Swiss Needle Cast Cooperative

ANNUAL REPORT 2008

Oregon State UNIVERSITY OSU

SNCC

SNCC

Swiss Needle Cast Cooperative
Annual Report 2008

Edited By Dave Shaw, SNCC Director
& Travis Woolley

SNCC Income Sources and Expenditures: 2008

Income

Membership dues	87,500
Oregon State Legislature	95,000
Carry-over	109,498
Total 2008 Budget	**$291,988**

Expenditures

Salaries and wages	114,455
Travel	1,774
Operating expenses	11,500
Contract Work	113,684
Materials and Supplies	2413
Indirect Costs	31697
Total 2008 Expenditures	**$275,523**

Contents

The SNC epidemic continues un-abated along the Oregon Coast this year; the estimated acres visible to aerial survey was 375,626 acres in 2008, our second highest acreage since 1996. Our (Maguire and Mainwaring) Growth Impact Study (GIS) plots and Precommercial Thinning Study (PCT) plots were re-measured this year (2008). Growth impacts in the GIS study continue to be similar to previously reported results. The lowest stand average needle retention was 1.47 years, with a growth loss of 43%. Average growth loss for the entire study area was 21%. Growth responses to the PCT treatments are encouraging, and precommercial thinning is recommended as used in normal operations.

Maguire and Mainwaring have compared needle retention on the GIS and PCT plots in 2005 to 2008. In 2005 needle retention averaged 2.51 in the GIS and 2.76 in the PCT, while in 2008, needle retention averaged 2.14 in the GIS and 2.36 in the PCT study, indicating a decrease in needle retention overall. Maguire, Mainwaring and associates have several other studies they continue to work on including the influence of soil amendments and foliage dynamics and chemistry associated with SNC.

Bryan Black, Jeff Stone and I have been working on a dendrochronology investigation into whether there have been previous SNC epidemics in the coast range. So far, one 300 year old stand (near Cape Perpetua) and one 100 year old stand (Euchre Mt., near Lincoln City) have been evaluated by coring Douglas-fir and western hemlocks to determining whether their growth tracks together. If Douglas-fir shows reduced growth and western hemlock does not, then it may indicate an effect from disease. So far, neither stand has shown any growth impacts from SNC, even since 1990. This is leading to a hypothesis that older trees may not be as impacted from SNC as young plantation trees. Only two sites have been investigated so more information is needed before drawing any conclusions.

Dan Luoma and Joyce Eberhart have continued work on the ectomycorrhizae of Douglas-fir, with special attention to site biodiversity and a search for a stress-tolerant species that might be helpful in improving Douglas-fir growth. So far, they have found that there is no general mycorrhizal fungus that meets that criteria. However, the biodiversity they have found indicates that these fungi are persisting on site even in the face of reduced carbon, albeit the high SNC sites with low needle retention still have fewer fungal species and root tips.

Cooperative studies with the Northwest Tree Improvement Cooperative have been encouraging and will continue into the future. Travis Woolley and I have also initiated studies on the relationship of crown expression of disease to geographic location, productivity, and management in the hope that silviculture can be a central factor in managing this important epidemic in Douglas-fir.

David Shaw, November 2008

Projects for 2008

- ◆ Aerial Survey, ODF/USFS cooperative survey.

- ◆ Remeasurement of the Growth Impact Study Plots.

- ◆ Remeasurement of the Precommercial Thinning Study Plots.

- ◆ Model validation efforts for the disease severity model.

- ◆ Foliage dynamics and nutrient flux of SNC impacted Douglas-fir.

- ◆ Response of ectomycorrhizae to Swiss Needle Cast of Douglas-fir.

- ◆ Refining techniques for detecting SNC outbreaks in tree-ring records from the western Oregon Coast Range.

- ◆ Economic and market modeling of impacts of SNC on Oregon Coast Range region.

- ◆ Crown expression of disease in Douglas-fir across a gradient of SNC infection

Background and Organization

A major challenge to intensive management of Douglas-fir in Oregon and Washington is the current Swiss Needle Cast (SNC) epidemic. Efforts to understand the epidemiology, symptoms, and growth losses from SNC have highlighted gaps in our knowledge of basic Douglas-fir physiology, growth, and silviculture. The original mission of the Swiss Needle Cast Cooperative (SNCC), formed in 1997, was broadened in 2004 to include research aiming to ensure that Douglas-fir remains a productive component of the Coast Range forests. SNCC is located in the Department of Forest Science within the College of Forestry at Oregon State University. The Membership is comprised of private, state, and federal organizations. Membership dues vary depending on forestland ownership. One annual report, project reports, and newsletters are distributed to members each year. All projects are carried out in cooperation with specific members on their land holdings.

Mission Statement

To conduct research on enhancing Douglas-fir productivity and forest health in the presence of Swiss needle cast and other diseases in coastal forests of Oregon and Washington.

Objectives

(1) Understand the epidemiology of Swiss needle cast and the basic biology of the causal fungus, *Phaeocryptopus gaeumannii*.

(2) Design silvicultural treatments and regimes to maximize Douglas-fir productivity and ameliorate disease problems in the Coast Range of Oregon and Washington.

(3) Understand the growth, structure, and morphology of Douglas-fir trees and stands as a foundation for enhancing productivity and detecting and combating various diseases of Douglas-fir in the Coast Range of Oregon and Washington.

Refereed Publications

2000

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Swiss Needle Cast Aerial Survey, 2008
*Alan Kanaskie and Michael McWilliams, Oregon Department of Forestry*

Swiss needle cast (SNC) is a native disease of Douglas-fir that has intensified dramatically in coastal western Oregon since 1990. The main effect of SNC on forests is reduction of tree growth and vitality. In addition to growth impacts, SNC alters wood properties and affects stand structure and development. This complicates stand management decisions, especially in pure Douglas-fir stands. Although the disease occurs throughout the range of Douglas-fir, it is most severe in the forests on the west slopes of the Coast range. In recent years the easternmost area with obvious SNC symptoms was approximately 28 miles inland from the coast (usually along the Highway 20 corridor), with the majority of area with symptoms occurring within 18 miles of the coast.

Aerial surveys to detect and map the distribution of SNC damage have been flown annually since 1996. The 2008 survey was not fully completed because of weather and aircraft availability. Three sample blocks were flown: Tillamook, Newport, and Coos Bay (figure 2). Data from the sample blocks were used to estimate overall survey results by multiplying percentage change from 2007 to 2008 for the sample blocks to the acreage estimate for the full 2007 survey. The impression of the observers and the limited data indicate that there was more visible SNC damage in 2008 than in 2007 (figure 1).

The total amount of forest affected by Swiss needle cast is much greater than indicated by the aerial survey maps because the aerial observers can map only those areas where disease is severe enough to be visible from the air. Although the acreage estimates are conservative, the survey does show the location of Douglas-fir stands with moderate to severe damage, and coarsely describes the trend in damage over time.

The 2008 survey covered 1,091,000 acres and cost $2,589 (plane and pilot only).
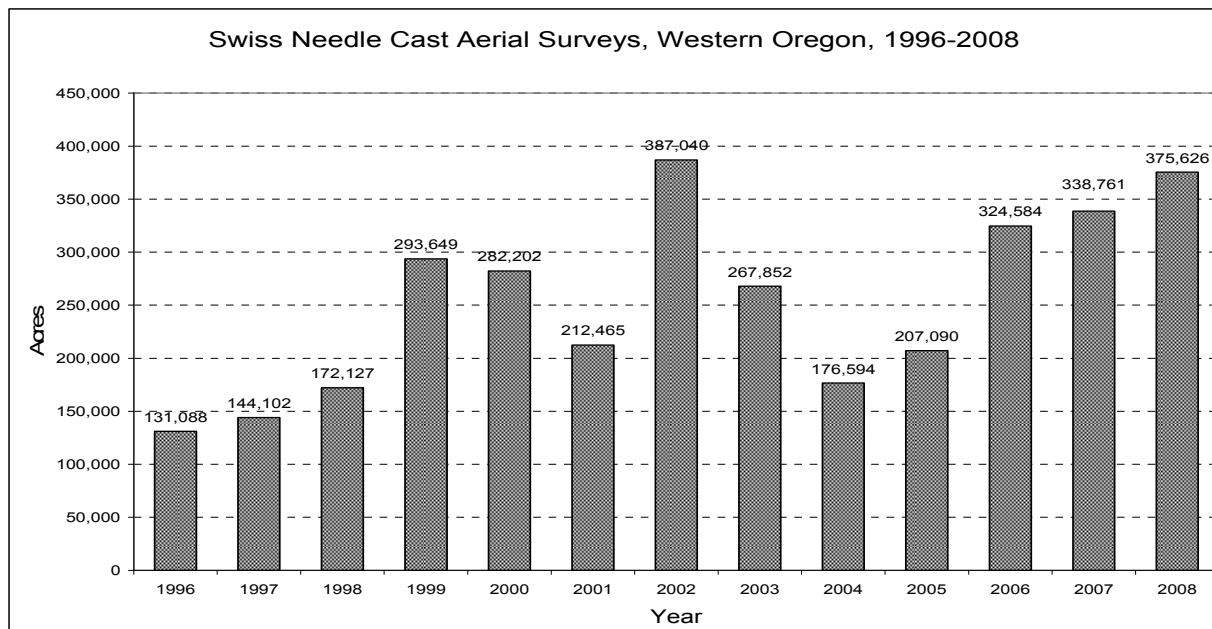
Figure 1. Trend in area of Douglas-fir forest in western Oregon with symptoms of Swiss needle cast detected during aerial surveys in April and May, 1996-2008. Results for 2008 were estimated by extrapolating from 3 sample survey blocks.
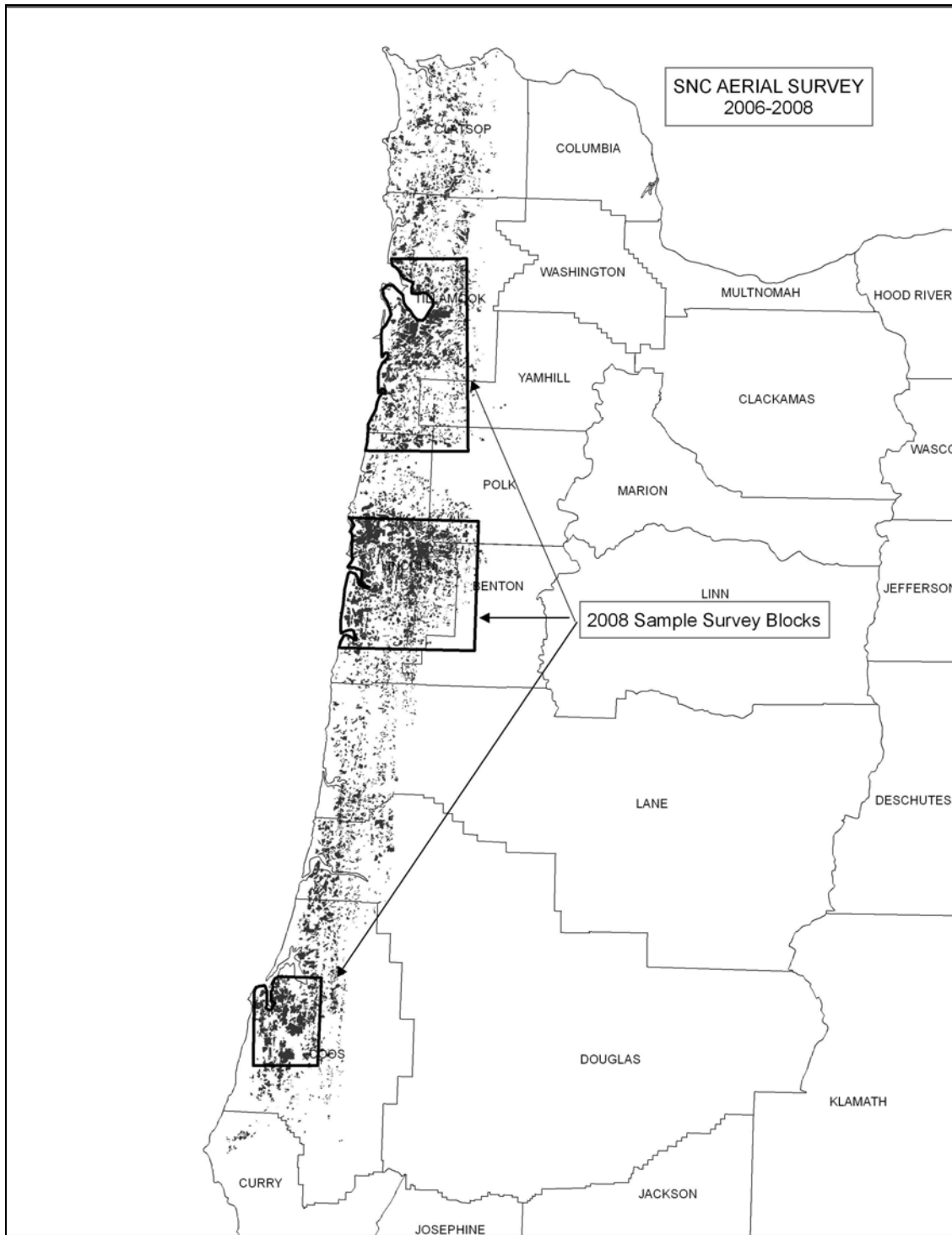
Figure 2. Swiss Needle Cast (SNC) aerial survey: areas of Douglas-fir forest with symptoms of Swiss Needle Cast detected in the 2006-2008 surveys. The 2008 survey was incomplete due to weather and aircraft availability. Solid black polygons (blotches) depict areas with severe or moderate damage from SNC.

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Growth Impact Study: Growth Trends During the Fourth Period Following Establishment of Permanent Plots

Doug Mainwaring and Doug Maguire, Oregon State University, Alan Kanaskie, Oregon Department of Forestry

Abstract

Permanent plots in the Growth Impact Study have been remeasured for a fourth growing period of four years duration. Needle retention was measured on an annual basis from 1997 through 2004, allowing the ratings from 2004 to serve as the initial condition for the 2004-2007 growing seasons. Cubic volume growth of surviving trees on plots with severe Swiss needle cast (SNC) was compared to volume growth of plots with the highest foliage retention (3.6 years), suggesting relative growth losses up to 43% for 2004-2007 (minimum foliage retention of 1.47 years), and average loss of 21% (mean retention of 2.5 years). While the reported losses from the 2002-2003 growth period were lower than this, the most recent data suggest that results from the prior period reflected a short term improvement rather than the start of a trend.

Introduction

The Growth Impact Study (GIS) was initiated in 1997 to address two major objectives: 1) to monitor Swiss needle cast (SNC) symptoms and tree growth in 10-30-yr-old Douglas-fir plantations in north coastal Oregon; and 2) to provide an improved estimate of growth losses associated with a given initial level of SNC. Retrospective work conducted in the spring of 1997 established growth losses across a range in SNC severity (Maguire et al. 1998, 2002). Volume growth losses were estimated to average 23% for the target population in 1996, with losses reaching almost 50% in the most severely impacted stands. Total losses in 1996 alone were therefore about 40 MMBF, given that the target population covers approximately 187,000 ac. Permanent plots established in the spring of 1998 and remeasured in 2000 and 2002 confirmed these growth losses. Reported growth losses during the 2002-2003 period decreased relative to previous periods, though it wasn't known whether this constituted a trend or a short term improvement in disease conditions. The most recent remeasurement was completed in the spring of 2008. The objectives of this report are: 1) to quantify the most recent 4-yr growth responses relative to initial (2004) SNC severity; and 2) to compare these 4-yr growth responses to those estimated retrospectively for 1996 and on permanent plots for 1998-99, 2000-2001, and 2002-2003.

Methods

In the late winter/early spring of 1998, a network of 76 permanent plots was established at locations previously sampled in Phases I and II (retrospective phase) of the Growth Impact Study. The plots were square and 0.08-ha (1/5-ac) in area (31.8 x 31.8 m). Each plot was centered on the 5th point of the ODF transect established in Spring 1997 (Phase I plots were centered on the 3rd point). On each measurement plot, all trees were tagged at breast height and measured for dbh (nearest 0.1 cm). A subsample of at least 40 Douglas-fir was measured for total height and height to crown base (nearest 0.1 m). After 2, 4 and 6 growing seasons, all trees were remeasured for dbh, and all trees from the original height subsample were remeasured for total height and height to lowest live branch. Trees on each plot were also scored for SNC at time of plot establishment in 1998 and just prior to bud break each year from 1999 through 2004. Ten dominant or codominant trees per plot were rated for SNC by dividing the crown vertically into thirds, and estimating the average number of years of foliage retention

in each third by visual examination (nearest 0.1 year). Plot ratings were computed as the average of crown thirds from all ten trees.

Statistical analysis

In growth analyses of the first through fourth periods, all variation in initial needle retention (1998, 2000, 2002, and 2004) was assumed totally controlled by SNC. Individual tree values were averaged for the 10 sample trees on each plot to arrive at a plot average. A simple growth model was fitted to the data from the 65 GIS plots remaining in 2008, using initial foliage retention as the index of SNC severity:

$$\ln[PAI] = b_0 + b_1X_1 + b_2X_2 + \ldots + b_kX_j + b_{k+1}FOLRET \quad [1]$$

where
   PAI=plot-level periodic annual increment for cubic volume of surviving Douglas-fir
   X_i=plot-level predictor variables
   FOLRET is FOLRET98, FOLRET00, FOLRET02, and FOLRET04.

