in soil nutrient across sites for one species but not the other, being significantly higher in all layers at the CF site for DF but not for WRC.

3.3. Correlations between Soil nutrient concentration and crop tree foliar nutrient concentration

Soil nutrient concentrations (weighted averaged across depths) were correlated with foliar nutrient concentrations for several nutrients and species. DF was the species that showed the greatest number of significant correlations, with foliar concentrations of P, B, Na, and Fe increasing with increasing soil concentrations (Figs. 5 and 6). Significant positive correlations were also observed between soil and foliar concentrations of Mg for WRC and between soil and foliar concentrations of Zn for GF. It is likely that the correlations observed for DF and WRC are driven by differences between sites. When the sites are analyzed separately, the only one of the above correlations for DF and WRC that remains marginally significant is the relationship between soil and foliar concentrations of Fe for DF at the CR site ($P = 0.093$, data not shown).

3.4. Midstory species nutrient concentrations

Nutrient concentrations for the stem and leaves of midstory species sampled at the CR site are presented in Tables A14 and A15. As with crop trees, foliage had higher concentrations of all nutrients than the stem with the exception of C, which was approximately 50% for both the foliage and stem. When compared to crop trees, several foliar nutrients tended to be higher in hardwood foliage. Midstory foliar nutrients generally had higher concentrations of N, K, Mg, and Cu than all crop species. P was generally higher in midstory foliage with ACMA, PREM, and FRPU average concentrations ranging from 0.331 to 0.412 ppm, ALRU was the exception to this trend with an average foliar concentration of 0.147 ppm which falls within the range of crop tree foliage.

4. Discussion

Treatment effects on nutrient concentration varied by site, tissue, and nutrient. Bark and forest floor were the two tissue types most affected by vegetation control treatment, followed by fine roots. Crop tree foliage, branches, and stemwood all showed no treatment differences for all species at both sites, except for foliar Mg at CR, branch N at CF, and stemwood Ca at CF. The forest floor was the tissue type most affected by treatment. This makes sense as the litter from the VM plots was almost entirely composed of conifer litter, with some inclusion of understory litter, whereas the forest floor of the C plots contained litter from midstory species, whose foliar nutrition differs significantly from the conifers. Concentrations of Cu and Mg were higher in the forest floor for control plots, although this trend was less pronounced for DF and WRC at the CF site, since untreated plots had less robust midstory development (Flamenco et al. 2019). Concentrations of K in forest floor were also higher in Control plots, but this trend was more pronounced for WRC. These trends of higher base cations in the forest floor without annual vegetation control agree with similar findings in 15 to 20-year-old Douglas-fir (Littke et al., 2020a, 2020b). Concentrations of Mn were higher in forest floor of VM plots, which makes sense because conifers are accumulators of this nutrient. As observed elsewhere, cascara buckthorn also accumulated high concentrations of Mn in its foliage, but other midstory species did not (Zasoski et al., 1990).

Bark was the tissue type second most often affected by treatment, with effects seen for P, K, Mg, and Ca. Generally, with the exception of DF K concentrations, bark nutrient concentrations were higher in Control plots at the CF site. Based on comparisons with a dataset that separated bark, phloem, and stemwood, it is likely that the bark samples in this study contained the phloem, which contains a significant portion of stem nutrients (Augusto et al., 2008). While the current foliage of trees tends to represent the current nutritional status, the bark is accumulated over the lifespan of the tree. P and K are highly mobile in tree tissues and are easily translocated, and Mg concentrations show similar patterns in bark tissue implying that it is also somewhat mobile (Helmisaari and Siltala, 1989). The fact that these concentrations are higher in Control plots may indicate that they had higher nutrient concentrations in the inner bark at the time of sampling or may suggest a larger portion of live inner bark. Generally, if this were the case it would be expected that foliage concentrations would show a similar pattern which they do not. While difficult to study in depth due to the small annual increment in bark tissues, it has been shown that certain nutrients (N, P, K, Ca, Mg and possibly Zn) are retranslocated from the bark, although this is likely a small overall source of nutrients (Helmisaari and Siltala, 1989; Hendrickson, 1987; Laclau et al., 2003). Thus, higher bark concentrations may indicate that these nutrients were poorly retranslocated from the outer bark before the tissue became dormant. This would suggest that the trees in the Control plots were less stressed for these nutrients over their lifetime resulting in a lower retranslocation efficiency.

The vegetation management treatments produced some differences in soil nutrient concentrations, although not many. Unlike other studies, results presented here are total concentrations of soil nutrients as opposed to exchangeable concentrations (with the exception of C, which is often presented as total). Total soil nutrients concentrations are larger than exchangeable concentrations and as some of the nutrients quantified are not accessible to plants or mobile enough to leach, total soil nutrients are less likely to change due to biotic or abiotic factors. Soil N concentration was affected by treatment differently for different species and soil depths. For all species, generally, N decreased with soil depth. N is a common limiting element in these forests and this indicates that for this slow growing species, sustained vegetation control may reduce the ability of the ecosystem to retain N, as was shown by Miller et al. (2006). Concentrations of C in the soil was, generally, not affected by VM treatment. Only one species and showed higher soil C in one layer in Control plots. Across all species, soil concentrations of Ca were higher in the 0.0–0.2 m layer of the VM treated plots, although a similar study that measured exchangeable Ca in soil of 15–20 year old Douglas-fir showed the opposite trend (Harrington et al., 2020; Littke et al., 2020b). The Matlock site of the LTSP displayed less C and N at both years 10 and 15, which agrees with our results, although they interpret this as due to Scotch broom infestation in the control plots (Harrington et al., 2020; Slesak et al., 2016). These studies also noted greater increases/concentrations in soil cations in plots without control of competing vegetation (although it should be noted they were measuring exchangeable cation pools and not total soil cations). Our study did not note any treatment differences in P and K concentrations, both of which were noted in Slesak et al. (2016). Another study of similar design conducted in western Washington noted no treatment differences in total soil N for all depths, but did note more C in the 0.6–1.0 m layer in herbicide treated plots (Knight et al., 2014). Additionally, this study did not note any difference in total soil P concentrations between vegetation management treatments.

The foliar nutrient concentrations measured here generally agree with published values. Moore et al. (2004) measured foliar concentrations of unfertilized GF and DF in the Intermountain West, calculating percentiles for each nutrient. DF foliar nutrient concentrations in this study generally fell within the ranges published for N, P, Mn, Fe, and Cu. Measured concentrations for K, Mg, and B ranged from 40th percentile to below levels measured in the study, whereas S concentrations ranged from 80th percentile to greater than observed concentrations. Measured concentrations for two of the elements were entirely outside of these published ranges- Ca concentrations being higher than the highest reported value, and Zn concentrations being lower. These differences may be due to different nutrient availabilities in different soil types- as the measured Ca concentrations in DF foliage agree better with data from sites in Oregon (Mainwaring et al., 2014). A study of old growth DF showed similar trends for N, P, Mg, and K. However, our reported Ca values were lower, although by less than a factor of 2 (Cross and Perakis, 2011). According to a nutrient diagnosis guide for Douglas-fir in western British Columbia, there are possible deficiencies of K, Mg (at the CR site), S, B (at the CF site), Cu, Fe, and Zn (Ballard and Carter, 1986). Additionally, this reference suggested that DF at both sites were severely to slightly-moderately deficient in N, though this guide was developed for current year foliage as opposed to composite samples (Ballard and Carter, 1986).

Nutrient concentrations of GF were less in line with concentrations in the Intermountain West as reported by Moore et al. (2004), although GF was the most variable of the species measured. Only N, P, S, Mg, and Zn fall entirely in the reported ranges. All other nutrients fell outside the published range, with Ca, Mn, Fe, and Cu being greater and K and B being lower (Moore et al., 2004).

Foliar nutrients of WRC also generally agree with published literature values. Radawan and Harrington (2011) measured foliar concentrations of WRC trees sampled from a range of different sites in Washington and British Columbia, with a couple of sites in Oregon. The concentrations measured here are generally within the published range for N, P, K, Mg, and, S- although the lowest concentrations measured by this study were lower than those of Radwan and Harrington (1986). However, the Ca concentrations measured in this study were almost two-fold higher than their published data. When compared to foliar concentrations from a different study in British Columbia- measured N, P, K, S, and Mg concentrations were lower than published values, whereas Ca concentrations are higher (Kranabetter et al., 2003).

As with the other species, most published foliar values of WH report concentrations in current year foliage. Foliar N was lower than values from old growth specimens in the coast range and stands in western Washington (Cross and Perakis, 2011; Radwan and DeBell, 1980). Concentrations of P, however, were higher than those reported for old growth specimens, slightly higher than coastal stands reported by Radwan and DeBell (1980), but fitting with stands in the Cascades. Ca values, as with other species, were higher than other published values (Cross and Perakis, 2011; Kranabetter et al., 2003; Radwan and DeBell, 1980).

Soil concentrations of C, N, and P are in line with other studies in the Oregon Coast Range (Cromack et al., 1999; Cross and Perakis, 2011). Concentrations of C and N from both sites are similar to the STR and CTC sites in Mainwaring et al. (2014), which are geographically very close to the CR and CF sites respectively. Soil concentrations of Cu, Mn and Zn are in or near the ranges predicted by the USGS, with Cu and Zn concentrations slightly lower than the predicted ranges. Concentrations of Ca, K and Mg are lower than USGS predictions by approximately an order of magnitude. Measurements of Ca in soil residue (<2 mm) in the Oregon Coast Range averaged 0.25% on sedimentary bedrock to 0.77% on basaltic bedrock (Hynicka et al., 2016). These values are only two-fold higher than the 0.13% average at the CR site (located on sedimentary bedrock) and 0.35% at the CF site (located on basaltic bedrock). It should be noted that the Basaltic bedrock sites in Hynicka et al. (2016) were from basaltic sites in the Oregon Coast range and not in the Cascade foothills.

Differences in nutrient concentration between site varied by nutrient and tissue type. Similar trends were noticed for both species, although DF displayed more site dependent nutrient differences. Most of the differences in tissue nutrient concentration were associated with differences in total soil nutrient concentration. Generally, soils at the CR site had higher concentrations of K, Mg, and Na while soils at the CF site had higher concentrations of Ca, B, Cu, Fe, and Mn. When there were differences in tissue concentrations, they generally followed similar trends, with the exception of branch Cu and bark Ca in WRC as well as forest floor and foliage K in DF. This suggests that, while the soil nutrients measured were total concentrations as opposed to accessible concentrations, they may be indicative of trends in available concentrations between sites.

Differences in parent material are able to explain some of the soil concentration differences between the two sites. Basaltic rocks tend to have higher concentrations of Fe, Mg, and Ca than sedimentary rock, although this can change depending upon the nature of the sedimentary material. This study found that there were higher soil concentrations of Fe at the CF site which is more volcanic, but less Mg. It is possible that this is due to the nature of sedimentary rock at the CR site or land use history at the CF site. The CF site was previously agricultural land that was relatively low yielding. It may be that farming procedures decreased soil Mg. It has been shown that application of lime in the form of Ca carbonate depletes the exchangeable Mg, although this may only be a small portion of the total Mg at a site. Additionally, studies of soils formed on the Tyee formation (which the CR site is located on) show that these sites contain a large amount of montmorillonite, a clay which commonly has Mg isomorphous substitutions in the Al layer (McBride, 1994; McWilliams, 1973; Metson, 1974).

P is almost entirely sourced from bedrock, with soil reserves declining with age. The bedrock from the Tyee formation formed in the middle Eocene, somewhere between 54 and 36 Ma. The bedrock that the CF site is located on is estimated to be between 32 and 11 Ma in various parts of the range. Additionally, the Oregon Coast Range (CR site) generally experiences greater rainfall and higher biomass production than the West Cascades (CF site) (Hudiburg et al., 2009). Both plant activity and moisture are important soil forming factors. Given this information it is reasonable to suspect that soils at the CR site are more developed which may have resulted in less soil P than the CF site.

Soil K levels in the PNW are low compared to the rest of the country due to a lack of K feldspar in the parent material. According to the USGS, concentrations near the study sites should range from 0.8 to 1.2% in the top 0.05 m and A horizon, although soil at 1 m depth by the CR site may have lower concentrations (Smith et al., 2019). Cu concentrations are high in the areas near both sites, ranging from 30 to 300 ppm or more in the top meter of soil (Smith et al., 2019). Soil Mn is high, ranging from 880 to 1210 ppm through A horizon, with samples at 1 m depth have higher concentrations near the CR site (Smith et al., 2019). Zn concentrations are also high, ranging from 80 to 100 ppm at both sites with possible higher concentration in the A horizon of the CF site. Soil Fe concentrations are also high in Oregon, ranging from 3 ppm to 14 ppm (Smith et al., 2019). Concentrations of Mg near the CF site range from 1 to 13% in the top 0.05 m and A horizon, whereas they range from 0.7 to 1.2% near the CR site (Smith et al., 2019).

Species differences in concentrations were more common than treatment differences and showed notably different, but expected, patterns when compared to site differences. Species differences in soil concentration were most common in the top 0.2 m, which is to be expected as this is where the greatest quantity of fine roots are found. The species effect was significant across all species for 5 nutrients (Table 1). However, when comparing one species to another, these trends were often not significant (Fig. 3). Lower soil C for DF may reflect a lower rate of fine root turnover or a higher rate of microbial respiration. Mg generally had the lowest concentrations under WH. This may indicate that there is greater uptake or leaching of this nutrient under this species. Even although root samples are a composite of fine roots from all vegetation within each plot, the higher concentrations of Zn, B, and Mn in fine roots of WRC may suggest that WRC invests more micronutrients to fine roots than the other species.

It is difficult to draw general trends for species differences in aboveground tissue concentrations. Elements such as B and Zn did not have strong trends that indicate the tendency of one species to accumulate more of a nutrient across all tissue types. Similarly, no tissue type tended to have higher concentrations of all or most nutrients in any given species. Mn had significantly higher tissue concentrations in the stemwood, bark, branches, and foliage of WH, which indicates that this species may accumulate more Mn than other species. WH, as a species, is capable of growing at lower soil pH than other conifers and soil Mn becomes more available at lower pH. The trend observed here may indicate that WH has adapted to survive with higher tissue concentrations of Mn due to its preference for acidic soils. Concentrations of P were highest for stemwood, bark and foliage of WH. This differs from old growth species in the Oregon Coast Range which showed DF species as having not significantly higher foliar concentrations than WH (Cross and Perakis, 2011). A study of WRC and WH in coastal British Columbia showed no differences across species on a number of different site types (Kranabetter et al., 2003)

5. Conclusions

Effects of VM on nutrient concentrations of plant derived tissue at ages 16–18 varied by site, species, nutrient, and tissue. Bark and forest floor were the two tissue types that were most sensitive to VM treatment. Differences in forest floor nutrient concentrations are likely driven by the changes in plant species composition between VM and Control plots, with midstory and understory species contributing chemically distinct litter in many Control plots. Differences in bark concentrations may indicate differences in nutrient retranslocation over the lives of the different stands. Since the treatment had little effect on foliar nutrient concentrations, we expect the physiology, including photosynthetic efficiency of the foliage, to also be similar between competing vegetation control treatments. This means that crop tree growth differences between Control and VM treatments cannot be explained by the foliar nutrient status at ages 16–18.

Few treatment effects on soil were discovered and varied by species, site, and depth. When differences were detectable, soil concentrations of N and Mg were higher in VM plots. The one exception was that soil N and Ca concentrations for WRC at the CR site were significantly lower for 0.2–0.4 m and 0.4–0.6 m depth increments in VM plots. Additionally, deep soil C (0.4–0.6 m) showed a significant decrease under VM for DF at the CR site. Generally, tissue concentrations were most affected by species and soil concentrations were most affected by site. This study does not indicate the potential for total soil nutrient reserves to be depleted by even sustained vegetation management treatment. WRC at the CR site was a notable exception, where VM plots showed significantly lower N concentrations. This may indicate the potential for reduced N retention on a slow growing species, such as WRC, receive five years of post-planting herbicide application. This study did not attempt to quantify fluxes between various available and unavailable soil nutrient pools, and as such there may be treatment differences in nutrient availability that cannot be observed from this data.

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CRediT authorship contribution statement

Callan Cannon: Project administration, Formal analysis, Funding acquisition, Visualization, Writing - review & editing. **Carlos Gonzalez-Benecke:** Supervision, Methodology, Project administration, Visualization. **Maxwell Wightman:** Project administration, Writing - review & editing.

Declaration of Competing Interest

The authors declare no conflict of interest.

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Appendix A

Tables A1-A14: Control: no post-planting vegetation control, VM: sustained vegetation control for first 5 years post planting. Trt: Effect of vegetation management treatment; Site: Effect of site; Site × Trt: Interactive effect of treatment and site. The P-value shown is in bold if the difference in concentration was significant at $\alpha = 0.05$.

Table A1
Average trees per ha (TPHA, ha^{-1}), mean height (height, m), quadratic mean diameter (QMD, cm), crop tree basal area (BA_{CT}, $m^2\ ha^{-1}$) and midstory basal area (BA_M, $m^2\ ha^{-1}$), for 18 year-old Douglas-fir (DF), western hemlock (WH), western redcedar (WRC), and grand fir (GF) planted stands growing under contrasting treatments of vegetation management on sites located in the central Coast Range (CR) and the Cascade foothills (CF) of western Oregon.

Site	Species	Treatment	TPHA (ha^{-1})	Height (m)	QMD (cm)	BA_{CT} ($m^2\ ha^{-1}$)	BA_M ($m^2\ ha^{-1}$)
CR	DF	Control	681	17.1	8.5	25.1	0.0
		VM	725	18.1	9.2	31.0	0.0
	WH	Control	868	13.5	6.7	19.4	16.1
		VM	1032	17.2	9.0	42.6	0.0
	WRC	Control	748	6.2	4.1	7.0	29.3
		VM	967	10.7	7.0	24.0	0.7
	GF	Control	907	11.8	5.9	16.5	17.7
		VM	987	15.6	9.2	42.5	0.0
CF	DF	Control	696	14.8	7.2	18.4	4.5
		VM	718	17.1	8.9	28.5	0.0
	WRC	Control	352	8.7	6.4	7.0	2.7
		VM	935	9.6	6.3	19.1	0.0

Table A2
Concentration (ppm) of Boron (B) of tree and ecosystem components for 16–18 year-old Douglas-fir (DF), western hemlock (WH), western redcedar (WRC), and grand fir (GF) stands growing under contrasting treatments of vegetation management on sites located in the central Coast Range (CR) and Cascade Foothills (CF) of western Oregon. SE is the standard error.

		CR Control		**CR VM**		**CF Control**		**CF VM**		**P-value**		
Species	**Tissue**	**ppm**	**SE**	**ppm**	**SE**	**ppm**	**SE**	**ppm**	**SE**	**Trt**	**Site**	**Site × Trt**
DF	Foliage	10.91	1.93	11.62	1.18	23.10	2.61	22.50	2.85	0.973	**0.001**	0.797
	Branches	9.90	1.82	9.69	0.54	10.69	1.19	10.85	1.93	0.905	0.548	0.818
	Bark	7.50	0.05	7.48	0.45	8.18	0.69	7.35	0.31	0.313	0.484	0.266
	Wood	1.72	0.14	1.66	0.12	2.52	0.69	1.96	0.19	0.421	0.162	0.511
	Understory	19.12	3.23	15.20	2.46	41.66	7.80	38.09	5.53	0.225	**0.006**	0.952
	Forest Floor	11.99	0.44	13.10	0.41	18.41	1.44	16.37	1.22	0.622	**0.001**	0.118
	Fine Roots	11.36	0.76	12.49	1.35	17.23	0.57	15.49	1.35	0.764	**0.002**	0.180
	Soil 0.0–0.2 *m*	31.00	1.54	33.55	2.03	68.33	5.28	61.98	3.67	0.575	**<0.001**	0.225
	Soil 0.2–0.4 *m*	36.97	1.13	39.07	2.62	77.37	7.35	80.97	1.70	0.486	**<0.001**	0.852
	Soil 0.4–0.6 *m*	39.87	1.57	38.51	4.63	80.37	6.93	78.39	2.85	0.716	**<0.001**	0.946
	Soil 0.6–1.0 *m*	34.42	3.03	34.87	2.70	89.67	19.77	91.31	7.43	0.924	**<0.001**	0.957
WH	Foliage	22.99	4.66	21.52	1.82	–	–	–	–	0.772	–	–
	Branches	10.33	0.59	9.93	1.14	–	–	–	–	0.692	–	–
	Bark	11.57	2.01	8.72	0.31	–	–	–	–	0.211	–	–
	Wood	2.75	0.22	2.01	0.02	–	–	–	–	**0.015**	–	–
	Understory	22.64	4.80	16.54	1.89	–	–	–	–	0.282	–	–
	Forest Floor	11.91	0.27	14.68	1.30	–	–	–	–	0.082	–	–
	Fine Roots	12.14	1.26	8.74	0.49	–	–	–	–	**0.046**	–	–
	Soil 0.0–0.2 *m*	33.44	1.55	34.01	1.41	–	–	–	–	0.477	–	–
	Soil 0.2–0.4 *m*	45.46	4.24	41.49	1.44	–	–	–	–	0.268	–	–
	Soil 0.4–0.6 *m*	45.09	0.92	45.17	1.82	–	–	–	–	0.970	–	–
	Soil 0.6–1.0 *m*	44.22	2.65	40.31	2.49	–	–	–	–	0.356	–	–
WRC	Foliage	11.89	2.35	11.50	1.03	12.81	0.27	13.36	1.30	0.954	0.355	0.751
	Branches	8.40	1.47	8.63	0.63	7.59	1.73	8.41	1.77	0.726	0.731	0.844
	Bark	15.46	2.15	14.34	2.86	12.98	1.41	15.25	1.33	0.783	0.705	0.420
	Wood	2.71	0.14	2.86	0.41	3.27	0.15	3.03	0.56	0.448	0.184	0.315
	Understory	15.22	3.04	20.71	4.39	40.55	9.78	50.86	15.73	0.496	**0.033**	0.833
	Forest Floor	17.85	0.59	13.23	3.28	14.52	2.77	14.78	3.67	0.492	0.777	0.444
	Fine Roots	14.13	1.84	12.47	0.93	20.45	2.55	17.28	1.77	0.152	0.071	0.622
	Soil 0.0–0.2 *m*	31.93	1.86	33.28	0.99	85.15	5.95	88.32	8.50	0.276	**<0.001**	0.645
	Soil 0.2–0.4 *m*	36.82	1.11	39.02	5.06	88.39	6.71	78.68	5.89	0.413	**<0.001**	0.215
	Soil 0.4–0.6 *m*	44.92	0.00	43.44	1.70	76.37	7.20	80.35	6.83	0.672	**<0.001**	0.369
	Soil 0.6–1.0 *m*	47.37	4.16	40.43	3.88	77.81	2.86	76.73	13.98	0.643	**0.014**	0.733
GF	Foliage	15.36	1.70	15.95	3.79	–	–	–	–	0.925	–	–
	Branches	11.81	0.95	17.37	4.21	–	–	–	–	0.245	–	–
	Bark	13.15	2.70	10.61	1.38	–	–	–	–	0.282	–	–
	Wood	2.73	0.73	2.94	0.49	–	–	–	–	0.822	–	–
	Understory	26.54	6.63	17.11	3.28	–	–	–	–	0.271	–	–
	Forest Floor	14.31	1.22	12.49	0.83	–	–	–	–	0.285	–	–
	Fine Roots	13.50	2.28	10.29	0.92	–	–	–	–	0.263	–	–
	Soil 0.0–0.2 *m*	23.79	5.27	29.40	1.21	–	–	–	–	0.358	–	–
	Soil 0.2–0.4 *m*	28.73	3.51	39.27	3.23	–	–	–	–	0.092	–	–
	Soil 0.4–0.6 *m*	40.80	10.37	41.39	1.74	–	–	–	–	0.953	–	–
	Soil 0.6–1.0 *m*	33.69	9.36	40.34	4.58	–	–	–	–	0.442	–	–

Table A3
Concentration (%) of carbon (C) of tree and ecosystem components for 16–18 year-old Douglas-fir (DF), western hemlock (WH), western redcedar (WRC), and grand fir (GF) stands growing under contrasting treatments of vegetation management on sites located in in the central Coast Range (CR) and Cascade Foothills (CF) of western Oregon. SE is the standard error.