Results and Discussion

For the most recent growth period (2004-2007), approximately 93% of the variation in cubic volume PAI was explained by the following model:

$$\ln[PAI] = 0.6548 + 0.9229 \ln(BADF) - 0.01505\ BANDF + 0.6292 \ln(FOLRET04) - 0.4169 \ln(BHAGE) \quad [2]$$

where   PAI = plot-level periodic annual cubic volume growth of Douglas-fir for 2004-2007(m^3/ ha)
   BADF = initial Douglas-fir basal area (m^2/ha in 2004-2007)
   BANDF = initial plot basal area of all species except Douglas-fir (m^2/ha in 2004)
   FOLRET04 = initial (2004) average foliage retention for plot (yrs)
   BHAGE = breast height age in 2004 (yrs)

All variables were significant ($p<0.0003$). As expected, Douglas-fir growing stock was the major predictor, and alone it accounted for approximately 78% of the Douglas-fir volume growth; however, growth of the plots also increased as foliage retention increased (Fig. 1). Assuming the healthiest stands were represented by the greatest value of FOLRET04 (3. 6 yrs), the model implies volume growth losses up to 43% for stands with the lowest estimated foliage retention (1.47 yrs in 2004) (Fig. 2). With Douglas-fir basal area set to the population average of 115 ft^2/ac (26.4 m^2/ha) and average non-Douglas-fir basal area of 27.4 ft^2/ac (6.3 m^2/ha), this condition implies an average growth rate of 182 ft^3/ac/yr (12.7 m^3/ha/yr) vs. an expected of 320 ft^3/ac/yr (22.4 m^3/ha/yr) under optimal levels of FOLRET04. The inferred cubic volume growth loss for stands experiencing the most severe SNC is therefore approximately 43%, with a population average of 21% growth loss (average foliage retention of 2.5 yrs).

Percent growth losses for previous periods varied according to the estimates of maximum and minimum foliage retentions among the permanent plots at the start of each growth period.

The marginal effect of foliage retention on volume growth can be evaluated by comparing the value of the foliage retention parameter estimate from equation [2] for different growth periods.   Results of this comparison suggest that the negative effect of foliage retention
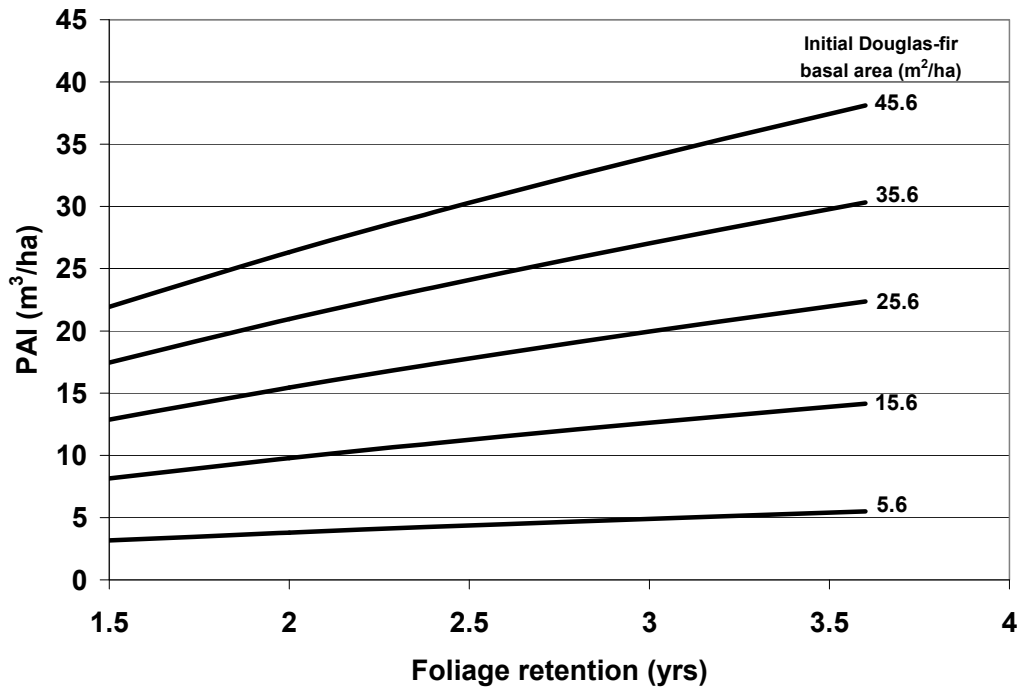
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Figure 1. Relationship between cubic volume PAI and SNC severity as measured by foliage retention (FOLRET02) for various levels of Douglas-fir growing stock (BADF). Estimates are for the 2004-2007 growth period, assuming bandf=6.3 m2ha-1, bhage=21 and yrs.
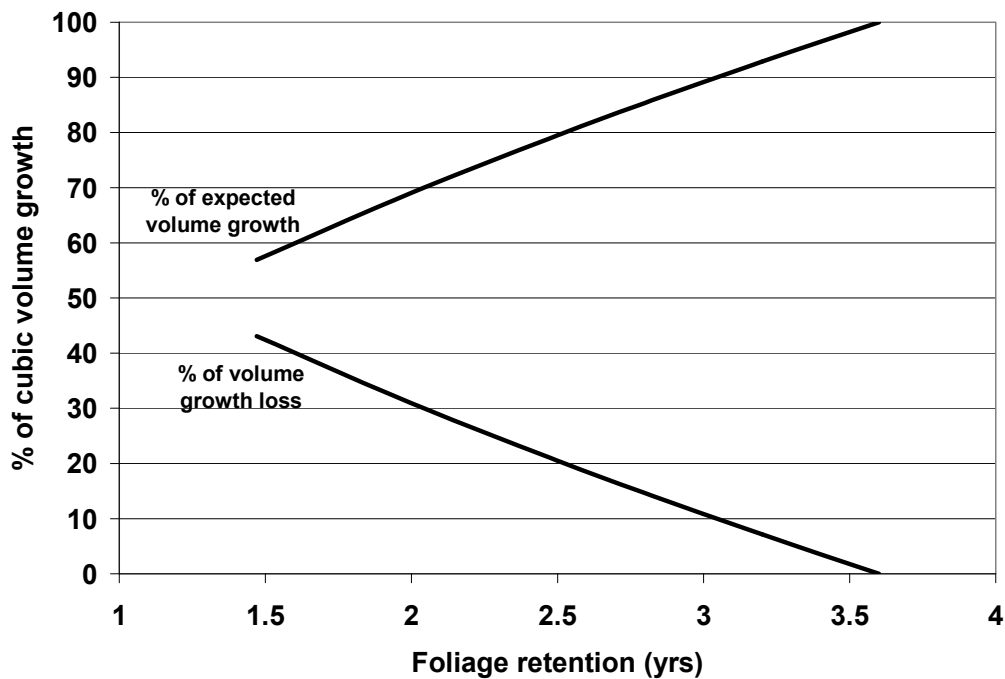

Figure 2. Percent of volume growth associated with varying levels of foliage retention (FOLRET04) for the 2004-2007 growth period.
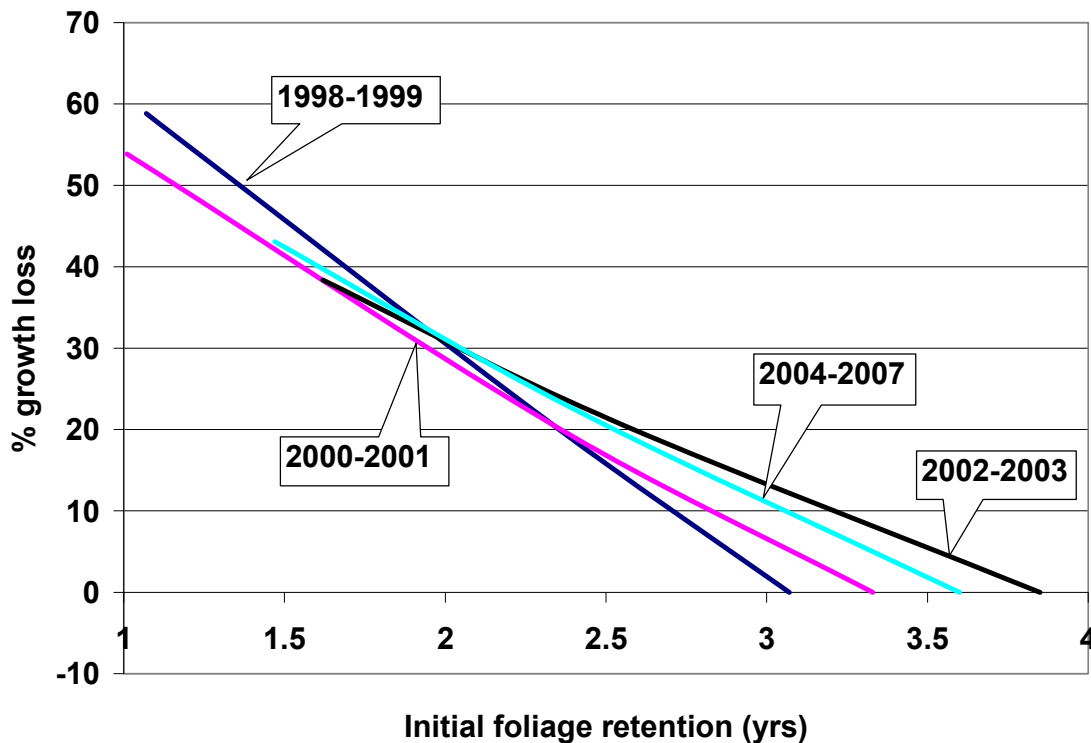
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Figure 3. Implied relative growth losses for the four GIS growth periods. Ranges of foliage retention represent those measured at the start of each growth period.

on volume growth (slope of the line shown in figure 3) was greatest in 1998-1999, followed by 2000-2001, 2004-2007, and 2002-2003.

This comparison has been made in previous reports, but has not always been based on the same model form, thereby producing slightly different slopes than shown here. For example, the slope of the foliage retention effect during the 1998-1999 growth period is steeper than shown previously (Maguire et al. 2001). However, the previous 1998-1999 estimate of foliage retention was based on a model that included crown sparseness (CL:SA). Crown sparseness is an appropriate index of SNC severity (Maguire and Kanaskie 2002) which appears to estimate other elements of needle loss. Used originally during the 1998-1999 growth period, it hasn't been remeasured for each period, though a remeasurement in 2004 indicated that it hadn't changed significantly. Secondarily, it hasn't always been a significant predictor for growth during each of the growth periods, though when included in equation [2], it invariably lowers the foliage retention parameter estimate. However, use of a second index of SNC complicates period-to-period comparison.

The negative effect of foliage retention on growth during the 2002-2003 was originally reported to be lower than reported here (Maguire et al. 2004). The model used for that analysis included site index. While it is an appropriate model covariate, because site index estimates for these young stands are influenced by SNC, its inclusion presumably partitions some of the variation attributable to SNC otherwise explained by foliage retention. For the sake of an accurate period to period comparison, it was therefore not included in equation [2]. Regardless of this change, figure 3 indicates that stands did experience a reduced negative effect from SNC

during the 2002-2003 growth period. However, results during this growth period indicate that this was less likely a trend than a periodic improvement in disease or growing conditions.

This analysis was based on the growth and initial stocking of surviving Douglas-fir trees only. Although previous analyses included all Douglas-fir trees, a few of the plots had experienced significant mortality due to as yet undetermined causes, and resulted in a few minimal or negative net stand growth rates. Because this complicated determination of the marginal effect of SNC on growth, the analysis was limited to survivors. It also indicates the necessity for an analysis of mortality patterns on the plots.

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Growth Responses to Pre-commercial Thinning Under Different Levels of Initial SNC Severity of North Coastal Oregon

Doug Mainwaring and Doug Maguire, Oregon State University

Abstract

A study of pre-commercial thinning was established in 1998 to test growth performance under differing initial severities of Swiss needle cast. Plots have now been through their fourth growth
period. During the 2004-2007 growing seasons, growth responses remained significantly positive for both levels of thinning intensity, amounting to a 39-48% increase in periodic annual volume growth for a given level of residual basal area, regardless of initial foliage retention.

Introduction

After six years of monitoring the pre-commercial thinning plots, early concerns that thinning would exacerbate symptoms of Swiss needle cast (SNC) and adversely impact growth responses have diminished. Previous results indicate that infected stands do respond to pre-commercial thinning (Maguire et al. 2004), and that foliage retention in the lower portions of crowns may improve (Kanaskie and Maguire 2004).
The original objectives of the ongoing pre-commercial thinning study were: 1) to test whether thinning in pre-commercial stands leads to intensification of SNC symptoms, particularly foliage retention; and 2) to test whether thinning in pre-commercial stands with a given initial intensity of SNC leads to growth rates below those that would be expected under the reduced stand density. This report addresses the second objective, providing results for the growth period 7-10 years after thinning.

Methods

In the late winter/early spring of 1998, 22 sets of plots were established across a range in initial Swiss needle cast (SNC) severity. Most of these sets contained a pair of plots, one thinned to 200 tpa and the other a control, but some included a third plot that allowed testing of 100 residual tpa.

The original thinning prescription called for leaving 200 tpa (494 tph), but because stand densities were already low on two installations, the target residual was lowered to 100 tpa (247 tph). The third plot was established on 5 installations. All control plots and 200-tpa plots were square and covered 0.08-ha (1/5-ac; 31.8 x 31.8 m), except for the two installations on which the thinned plot was reduced to 100 tpa. The control plots matching the latter two 100-tpa plots, as well as all 7 plots thinned to 100 tpa, encompassed an area of 0.16-ha (2/5-ac). On each measurement plot, all trees were tagged and measured for diameter at breast height. At least 40 Douglas-fir trees on each plot were also measured for total height and height to crown base. The treated plots were thinned before the growing season started in 1998. After 2, 4 and 6 growing seasons (after the 1998-99, 2000-01, and 2002-2003 growth periods), all trees were remeasured for dbh, and all trees from the original height subsample were remeasured for total height and height to crown base. Where necessary, replacement trees for the height subsample were substituted with another tree of a similar diameter. Ten dominant or codominant trees on each plot were also scored for SNC at time of plot establishment in 1998 and during annual visits in the spring (1999-2004).

Factors influencing growth responses in 2004-07 were investigated in two ways: 1) as a randomized block experiment with covariates (analyzed with a multiple regression model); and 2) as a multiple regression problem with a large number of potential predictors such as initial stand density, initial SNC severity, and thinning intensity.

Results and Discussion

Block effects, accounting for site productivity, climate, Swiss needle cast intensity and stand age, explained 79% of the variation in periodic annual volume increment (VPAI) between sites. With the addition of initial Douglas-fir stocking and thinning indicator variables, approximately 94% of the variation in VPAI was explained with the following model:

ln[PAI] = BLOCK + 0.8423 ln(BADF) + 0.3310*PCT100 + 0.3945*PCT200 [1]

where PAI = plot-level periodic annual cubic volume growth of Douglas-fir for 2004-
2007(m^3/ha)
BLOCK = set of indicator variables and associated parameter estimates representing the block effect
BADF = initial Douglas-fir basal area (m^2/ha in 2004)
PCT100 = 1 if plot was thinned to 100 tpa; 0 otherwise
PCT200 = 1 if plot was thinned to 200 tpa; 0 otherwise

To determine the marginal effect of SNC on growth, foliage retention was substituted for block-level effects. Approximately 79% of the variability in volume PAI was explained by the following model:

ln[PAI] = -08522 + 0.8996 ln(BADF) + 0.8605*ln(folret) + 0.4178*PCT100 + 0.3990*PCT200 [2]
where PAI = plot-level periodic annual cubic volume growth of Douglas-fir for 2004-
2007(m^3/ha)
BADF = initial Douglas-fir basal area (m^2/ha in 2004)
PCT100 = 1 if plot was thinned to 100 tpa; 0 otherwise
PCT200 = 1 if plot was thinned to 200 tpa; 0 otherwise

Table 1 thinning coefficients from equation [2]

Both levels of thinning produced significantly greater volume after accounting for different levels of basal area. Although the 100 TPA treatments produced more volume than the 200 TPA treatments after accounting for basal area, the difference was not significant (p=0.84).

	PCT100	PCT200
98-99	0.0231	0.1198
00-01	0.3556	0.4066
02-03	0.2922	0.3929
04-07	0.4178	0.3990

Table 1 shows the value of T100 and T200 after applying model [2] to all four growing periods. The changing values of the indicator variables over the course of the study indicate that that the effect of thinning, while small and statistically insignificant during the first growth period following treatment, has increased over time. While the difference between the two treatments has never been statistically significant, the increasing value of the PCT100 coefficient suggests that the effect of the heavier thin may surpass that of the lighter thin as the latter closes up and crowns begin to recede. Whether the greater value of VPAI for T100 in 2004-07 constitutes the beginning of this process or natural variation is unknown.

Foliage retention in 2004 ranged from a low of 1.17 years to a high of 4.96 years, suggesting that plots with severe SNC were only growing 29% of the volume of the most foliated plots, all else being equal. Nevertheless, the growth response from thinning was independent of

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foliage retention, meaning that on average, thinning will improve growth regardless of SNC level. Nevertheless, because the infected stand is growing slowly, the increase in absolute volume growth will remain low relative to healthy stands.
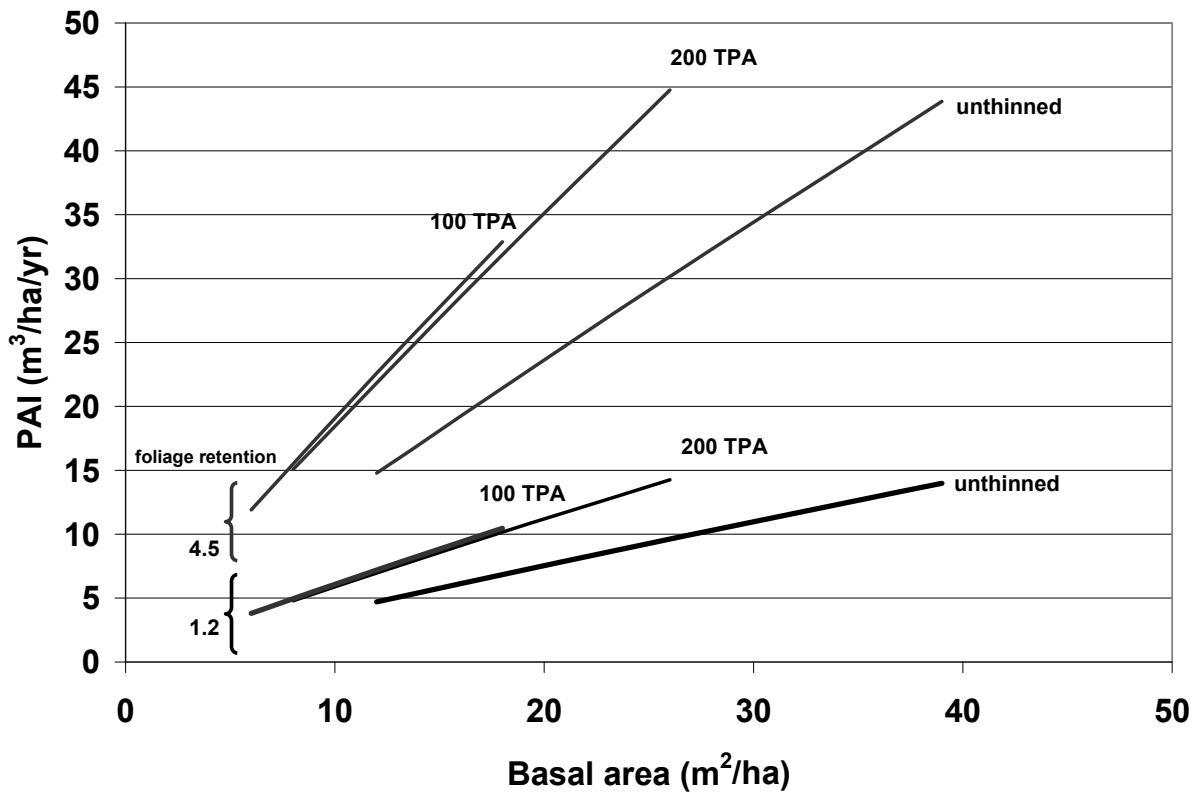

Figure 1 Periodic annual increment as a function of residual Douglas-fir stocking, foliage retention level, and residual tpa after thinning (trends estimated from equation [2]).

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Trends in Foliage Retention on the Growth Impact and Pre-commercial Thinning Plots *Doug Mainwaring and Doug Maguire, Oregon State University*

Abstract

Permanent plots in the Growth Impact Study and Pre-Commercial Thinning study have been rated annually for Swiss needle cast (SNC) severity from 1998-2005, based originally on ground observation, followed in 2005 and 2008 by individually sampled branches. Foliar retention on branches collected in the spring 2008 were lower on both plot types than in 2005, decreasing from an average of 2.51 yrs to 2.14 yrs on GIS plots and from 2.76 yrs to 2.36 yrs on PCT plots.

Introduction

The Growth Impact Study (GIS) was initiated in 1997 to monitor Swiss needle cast (SNC) symptoms and tree growth in 10-30-yr-old Douglas-fir plantations, and the Pre-Commercial Thinning Study (PCT) was initiated in 1998 to test the effect of thinning and initial SNC severity on symptom development and growth response. In both studies, the primary index of SNC severity has been foliage retention. This index has been estimated on ten standing trees per plot by dividing the tree crown into thirds and visually estimating average retention on representative branches, ignoring the main axis of the primary branch. The decision was made in 2005 to switch from this method to estimating foliage retention on a single individually sampled 5-yr-old whorl branch, the change due to the increasing difficulty of accurately estimating foliage retention from the ground as crowns receded. The objective of this report is to describe trends in the severity of damage from Swiss needle cast in randomly chosen 10- to 30-year-old Douglas-fir plantations in the Coast Range of western Oregon; and 2) to estimate the area (acres) affected by SNC.

Methods

From March to May of 2008, five of the randomly selected SNC rating trees from the remaining GIS and PCT plots were climbed to collect the southernmost 5-yr-old whorl branch. Except where damaged trees needed to be replaced, these were the same trees climbed in 2005. The branch was cut flush with the bole, wrapped in a plastic bag and kept cool prior to transport to the lab. In the lab, each branch was rated for average foliage retention, and plot-level retention was computed from the five sample branches collected from each plot. This procedure was similar to that employed in 2005.

Results and Discussion

Mean foliage retention in 2008 was significantly lower than any other year except 2001 on both GIS and PCT plots (figures 1 and 2). Because numerous GIS plots have been harvested, the analysis was run two ways: 1) with the complete list of plots remaining in a given year (as presented in figure 1), and 2) with only those plots still remaining in 2008. Using the second procedure, differences between foliage retention in 2008 and all other years were even greater. Graphical display of foliage retention for individual plots on both the GIS and PCT plots indicates that in all but a few exceptions, foliage retention declined from 2005 to 2008 (figures 3 and 4), regardless of initial foliage retention. The fact that foliage retention diminished on healthy as well as infected sites could indicate a measurement bias, except that values were
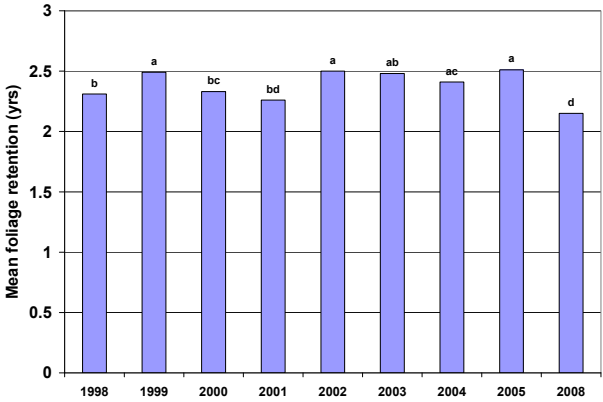
Figure 1 Mean foliage retention on GIS plots. Means with the same letters are not significantly different (ANOVA, Fisher's LSD, α=0.05)

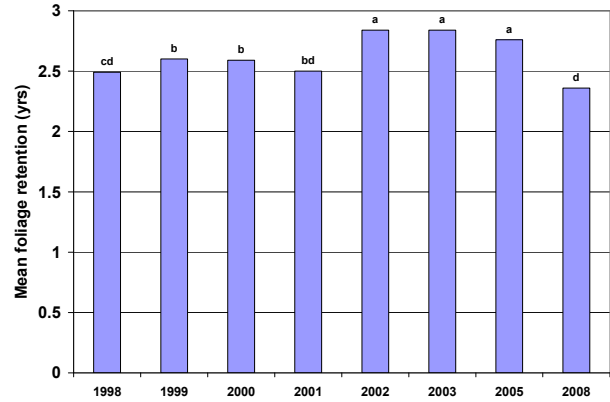*Figure 2 Mean foliage retention on PCT plots. Means with the same letters are not significantly different (ANOVA, Fisher's LSD, α=0.05)*

estimated by the same person in each year. The person making the estimates is arguably the most experienced person in the area for this type of work. Another possible explanation is that the same conditions associated with SNC-related foliar loss cause needle loss in relatively healthy stands. Fungal germination and development has been positively associated with abundant spring moisture and warm winter temperature (Manter et al. 2005). In 2005, three year-old foliage originated in 2002, a relatively dry spring which produced needles with lesser rates of infection (based on observations of high retention within the 2002 cohort). In contrast, three year-old foliage in 2008 was produced during the relatively wet spring of 2005 (figure 5). On the same trees from 10 randomly chosen GIS plots, 3 year old foliage dropped from 0.47 years in 2005 to 0.19 years in 2008, constituting 74% of the difference in foliage retention between the chosen plots.
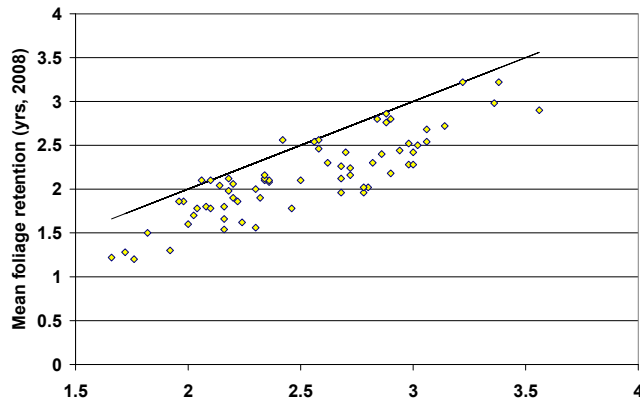
Figure 3 GIS foliage retention in 2008 vs. foliage retention in 2005. Line represents 1:1 line for 2005 foliage retention
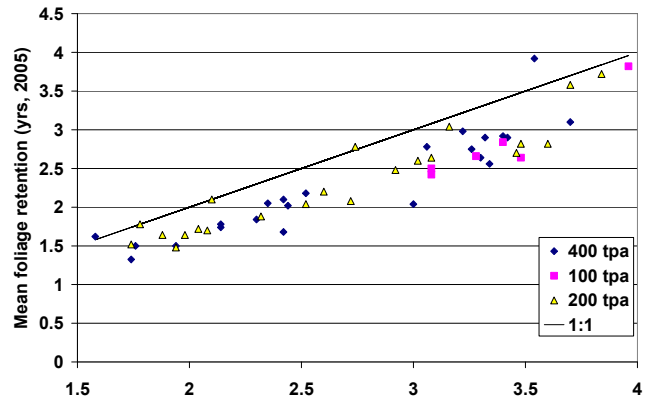

Figure 4 PCT foliage retention in 2008 vs. foliage retention in 2005. Line represents 1:1 line for 2005 foliage retention
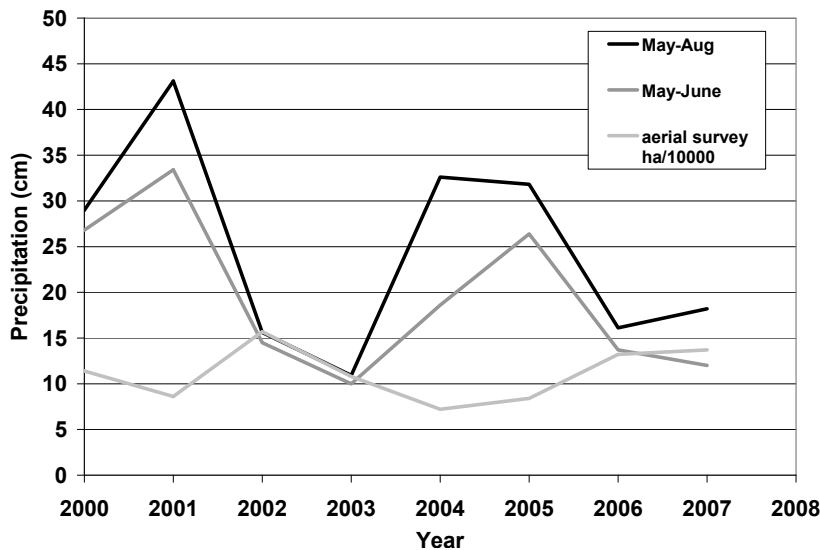

Figure 5 Average summer precipitation from 5 NW Oregon weather stations; total area (% x 100) showing SNC discoloration detectable from ODF aerial surveys.

Of the 187,545 acres of Douglas-fir plantations represented by the GIS plots, in 2008 approximately 77,300 acres had foliage retentions of 1.75 and below versus fewer than 2000 acres in 2005 (figure 6). As of 2004, foliage retention on the PCT plots was showing an increasing trend in the lower crown thirds (Kanaskie and Maguire 2004). In fact, analysis of variance analysis of the 2003 data indicates that after accounting for site-level differences, foliage retention on thinned plots was greater than on control plots. This is not surprising due to the generally greater levels of retention low in the crown and the crown elongation taking place on thinned plots relative to controls. When the same analysis was run on the 2005 and 2008 data, no significant differences were apparent, due no doubt to the fact that sample branches were taken from the 5th whorl, which on most of these sites is in the upper half of the crown where little difference is expected to occur.
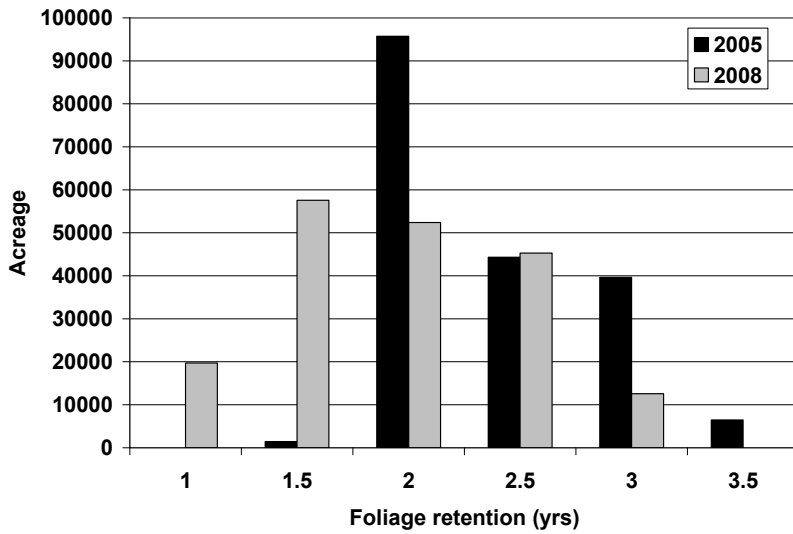
Figure 6 Distribution of Douglas-fir plantation acreage by needle retention class for the 187,545-acre population from which sample plantations were chosen.

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Seasonal Adjustment of Foliage Retention for Swiss Needle Cast Infected Stands

Doug Mainwaring, Doug Maguire, and Jeff DeRoss Oregon State University

Introduction

Phaeocryptopus gaeumannii (Rohde) Petrak is an endemic foliar pathogen of Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) (Hansen et al. 2000) and causes the disease known as Swiss needle cast (SNC). Since 1990, this pathogen has been present in epidemic levels in coastal forests of the Pacific Northwest, causing millions of dollars in annual losses due to diminished growth of Douglas-fir (Maguire et. al. 2002). Because of the high value of the Douglas-fir resource, a major research effort was initiated to understand the biology and epidemiology of the fungus (Manter et al. 2000, Manter et al. 2003, El-Hajj et al. 2004), its effect on growth and yield (Maguire et al. 2002, Mainwaring et al. 2005), and its response to various silvicultural treatments (Johnson 2002, Mainwaring et al. 2005).

Quantitative measures of disease severity are necessary for gauging the effect of the disease on any number of tree or stand variables. *Phaeocryptopus gaeumannii* enters needles through the stomates, and eventually produces fruiting bodies that physically block gas exchange, reduce carbon assimilation, and ultimately cause premature abscission (Manter et. al. 2000). The combination of premature needle abscission, reduced gas exchange of infected needles, and other non-stomatal limitations (Manter et al. 2000) result in reduced growth. Any estimate of disease severity should reflect the degree of reduction in photosynthetic capacity. Although numerous indices can measure SNC severity, the number of years of foliage retention is one of the most highly correlated with growth (Maguire et al. 2002). As a result, growth losses have been estimated as a function of foliage retention (Maguire et al. 2002, Mainwaring et al. 2005) and this relationship has recently been incorporated into a widely used regional growth model ORGANON (Garber et al. 2007).

Phaeocryptopus gaeumannii only infects the needles of newly expanding shoots, and the physical symptoms associated with fungal development over the following winter are most obvious in 1-yr old and older cohorts during the period just prior to budbreak. As a result, foliage retention has conventionally been assessed in April or May. This restriction of SNC severity rating to such a limited portion of the year increases the cost of assessments and reduces the total area that can be visited in any given year. The objective of this study was to document the seasonal change in foliage retention by repeatedly visiting sample trees, and to develop a calibration equation that allows pre-budbreak foliage retention to be predicted from foliage retention estimated at any other time of the year.

Methods

From part of a larger study looking at Douglas-fir response to different fertilizer treatments in SNC-infected stands, three stands along a gradient of SNC infection intensity were selected for repeated observation of foliage retention (figure 1, table 1). Because another objective of repeated observation was to sample the trend in foliar chemistry after different fertilizer treatments, four trees were selected at each site, one from each of four fertilizer treatments (control, urea, lime, and phosphorus). Foliage retention was assessed in May, June, July, August, September, and November of 2007, and in January, March and May of 2008. Four five-year old
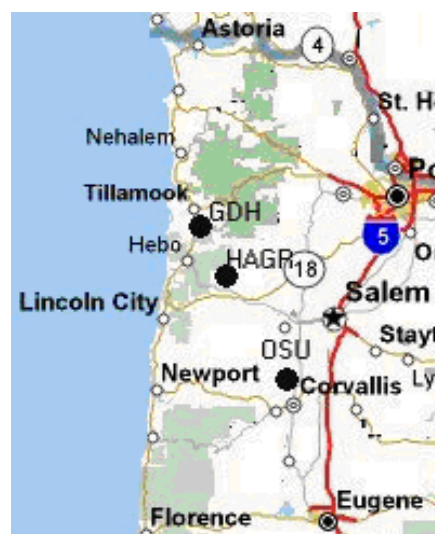

Fig. 1   Location of three sites

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lateral branches were observed per tree: the two largest laterals on the southernmost 8-year-old primary branch and the two largest laterals on the northernmost 8-year old primary branch. Needle retention was recorded as the percentage of retained needles per age class (nearest 10%). Multiple digital photographs were taken of each annual shoot as a means of maintaining a record of needle loss during the course of the year.

Table 1: Stand information

	Tree data					Plot data
Site	Foliage retention (av)	QMD (cm)	Ht (m)	CR	Age	TPH, df
GDH	1.62	29.2	21.1	0.64	19.8	751.2
HAGR	2.22	27.2	16.6	0.75	15.9	629.2
OSU	3.31	25.9	18	0.67	14.8	817.9

Of the three sites monitored, one showed significantly less than one year of needle loss during the year. Although this is probably a regular occurrence, it is an unpredictable complication which can't be estimated at the time of year that a foliage retention calibration equation would be used. Accordingly, we standardized actual foliar loss between June 2007 and May 2008 to one year by multiplying the cumulative loss during a given time period by (1/final measured loss). This standardization makes possible a calibration equation that may be applied in a stand assumed to have a stable disease presence.