		CR Control		CR VM		CF Control		CF VM		P-value		
Species	**Tissue**	**%**	**SE**	**%**	**SE**	**%**	**SE**	**%**	**SE**	**Trt**	**Site**	**Site × Trt**
DF	Foliage	49.20	0.23	49.26	0.57	50.00	0.04	49.38	0.25	0.439	0.267	0.310
	Branches	47.32	0.24	47.45	0.11	47.07	0.19	47.10	0.25	0.700	0.172	0.800
	Bark	48.32	0.74	49.21	1.11	49.74	0.49	49.63	0.40	0.702	0.182	0.595
	Wood	47.77	0.08	47.57	0.18	47.76	0.26	48.03	0.08	0.827	0.234	0.190
	Understory	37.22	5.54	31.50	1.87	42.31	1.72	44.34	0.76	0.559	**0.013**	0.231
	Forest Floor	31.22	4.08	35.34	2.26	41.64	1.97	41.37	3.06	0.527	**0.017**	0.472
	Fine Roots	31.74	2.06	30.57	2.01	23.86	2.82	26.85	1.32	0.676	**0.027**	0.350
	Soil 0.0–0.2 *m*	3.80	0.12	4.20	1.04	4.26	0.46	4.53	0.36	0.584	0.521	0.925
	Soil 0.2–0.4 *m*	2.87	0.58	2.43	0.49	2.80	0.53	3.14	0.49	0.849	**0.038**	0.168
	Soil 0.4–0.6 *m*	2.37	0.24	1.09	0.26	0.82	0.14	1.36	0.11	0.102	**0.012**	**0.002**
	Soil 0.6–1.0 *m*	0.65	0.23	0.82	0.02	0.54	0.12	0.81	0.13	0.166	0.945	0.711
WH	Foliage	49.22	0.53	49.41	0.19	–	–	–	–	0.719	–	–
	Branches	46.68	0.10	46.33	0.18	–	–	–	–	0.060	–	–
	Bark	47.08	1.06	45.18	0.45	–	–	–	–	0.152	–	–
	Wood	47.63	0.41	47.85	0.13	–	–	–	–	0.544	–	–
	Understory	42.05	1.25	42.19	0.76	–	–	–	–	0.928	–	–
	Forest Floor	40.93	1.70	41.01	2.27	–	–	–	–	0.976	–	–
	Fine Roots	32.73	3.51	35.08	0.93	–	–	–	–	0.542	–	–
	Soil 0.0–0.2 *m*	4.64	0.42	5.28	0.44	–	–	–	–	0.324	–	–
	Soil 0.2–0.4 *m*	2.75	0.89	2.64	0.22	–	–	–	–	0.906	–	–
	Soil 0.4–0.6 *m*	1.11	0.22	1.92	0.54	–	–	–	–	0.234	–	–
	Soil 0.6–1.0 *m*	0.71	0.16	0.61	0.14	–	–	–	–	0.659	–	–
WRC	Foliage	48.92	0.47	48.07	0.56	48.89	0.36	48.81	0.23	0.288	0.415	0.378
	Branches	46.97	0.11	46.69	0.12	46.06	0.24	42.87	3.87	0.353	0.288	0.429
	Bark	48.35	0.19	48.95	0.63	47.04	0.60	47.15	0.37	0.302	**0.015**	0.338
	Wood	48.62	0.04	48.52	0.10	46.97	0.95	46.88	0.80	0.793	**0.001**	0.592
	Understory	43.59	0.20	36.95	5.72	41.62	1.83	44.05	0.55	0.437	0.439	0.124
	Forest Floor	39.32	0.95	38.15	4.02	42.55	4.35	39.15	4.44	0.368	0.434	0.650
	Fine Roots	34.52	4.10	29.84	1.72	24.28	2.88	23.19	0.73	0.290	**0.026**	0.490
	Soil 0.0–0.2 *m*	5.29	0.88	4.62	0.17	4.75	0.35	4.85	0.69	0.646	0.799	0.535
	Soil 0.2–0.4 *m*	3.91	1.13	2.71	0.43	3.16	0.47	2.66	0.57	0.087	0.250	0.419
	Soil 0.4–0.6 *m*	2.23	0.44	1.33	0.25	1.68	0.39	0.78	0.12	**0.018**	0.114	0.998
	Soil 0.6–1.0 *m*	0.62	0.17	0.50	0.08	0.74	0.06	0.56	0.08	0.156	0.374	0.745
GF	Foliage	48.73	0.13	48.61	0.23	–	–	–	–	0.650	–	–
	Branches	46.70	0.31	45.99	0.30	–	–	–	–	0.153	–	–
	Bark	46.81	0.55	46.61	0.59	–	–	–	–	**0.044**	–	–
	Wood	47.28	0.12	47.44	0.16	–	–	–	–	0.374	–	–
	Understory	44.33	0.13	40.32	1.38	–	–	–	–	0.099	–	–
	Forest Floor	34.17	3.39	36.81	1.88	–	–	–	–	0.534	–	–
	Fine Roots	27.79	2.74	26.95	2.71	–	–	–	–	0.839	–	–
	Soil 0.0–0.2 *m*	6.71	1.42	5.53	0.34	–	–	–	–	0.462	–	–
	Soil 0.2–0.4 *m*	2.47	0.07	2.61	0.49	–	–	–	–	0.787	–	–
	Soil 0.4–0.6 *m*	1.55	0.21	1.70	0.49	–	–	–	–	0.790	–	–
	Soil 0.6–1.0 *m*	0.78	0.26	0.51	0.13	–	–	–	–	0.415	–	–

Table A4
Concentration (%) of calcium (Ca) of tree and ecosystem components for 16–18 year-old Douglas-fir (DF), western hemlock (WH), western redcedar (WRC), and grand fir (GF) stands growing under contrasting treatments of vegetation management on sites located in the central Coast Range (CR) and Cascade Foothills (CF) of western Oregon. SE is the standard error.

		CR Control		CR VM		CF Control		CF VM		P-value		
Species	**Tissue**	**%**	**SE**	**%**	**SE**	**%**	**SE**	**%**	**SE**	**Trt**	**Site**	**Site × Trt**
DF	Foliage	0.561	0.108	0.573	0.090	0.627	0.046	0.641	0.069	0.878	0.426	0.994
	Branches	0.352	0.076	0.344	0.073	0.293	0.031	0.285	0.067	0.638	0.532	0.752
	Bark	0.324	0.040	0.228	0.055	0.355	0.071	0.294	0.042	0.121	0.228	0.717
	Wood	0.086	0.047	0.036	0.001	0.045	0.006	0.036	0.000	0.232	0.402	0.409
	Understory	0.649	0.114	0.606	0.055	1.216	0.312	1.037	0.121	0.545	**0.016**	0.712
	Forest Floor	0.707	0.065	0.749	0.038	0.987	0.054	0.996	0.061	0.660	**0.003**	0.774
	Fine Roots	0.387	0.045	0.320	0.037	0.679	0.059	0.521	0.028	**0.024**	**<0.001**	0.322
	Soil 0.0–0.2 *m*	0.151	0.034	0.133	0.022	0.371	0.049	0.378	0.034	0.878	**<0.001**	0.748
	Soil 0.2–0.4 *m*	0.108	0.030	0.113	0.048	0.339	0.057	0.376	0.019	0.512	**<0.001**	0.606
	Soil 0.4–0.6 *m*	0.103	0.037	0.062	0.016	0.231	0.047	0.221	0.034	0.369	**0.038**	0.587
	Soil 0.6–1.0 *m*	0.048	0.013	0.041	0.008	0.183	0.054	0.141	0.049	0.336	0.118	0.479
WH	Foliage	0.577	0.120	0.761	0.092	–	–	–	–	0.295	–	–
	Branches	0.252	0.042	0.265	0.022	–	–	–	–	0.790	–	–
	Bark	0.347	0.027	0.439	0.022	–	–	–	–	**0.040**	–	–
	Wood	0.085	0.014	0.066	0.004	–	–	–	–	0.232	–	–
	Understory	0.803	0.068	0.747	0.056	–	–	–	–	0.565	–	–
	Forest Floor	0.759	0.059	0.749	0.061	–	–	–	–	0.905	–	–
	Fine Roots	0.451	0.023	0.367	0.048	–	–	–	–	0.166	–	–
	Soil 0.0–0.2 *m*	0.106	0.018	0.116	0.022	–	–	–	–	0.736	–	–
	Soil 0.2–0.4 *m*	0.080	0.034	0.076	0.011	–	–	–	–	0.927	–	–
	Soil 0.4–0.6 *m*	0.083	0.032	0.057	0.006	–	–	–	–	0.466	–	–
	Soil 0.6–1.0 *m*	0.034	0.002	0.040	0.003	–	–	–	–	0.184	–	–
WRC	Foliage	1.138	0.158	1.265	0.103	1.446	0.152	1.350	0.142	0.950	0.339	0.609
	Branches	0.563	0.095	0.666	0.074	0.774	0.121	0.493	0.031	0.337	0.846	0.052
	Bark	1.230	0.077	1.078	0.047	0.936	0.079	0.790	0.053	**0.042**	**0.001**	0.959
	Wood	0.125	0.003	0.210	0.082	0.124	0.003	0.107	0.006	0.369	0.194	0.251
	Understory	0.896	0.086	0.785	0.018	1.313	0.139	1.106	0.128	0.206	**0.011**	0.690
	Forest Floor	1.084	0.107	1.080	0.130	0.897	0.165	1.411	0.257	0.117	0.796	0.114
	Fine Roots	0.495	0.093	0.412	0.013	0.683	0.089	0.655	0.086	0.519	**0.027**	0.753
	Soil 0.0–0.2 *m*	0.169	0.063	0.147	0.037	0.418	0.052	0.317	0.023	0.212	**0.004**	0.398
	Soil 0.2–0.4 *m*	0.137	0.009	0.082	0.022	0.342	0.044	0.260	0.044	**0.007**	**0.002**	0.414
	Soil 0.4–0.6 *m*	0.110	0.022	0.045	0.002	0.270	0.010	0.238	0.023	**0.019**	**<0.001**	0.371
	Soil 0.6–1.0 *m*	0.055	0.005	0.042	0.006	0.181	0.040	0.250	0.105	0.683	**0.031**	0.550
GF	Foliage	1.254	0.192	1.156	0.075	–	–	–	–	0.836	–	–
	Branches	0.438	0.074	0.468	0.050	–	–	–	–	0.751	–	–
	Bark	0.869	0.128	0.562	0.021	–	–	–	–	0.055	–	–
	Wood	0.092	0.011	0.082	0.008	–	–	–	–	0.466	–	–
	Understory	0.743	0.175	0.915	0.015	–	–	–	–	0.399	–	–
	Forest Floor	1.408	0.322	1.792	0.120	–	–	–	–	0.350	–	–
	Fine Roots	0.531	0.039	0.404	0.068	–	–	–	–	0.190	–	–
	Soil 0.0–0.2 *m*	0.187	0.023	0.186	0.017	–	–	–	–	0.961	–	–
	Soil 0.2–0.4 *m*	0.108	0.017	0.110	0.037	–	–	–	–	0.950	–	–
	Soil 0.4–0.6 *m*	0.107	0.028	0.063	0.015	–	–	–	–	0.160	–	–
	Soil 0.6–1.0 *m*	0.082	0.031	0.060	0.015	–	–	–	–	0.302	–	–

Table A5
Concentration (%) of calcium (Cu) of tree and ecosystem components for 16–18 year-old Douglas-fir (DF), western hemlock (WH), western redcedar (WRC), and grand fir (GF) stands growing under contrasting treatments of vegetation management on sites located in the central Coast Range (CR) and Cascade Foothills (CF) of western Oregon. SE is the standard error.