Statistical analysis

The trend in foliage retention over an annual cycle was examined relative to initial foliage retention, defined as the foliage retention on May 17, 2007, just prior to budbreak. Under the assumption that foliage longevity is more or less at steady state, an entire age class of needles would have to be lost by the end of the annual cycle, i.e., by just prior to budbreak in 2008. However, annual fluctuations in foliage retention have been observed over the last 10 years, corresponding to annual weather variation and its effect on both the physiology of the tree and infection by *P. gaeumannii*. At each of the three study sites, final foliage retention (May 12, 2008) was slightly greater than initial foliage retention (May 19, 2007). To eliminate the effect of annual fluctuation on seasonal change in foliage retention, final retention was assumed equal to initial retention. Scaled foliage retention on any given sampling date was therefore computed as:

$$sFR_t = FR_0 + (FR_{peak} - FR_0) \cdot \frac{FR_t - FR_{end}}{FR_{peak} - FR_{end}}$$

[1]

where sFR_t is the scaled foliage retention at time t, FR_0 is initial foliage retention, FR_{peak} is peak foliage retention just after budbreak, FR_t is observed foliage retention at time t, and FR_{end} is observed foliage retention at end of annual cycle (fig. 2).

If foliage retention is observed any time between its peak just after budbreak and the following spring, standardization
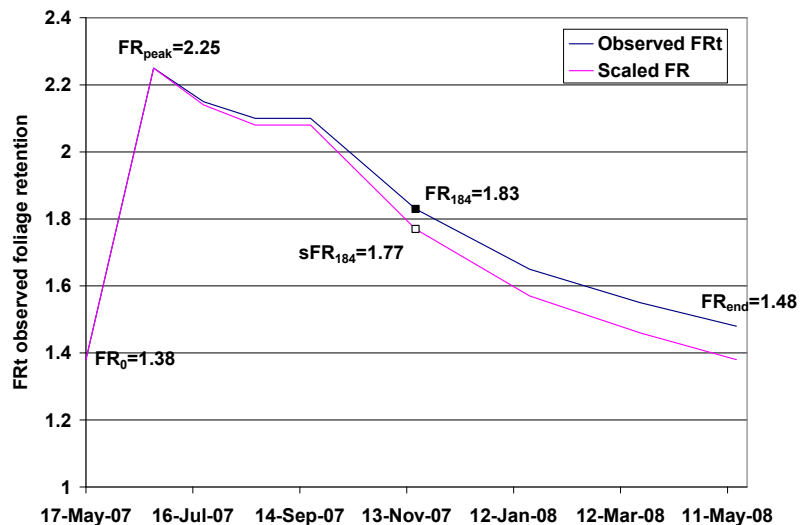

Fig 2: Example of scaled foliage retention relative to observed foliage retention.

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to spring retention, FR_0, can be achieved by determining the average trend in foliage retention in the sample trees. A regression model was fitted with the following response variable:

$$Y = sFR_t - FR_0 = (FR_{peak} - FR_0) \cdot \frac{FR_t - FR_{end}}{FR_{peak} - FR_{end}}$$
[2]

Standardization would be a function of the number of days since budbreak, so the following model was fitted to the data:

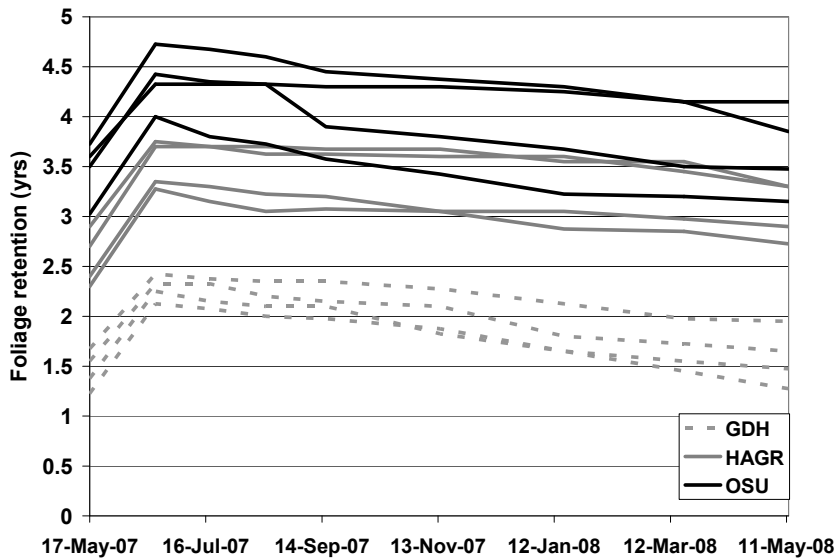$$Y = \frac{\alpha_0}{1 + \exp(\alpha_1 - \alpha_2 D)} + \varepsilon$$
[3]

where Y is defined above, D is the number of days after budbreak, α_0-α_2 are parameters to be estimated from the data, and $\varepsilon \sim N(0,\sigma^2)$. Random effects of tree and site on parameter α_1 were also tested by fitting non-linear mixed-effects models with SAS PROC NLMIXED (SAS Institute Inc. 1996).

Table 2. Parameter estimates for model describing an increase in foliage retention from May 17, 2007 (equation[1]).

Variable	Parameter Estimate	Standard Error
α_0	0.9693	0.09791
α_1	2.3289	0.1963
α_2	0.01310	0.00207

Results

Foliage was lost progressively during the year regardless of initial foliage retention, with considerable variation between and within sites (fig. 3,4,5). Tree level random effects were only marginally significant (p=0.092) and thus not included in the final model output. Parameter estimates for equation [3] (table 2) indicated the decline in foliage retention from the beginning of the growing season through the summer, fall, winter, early spring. The trend in foliage loss predicted by the model (fig. 6) was most rapid during the fall, similar to that found in other studies (Weiskittel and Maguire 2007). At the moderately infected site (HAGR), only about 0.5 yrs of foliage was lost during the course of the year, implying that total net foliage retention improved from spring 2007 to spring 2008 (fig. 4).

Fig. 3 Foliage retention of the 12 sampled trees between May 17, 2007, and May 12, 2008.
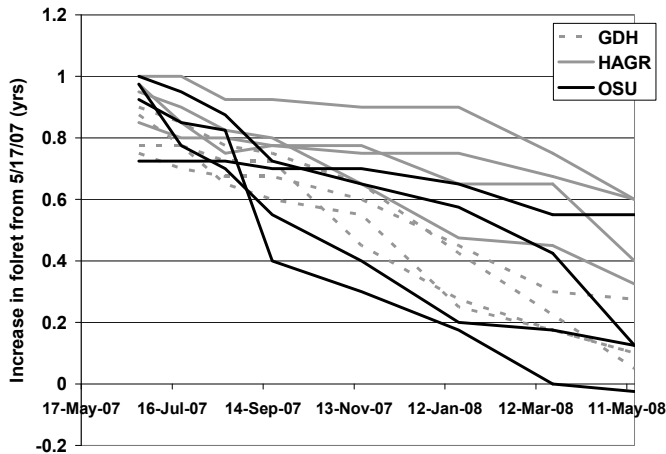
Fig 4: Decrease in foliage retention per tree relative to May 17, 2007 following budbreak
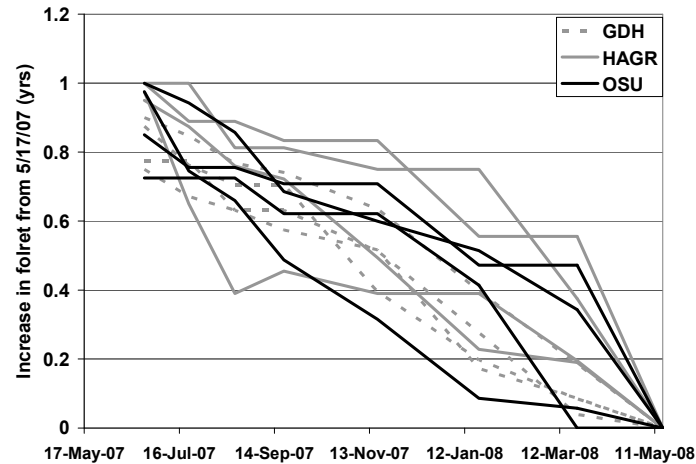
Discussion

Fig 5: Scaled decrease in foliage retention on each tree following budbreak in May 2007.

In contrast to some foliar diseases, foliage retention in SNC-infected trees is negatively associated with height in the crown (Hansen et al. 2000). The standard procedure for assessing foliage retention from the ground in trees of this age involves estimating values for each of the upper, middle, and lower crown thirds, and then averaging the three values for a tree-level estimate. Generally speaking, this tree-level value is similar to that of the middle crown third. For the trees sampled, the eighth whorl corresponds to 30-48% of height within the crown, and is thus roughly comparable to the lower half of the middle crown-third. Branch monitoring on these sites began in December 2006; regular needle collections began on branches of the sixth whorl, and foliage retention was assessed on branches of the seventh whorl. Continued monitoring of foliage retention for a full year starting in May 2007 on the same branches meant that assessments were the made on the eighth whorl, somewhat lower than what might be considered representative of the whole crown.

A calibration equation based on only one growing season must be used with caution. These results, based on scaled foliar loss, will accurately estimate foliar loss on a site experiencing stable SNC infection levels. If foliage retention is predicted to increase or decrease, scaled predictions from the model can be applied as relative loss and multiplied by net gains or losses of >1 or <1, respectively. In fact, Swiss needle cast infection and
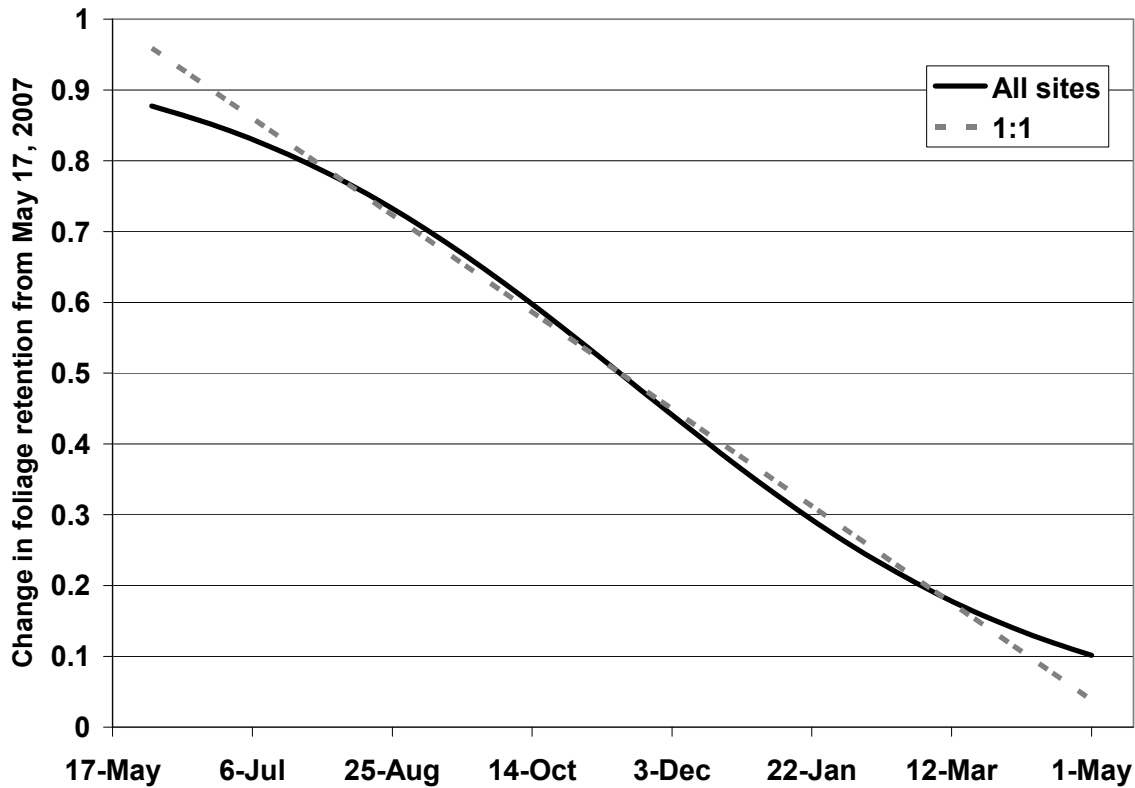
28

Fig 6: Predicted trend in average foliage retention from time of peak retention (just after budbreak) to the end of the annual cycle (just prior to budbreak), compared to a linear trend over the same period.

development rates are related to climate variables (Manter et al. 2005), so infection levels and related symptoms such as annual foliar loss can differ between years. Positive and negative changes in foliage retention have been noted in different years on repeatedly measured plots (Mainwaring et al. 2007), and some evidence of this was evident on the HAGR site, where there was less 2004 foliage than 2003 foliage. The HAGR site also has experienced the least amount of foliar loss of any of the sites (fig. 4), and has lost less foliage than the infection-free site at OSU. This result suggests that while the OSU site lost foliage from older age classes at rates expected of trees under endemic or very low SNC severity, infected needles from older age classes at HAGR have already abscised, and younger age classes (2005 and newer) that are only lightly infected are being retained. The parameter estimates provided in table 2 are easily adapted to successive years experiencing or predicted to experience a net increase or decrease in foliage retention.

The 1:1 line in Figure 6 indicates that a linear decline in foliage retention from budbreak provides a close approximation to average foliage loss over the course of a year. The difference between the predicted trend and the 1:1 line never exceeds 0.1 yrs, with the largest difference occurring during the 1.5 months following budbreak. Table 3 provides calibration values based on both equation [1] and a linear trend over the same annual cycle. Managers can standardize foliage retention values observed on any date by subtracting the listed value.

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The adjusted foliage retention represents an estimate of foliage retention that would have been observed just prior to budbreak.

Date	Eqn [1]	1:1
31-May	0.88	0.96
14-Jun	0.86	0.92
28-Jun	0.84	0.88
12-Jul	0.82	0.84
26-Jul	0.80	0.81
9-Aug	0.77	0.77
23-Aug	0.74	0.73
6-Sep	0.70	0.69
20-Sep	0.67	0.65
4-Oct	0.63	0.61
18-Oct	0.59	0.58
1-Nov	0.54	0.54
15-Nov	0.50	0.50
29-Nov	0.45	0.46
13-Dec	0.41	0.42
27-Dec	0.37	0.38
10-Jan	0.33	0.35
24-Jan	0.29	0.31
7-Feb	0.25	0.27
21-Feb	0.22	0.23
6-Mar	0.19	0.19
20-Mar	0.16	0.15
3-Apr	0.14	0.12
17-Apr	0.12	0.08
1-May	0.10	0.04

Table 3. Calibration values in years of foliage by date: based on equation [1] and linear change (1:1). Values should be subtracted from foliage retention at given date, providing estimated pre-budbreak foliage retention. Assumes bud break prior to May 31

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Sampling Efforts of Foliar Nutrients in Coastal Douglas-fir
Tzeng Tih Lam and Doug Maguire, Oregon State University

Introduction

Chemical analysis of foliage plays an important role in understanding the current status of nutrient levels or ratios in a forest stand. It can also be used to diagnose any nutrient limitation and imbalances that might occur in the given forest stand. Numerous studies have looked at how foliar nutrients vary by season, age, crown position and species (e.g. Lamb 1976, Zhang and Allen 1996). Recognizing the variability of nutrient content within tree crowns, one of the objectives of the studies is to develop appropriate and efficient sampling design. Multilevel subsampling is the general strategy in sampling foliage for chemical analysis. However there is a need to understand how to allocate sampling efforts to each level.

The objectives of this study are to understand the variability in different levels of subsampling, and recommend where one should allocate the sampling efforts to reduce variability and to achieve precise estimates of nutrients levels.

Methods

The methods and foliar analysis are based on those described in "Within-crown variability of foliar nutrients in coastal Douglas-fir" (Doug Mainwaring and Doug Maguire; 2008 SNCC Annual Report). Briefly, three study sites of young Douglas-fir were selected. Within each site, four trees were sampled (individual tree plot). Four different treatments were randomly assigned to each tree. For each tree within a site, six whorls were selected where one branch per whorl was chosen. Two laterals per branch were selected. For each lateral, enough foliage was removed to provide ~1 g of dried foliage for each age class for up to five cohorts.

Statistical Analysis

The first analysis investigated the nutrient level variability in different levels of subsampling. The analysis used nutrient levels from 1 year-old and 2 year-old foliage. 1 year-old and 2 year-old foliage were used as this is often the standard method for other nutrient level analysis. The analysis was carried in SAS PROC MIXED based on the following model:

Let,

y_{ijkl} Year 1 or 2 needle nutrient level of lth lateral on j^{th} whorl in i^{th} treatment of kth site

μ Overall mean

α_i i^{th} treatment effect

b_k k^{th} site effect

$(ab)_{ik}$ Interaction effect of ith treatment and k^{th} site

d_{ijk} Sampling error of jth whorl in i^{th} treatment of kth site

m_{ijkl} Sampling error of lth lateral on j^{th} whorl in i^{th} treatment of kth site

σ_b^2 Variation between sites

σ_e^2 Variance of interaction effect

σ_d^2 Variation between whorls of a given treatment in a site

σ_m^2 Variation within whorl of a given treatment in a site

$$y_{ijkl} = \mu + \alpha_i + b_k + (ab)_{ik} + d_{ijk} + m_{ijkl}$$

From the model, one is most interested in the estimated values of σ_d^2, σ_b^2 and variance σ_m^2. σ_m^2 describes the variation in nutrient content for 1 or 2 year-old foliage within a given whorl of a treatment in a site. σ_d^2 and σ_b^2 describes variation in the nutrient content between whorls of a given treatment in a site and between sites respectively. Estimated relative variances of between whorls and between sites are calculated as (σ_b^2/σ_m^2) and (σ_d^2/σ_m^2) respectively. The relative variances provide clues to the magnitude of difference in the three variances and suggest allocation of sampling efforts.