Species	Tissue	CR Control %	SE	CR VM %	SE	CF Control %	SE	CF VM %	SE	P-value Trt	Site	Site × Trt
DF	Foliage	2.821	0.296	2.760	0.171	3.125	0.199	3.135	0.382	0.977	0.214	0.990
	Branches	4.097	0.348	3.679	0.157	3.321	0.242	3.380	0.312	0.497	0.119	0.383
	Bark	3.163	0.219	3.558	0.226	3.728	0.339	3.982	0.049	0.188	0.055	0.767
	Wood	0.980	0.193	0.668	0.124	1.623	0.451	1.974	0.359	0.965	0.016	0.289
	Understory	7.299	2.644	5.558	1.081	5.588	0.282	5.629	0.629	0.574	0.587	0.556
	Forest Floor	2.591	0.368	2.717	0.307	5.497	0.597	3.991	0.268	0.050	0.001	0.027
	Fine Roots	5.472	0.462	4.780	0.504	6.205	0.272	5.060	0.211	0.015	0.204	0.462
	Soil 0.0–0.2 *m*	21.488	1.366	23.100	2.299	34.138	2.300	36.947	1.454	0.239	<0.001	0.739
	Soil 0.2–0.4 *m*	23.435	1.899	22.904	1.560	39.889	3.648	44.601	4.543	0.110	<0.001	0.055
	Soil 0.4–0.6 *m*	25.346	2.176	25.383	1.879	40.184	4.020	48.353	5.205	0.034	<0.001	0.036
	Soil 0.6–1.0 *m*	26.786	1.575	25.605	1.904	32.147	3.515	52.624	2.422	0.001	<0.001	0.001
WH	Foliage	3.219	0.415	3.482	1.004	–	–	–	–	0.817	–	–
	Branches	5.036	0.225	4.516	0.343	–	–	–	–	0.098	–	–
	Bark	4.270	0.464	3.117	0.318	–	–	–	–	0.032	–	–
	Wood	1.374	0.228	1.672	0.102	–	–	–	–	0.181	–	–
	Understory	6.412	0.734	3.327	0.262	–	–	–	–	0.022	–	–
	Forest Floor	4.497	0.644	3.441	0.448	–	–	–	–	0.227	–	–
	Fine Roots	4.689	0.332	4.168	0.265	–	–	–	–	0.164	–	–
	Soil 0.0–0.2 *m*	23.383	0.642	22.839	2.147	–	–	–	–	0.764	–	–
	Soil 0.2–0.4 *m*	25.657	1.331	25.124	2.029	–	–	–	–	0.793	–	–
	Soil 0.4–0.6 *m*	25.295	0.936	28.228	1.313	–	–	–	–	0.143	–	–
	Soil 0.6–1.0 *m*	25.344	1.860	26.789	1.701	–	–	–	–	0.052	–	–
WRC	Foliage	3.766	0.401	3.107	0.207	4.580	0.893	3.672	0.650	0.013	0.036	0.679
	Branches	3.131	0.400	3.173	0.133	1.984	0.198	1.851	0.119	0.854	<0.001	0.723
	Bark	3.104	0.111	3.008	0.235	3.487	0.349	3.465	0.585	0.941	0.363	0.873
	Wood	1.309	0.224	1.121	0.117	1.515	0.303	1.137	0.131	0.207	0.531	0.447
	Understory	6.137	1.438	4.660	1.062	6.453	0.761	7.421	0.804	0.673	0.179	0.077
	Forest Floor	5.269	1.067	2.943	0.333	3.767	0.256	3.512	0.991	0.107	0.597	0.181
	Fine Roots	5.202	0.571	4.553	0.795	8.444	1.194	6.605	0.483	0.181	0.012	0.507
	Soil 0.0–0.2 *m*	25.250	0.545	25.630	0.749	37.249	1.868	37.493	1.642	0.754	<0.001	0.946
	Soil 0.2–0.4 *m*	28.743	1.705	27.367	0.770	43.444	2.803	42.652	2.547	0.658	<0.001	0.905
	Soil 0.4–0.6 *m*	29.174	1.398	29.736	1.692	47.158	3.378	46.073	2.921	0.927	<0.001	0.774
	Soil 0.6–1.0 *m*	28.440	0.316	30.504	2.314	47.089	4.222	39.943	7.768	0.643	0.025	0.407
GF	Foliage	3.604	0.251	3.561	0.386	–	–	–	–	0.929	–	–
	Branches	4.350	0.246	8.449	3.691	–	–	–	–	0.224	–	–
	Bark	4.917	0.619	3.371	0.556	–	–	–	–	0.113	–	–
	Wood	1.492	0.196	1.717	0.143	–	–	–	–	0.384	–	–
	Understory	5.797	1.227	5.459	0.006	–	–	–	–	0.797	–	–
	Forest Floor	3.588	0.204	3.166	0.345	–	–	–	–	0.101	–	–
	Fine Roots	5.211	0.727	4.452	0.550	–	–	–	–	0.445	–	–
	Soil 0.0–0.2 *m*	19.904	2.373	22.552	0.117	–	–	–	–	0.362	–	–
	Soil 0.2–0.4 *m*	22.744	1.796	25.057	0.925	–	–	–	–	0.361	–	–
	Soil 0.4–0.6 *m*	25.506	2.670	27.250	0.732	–	–	–	–	0.489	–	–
	Soil 0.6–1.0 *m*	25.516	3.262	28.778	0.993	–	–	–	–	0.316	–	–

Table A6
Concentration (%) of Iron (Fe) of tree and ecosystem components for 16–18 year-old Douglas-fir (DF), western hemlock (WH), western redcedar (WRC), and grand fir (GF) stands growing under contrasting treatments of vegetation management on sites located in the central Coast Range (CR) and Cascade Foothills (CF) of western Oregon. SE is the standard error.

		CR Control		CR VM		CF Control		CF VM		P-value		
Species	**Tissue**	**ppm**	**SE**	**ppm**	**SE**	**ppm**	**SE**	**ppm**	**SE**	**Trt**	**Site**	**Site × Trt**
DF	Foliage	40.374	3.729	49.468	4.865	52.809	2.079	68.790	11.367	0.079	**0.032**	0.608
	Branches	32.965	6.804	31.799	7.397	19.074	3.130	41.479	21.153	0.386	0.862	0.338
	Bark	32.919	2.797	33.206	4.116	54.570	10.560	60.521	8.608	0.675	**0.006**	0.703
	Wood	15.673	2.541	12.119	0.381	24.705	4.188	25.887	2.668	0.679	**0.002**	0.414
	Understory	746.5	321.0	1199.1	241.2	1016.8	787.2	439.7	99.0	0.874	0.865	0.212
	Forest Floor	1356	157	1244	131	1204	84	1321	206	0.986	0.809	0.465
	Fine Roots	1332	87	1313	68	1854	214	1697	66	0.493	**0.003**	0.589
	Soil 0.0–0.2 *m*	18,052	933	18,671	534	25,711	546	25,234	492	0.915	**<0.001**	0.417
	Soil 0.2–0.4 *m*	19,436	243	19,776	770	26,252	432	26,066	85	0.870	**<0.001**	0.578
	Soil 0.4–0.6 *m*	20,096	451	19,478	1125	26,735	478	26,931	123	0.745	**<0.001**	0.536
	Soil 0.6–1.0 *m*	19,962	957	19,936	769	26,681	1329	27,979	664	0.522	**<0.001**	0.505
WH	Foliage	42.439	6.768	67.957	29.388	–	–	–	–	0.430	–	–
	Branches	25.985	3.878	33.484	3.966	–	–	–	–	0.225	–	–
	Bark	38.260	12.915	54.005	11.879	–	–	–	–	0.378	–	–
	Wood	26.125	8.471	13.569	0.725	–	–	–	–	0.217	–	–
	Understory	691.6	195.1	1070.4	146.1	–	–	–	–	0.171	–	–
	Forest Floor	837	178	991	282	–	–	–	–	0.587	–	–
	Fine Roots	1365	251	1230	90	–	–	–	–	0.629	–	–
	Soil 0.0–0.2 *m*	19,842	228	19,509	764	–	–	–	–	0.636	–	–
	Soil 0.2–0.4 *m*	21,842	466	20,587	447	–	–	–	–	**0.046**	–	–
	Soil 0.4–0.6 *m*	21,574	433	21,462	233	–	–	–	–	0.829	–	–
	Soil 0.6–1.0 *m*	22,408	344	21,730	267	–	–	–	–	0.170	–	–
WRC	Foliage	55.945	2.035	49.319	3.265	108.640	35.892	95.675	33.281	0.483	0.515	0.929
	Branches	35.320	6.059	49.661	16.892	64.994	32.138	17.001	0.599	0.408	0.893	0.127
	Bark	41.827	3.792	59.508	21.698	67.886	12.104	56.334	7.116	0.796	0.515	0.300
	Wood	17.690	4.188	46.565	28.724	18.277	3.498	22.328	1.780	0.283	0.435	0.413
	Understory	710.9	161.8	1269.6	262.2	1488.4	799.3	436.7	99.0	0.628	0.956	0.134
	Forest Floor	1009	156	1276	151	1076	448	1179	255	0.534	0.958	0.779
	Fine Roots	1045	273	1207	233	1827	162	1923	73	0.459	**0.009**	0.843
	Soil 0.0–0.2 *m*	18,754	527	19,125	216	25,953	587	26,381	596	0.073	**<0.001**	0.878
	Soil 0.2–0.4 *m*	20,710	454	19,802	1025	26,331	415	26,317	336	0.344	**<0.001**	0.358
	Soil 0.4–0.6 *m*	20,918	241	21,072	308	27,077	489	26,862	307	0.895	**<0.001**	0.435
	Soil 0.6–1.0 *m*	22,655	1529	20,397	1158	27,408	407	26,421	1494	0.212	**0.001**	0.613
GF	Foliage	75.395	13.104	69.281	10.755	–	–	–	–	0.796	–	–
	Branches	42.971	9.619	33.885	6.139	–	–	–	–	0.456	–	–
	Bark	100.507	48.424	96.906	48.725	–	–	–	–	0.224	–	–
	Wood	12.196	1.599	26.540	4.913	–	–	–	–	**0.032**	–	–
	Understory	524.4	347.0	1514.9	66.2	–	–	–	–	0.075	–	–
	Forest Floor	1357	199	1061	109	–	–	–	–	0.263	–	–
	Fine Roots	1365	157	1404	83	–	–	–	–	0.670	–	–
	Soil 0.0–0.2 *m*	16,258	2412	19,209	300	–	–	–	–	0.292	–	–
	Soil 0.2–0.4 *m*	16,941	1953	20,432	386	–	–	–	–	0.154	–	–
	Soil 0.4–0.6 *m*	18,975	2910	20,353	364	–	–	–	–	0.643	–	–
	Soil 0.6–1.0 *m*	18,841	3190	21,689	327	–	–	–	–	0.451	–	–

Table A7
Concentration (%) of potassium (K) of tree and ecosystem components for 16–18 year-old Douglas-fir (DF), western hemlock (WH), western redcedar (WRC), and grand fir (GF) stands growing under contrasting treatments of vegetation management on sites located in the central Coast Range (CR) and Cascade Foothills (CF) of western Oregon. SE is the standard error.

		CR Control		CR VM		CF Control		CF VM		P-value		
Species	**Tissue**	**%**	**SE**	**%**	**SE**	**%**	**SE**	**%**	**SE**	**Trt**	**Site**	**Site × Trt**
DF	Foliage	0.580	0.042	0.446	0.026	0.750	0.056	0.654	0.069	**0.043**	**0.003**	0.720
	Branches	0.235	0.061	0.229	0.016	0.266	0.033	0.215	0.052	0.523	0.850	0.611
	Bark	0.230	0.013	0.283	0.034	0.200	0.012	0.175	0.027	0.576	0.052	0.065
	Wood	–	–	–	–	–	–	–	–	–	–	–
	Understory	1.465	0.652	0.770	0.368	1.702	0.233	1.528	0.412	0.345	0.310	0.565
	Forest Floor	0.155	0.025	0.117	0.014	0.251	0.024	0.179	0.016	**0.014**	**0.004**	0.326
	Fine Roots	0.208	0.026	0.199	0.044	0.091	0.010	0.075	0.012	0.645	**0.001**	0.906
	Soil 0.0–0.2 *m*	0.166	0.000	0.169	0.021	0.095	0.004	0.087	0.006	0.841	**<0.001**	0.647
	Soil 0.2–0.4 *m*	0.160	0.020	0.145	0.019	0.081	0.009	0.069	0.005	0.345	**<0.001**	0.900
	Soil 0.4–0.6 *m*	0.164	0.019	0.159	0.017	0.059	0.003	0.068	0.006	0.896	**<0.001**	0.581
	Soil 0.6–1.0 *m*	0.173	0.009	0.162	0.019	0.057	0.002	0.064	0.007	0.838	**<0.001**	0.383
WH	Foliage	0.620	0.062	0.478	0.036	–	–	–	–	0.094	–	–
	Branches	0.157	0.007	0.169	0.043	–	–	–	–	0.791	–	–
	Bark	0.333	0.045	0.232	0.032	–	–	–	–	0.113	–	–
	Wood	–	–	–	–	–	–	–	–	–	–	–
	Understory	1.175	0.401	0.840	0.182	–	–	–	–	0.476	–	–
	Forest Floor	0.210	0.048	0.148	0.024	–	–	–	–	0.295	–	–
	Fine Roots	0.174	0.027	0.144	0.030	–	–	–	–	**0.037**	–	–
	Soil 0.0–0.2 *m*	0.153	0.015	0.135	0.006	–	–	–	–	0.289	–	–
	Soil 0.2–0.4 *m*	0.146	0.012	0.138	0.007	–	–	–	–	0.585	–	–
	Soil 0.4–0.6 *m*	0.135	0.012	0.144	0.009	–	–	–	–	0.579	–	–
	Soil 0.6–1.0 *m*	0.124	0.012	0.146	0.014	–	–	–	–	0.286	–	–
WRC	Foliage	0.339	0.071	0.346	0.031	0.358	0.042	0.482	0.045	0.068	0.243	0.423
	Branches	0.133	0.027	0.116	0.036	0.191	0.026	0.145	0.023	0.212	0.608	0.488
	Bark	0.162	0.041	0.140	0.017	0.146	0.020	0.170	0.030	0.995	0.468	0.933
	Wood	–	–	–	–	–	–	–	–	–	–	–
	Understory	1.024	0.488	0.790	0.370	1.147	0.206	1.540	0.171	0.641	0.762	0.112
	Forest Floor	0.431	0.148	0.160	0.025	0.185	0.070	0.149	0.087	0.122	0.186	0.226
	Fine Roots	0.177	0.016	0.129	0.010	0.108	0.011	0.078	0.010	**0.009**	**0.001**	0.469
	Soil 0.0–0.2 *m*	0.176	0.011	0.180	0.022	0.127	0.019	0.094	0.006	0.364	**0.002**	0.265
	Soil 0.2–0.4 *m*	0.171	0.005	0.166	0.013	0.082	0.011	0.086	0.011	0.967	**<0.001**	0.380
	Soil 0.4–0.6 *m*	0.164	0.005	0.172	0.020	0.074	0.013	0.078	0.008	0.602	**<0.001**	0.872
	Soil 0.6–1.0 *m*	0.182	0.036	0.201	0.036	0.079	0.018	0.061	0.010	0.990	**0.001**	0.371
GF	Foliage	0.433	0.034	0.586	0.072	–	–	–	–	0.064	–	–
	Branches	0.277	0.048	0.469	0.063	–	–	–	–	0.074	–	–
	Bark	0.371	0.071	0.240	0.032	–	–	–	–	0.140	–	–
	Wood	–	–	–	–	–	–	–	–	–	–	–
	Understory	1.263	0.254	0.627	0.063	–	–	–	–	0.082	–	–
	Forest Floor	0.153	0.021	0.111	0.017	–	–	–	–	0.068	–	–
	Fine Roots	0.130	0.015	0.142	0.018	–	–	–	–	0.438	–	–
	Soil 0.0–0.2 *m*	0.178	0.023	0.174	0.014	–	–	–	–	0.892	–	–
	Soil 0.2–0.4 *m*	0.141	0.009	0.159	0.010	–	–	–	–	0.241	–	–
	Soil 0.4–0.6 *m*	0.141	0.004	0.166	0.022	–	–	–	–	0.337	–	–
	Soil 0.6–1.0 *m*	0.157	0.017	0.196	0.037	–	–	–	–	0.396	–	–

Table A8
Concentration (%) of magnesium (Mg) of tree and ecosystem components for 16–18 year-old Douglas-fir (DF), western hemlock (WH), western redcedar (WRC), and grand fir (GF) stands growing under contrasting treatments of vegetation management on sites located in the central Coast Range (CR) and Cascade Foothills (CF) of western Oregon. SE is the standard error.

		CR Control		CR VM		CF Control		CF VM		P-value		
Species	**Tissue**	**%**	**SE**	**%**	**SE**	**%**	**SE**	**%**	**SE**	**Trt**	**Site**	**Site × Trt**
DF	Foliage	0.108	0.016	0.100	0.008	0.079	0.003	0.103	0.007	0.311	0.184	0.161
	Branches	0.052	0.015	0.039	0.004	0.032	0.003	0.035	0.003	0.305	0.393	0.168
	Bark	0.046	0.004	0.038	0.004	0.029	0.003	0.032	0.002	0.502	**0.004**	0.143
	Wood	0.011	0.002	0.010	0.001	0.009	0.001	0.007	0.000	0.196	0.144	0.594
	Understory	0.244	0.046	0.188	0.037	0.289	0.026	0.321	0.031	0.697	0.166	0.180
	Forest Floor	0.121	0.004	0.102	0.002	0.146	0.005	0.096	0.010	**<0.001**	0.051	**0.016**
	Fine Roots	0.083	0.002	0.070	0.004	0.064	0.003	0.053	0.001	**0.001**	**<0.001**	0.819
	Soil 0.0–0.2 *m*	0.287	0.009	0.287	0.013	0.146	0.009	0.157	0.015	0.650	**<0.001**	0.641
	Soil 0.2–0.4 *m*	0.296	0.009	0.297	0.007	0.153	0.010	0.172	0.010	0.290	**<0.001**	0.351
	Soil 0.4–0.6 *m*	0.304	0.012	0.303	0.008	0.143	0.011	0.155	0.019	0.505	**<0.001**	0.454
	Soil 0.6–1.0 *m*	0.315	0.013	0.306	0.015	0.142	0.011	0.145	0.026	0.866	**<0.001**	0.748
WH	Foliage	0.130	0.013	0.097	0.005	–	–	–	–	**0.042**	–	–
	Branches	0.035	0.003	0.031	0.005	–	–	–	–	0.258	–	–
	Bark	0.050	0.006	0.035	0.000	–	–	–	–	**0.048**	–	–
	Wood	0.017	0.002	0.013	0.000	–	–	–	–	0.125	–	–
	Understory	0.343	0.076	0.228	0.037	–	–	–	–	0.226	–	–
	Forest Floor	0.168	0.019	0.123	0.018	–	–	–	–	0.129	–	–
	Fine Roots	0.100	0.006	0.088	0.008	–	–	–	–	0.297	–	–
	Soil 0.0–0.2 *m*	0.257	0.006	0.258	0.006	–	–	–	–	0.816	–	–
	Soil 0.2–0.4 *m*	0.267	0.007	0.274	0.010	–	–	–	–	0.567	–	–
	Soil 0.4–0.6 *m*	0.272	0.011	0.278	0.015	–	–	–	–	0.743	–	–
	Soil 0.6–1.0 *m*	0.235	0.030	0.286	0.012	–	–	–	–	0.161	–	–
WRC	Foliage	0.138	0.016	0.108	0.015	0.092	0.009	0.083	0.015	0.149	0.063	0.417
	Branches	0.037	0.005	0.040	0.004	0.039	0.005	0.026	0.004	0.316	0.230	0.101
	Bark	0.064	0.006	0.049	0.005	0.049	0.004	0.046	0.004	0.079	0.065	0.223
	Wood	0.017	0.001	0.021	0.004	0.016	0.001	0.015	0.001	0.532	0.182	0.261
	Understory	0.242	0.065	0.264	0.092	0.274	0.074	0.329	0.021	0.486	0.614	0.764
	Forest Floor	0.232	0.033	0.111	0.014	0.098	0.018	0.089	0.030	**0.030**	**0.019**	0.054
	Fine Roots	0.091	0.017	0.095	0.010	0.071	0.007	0.067	0.008	0.997	**0.045**	0.741
	Soil 0.0–0.2 *m*	0.289	0.012	0.306	0.020	0.156	0.011	0.149	0.006	0.666	**<0.001**	0.344
	Soil 0.2–0.4 *m*	0.298	0.003	0.314	0.015	0.160	0.010	0.161	0.012	0.364	**<0.001**	0.456
	Soil 0.4–0.6 *m*	0.295	0.009	0.324	0.016	0.160	0.019	0.168	0.012	0.271	**<0.001**	0.526
	Soil 0.6–1.0 *m*	0.276	0.014	0.329	0.030	0.147	0.027	0.171	0.024	0.162	**0.000**	0.585
GF	Foliage	0.137	0.019	0.124	0.015	–	–	–	–	0.306	–	–
	Branches	0.042	0.003	0.065	0.019	–	–	–	–	0.273	–	–
	Bark	0.062	0.007	0.048	0.004	–	–	–	–	0.151	–	–
	Wood	0.016	0.002	0.016	0.001	–	–	–	–	0.850	–	–
	Understory	0.326	0.062	0.203	0.027	–	–	–	–	0.143	–	–
	Forest Floor	0.129	0.005	0.116	0.004	–	–	–	–	0.112	–	–
	Fine Roots	0.109	0.005	0.101	0.010	–	–	–	–	0.476	–	–
	Soil 0.0–0.2 *m*	0.262	0.016	0.306	0.010	–	–	–	–	0.134	–	–
	Soil 0.2–0.4 *m*	0.290	0.004	0.309	0.003	–	–	–	–	0.057	–	–
	Soil 0.4–0.6 *m*	0.289	0.018	0.318	0.009	–	–	–	–	0.211	–	–
	Soil 0.6–1.0 *m*	0.295	0.025	0.321	0.009	–	–	–	–	0.378	–	–

Table A9
Concentration (ppm) of manganese (Mn) of tree and ecosystem components for 16–18 year-old Douglas-fir (DF), western hemlock (WH), western redcedar (WRC), and grand fir (GF) stands growing under contrasting treatments of vegetation management on sites located in the central Coast Range (CR) and Cascade Foothills (CF) of western Oregon. SE is the standard error.