The second analysis is investigating tree-to-tree variation. The current experimental design does not permit such analysis as we did not have more replicates of each treatment within a site. Alternatively, it is possible to make informal analysis if we pretend that the four trees within a site were not treated. The model for the analysis based on 2-year old foliage is,
Let,

y_{ijkl} Year 2 needle nutrient response of lth lateral on j^{th} whorl in i^{th} tree of kth site

μ Overall mean

$a_{i(k)}$ i^{th} tree effect nested in k^{th} site

b_k k^{th} site effect

d_{ijk} Sampling error of jth whorl in i^{th} tree of kth site

m_{ijkl} Sampling error of lth lateral on j^{th} whorl in i^{th} tree of kth site

σ_a^2 Variation between trees in a site

σ_b^2 Variation between site

σ_d^2 Variation between whorls of a given tree in a site

σ_m^2 Variation within whorl of a given tree and a site

$$y_{ijkl} = \mu + a_{i(k)} + b_k + d_{ijk} + m_{ijkl}$$

σ_a^2 measures tree-to-tree variation within a site as if the trees were not treated. We can assume that the estimated value is the maximum amount of variability between trees of a site. It can serve as the upper bound of variability. In other words, if value of σ_a^2 is very small, it implies that trees are very similar within a site (i.e. 4 individual tree plots are sufficient for the current experiment). On the contrary, if value of σ_a^2 is large, this says that trees are different within the site and we would need to have more than one replicates for each treatments.

Results

Table 1. Relative variance for between whorls variance and between sites variance based on 1 year-old foliage.

	Relative Variance of 1 Year-Old Foliage		
	Within Whorl	Between Whorls[1]	Between Sites[2]
Boron	1.00	0.09	0.78
Calcium	1.00	0.00	1.03
Carbon	1.00	0.00	0.03
Copper	1.00	0.10	0.00
Iron	1.00	0.00	0.01
Magnesium	1.00	0.18	1.29
Manganese	1.00	0.10	0.87
Nitrogen	1.00	0.96	0.18
Phosphorus	1.00	0.08	1.77
Potassium	1.00	0.52	0.78
Sulfur	1.00	0.00	0.19
Zinc	1.00	0.00	0.00

[1] estimated as σ_b^2 / σ_m^2 ; [2] estimated as σ_d^2 / σ_m^2

Table 1 summarizes the relative variance of between sites (σ_b^2) and between whorls of a given treatment in a site (σ_d^2) to variance of within whorls of a given treatment in a site (σ_m^2) for each nutrient based on foliage nutrient analysis for 1 year-old foliage. The variances of between whorls are very small – the magnitude of relative variances are generally less than 0.10 – compared to variance of within whorls for all nutrients except nitrogen and potassium. This indicates that 1 year-old needles from different laterals within a whorl are very different in the amount of majority of the nutrients. On the other hand, nutrient content of most of the nutrients is rather consistent within a tree crown. The variances between sites are generally as large as or larger than variances within whorl except for carbon, copper, nitrogen, iron, sulfur and zinc. This is expected as sites are different from each other.

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Table 2. Relative variance for between whorls variance and between sites variance based on 2 year-old foliage.

	Relative Variance of 2 Year-Old Foliage		
	Within Whorl	Between Whorls	Between Sites
Boron	1.00	0.39	1.18
Calcium	1.00	0.10	1.30
Carbon	1.00	0.04	0.17
Copper	1.00	0.34	0.00
Iron	1.00	0.07	0.00
Magnesium	1.00	0.48	0.08
Manganese	1.00	0.37	2.76
Nitrogen	1.00	0.72	1.10
Phosphorus	1.00	1.79	5.50
Potassium	1.00	1.22	0.85
Sulfur	1.00	0.01	0.26
Zinc	1.00	0.38	0.14

According to Table 2, the relative variance results are different for 2-year old foliage compared to 1-year old foliage. Only the relative variances between whorl for calcium, carbon and sulfur are fairly small. This implies that the amount of majority nutrients on 2 year-old needles is fairly different between whorls in a tree. Except for copper and iron, Table 2 shows that – as expected – site to site variation for a nutrient is fairly large.

Table 3. Relative variance of between trees based on 2 year-old needles.

	Relative Variance of 2 Year-Old Foliage	
	Within Whorl	Between Trees[1]
Boron	1.00	0.81
Calcium	1.00	0.52
Carbon	1.00	0.01
Copper	1.00	0.96
Iron	1.00	0.21
Magnesium	1.00	0.78
Manganese	1.00	1.47
Nitrogen	1.00	0.87
Phosphorus	1.00	0.82
Potassium	1.00	1.37
Sulfur	1.00	0.35
Zinc	1.00	0.83

[1] estimated as σ_a^2 / σ_m^2 ;

Table 3 clearly shows that, except for carbon, nutrient content is fairly different between trees within a site. Some nutrients such as manganese and potassium can be more different between trees than within a whorl for a given trees.

Discussions

Recommendations and results can be summarized into three points as follows:

(1)   For allocating sampling effort, it will depend whether 1 or 2 year-old needles are used for the analysis. If 1 year-old needles are used for analysis, then sampling six whorls along tree crown would be sufficient for our sites (except for nitrogen and potassium). If 2 year-old needles are used for analysis, then we would have to sample more whorls within tree crown. Nonetheless, within whorl variation is large for most of the nutrients; this is to say that it would be worthwhile to sample more than two laterals along a branch for 1 and 2 year-old needles.

(2)   Although for most nutrients the variation in amount between whorls is much smaller than variation in amount within whorl, previous study on "Within-crown variability of foliar nutrients in coastal Douglas-fir" (Mainwaring and Maguire, 2008 SNCC Annual Report) shows that gradient of nutrient content still exists within crown.

(3)   Except for carbon, nutrient amount between trees within a site for a given nutrient is very variable. This suggests that some effort should be spent in creating more individual tree plots; i.e. more than one replicate for each treatment within a site.

Literature Cited

Lamb, D. 1976. Variations in the foliar concentrations of macro and micro elements in a fast growing tropical eucalypt. Plant and Soil. 45:477-492.

Zhang, S. and Allen, H.L. Foliar nutrient dynamics of 11-yr old loblolly pine following nitrogen fertilization. Can. J. For. Res. 26:1426-1439.

Foliar Nutrient Dynamics of Swiss Needle Cast Infected Douglas-fir Following Fertilization

Doug Mainwaring and Doug Maguire, Oregon State University

Introduction

Chemical analysis of foliage has often been used as a means of determining the nutritional status of a tree or stand (Weetman 1992). With prior knowledge of species-level nutrient requirements, foliar chemistry can be used to diagnose nutrient limitations and determine fertilizer treatments to address these limitations. It is well known that foliar chemistry varies greatly by species, site, season, crown position, and foliage age (Turner et al. 1977). Sampling protocols for Douglas-fir foliage have been based on limited studies addressing sources of foliar nutrient variability for both Douglas-fir and other species (Lavender and Carmichael 1966, Turner et al. 1977). However, many questions remain about sampling foliage and interpreting foliar chemistry to prescribe fertilization treatment, (e.g. the influence of Swiss needle cast (SNC)). Samples collected from the Beyond Nitrogen fertilizer trial sites, representing a gradient of SNC-severity, made it possible to quantify mean trends and variability in foliage dynamics of Douglas-fir across a range in fertilizer treatments and SNC intensities.

The goal of this project was to quantify patterns in Douglas-fir foliar chemistry under SNC and several fertilization treatments. Specific objectives include:

(1) Quantify the effects of SNC and fertilization treatments (including control) on needle size and needle nutrient concentration by age class;

(2) test and quantify the effects of SNC and fertilization on needle size and nutrient concentrations among age classes over the course of a year.

Other objectives originally part of this project included 1) the development of an equation able to standardize field estimates of foliage retention conducted at any time of the year to the pre-budbreak period; and intensive crown sampling of Douglas-fir trees to both 2) develop quantitative relationships between foliar nutrient levels and variables such as crown position, needle age, and foliage retention; and 3) analyze sources of sampling error during collection of foliage samples for chemical analysis so as to develop better guidelines for needle sampling. These three subjects are addressed in other reports within this publication.

Methods

The Beyond Nitrogen Fertilization project involves 16 separate sites, each with five or seven treatments distributed among 10 individual dominant/codominant trees. Treatments include 1) control; 2) nitrogen; 3) Lime; 4) Calcium chloride; 5) Phosphorus; 6) Site specific Kinsey blend; 7) Site-specific Fenn blend. Sites were fertilized in February-April 2007. Specific fertilizer quantities are shown in the **One year response to fertilization on the Beyond Nitrogen plots** report contained in this publication.

Objective one: needle weight and nutrient correlations
On all measurement trees on all sites, a 20-needle subsample was randomly picked from each foliage age class of the 5-yr-old fall 2007 sample branch, then lumped into a composite sample by site and treatment. Samples were dried, weighed, and submitted to the OSU Central Analytical Laboratory for chemical analysis. This data represented conditions one growing after treatment.

Objective two: seasonal trends

On three sites of the BNF project (Green Diamond/Hemlock, Hampton/Grand Ronde, and OSU's MacDonald-Dunn Research Forest) one average tree from each of four treatments (control, N, P, lime) was selected from among the 10 trees in each treatment (table 1). Nine separate visits were made to each site in the middle of January, March, April, May, June, July, August, September, and November 2007. Starting in January ~200 needles were picked from each of the four age classes on a five-year secondary lateral of a 6th whorl branch. Needles were picked from the same branches following the flush of new shoots in June, thus constituting the six year-old lateral of a 7th whorl branch. Each 200-needle sample was dried, weighed, and submitted to the OSU Central Analytical Laboratory for chemical analysis.
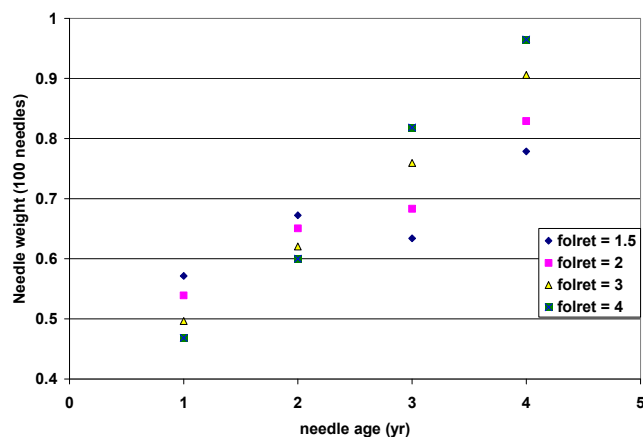
Table 1: Characteristics of the repeatedly sampled trees

Site	Tree	Trt	dbh (cm)	ht (m)	cr	Foliage retention (April 2007)
GDH	644	Control	30.3	21.1	0.60	1.68
GDH	647	Lime	29.5	21.6	0.70	1.55
GDH	640	Nitrogen	28.9	20.6	0.66	1.23
GDH	653	Phosphorus	28.5	20.4	0.61	1.38
HAGR	258	Control	26.4	15.7	0.72	2.30
HAGR	253	Lime	28.5	19.2	0.74	2.40
HAGR	260	Nitrogen	27.9	16.3	0.75	2.90
HAGR	254	Phosphorus	27	17.5	0.77	2.70
OSU	2263	Control	25.9	18.3	0.62	3.50
OSU	2982	Lime	25.8	17.2	0.59	3.73
OSU	2976	Nitrogen	25.8	18.1	0.62	3.03
OSU	2264	Phosphorus	25.5	18.4	0.64	3.60

Results and Discussion

Objective one: needle weight and nutrient correlations

The logarithm of needle weight was highly dependent on age class, foliage retention, and their interaction, which together explained ~76% of the variation in needle weight. Figure 1 shows the implied needle weights for 1-4 year old needles at different levels of foliage retention. In stands with little or no SNC, annual gains in needle weight are roughly equivalent. Stands with a significant SNC presence showed relatively high weights in young cohorts and relatively low weights in older cohorts. It should be pointed out that these results are specific to four year old branches collected in 2007, thereby reflecting the SNC levels during the previous four years rather than a universal result.
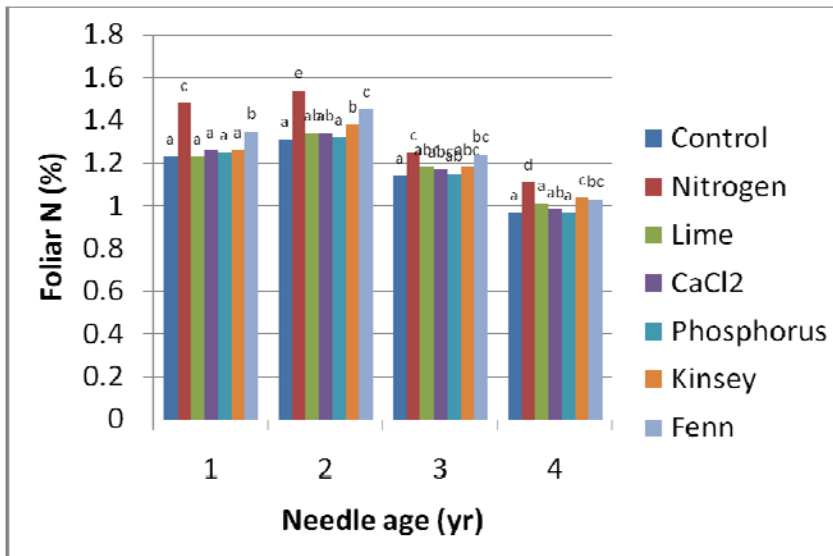

Figure 1 Implied needle weight by age and foliage retention

Figure 2 Foliar nitrogen 1 yr after treatment. Columns with different letters are significantly different from each other, within age class.

Figure 4 Foliar potassium 1 yr after treatment. Columns with different letters are significantly different from each other, within age class.
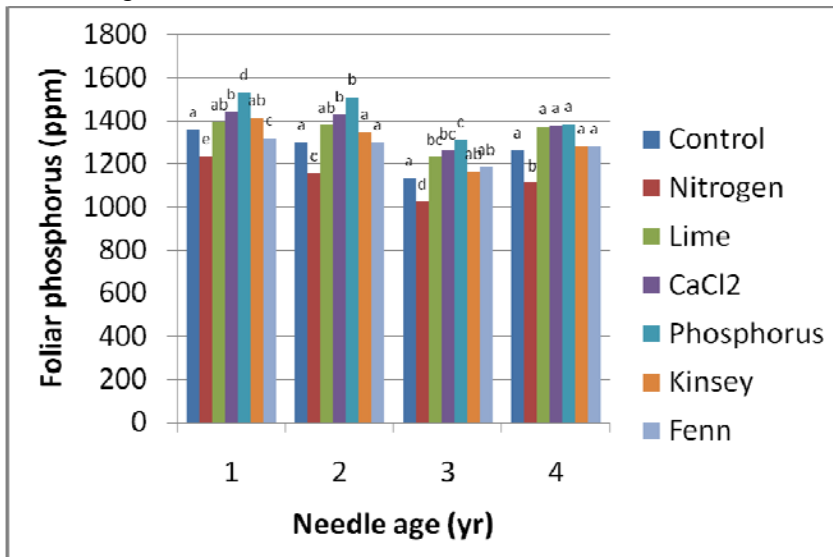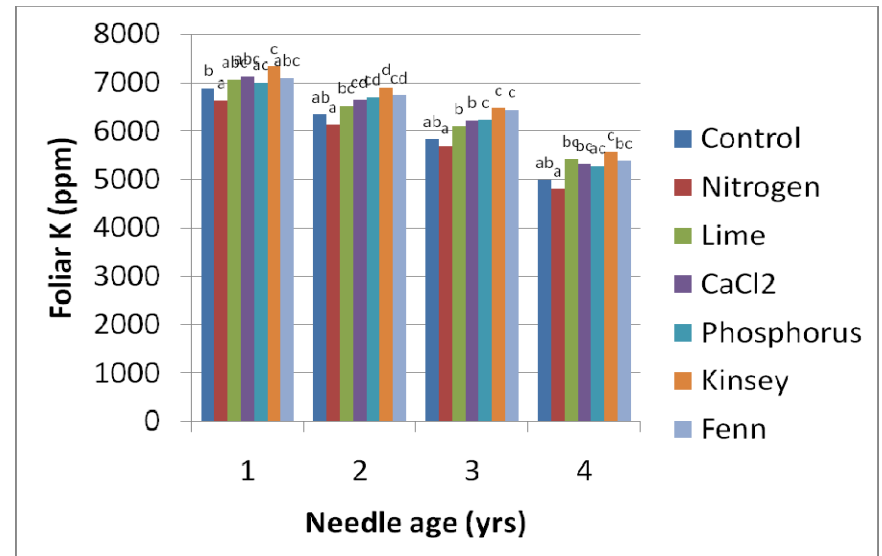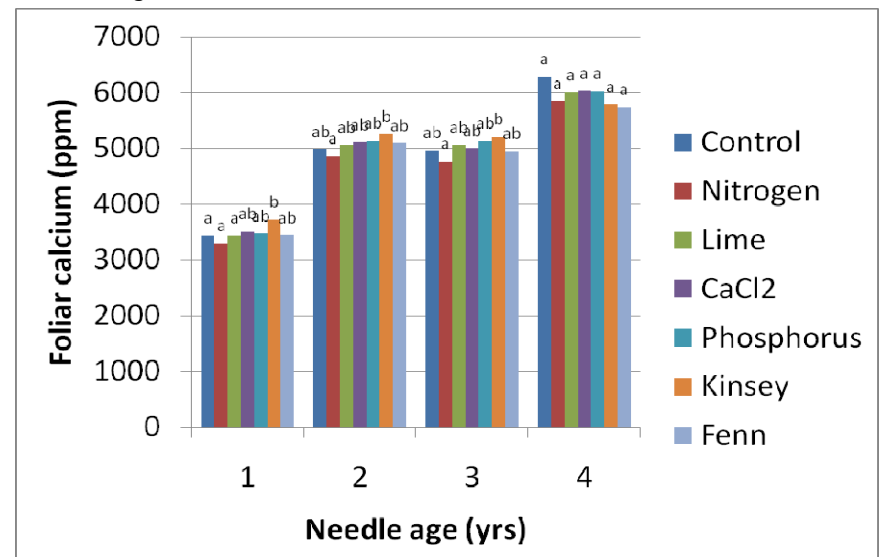

Figure 3 Foliar phosphorus 1 yr after treatment. Columns with different letters are significantly different from each other, within age class.