		CR Control		CR VM		CF Control		CF VM		P-value		
Species	Tissue	ppm	SE	ppm	SE	ppm	SE	ppm	SE	Trt	Site	Site × Trt
DF	Foliage	271.57	61.57	345.00	67.39	432.70	38.33	426.92	27.68	0.539	**0.039**	0.460
	Branches	129.63	71.13	106.28	28.22	121.68	7.84	120.08	8.28	0.394	0.483	0.422
	Bark	98.11	18.56	90.84	22.47	191.67	47.24	138.88	14.17	0.259	**0.022**	0.337
	Wood	11.54	1.83	14.20	2.19	33.35	5.44	23.11	4.39	0.335	**0.002**	0.113
	Understory	758.15	473.96	472.71	140.72	654.28	75.68	767.36	153.95	0.702	0.979	0.386
	Forest Floor	392.41	38.08	496.48	47.81	771.35	56.15	892.64	77.42	0.070	**<0.001**	0.882
	Fine Roots	178.05	29.82	203.47	19.50	632.16	106.62	516.00	40.72	0.463	**<0.001**	0.259
	Soil 0.0–0.2 *m*	1080.93	150.39	1060.01	196.26	3232.82	184.29	3249.19	473.06	0.994	**<0.001**	0.948
	Soil 0.2–0.4 *m*	870.24	175.56	804.17	165.54	2366.88	384.96	3112.45	699.82	0.426	**0.002**	0.346
	Soil 0.4–0.6 *m*	723.95	155.04	654.69	114.49	811.16	192.02	1887.14	343.45	**0.033**	**0.046**	**0.020**
	Soil 0.6–1.0 *m*	225.84	28.98	395.10	97.23	966.85	461.01	1064.67	246.35	0.625	**0.021**	0.896
WH	Foliage	799.00	168.96	1073.50	242.65	–	–	–	–	0.389	–	–
	Branches	189.01	25.44	247.77	28.19	–	–	–	–	0.152	–	–
	Bark	249.82	28.86	286.52	24.11	–	–	–	–	0.191	–	–
	Wood	51.26	27.15	93.46	7.96	–	–	–	–	0.176	–	–
	Understory	501.81	80.44	463.83	65.70	–	–	–	–	0.727	–	–
	Forest Floor	551.48	69.67	1115.21	217.07	–	–	–	–	**0.045**	–	–
	Fine Roots	235.67	20.23	209.59	9.72	–	–	–	–	0.230	–	–
	Soil 0.0–0.2 *m*	1062.13	167.14	1039.16	56.49	–	–	–	–	0.888	–	–
	Soil 0.2–0.4 *m*	923.23	201.51	940.08	92.12	–	–	–	–	0.942	–	–
	Soil 0.4–0.6 *m*	828.76	166.23	737.71	147.34	–	–	–	–	0.696	–	–
	Soil 0.6–1.0 *m*	524.78	135.60	301.76	38.43	–	–	–	–	0.165	–	–
WRC	Foliage	160.70	16.86	164.77	22.53	202.88	45.27	180.77	28.59	0.771	0.355	0.673
	Branches	37.94	5.15	45.61	12.22	54.78	8.18	32.66	1.73	0.425	0.623	0.113
	Bark	64.10	10.46	56.80	13.90	64.91	21.09	58.20	7.81	0.520	0.772	0.966
	Wood	11.51	2.55	5.12	1.29	9.01	1.79	7.44	0.70	0.128	0.810	0.297
	Understory	232.24	27.57	292.00	41.97	685.59	121.57	761.36	168.16	0.369	**0.013**	0.912
	Forest Floor	260.36	64.68	258.04	87.90	638.73	300.78	543.66	113.71	0.781	0.201	0.792
	Fine Roots	196.30	36.94	287.89	54.12	706.62	71.83	782.38	18.06	0.137	**<0.001**	0.881
	Soil 0.0–0.2 *m*	1393.03	206.25	1625.14	256.60	4086.64	682.47	4759.76	421.65	0.175	**0.000**	0.479
	Soil 0.2–0.4 *m*	1616.05	3.18	1409.30	245.83	3546.61	625.99	3806.35	505.71	0.924	**0.003**	0.416
	Soil 0.4–0.6 *m*	1298.11	204.81	1076.09	289.72	2603.45	397.55	1762.51	529.58	0.264	0.085	0.493
	Soil 0.6–1.0 *m*	525.45	147.26	554.84	230.62	1166.43	211.36	931.87	181.01	0.620	**0.029**	0.525
GF	Foliage	554.18	72.75	544.60	117.14	–	–	–	–	0.947	–	–
	Branches	121.21	15.72	151.75	56.15	–	–	–	–	0.619	–	–
	Bark	250.71	81.15	237.25	44.46	–	–	–	–	0.526	–	–
	Wood	38.85	8.02	31.82	8.36	–	–	–	–	0.478	–	–
	Understory	589.42	295.82	380.89	2.29	–	–	–	–	0.520	–	–
	Forest Floor	579.36	28.53	793.76	88.66	–	–	–	–	0.088	–	–
	Fine Roots	258.02	30.46	268.60	21.84	–	–	–	–	0.792	–	–
	Soil 0.0–0.2 *m*	1085.16	125.94	1802.15	131.35	–	–	–	–	**0.017**	–	–
	Soil 0.2–0.4 *m*	1047.57	145.00	1274.89	286.61	–	–	–	–	0.518	–	–
	Soil 0.4–0.6 *m*	757.21	230.04	1117.80	266.10	–	–	–	–	0.363	–	–
	Soil 0.6–1.0 *m*	437.78	201.84	449.65	143.25	–	–	–	–	0.964	–	–

Table A10
Concentration (%) of nitrogen (N) of tree and ecosystem components for 16–18 year-old Douglas-fir (DF), western hemlock (WH), western redcedar (WRC), and grand fir (GF) stands growing under contrasting treatments of vegetation management on sites located in the central Coast Range (CR) and Cascade Foothills (CF) of western Oregon. SE is the standard error.

		CR Control		CR VM		CF Control		CF VM		P-value		
Species	**Tissue**	**%**	**SE**	**%**	**SE**	**%**	**SE**	**%**	**SE**	**Trt**	**Site**	**Site × Trt**
DF	Foliage	1.174	0.044	1.348	0.267	1.232	0.061	1.255	0.028	0.495	0.901	0.598
	Branches	0.336	0.041	0.313	0.018	0.222	0.019	0.223	0.032	0.708	**0.004**	0.696
	Bark	0.338	0.044	0.313	0.042	0.256	0.017	0.270	0.036	0.874	0.109	0.594
	Wood	0.043	0.005	0.042	0.007	0.134	0.024	0.091	0.025	0.273	**0.007**	0.273
	Understory	1.344	0.378	1.034	0.034	1.378	0.134	1.638	0.091	0.902	0.181	0.181
	Forest Floor	0.938	0.201	1.080	0.074	0.968	0.025	0.958	0.078	0.571	0.719	0.511
	Fine Roots	0.647	0.027	0.611	0.066	0.580	0.054	0.525	0.017	0.291	0.114	0.824
	Soil 0.0–0.2 *m*	0.239	0.007	0.249	0.050	0.263	0.026	0.249	0.022	0.943	0.703	0.709
	Soil 0.2–0.4 *m*	0.162	0.023	0.113	0.004	0.179	0.027	0.206	0.026	0.547	**0.016**	0.061
	Soil 0.4–0.6 *m*	0.137	0.022	0.069	0.016	0.084	0.010	0.115	0.008	0.161	0.602	**0.004**
	Soil 0.6–1.0 *m*	0.046	0.003	0.061	0.004	0.048	0.008	0.066	0.009	**0.011**	0.144	0.791
WH	Foliage	1.065	0.024	1.002	0.059	–	–	–	–	0.237	–	–
	Branches	0.270	0.026	0.252	0.025	–	–	–	–	0.622	–	–
	Bark	0.283	0.049	0.320	0.020	–	–	–	–	0.506	–	–
	Wood	0.076	0.007	0.069	0.005	–	–	–	–	0.412	–	–
	Understory	1.625	0.219	1.319	0.074	–	–	–	–	0.275	–	–
	Forest Floor	1.125	0.027	0.680	0.028	–	–	–	–	**<0.001**	–	–
	Fine Roots	0.538	0.053	0.506	0.014	–	–	–	–	0.592	–	–
	Soil 0.0–0.2 *m*	0.197	0.015	0.215	0.019	–	–	–	–	0.378	–	–
	Soil 0.2–0.4 *m*	0.148	0.036	0.156	0.013	–	–	–	–	0.817	–	–
	Soil 0.4–0.6 *m*	0.084	0.010	0.127	0.030	–	–	–	–	0.224	–	–
	Soil 0.6–1.0 *m*	0.059	0.006	0.053	0.006	–	–	–	–	0.502	–	–
WRC	Foliage	0.982	0.059	1.137	0.218	1.037	0.213	0.757	0.070	0.700	0.327	0.196
	Branches	0.262	0.046	0.264	0.033	0.223	0.023	0.117	0.015	0.120	**0.012**	0.111
	Bark	0.234	0.019	0.221	0.004	0.304	0.021	0.291	0.041	0.618	**0.017**	0.995
	Wood	0.114	0.013	0.097	0.020	0.390	0.050	0.350	0.096	0.345	**0.006**	0.570
	Understory	1.600	0.367	1.243	0.199	1.181	0.261	1.502	0.081	0.926	0.712	0.115
	Forest Floor	1.227	0.217	0.690	0.065	0.638	0.077	0.635	0.109	0.054	**0.026**	0.056
	Fine Roots	0.589	0.078	0.555	0.065	0.545	0.026	0.530	0.011	0.597	0.466	0.833
	Soil 0.0–0.2 *m*	0.299	0.029	0.223	0.019	0.240	0.022	0.244	0.010	0.107	0.359	0.077
	Soil 0.2–0.4 *m*	0.196	0.038	0.155	0.014	0.198	0.033	0.162	0.027	**0.041**	0.362	0.851
	Soil 0.4–0.6 *m*	0.140	0.024	0.089	0.016	0.128	0.027	0.078	0.006	**0.034**	0.580	0.998
	Soil 0.6–1.0 *m*	0.063	0.012	0.051	0.001	0.078	0.010	0.053	0.009	0.070	0.284	0.436
GF	Foliage	1.150	0.085	1.072	0.047	–	–	–	–	0.525	–	–
	Branches	0.281	0.045	0.476	0.170	–	–	–	–	0.312	–	–
	Bark	0.408	0.045	0.288	0.047	–	–	–	–	0.116	–	–
	Wood	0.096	0.010	0.086	0.020	–	–	–	–	0.708	–	–
	Understory	1.307	0.285	1.323	0.107	–	–	–	–	0.959	–	–
	Forest Floor	1.033	0.154	0.977	0.201	–	–	–	–	0.834	–	–
	Fine Roots	0.637	0.119	0.557	0.040	–	–	–	–	0.560	–	–
	Soil 0.0–0.2 *m*	0.322	0.064	0.262	0.011	–	–	–	–	0.411	–	–
	Soil 0.2–0.4 *m*	0.156	0.004	0.167	0.032	–	–	–	–	0.753	–	–
	Soil 0.4–0.6 *m*	0.105	0.010	0.107	0.026	–	–	–	–	0.965	–	–
	Soil 0.6–1.0 *m*	0.067	0.014	0.050	0.006	–	–	–	–	0.315	–	–

Table A11
Concentration (ppm) of sodium (Na) of tree and ecosystem components for 16–18 year-old Douglas-fir (DF), western hemlock (WH), western redcedar (WRC), and grand fir (GF) stands growing under contrasting treatments of vegetation management on sites located in the central Coast Range (CR) and Cascade Foothills (CF) of western Oregon. SE is the standard error.