Figure 5 Foliar calcium 1 yr after treatment. Columns with different letters are significantly different from each other, within age class.
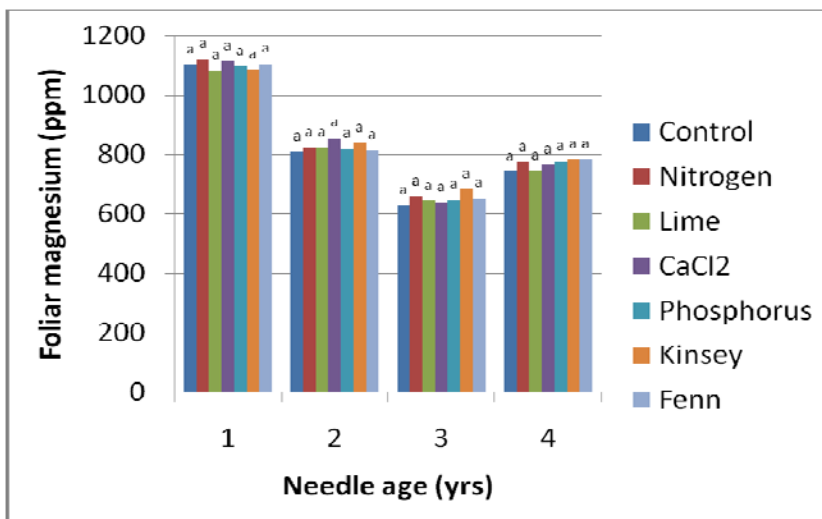
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Figure 6 Foliar magnesium 1 yr after treatment. Columns with different letters are significantly different from each other, within age class.

Figure 8 Foliar copper 1 yr after treatment. Columns with different letters are significantly different from each other, within age class.
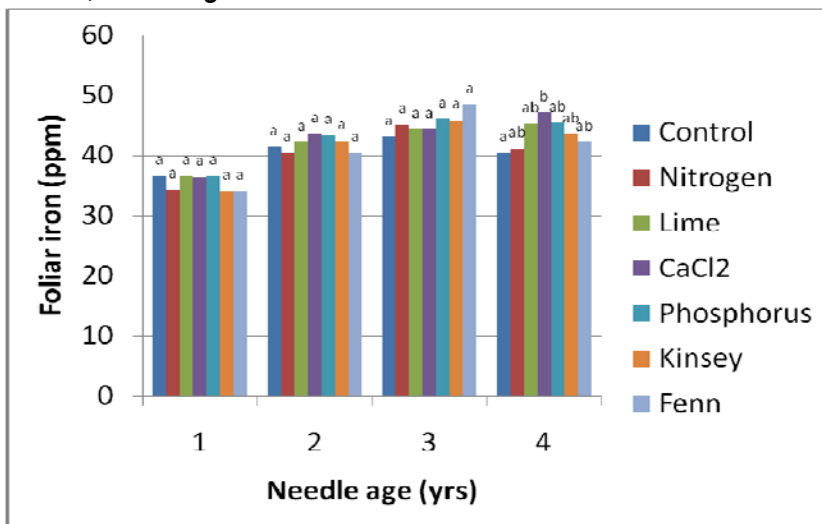

Figure 7 Foliar iron 1 yr after treatment. Columns with different letters are significantly different from each other, within age class.
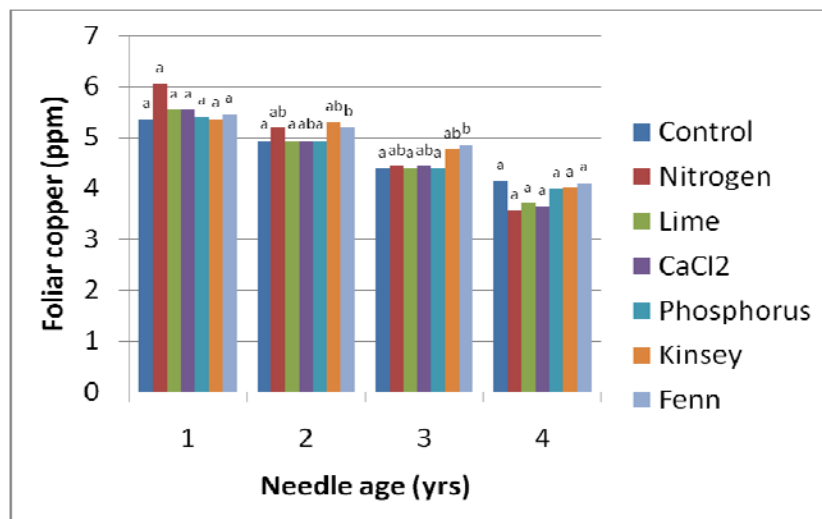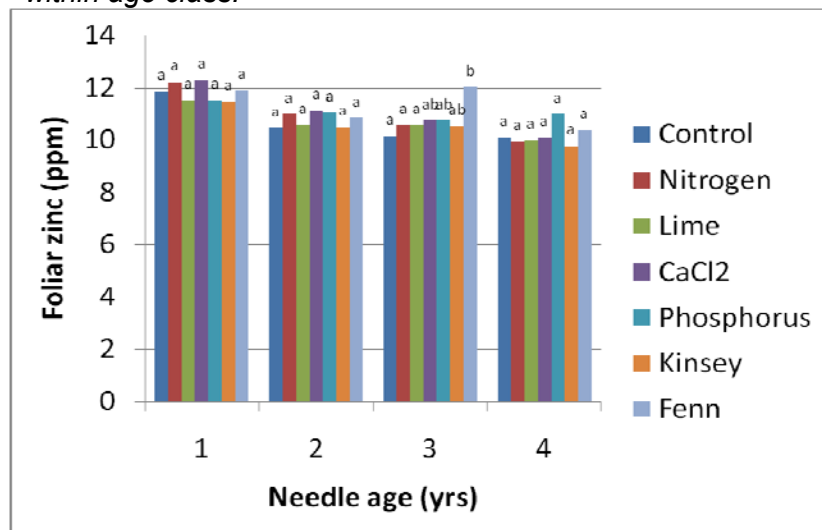

Figure 9 Foliar zinc 1 yr after treatment. Columns with different letters are significantly different from each other, within age class.

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These results, combined with Weiskittel's (2003) positive correlation between needle weight and foliage retention suggest that infection rates were relatively high for the 2004 and 2005 needle cohorts, which has been speculated based on other information (Mainwaring et al. 2007). The greater mass of the one and two year old cohorts in infected stands is perplexing, given the results of Weiskittel (2003). It has been observed that highly infected trees can produce relatively large needles in low numbers. Although it's possible that larger/heavier (main branch axis) needles may be held longer by the tree, this would more likely be reflected in a larger relative mass in older cohorts, after casting has largely occurred.

Fertilizer treatment was a marginally significant factor in predicting foliar weights (p=0.088) after accounting for site, year, and a site*year interaction. Predictably, given the only marginal significance of the factor as a whole, foliar weights on trees of the individual fertilizer treatments did not differ from the control.
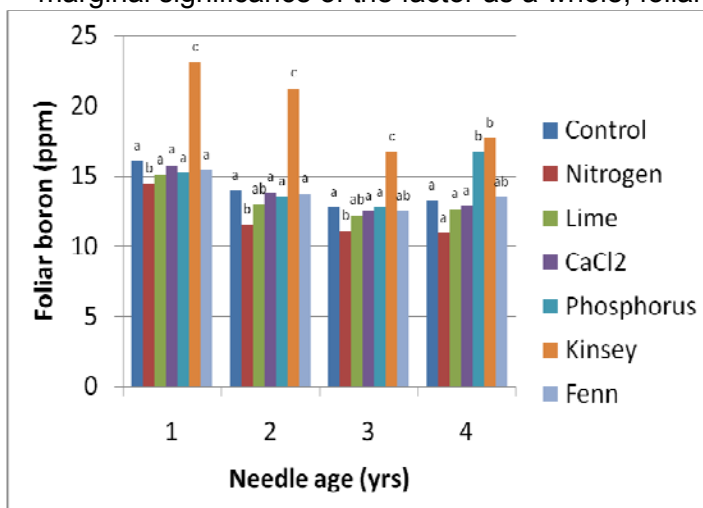

Figure 10 Foliar boron 1 yr after treatment. Columns with different letters are significantly different from each other, within age class.
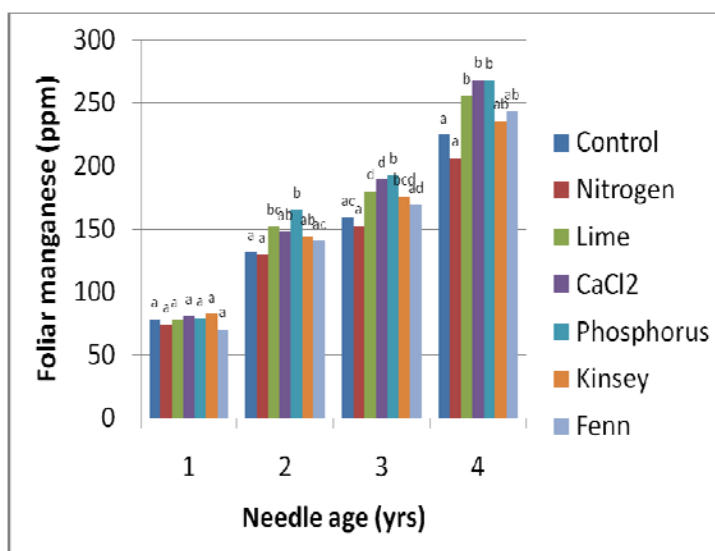

Figure 11 Foliar manganese 1 yr after treatment. Columns with different letters are significantly different from each other, within age class.

Graphs of nutrient concentrations by treatment by age class are presented in figures 2-11. Nitrogen (fig. 2), phosphorus (fig. 3), and boron (fig. 10) appear to have the largest direct increases in concentration following treatment. In contrast, numerous nutrients appear to have been diminished in concentration within all age classes following urea treatment, likely due to growth fueled dilution. Specifically, this would include phosphorus (fig. 3), potassium (fig. 4), calcium (fig. 5), boron (fig. 10), and manganese (fig. 11). Certain elements show clear gradients in concentration with age class, whether positive (calcium, iron, manganese) or negative (nitrogen, potassium, magnesium, copper, and zinc). These patterns are generally consistent with previous work (Lavender and Carmichael 1966, Marschner 1995).

When foliage retention was added as a covariate to the model accounting for site and treatment, it was not statistically significant. This is not surprising given the relatively small range of foliage retentions within a site. If site was not included in the model, foliage retention was positively correlated with phosphorus, potassium, calcium, magnesium, boron, and manganese, and negatively correlated with nitrogen and iron. Some of these relationships have been reported previously (Maguire et al. 2000). Nevertheless, because of the geographic

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gradient of foliage retention, it is difficult to determine how much of the correlations are related to SNC severity, and how much they are related to site factors for which foliage retention is a surrogate.

Table 2 p-values associated with tests of nitrogen difference between urea and control treatment

foliage age	factor	Jan	March	April	May	June	July	August	Sept.	Nov.
Year1	Trr	0.175	0.16	0.243	0.152	0.087	**0.011**	0.092	**0.009**	**0.0243**
	Site	0.266	0.117	0.101	0.181	0.131	0.875	0.933	0.176	0.239
Year2	Trt	0.585	0.693	0.793	0.556	0.201	0.121	0.132	0.089	0.137
	Site	0.164	0.148	0.112	0.193	0.353	0.226	0.552	0.161	0.321
Year3	Trt	0.766	0.861	1	0.972	0.494	0.354	0.252	0.33	0.295
	Site	0.353	0.451	0.415	0.544	0.305	0.242	0.62	0.269	0.255
Year4	Trt	0.93	0.934	0.902	0.921	0.942	0.76	0.774	0.476	0.609
	Site	0.282	0.34	0.515	0.542	0.619	0.5	0.482	0.382	0.405
Year5	Trt					0.805	0.838	0.77	0.724	0.143
	Site					0.569	0.529	0.562	0.431	0.328

Table 3 p-values associated with tests of calcium difference between lime and control treatment

foliage age	factor	Jan	March	April	May	June	July	August	Sept.	Nov.
Year1	Trr	0.297	0.216	0.609	0.317	0.163	0.255	0.383	0.296	0.479
	Site	0.055	0.06	0.084	0.072	**0.027**	**0.046**	0.1	**0.047**	0.081
Year2	Trt	0.0259	0.283	0.351	0.378	0.959	0.292	0.573	0.321	0.292
	Site	0.094	0.125	0.137	0.135	0.498	0.092	0.165	0.138	0.166
Year3	Trt	0.884	0.25	0.246	0.283	0.396	0.282	0.254	0.404	0.249
	Site	0.463	0.168	0.156	0.157	0.087	0.137	0.096	0.101	0.105
Year4	Trt	0.26	0.283	0.309	0.37	0.346	0.296	0.278	0.271	0.194
	Site	0.128	0.175	0.19	0.176	0.155	0.217	0.165	0.13	0.165
Year5	Trt					0.555	0.294	0.201	0.222	0.345
	Site					0.109	0.175	0.101	0.077	0.207

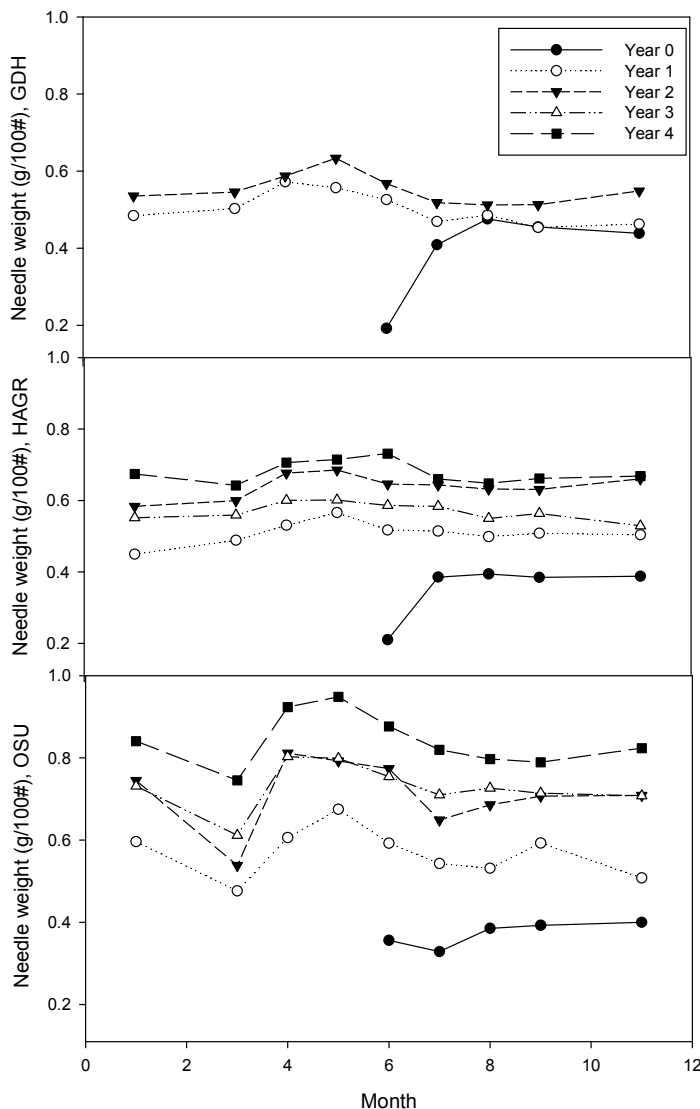*Table 4 p-values associated with tests of phosphorus difference between P and control treatment*

foliage age	factor	Jan	March	April	May	June	July	August	Sept.	Nov.
Year1	Trr	0.438	0.151	0.569	0.562	0.505	0.377	0.523	0.348	0.358
	Site	0.227	**0.022**	0.817	0.609	0.76	0.274	0.314	0.223	0.603
Year2	Trt	0.762	0.846	0.673	0.751	0.8436	0.488	0.578	0.452	0.251
	Site	0.5	**0.038**	0.506	0.212	0.118	0.323	0.484	0.414	0.536
Year3	Trt	0.5	0.295	0.704	0.325	0.835	0.624	0.492	0.368	0.289
	Site	0.164	0.107	0.27	0.093	**0.034**	0.205	0.168	0.134	0.295
Year4	Trt	0.742	0.644	0.561	0.769	0.064	0.373	0.448	0.287	0.224
	Site	0.225	0.162	0.214	0.191	0.109	0.136	0.169	0.103	0.183
Year5	Trt					0.721	0.594	0.527	0.423	0.509
	Site					0.075	0.182	0.237	0.138	0.354

Objective two: seasonal trends

Needle weights were generally positively correlated with age with the exception of year 3 needles at OSU and HAGR (fig. 12). Needle weights were variable throughout the year, with each cohort reaching a maximum value just prior to the onset of shoot growth and then decreasing. Presumably, this maximum results from older needles acting as a reservoir of resources for the newly expanding shoots. Tests of significance for an SNC effect were negative.

Monthly foliar analysis makes it possible to monitor the timing of uptake of specific nutrients. Tables 2-4 provide tests of statistical significance for treatment and site effects on N, P, and Ca by month on the urea, phosphorus and lime treatment plots, respectively. These results indicate that significant increases in applied nutrients were apparent only for nitrogen in current year foliage. In addition, there is some evidence of a nitrogen increase in two-yr-old foliage marginal difference in Sept, relatively low p-values in other months). The difference between these results and that shown in figures 2 and 3 (where nitrogen and phosphorus concentrations are significantly greater in N and P treated trees than control trees in all but one age class) can probably be attributed to both the small number of trees and sites being compared in the monthly sample. In contrast, figures 2-11 are based on all trees from all sites, and thereby represent an average response from all sites: a specific site (including one or more of those repeatedly sampled) may not respond similarly, and given the between-tree variability, a small number of sample trees makes discerning significant responses still more difficult.

Because the three sites used for repeated sampling correspond to high, moderate, and minimal SNC-infection severity, site is included in tables 2-4 as a test of SNC-influence on nutrient concentration. SNC severity is apparently not related to differences in N, P, and Ca concentrations following treatment. Particularly in the case of calcium (table 4), marginally significant site differences were apparent before and

Figure 12 Needle weights by month, site, and needle cohort
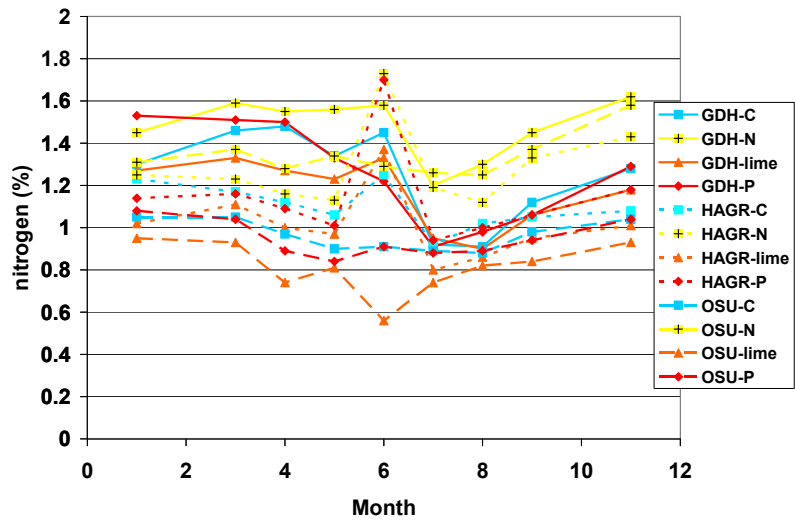
43

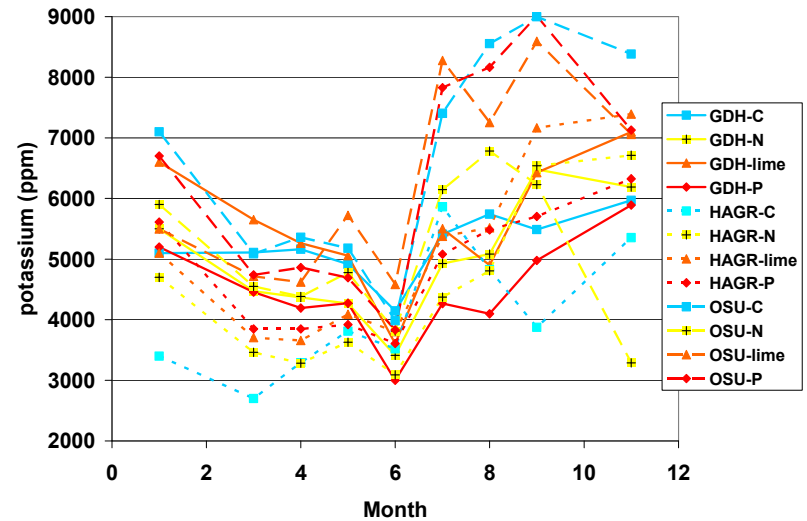*Figure 13   Foliar nitrogen by month on 12 sampled*

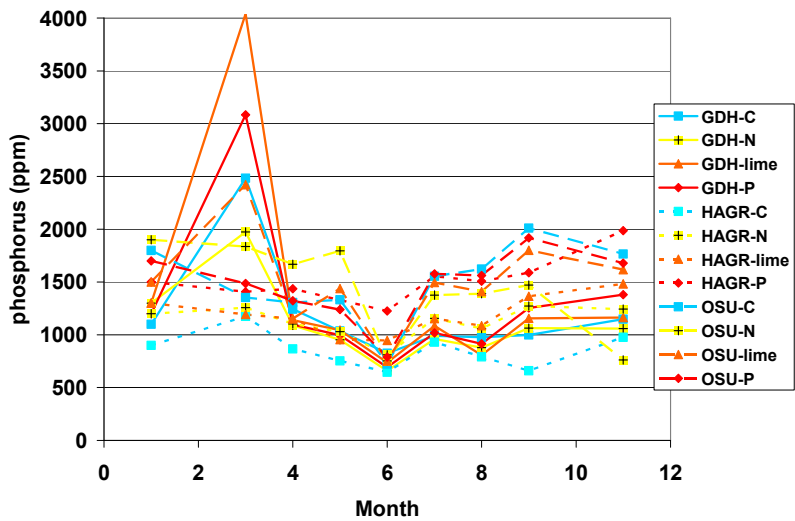*Figure 15 Foliar potassium by month on 12*

Figure 14 Foliar phosphorus by month on 12
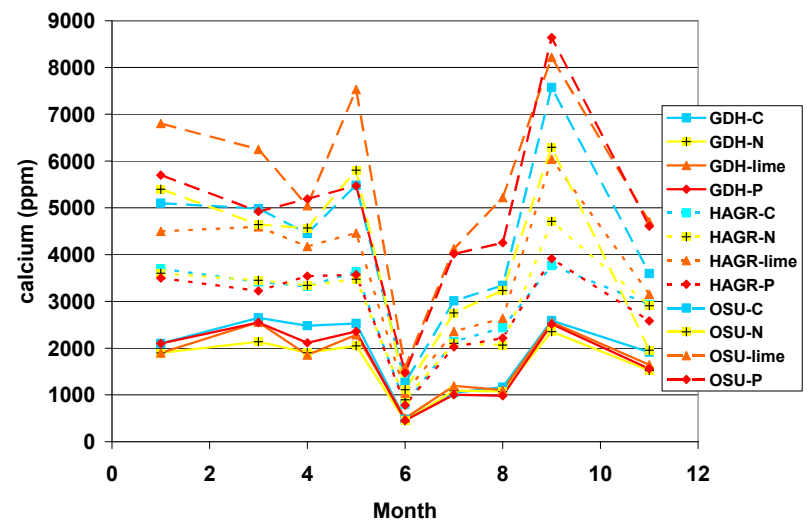

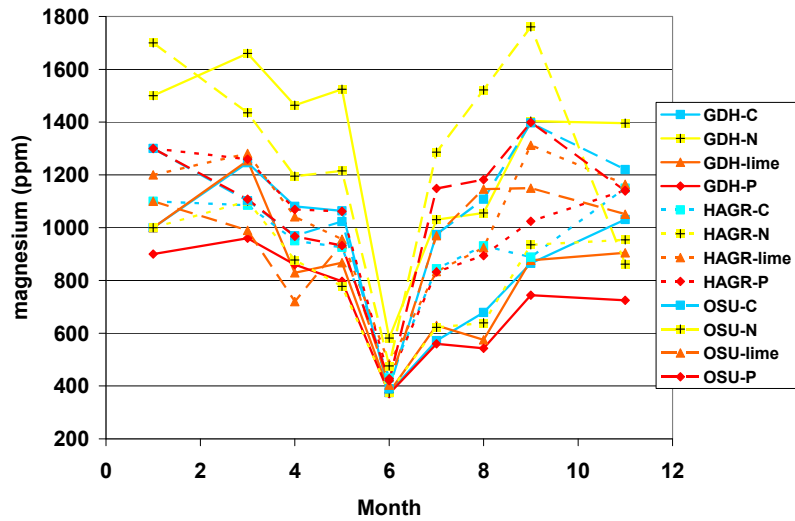*Figure 16 Foliar calcium by month on 12 sampled*

Figure 17   Foliar magnesium by month on 12
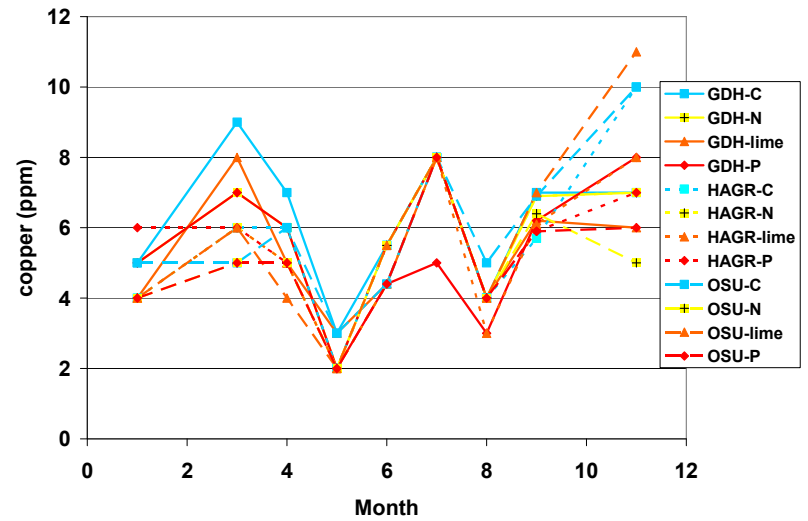

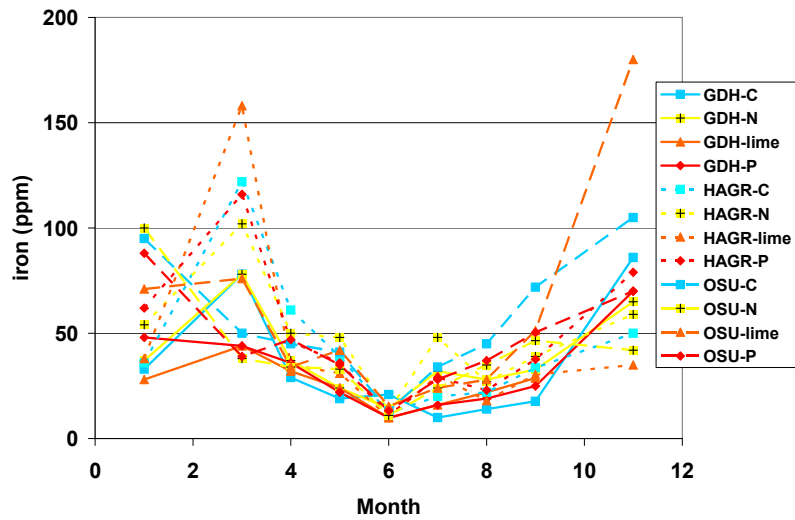Figure 19   Foliar copper by month on 12 sampled

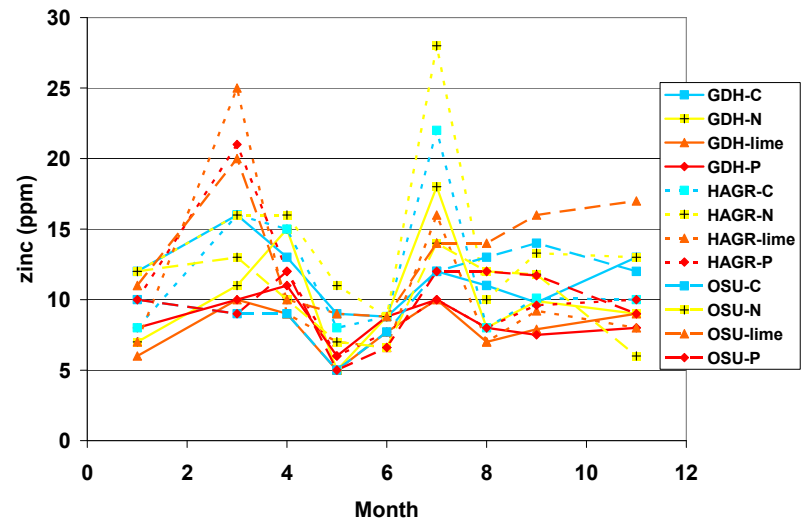Figure 18   Foliar iron by month on 12 sampled trees

Figure 20   Foliar zinc by month on 12 sampled
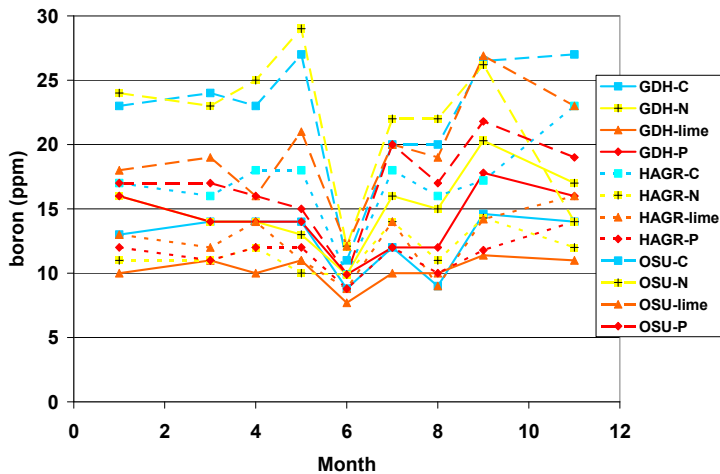
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Figure 21 Foliar boron by month on 12 sampled

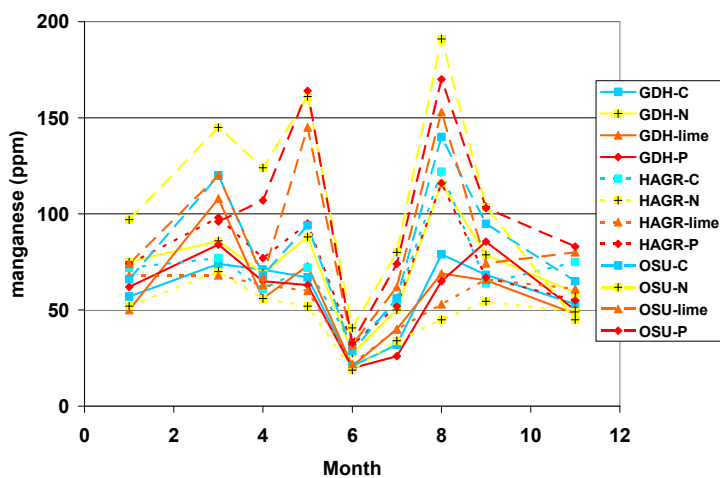Figures 13-22 suggest that the proper sampling date or period depends on the nutrient of interest. Trends in foliar nitrogen (fig 13), phosphorus (fig. 14), magnesium (fig. 17), zinc (fig. 20), boron (fig. 21), and manganese (fig. 22) during the course of the year appear to be compatible with fall sampling. Potassium levels (fig. 15) appear to be most stable in March and April, and calcium appears to be most stable in January-March (fig. 16). Both copper (fig. 19) and iron (fig. 18) appear not to have a stable period with the exception of the growing season for iron. That said, the variability of some of the fall/winter measurements for these two elements appear aberrational.

after treatment. Within the Beyond N dataset, the coastal GDH site has the lowest soil calcium, and the valley OSU site has among the greatest. Whether or not these site factors are pertinent to SNC infection has been debated (Maguire et al. 2000).

In Douglas-fir, foliage sampling has traditionally been done during the fall dormant season (Lavender 1970). This is based on the fact that any sampling of foliage done with the object of diagnosing nutrient deficiencies is ideally done at a time of year exhibiting stable nutrient levels (Turner et al. 1977).

Figure 22   Foliar manganese by month on 12

Importantly, based on the comparative trends among the three sites, SNC is uninfluential in the seasonal concentration patterns of all nutrients.

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Within-crown Variability of Foliar Nutrients in Coastal Douglas-fir
Doug Mainwaring and Doug Maguire, Oregon State University

Introduction

Chemical analysis of foliage has long been used as a means of determining the nutritional status of a tree or stand. Based on known nutrient requirements of a tree species, foliar nutrient levels or ratios can be used to diagnose nutrient limitations or imbalances and ascertain the necessary fertilizer treatments to address these limitations.

Numerous studies have looked at the how foliar nutrients vary by season, age, crown position and species (Lavender and Carmichael 1966, Myre and Camire 1996, Comerford 1981, MacLean and Robertson 1981, Lamb, 1976, Zhang and Allen 1996). Due to the variability of nutrient content within tree crowns, among the objectives of such studies is the determination of an appropriate season, crown position, and intensity for sampling, such that precise or standardized values of nutrients can be obtained for any number of practical uses. Although one previous study reported trends in mineral nutrient concentrations for Douglas-fir by season and crown position (Lavender and Carmichael 1966), quantitative relationships were not determined, lessening the utility of the data for anything other than a qualitative analysis of within-crown variation of foliar nutrients.

Because silvicultural treatments such as fertilization affect trees primarily through their effect on individual branches and crowns, quantitative understanding of the branch and crown response to treatment is important. Furthermore, the utility of this knowledge is of increasing value, as more attention is being focused on the development of hybrid or mechanistic models as a means to improve growth predictions and understanding of influential physiological processes (Weiskittel et al. 2007).

The objective of this study was to establish quantitative relationships between nutrient content and foliage age, crown position, foliage retention, and fertilization.

Methods

The study sites were part of a larger study looking at fertilizer response of young Douglas-fir across a gradient of Swiss needle cast. The target population for site selection was specified by total age (20 ± 5 yrs), stand density (300 ± 100 trees/ac), time since thinning (7 yrs), and past fertilization (none).