		CR Control		CR VM		CF Control		CF VM		P-value		
Species	**Tissue**	**ppm**	**SE**	**ppm**	**SE**	**ppm**	**SE**	**ppm**	**SE**	**Trt**	**Site**	**Site × Trt**
DF	Foliage	148.58	25.34	229.92	41.50	94.07	12.77	70.10	3.90	0.277	**0.001**	0.059
	Branches	47.097	20.326	33.214	4.105	2.848	3.269	6.462	7.574	0.619	**0.018**	0.417
	Bark	252.50	122.42	102.55	3.745	28.500	4.201	41.981	8.322	0.288	0.073	0.212
	Wood	–	–	–	–	–	–	–	–	–	–	–
	Understory	205.89	48.98	171.86	25.79	177.92	30.71	148.38	34.07	0.309	0.460	0.941
	Forest Floor	177.49	13.68	160.98	8.77	133.90	1.00	128.11	12.63	0.193	**0.005**	0.511
	Fine Roots	157.85	28.11	139.01	8.50	92.85	13.78	80.67	7.66	0.232	**0.005**	0.786
	Soil 0.0–0.2 *m*	173.16	14.92	186.22	5.97	122.03	2.45	124.80	3.52	0.360	**<0.001**	0.548
	Soil 0.2–0.4 *m*	171.23	8.21	173.98	4.29	174.77	17.92	185.24	21.00	0.544	0.200	0.720
	Soil 0.4–0.6 *m*	217.99	12.33	255.96	15.92	137.91	3.83	135.33	9.93	0.055	**<0.001**	**0.034**
	Soil 0.6–1.0 *m*	161.13	6.46	174.59	5.52	123.29	7.92	116.91	6.87	0.469	**<0.001**	0.066
WH	Foliage	117.29	10.84	142.83	36.38	–	–	–	–	0.526	–	–
	Branches	1.778	4.232	6.563	2.151	–	–	–	–	0.165	–	–
	Bark	89.351	21.525	76.812	8.700	–	–	–	–	0.610	–	–
	Wood	–	–	–	–	–	–	–	–	–	–	–
	Understory	246.05	42.27	191.50	31.67	–	–	–	–	0.341	–	–
	Forest Floor	163.11	11.97	160.60	3.07	–	–	–	–	0.845	–	–
	Fine Roots	119.53	8.76	130.86	6.55	–	–	–	–	0.211	–	–
	Soil 0.0–0.2 *m*	153.37	3.94	158.00	7.24	–	–	–	–	0.595	–	–
	Soil 0.2–0.4 *m*	187.92	9.38	204.82	15.36	–	–	–	–	0.384	–	–
	Soil 0.4–0.6 *m*	188.64	9.19	189.55	15.14	–	–	–	–	0.954	–	–
	Soil 0.6–1.0 *m*	149.90	1.42	149.69	9.37	–	–	–	–	0.983	–	–
WRC	Foliage	130.18	36.39	96.33	5.04	66.37	29.55	66.15	9.66	0.409	0.122	0.416
	Branches	14.398	14.133	11.174	2.879	2.072	6.913	−7.412	2.992	0.450	0.082	0.707
	Bark	63.242	6.253	55.987	5.957	22.849	4.542	20.074	5.938	0.397	**<0.001**	0.702
	Wood	–	–	–	–	–	–	–	–	–	–	–
	Understory	164.66	35.07	237.94	68.48	171.04	46.74	179.00	55.39	0.247	0.111	0.338
	Forest Floor	203.49	19.58	164.50	3.94	94.85	8.27	101.09	8.60	0.164	**<0.001**	0.074
	Fine Roots	180.45	58.79	132.43	4.16	131.37	31.66	78.64	7.98	0.126	0.193	0.937
	Soil 0.0–0.2 *m*	156.19	19.24	158.06	7.61	132.26	9.62	136.84	9.04	0.786	0.116	0.909
	Soil 0.2–0.4 *m*	229.57	16.06	212.81	22.44	189.91	12.14	235.59	11.64	0.365	0.592	0.068
	Soil 0.4–0.6 *m*	190.92	12.75	169.88	6.10	133.48	5.52	135.68	9.11	0.301	**<0.001**	0.209
	Soil 0.6–1.0 *m*	180.45	9.67	188.02	7.09	116.35	8.89	119.86	6.11	0.510	**<0.001**	0.808
GF	Foliage	67.127	15.166	72.742	10.920	–	–	–	–	0.774	–	–
	Branches	30.592	17.391	36.721	9.497	–	–	–	–	0.665	–	–
	Bark	62.789	6.010	50.629	7.701	–	–	–	–	0.083	–	–
	Wood	–	–	–	–	–	–	–	–	–	–	–
	Understory	248.70	21.53	222.58	1.61	–	–	–	–	0.337	–	–
	Forest Floor	135.31	4.48	140.73	8.22	–	–	–	–	0.302	–	–
	Fine Roots	122.17	9.84	158.62	27.13	–	–	–	–	0.268	–	–
	Soil 0.0–0.2 *m*	166.06	10.84	196.64	1.72	–	–	–	–	**0.050**	–	–
	Soil 0.2–0.4 *m*	206.18	4.78	212.21	22.39	–	–	–	–	0.812	–	–
	Soil 0.4–0.6 *m*	185.03	1.59	188.50	8.36	–	–	–	–	0.675	–	–
	Soil 0.6–1.0 *m*	178.57	16.87	159.85	21.69	–	–	–	–	0.353	–	–

Table A12
Concentration (%) of phosphorus (P) of tree and ecosystem components for 16–18 year-old Douglas-fir (DF), western hemlock (WH), western redcedar (WRC), and grand fir (GF) stands growing under contrasting treatments of vegetation management on sites locate d in the central Coast Range (CR) and Cascade Foothills (CF) of western Oregon. SE is the standard error.

		CR Control		CR VM		CF Control		CF VM		P-value		
Species	**Tissue**	**%**	**SE**	**%**	**SE**	**%**	**SE**	**%**	**SE**	**Trt**	**Site**	**Site × Trt**
DF	Foliage	0.163	0.018	0.169	0.019	0.213	0.005	0.193	0.023	0.664	0.084	0.462
	Branches	0.060	0.014	0.056	0.007	0.065	0.009	0.061	0.010	0.610	0.484	0.942
	Bark	0.059	0.005	0.059	0.006	0.055	0.002	0.053	0.003	0.780	0.417	0.927
	Wood	0.004	0.000	0.003	0.000	0.007	0.002	0.004	0.001	0.155	0.092	0.189
	Understory	0.146	0.046	0.105	0.012	0.207	0.027	0.254	0.034	0.895	**0.008**	0.088
	Forest Floor	0.087	0.009	0.089	0.006	0.093	0.008	0.096	0.006	0.730	0.371	0.991
	Fine Roots	0.078	0.004	0.080	0.012	0.068	0.002	0.081	0.009	0.242	0.334	0.378
	Soil 0.0–0.2 *m*	0.526	0.028	0.555	0.041	1.018	0.078	0.954	0.054	0.752	**<0.001**	0.404
	Soil 0.2–0.4 *m*	0.561	0.120	0.380	0.024	0.879	0.086	0.877	0.080	0.276	**0.001**	0.285
	Soil 0.4–0.6 *m*	0.504	0.077	0.349	0.026	0.662	0.058	0.687	0.054	0.273	**0.001**	0.138
	Soil 0.6–1.0 *m*	0.273	0.028	0.334	0.028	0.736	0.193	0.647	0.048	0.892	**0.002**	0.475
WH	Foliage	0.280	0.044	0.230	0.031	–	–	–	–	0.397	–	–
	Branches	0.043	0.004	0.044	0.005	–	–	–	–	0.875	–	–
	Bark	0.095	0.009	0.077	0.005	–	–	–	–	0.127	–	–
	Wood	0.010	0.003	0.010	0.002	–	–	–	–	0.973	–	–
	Understory	0.197	0.044	0.157	0.005	–	–	–	–	0.405	–	–
	Forest Floor	0.105	0.004	0.109	0.005	–	–	–	–	0.413	–	–
	Fine Roots	0.086	0.006	0.083	0.012	–	–	–	–	0.695	–	–
	Soil 0.0–0.2 *m*	0.708	0.154	0.674	0.074	–	–	–	–	0.814	–	–
	Soil 0.2–0.4 *m*	0.637	0.174	0.617	0.103	–	–	–	–	0.921	–	–
	Soil 0.4–0.6 *m*	0.541	0.083	0.505	0.061	–	–	–	–	0.710	–	–
	Soil 0.6–1.0 *m*	0.362	0.071	0.332	0.039	–	–	–	–	0.408	–	–
WRC	Foliage	0.127	0.009	0.113	0.007	0.113	0.012	0.109	0.015	0.440	0.441	0.650
	Branches	0.031	0.006	0.039	0.004	0.044	0.005	0.042	0.007	0.700	0.361	0.404
	Bark	0.053	0.007	0.039	0.002	0.052	0.002	0.050	0.006	0.140	0.319	0.228
	Wood	0.005	0.000	0.006	0.001	0.007	0.001	0.006	0.001	0.694	0.133	0.250
	Understory	0.164	0.041	0.168	0.045	0.176	0.040	0.246	0.030	0.357	0.344	0.403
	Forest Floor	0.100	0.018	0.090	0.021	0.064	0.012	0.064	0.021	0.713	0.060	0.726
	Fine Roots	0.082	0.003	0.078	0.013	0.064	0.003	0.081	0.005	0.371	0.310	0.162
	Soil 0.0–0.2 *m*	0.763	0.084	0.826	0.076	1.083	0.161	1.150	0.180	0.438	**0.005**	0.981
	Soil 0.2–0.4 *m*	0.642	0.079	0.602	0.056	0.805	0.102	0.869	0.151	0.838	**0.009**	0.404
	Soil 0.4–0.6 *m*	0.560	0.008	0.484	0.030	0.683	0.111	0.575	0.103	0.112	**0.018**	0.749
	Soil 0.6–1.0 *m*	0.400	0.018	0.364	0.032	0.548	0.071	0.536	0.156	0.819	0.202	0.909
GF	Foliage	0.136	0.008	0.155	0.016	–	–	–	–	0.348	–	–
	Branches	0.064	0.009	0.112	0.025	–	–	–	–	0.122	–	–
	Bark	0.078	0.010	0.052	0.006	–	–	–	–	0.073	–	–
	Wood	0.006	0.000	0.007	0.002	–	–	–	–	0.547	–	–
	Understory	0.175	0.053	0.144	0.005	–	–	–	–	0.594	–	–
	Forest Floor	0.098	0.012	0.111	0.011	–	–	–	–	0.468	–	–
	Fine Roots	0.098	0.008	0.111	0.020	–	–	–	–	0.586	–	–
	Soil 0.0–0.2 *m*	0.732	0.174	0.923	0.166	–	–	–	–	0.471	–	–
	Soil 0.2–0.4 *m*	0.464	0.057	0.649	0.157	–	–	–	–	0.331	–	–
	Soil 0.4–0.6 *m*	0.481	0.148	0.498	0.091	–	–	–	–	0.925	–	–
	Soil 0.6–1.0 *m*	0.382	0.161	0.365	0.006	–	–	–	–	0.923	–	–

Table A13
Concentration (%) of Sulfur (S) of tree and ecosystem components for 16–18 year-old Douglas-fir (DF), western hemlock (WH), western redcedar (WRC), and grand fir (GF) stands growing under contrasting treatments of vegetation management on sites located in the central Coast Range (CR) and Cascade Foothills (CF) of western Oregon. SE is the standard error.

		CR Control		CR VM		CF Control		CF VM		P-value		
Species	**Tissue**	**%**	**SE**	**%**	**SE**	**%**	**SE**	**%**	**SE**	**Trt**	**Site**	**Site × Trt**
DF	Foliage	0.121	0.006	0.154	0.039	0.115	0.004	0.111	0.002	0.463	0.229	0.367
	Branches	0.065	0.005	0.061	0.004	0.049	0.002	0.052	0.003	0.244	**0.006**	**0.024**
	Bark	0.065	0.011	0.051	0.002	0.049	0.003	0.049	0.002	0.291	0.188	0.308
	Wood	0.032	0.001	0.034	0.003	0.030	0.000	0.033	0.001	0.244	0.509	0.790
	Understory	0.157	0.029	0.113	0.004	0.147	0.012	0.168	0.017	0.554	0.279	0.099
	Forest Floor	0.106	0.012	0.112	0.007	0.114	0.006	0.113	0.002	0.592	0.994	0.494
	Fine Roots	0.079	0.005	0.080	0.001	0.071	0.005	0.075	0.002	0.524	0.103	0.661
WH	Foliage	0.110	0.018	0.092	0.019	–	–	–	–	0.481	–	–
	Branches	0.052	0.003	0.050	0.003	–	–	–	–	0.370	–	–
	Bark	0.055	0.004	0.057	0.006	–	–	–	–	0.529	–	–
	Wood	0.032	0.000	0.032	0.001	–	–	–	–	0.878	–	–
	Understory	0.160	0.015	0.172	0.006	–	–	–	–	0.452	–	–
	Forest Floor	0.104	0.006	0.107	0.006	–	–	–	–	0.784	–	–
	Fine Roots	0.075	0.004	0.068	0.002	–	–	–	–	0.234	–	–
WRC	Foliage	0.077	0.011	0.058	0.001	0.084	0.003	0.078	0.003	0.071	0.071	0.399
	Branches	0.048	0.004	0.050	0.001	0.045	0.002	0.036	0.003	0.301	**0.011**	0.081
	Bark	0.063	0.010	0.055	0.004	0.048	0.000	0.047	0.001	0.429	**0.012**	0.449
	Wood	0.035	0.001	0.036	0.002	0.036	0.001	0.035	0.002	0.663	0.680	0.119
	Understory	0.148	0.014	0.150	0.016	0.121	0.012	0.122	0.003	0.886	**0.026**	0.957
	Forest Floor	0.116	0.017	0.100	0.015	0.080	0.005	0.074	0.005	0.302	**0.027**	0.648
	Fine Roots	0.079	0.005	0.080	0.005	0.074	0.003	0.076	0.002	0.524	0.103	0.661
GF	Foliage	0.102	0.015	0.090	0.011	–	–	–	–	0.900	–	–
	Branches	0.053	0.003	0.070	0.008	–	–	–	–	0.113	–	–
	Bark	0.062	0.002	0.053	0.002	–	–	–	–	**0.019**	–	–
	Wood	0.033	0.002	0.034	0.003	–	–	–	–	0.873	–	–
	Understory	0.187	0.019	0.150	0.005	–	–	–	–	0.134	–	–
	Forest Floor	0.101	0.007	0.099	0.011	–	–	–	–	0.885	–	–
	Fine Roots	0.084	0.004	0.074	0.004	–	–	–	–	11.520	–	–

Table A14
Concentration (ppm) of zinc (Zn) of tree and ecosystem components for 16–18 year-old Douglas-fir (DF), western hemlock (WH), western redcedar (WRC), and grand fir (GF) stands growing under contrasting treatments of vegetation management on sites located in the central Coast Range (CR) and Cascade Foothills (CF) of western Oregon. SE is the standard error.

		CR Control		CR VM		CF Control		CF VM		P-value		
Species	Tissue	ppm	SE	ppm	SE	ppm	SE	ppm	SE	Trt	Site	Site × Trt
DF	Foliage	11.031	2.015	10.416	0.856	12.386	1.079	11.922	2.705	0.897	0.841	0.881
	Branches	19.187	2.456	18.013	1.075	14.970	2.112	13.522	2.780	0.422	0.092	0.965
	Bark	16.825	0.555	18.194	1.248	17.993	3.263	16.904	1.087	0.927	0.997	0.515
	Wood	3.674	0.681	3.001	0.380	4.635	0.741	4.906	0.793	0.769	0.053	0.494
	Understory	26.617	11.655	16.493	6.024	21.821	2.580	33.762	5.748	0.903	0.408	0.155
	Forest Floor	9.793	1.488	10.135	1.217	15.676	1.857	14.442	1.495	0.777	**0.020**	0.620
	Fine Roots	10.979	0.876	12.399	1.642	12.767	1.252	10.983	0.367	0.836	0.799	0.102
	Soil 0.0–0.2 *m*	58.228	3.024	65.472	7.464	67.605	3.764	69.057	11.592	0.527	0.534	0.671
	Soil 0.2–0.4 *m*	61.790	2.428	56.924	6.136	62.827	3.904	69.478	11.360	0.892	0.471	0.396
	Soil 0.4–0.6 *m*	62.669	2.541	57.902	7.540	50.524	3.791	57.838	9.597	0.846	0.405	0.375
	Soil 0.6–1.0 *m*	50.815	4.120	54.975	5.893	49.460	12.250	51.591	8.244	0.679	0.658	0.893
WH	Foliage	11.686	0.896	10.341	0.983	–	–	–	–	0.351	–	–
	Branches	9.741	2.491	7.155	1.007	–	–	–	–	0.373	–	–
	Bark	7.075	1.283	5.218	1.207	–	–	–	–	0.333	–	–
	Wood	3.645	0.942	3.168	0.487	–	–	–	–	0.683	–	–
	Understory	27.572	7.117	13.608	0.456	–	–	–	–	0.131	–	–
	Forest Floor	14.366	0.997	12.490	1.538	–	–	–	–	0.346	–	–
	Fine Roots	10.428	0.565	10.376	1.370	–	–	–	–	0.973	–	–
	Soil 0.0–0.2 *m*	67.528	3.716	66.495	2.980	–	–	–	–	0.836	–	–
	Soil 0.2–0.4 *m*	70.611	4.061	65.751	4.357	–	–	–	–	0.446	–	–
	Soil 0.4–0.6 *m*	67.979	5.162	64.724	2.614	–	–	–	–	0.594	–	–
	Soil 0.6–1.0 *m*	53.941	5.279	53.569	1.731	–	–	–	–	0.935	–	–
WRC	Foliage	16.022	1.474	12.557	0.827	15.489	1.906	13.358	1.630	0.089	0.931	0.667
	Branches	10.508	1.384	9.513	0.823	9.059	2.663	5.889	0.947	0.225	0.145	0.516
	Bark	18.825	5.188	12.305	2.538	11.587	2.558	9.807	0.453	0.215	0.150	0.469
	Wood	2.012	0.044	2.494	0.350	2.889	0.592	3.038	0.564	0.492	0.136	0.716
	Understory	19.021	6.003	14.034	3.098	20.366	5.086	31.775	5.296	0.549	0.095	0.145
	Forest Floor	13.283	1.445	14.650	7.188	15.039	2.856	10.771	2.520	0.691	0.708	0.448
	Fine Roots	13.898	1.484	10.095	0.611	35.193	17.267	19.389	4.405	0.287	0.365	0.499
	Soil 0.0–0.2 *m*	67.375	7.071	71.251	4.990	80.082	9.555	86.671	4.025	0.292	**0.036**	0.772
	Soil 0.2–0.4 *m*	77.650	6.002	68.045	5.955	71.207	6.946	78.539	6.081	0.749	0.535	0.051
	Soil 0.4–0.6 *m*	75.434	9.748	66.819	4.836	62.587	6.037	68.148	5.730	0.823	0.604	0.334
	Soil 0.6–1.0 *m*	46.951	8.450	57.207	4.117	50.765	4.232	61.533	12.002	0.238	0.570	0.975
GF	Foliage	24.702	3.402	24.965	5.025	–	–	–	–	0.300	–	–
	Branches	14.174	3.192	16.743	2.596	–	–	–	–	0.562	–	–
	Bark	17.857	2.810	8.741	0.635	–	–	–	–	**0.019**	–	–
	Wood	4.353	0.877	3.680	0.325	–	–	–	–	0.499	–	–
	Understory	19.750	7.024	17.388	5.177	–	–	–	–	0.800	–	–
	Forest Floor	17.965	3.157	20.271	2.256	–	–	–	–	0.584	–	–
	Fine Roots	14.379	0.757	16.935	5.214	–	–	–	–	0.624	–	–
	Soil 0.0–0.2 *m*	65.707	1.521	83.900	6.691	–	–	–	–	0.078	–	–
	Soil 0.2–0.4 *m*	75.079	3.157	75.342	10.140	–	–	–	–	0.976	–	–
	Soil 0.4–0.6 *m*	66.434	2.161	75.266	8.629	–	–	–	–	0.377	–	–
	Soil 0.6–1.0 *m*	56.841	5.840	57.043	4.607	–	–	–	–	0.980	–	–

Table A15
Average concentrations in percent and standard errors (SE) of the macronutrients carbon, nitrogen, phosphorous, potassium, magnesium, calcium, and sulfur for the understory and the foliage and wood of the midstory species: bigleaf maple (ACMA), red alder (ALRU), Oregon bitter cherry (PREM), and cascara buckthorn (FRPU). Understory average was taken across sites, species, and treatments. BLD stands for below detectable levels.

		Carbon		Nitrogen		Phosphorous		Potassium		Magnesium		Calcium		Sulfur	
		%	SE	%	SE	%	SE	%	SE	%	SE	%	SE	%	SE
ACMA	Foliage	44.917	0.380	3.010	0.116	0.371	0.043	1.496	0.034	0.344	0.014	1.163	0.134	0.204	0.010
	Stem	45.472	0.127	0.117	0.002	0.017	0.005	BLD	–	0.036	0.001	0.082	0.003	0.043	0.000
ALRU	Foliage	47.240	0.330	2.938	0.154	0.147	0.007	1.083	0.142	0.253	0.003	0.590	0.052	0.087	0.010
	Stem	53.112	0.448	0.552	0.004	0.009	0.001	BLD	–	0.026	0.002	0.087	0.015	0.048	0.003
PREM	Foliage	44.108	0.576	3.248	0.100	0.412	0.032	1.506	0.049	0.397	0.018	1.147	0.126	0.160	0.002
	Stem	44.916	0.088	0.110	0.003	0.021	0.010	BLD	–	0.027	0.005	0.124	0.017	0.049	0.003
RHPU	Foliage	42.813	0.101	2.678	0.049	0.331	0.009	1.709	0.056	0.351	0.012	1.213	0.082	0.117	0.002
	Stem	45.212	0.095	0.143	0.005	0.007	0.002	BLD	–	0.042	0.001	0.125	0.008	0.045	0.001
Understory	Total	40.834	0.845	1.375	0.059	0.180	0.011	1.177	0.104	0.272	0.015	0.907	0.049	0.000	0.000

Table A16
Average concentrations in mg kg^{-1} (ppm) and standard errors (SE) of the micronutrients boron, copper, iron, sodium, and zinc for the understory and the foliage and wood of the midstory species: bigleaf maple (ACMA), red alder (ALRU), Oregon bitter cherry (PREM), and cascara buckthorn (FRPU). Understory average was taken across sites, species, and treatments. BLD stands for below detectable levels.

		Boron		Copper		Iron		Manganese		Sodium		Zinc	
		ppm	SE	ppm	SE	ppm	SE	ppm	SE	ppm	SE	ppm	SE
ACMA	Foliage	14.66	2.91	6.589	0.381	100.00	17.40	180.98	15.05	192.61	31.74	52.05	4.65
	Stem	2.70	0.10	3.332	0.598	100.46	10.53	24.51	4.02	BLD	–	5.66	0.81
ALRU	Foliage	15.50	0.42	8.179	0.458	62.62	4.17	229.03	16.38	166.26	23.17	26.30	2.61
	Stem	2.36	0.08	2.239	0.097	135.46	29.79	17.74	0.69	BLD	–	5.09	0.32
PREM	Foliage	18.53	1.29	5.681	0.478	156.25	1.79	58.01	3.16	93.55	19.47	11.73	1.66
	Stem	3.62	0.44	2.121	0.246	89.29	5.48	4.74	0.11	BLD	–	2.49	0.19
RHPU	Foliage	32.07	0.34	6.845	0.684	138.71	9.10	833.53	12.75	157.24	11.48	23.73	1.44
	Stem	2.72	0.09	2.377	0.412	109.86	38.47	31.32	1.13	BLD	–	2.37	0.39
Understory	Total	27.67	2.59	5.839	0.330	918.54	115.52	562.36	55.27	195.19	11.32	22.24	1.84

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