These sites used individual tree plots, each centered on an undamaged dominant or codominant tree. Three sites were selected from this study for intensive crown sampling, the choice being based both on the gradient of SNC infection they represented and their relative proximity to each other.

A total of twelve sample trees were chosen, four from each site, each having received one of four different randomly assigned fertilizer treatments (control, 224 Kg

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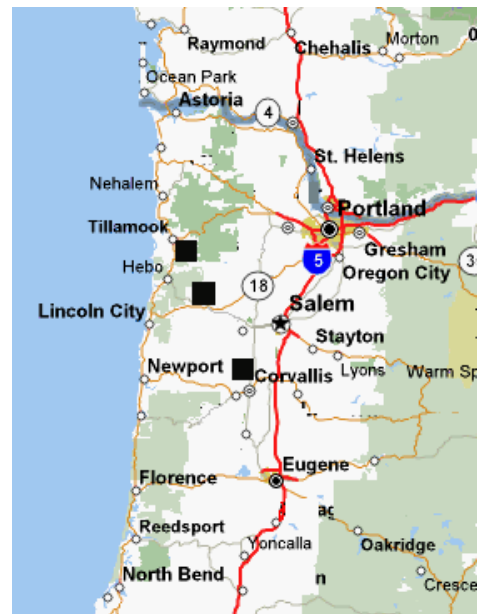
N/ha, 1000 Kg Ca/ha as lime, 560 Kg P/ha as mono-sodium phosphate). Each of the sampled trees was subjectively chosen from among 10 similarly treated trees per site to approximate the average sized treated tree at each site (table 1).

Samples were collected from two separate laterals of six branches per tree, distributed among six whorls (5th, 6th, 8th, 9th, 11th, and 12th) so as to cover the range in crown depth and azimuth. In some cases, different laterals or whorls were used if broken branches or low foliage retention limited sample quantities. Laterals or branches were removed from the tree, and enough foliage was removed to provide ~1 g of dried foliage for each age class for up to five cohorts. On each lateral branch, needles were collected from both the main-axis and secondary lateral branches in approximately equal numbers.   Needles were oven dried for 48 hours at 60° C, afterwhich they were weighed and submitted for foliar analysis.

Table 1: Characteristics of individual sample trees

Plot	Tree	Trt	Dbh (in)	Ht (ft)	CR	FOLRET	Age
HAGR	251	urea	10.9	59.4	0.80	2.3	16
HAGR	279	control	10.0	52.8	0.68	1.8	16
HAGR	305	lime	9.9	56.1	0.76	2.1	16
HAGR	309	phosphorus	10.7	49.5	0.77	2.4	16
GDH	649	lime	12.6	73.8	0.60	1.4	20
GDH	662	urea	11.7	70.2	0.65	1.8	20
GDH	668	control	11.7	69.9	0.64	1.2	20
GDH	669	phosphorus	11.1	68.2	0.71	1.5	20
OSU	2271	lime	10.3	61.0	0.72	3.8	15
OSU	2272	phosphorus	10.4	60.0	0.64	3.7	15
OSU	2975	urea	10.4	63.6	0.61	3.8	15
OSU	2983	control	10.2	59.4	0.75	3	15

Foliar analysis
Chemical analysis was performed by the Central Analytical Laboratory at OSU. All samples were ground and dried. Total nitrogen was determined by a LECO CNS-2000 analyzer (combustion). All other element concentrations were determined using a Perkin Elmer Optima 3000DV ICP optical emission spectrometer following an extraction by 5% HNO3.

Statistical analysis
Correlations between foliar age, crown position, foliage retention, and their interactions with foliar nutrient levels were determined using SAS Proc Mixed. The response variable for each regression was the ratio of nutrient concentration at a specific crown location to average tree-level nutrient concentration (termed relative concentration). Crown position was represented by three variables: RCH (relative crown height); RBL (relative branch length) (see figure two); and azi (cosine transformation of azimuth).
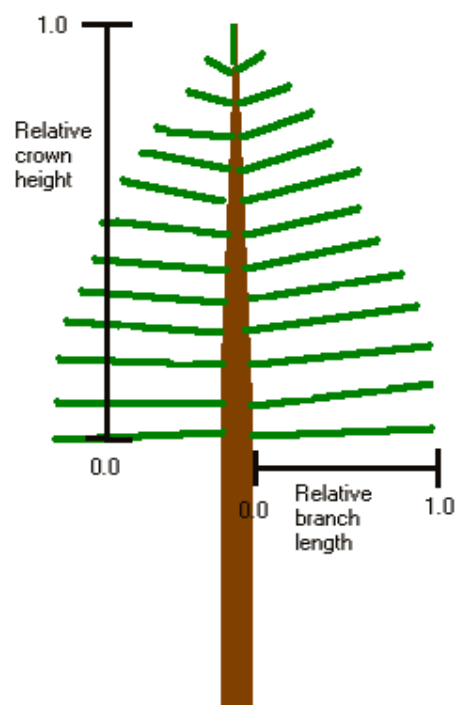

Fig. 2 Crown position measures

Results and Discussion

The relationship between nutrient concentration and crown position depended on nutrient, cohort age, relative crown height, relative branch length, azimuth, foliage retention and treatment (table 2).

Nitrogen

Relative nitrogen concentration was negatively associated with age class, and positively correlated with relative crown height and relative branch length as shown in table 2 and figures 3 and 4. The effect of each depended on foliage retention: as foliage retention decreased, the range of nitrogen concentration with age diminished while the gradient of nitrogen concentration with RCH and RBL steepened (figure 5). Azimuth was only marginally correlated with N concentration after accounting for the other variables in the full model and its interaction with relative crown height ($p=0.0929$). Treatment and its interaction with RCH was also a significant influence on nitrogen concentration (figure 6).
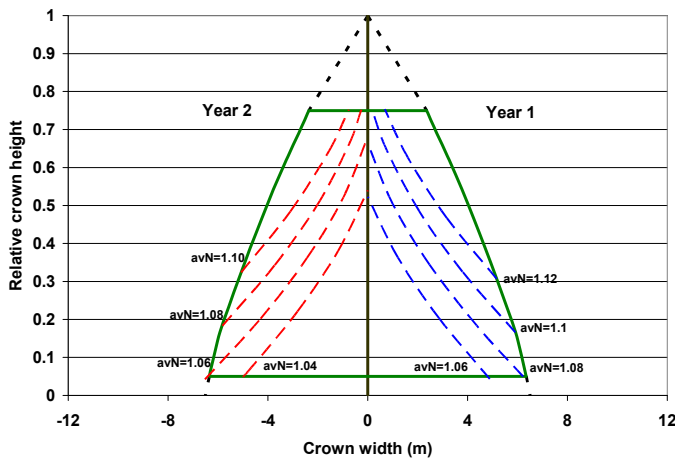

Figure 3 Gradients of relative N concentration for 1 and 2 year old foliage by relative crown height and relative branch length for tree of average crown width.
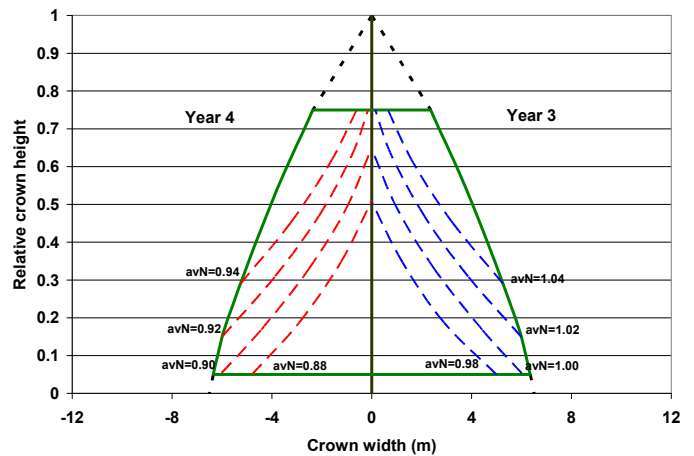
Figure 4 Gradients of relative N concentration for 3 and 4 year old foliage by relative crown height and relative branch length for tree of average crown width

Nearly all guidelines for foliar sampling recommend collecting south-side foliage, based on the greater likelihood of illumination on the south-side of the tree and the correlation between illumination and nitrogen concentration (Brooks et al. 1996, Schoettle and Smith 1998). To further test the correlation between aspect and N concentration, a simple analysis was performed using only those branches higher than the crown height midpoint (RCH>0.5), the assumption being that only those branches in the upper portion of the crown would experience considerable aspect-influenced differences in illumination. Using this subset, RCH ceased to be a significant interaction, and azimuth alone was positively correlated with southside relative N concentration ($p=0.02$). Nevertheless, the implied relative difference between southern and northern N concentration was less than 0.1%.

The relationship between N concentration and RCH or RBL was steeper for SNC-infected trees than for healthy trees. This is counterintuitive, given the general relationship between foliar nitrogen concentration and within-crown light level (Shoettle and Smith 1998)

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Table 3 Parameter estimates for equations describing relative nutrient concentration. The presence of values indicates predictor variables for specific nutrient

| Variable	Nitrogen	Phosphorus	Potassium	Calcium	Magnesium	Sulfur	Iron	Boron	Copper	Zinc
intercept	0.6113	0.1967	1.0964	2.1857	1.4844	0.75	0.0991	0.8542	1.2515	0.9216
yr1	-0.1716	0.8532	0.08034	-0.4952	-0.3084	-0.1432	0.2736	0.1954	-0.3059	0.02839
yr2	-0.00455	0.7723	-0.02343	-0.2257	-0.1332	-0.03437	0.2005	0.3217	-0.3253	-0.1398
yr3	-0.09561	0.5127	-0.1158	-0.0904	-0.09267	-0.05299	0.05912	0.00643	-0.256	-0.08739
yr4	0	0	0	0	0	0	0	0	0	0
RCH	0.6394	0.4231	-0.1206	-1.655	-0.7173	0.6021	1.8063	0.06318	-0.03711	0.2043
RBL	0.3792	0.2597	0.4065	-0.3271		0.3922	0.2447	0.1894		0.1072
lfolret	0.1518	0.6306	-0.1452	-0.5953	-0.1708		0.5327		-0.1298	
RCH*RBL		-0.5731	-1.386			-0.5331				
RCH*lfolret	-0.3893			0.9382			-1.2763		-0.533	
RBL*lfolret	-0.2304									
lfolret*yr1	0.2789	-0.8355	0.3419		0.2795				0.6612	
lfolret*yr2	0.1276	-0.838	0.1969		0.0824				0.4773	
lfolret*yr3	0.1562	-0.6351	0.1975		0.01382				0.3037	
lfolret*yr4	0	0	0		0				0	
RCH*yr1							-0.8458	-0.1535		
RCH*yr2							-0.3153	-0.6954		
RCH*yr3							-0.2344	-0.1391		
RCH*yr4							0	0		
trt1	0.006651	-0.1269	0.05065							
trt2	-0.1199	-0.08266	-0.1028							
trt3	-0.03152	-0.3291	-0.1794							
trt5	0	0	0							
RCH*trt1	-0.0079	0.1689	-0.1382							
RCH*trt2	0.3011	0.1472	0.1837							
RCH*trt3	0.1005	0.6552	0.4362							
RCH*trt5	0	0	0							
azi		0.000204	-0.00064		-0.00055				-0.00081	
RCH*azi		-0.00083	0.001162		0.001319				0.001655	
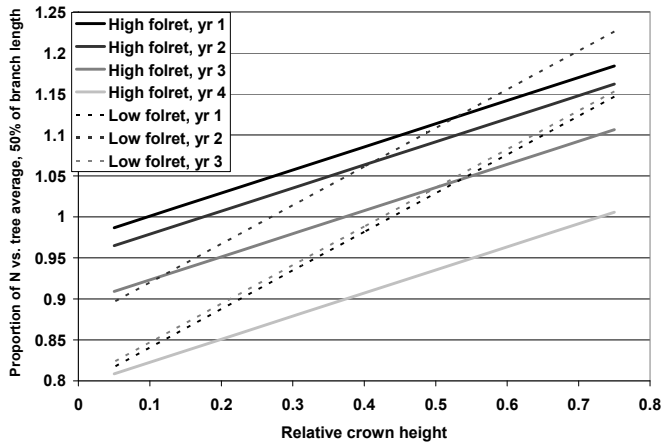
Figure 5 Relative nutrient concentration of nitrogen versus relative tree height, high folret=3.5 yr, low folret=1.8 yr
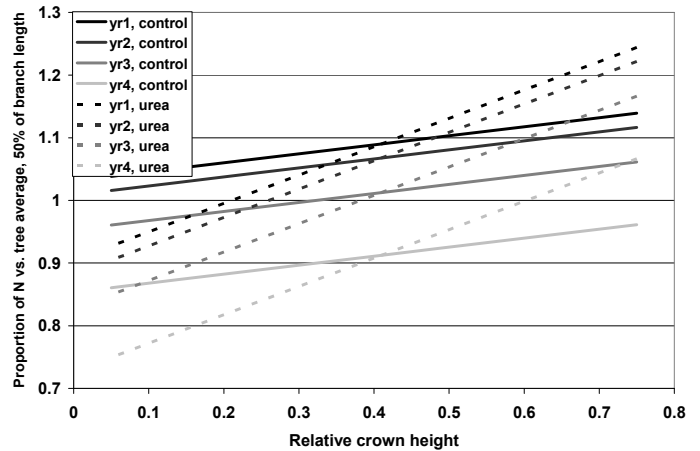

Figure 6 Relative nutrient concentration of nitrogen versus relative tree height, control and urea treatments, high foliage retention

and the fact that interior and lower foliage within the sparser SNC-infected crowns (Maguire and Kanaskie 2002) would presumably have greater relative light exposure than in healthy trees. Previous studies addressing the effect of insect defoliation on foliar nutrient levels within evergreen conifers have noted the general increases in nutrient concentration following defoliation (Piene 1980, Mcmillin and Wagner, 1997). This relationship has been attributed to a post-defoliation reduction in foliar carbon reserves and subsequent relative increase in mineral concentration (Ericsson et al. 1985) or to the simple fact that fewer needles having a fixed amount of mineral content will lead to higher concentrations (Piene 1980). Defoliation in SNC-infected trees increases from bottom to top (Hansen et al. 2000), likely due to harsher physical conditions (and greater likelihood of casting), and possibly due to better infection conditions toward the top of the tree. Whether the same pattern holds from outside the crown to the inside is unknown, but the inverse relationship between chemical concentration gradient and the gradient in needle retention matches what would be expected given the relationship between defoliation and mineral nutrition.

Of the three fertilizer treatments, only the urea treatment differed significantly from the other three, resulting in steeper positive gradients of nitrogen concentration with RCH and RBL (figure 6). Previous work has shown that nitrogen fertilized Douglas-fir experience an increase in maximum branch size in the upper third of the crown (Weiskittel et al. 2007a) and a greater branch diameter growth for a given height above crown base (Weiskittel et al. 2007b). Measured increases of branch diameter growth in the upper portions of crowns have been accompanied by branch diameter growth deceleration in the lower portion of the crown, attributed to increased self-shading of lower branches due to increased whole-crown foliar biomass (Weiskittel et al. 2007b). While self-shading may properly explain the observed branch diameter growth patterns after the crown-densifying effect of fertilization has taken place, the altered gradient of nitrogen concentration within the crown is a second, and more immediate explanation. For the treatment-level average N concentrations of this dataset, the absolute nitrogen concentration in the lowest and most inner branches is implied to be greater for the N fertilized trees than for control trees. Nevertheless, the gradient will almost certainly accelerate upper crown densification, and the development of branch growth patterns described by Weiskittel et al. (2007b).

Phosphorus

Phosphorus concentration was negatively correlated with age class, relative crown height, and relative branch length (figure 7). Phosphorus concentrations tended to be greater on the south sides of crowns, though this depended on the relative crown depth. Nevertheless, the absolute difference was less than 1 ppm. The phosphorus concentration of fertilized trees did not differ significantly from control, though marginal differences were detected for trees treated with phosphorus after the interaction between treatment and relative crown height were taken into account (p=0.0974). Urea treated trees exhibited a steeper negative relationship between relative crown height and P concentration than did the lime or phosphorus treated trees, with a smaller relative concentration at the top of trees and a greater relative concentration at the base of the crown. This difference is possibly due to P dilution within urea treated trees and/or greater P concentrations in lime and P treated trees due to direct treatment or increased-pH related availability.
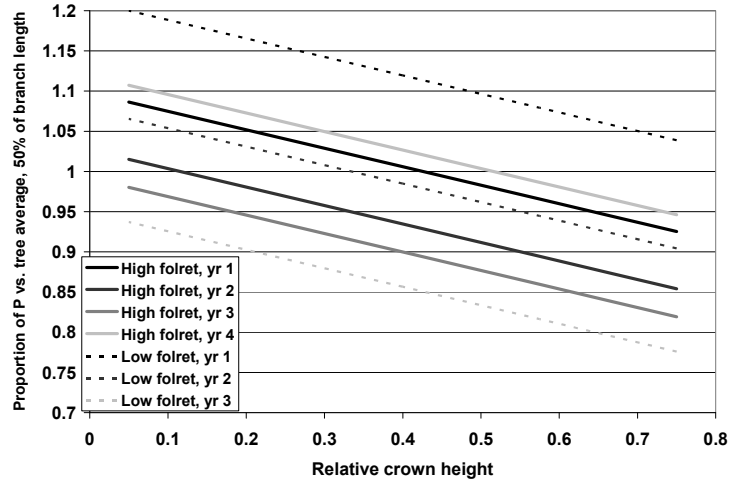

Figure 7 Relative nutrient concentration of phosphorus versus relative tree height, high folret=3.5 yr, low folret=1.8 yr

In contrast to these results, previous work in Douglas-fir reported that phosphorus levels were generally greatest in the top of the crown (Lavender and Carmichael 1966). However, Lavender and Carmichael reported that their phosphorus results contrasted with a number of other studies, including one that analyzed patterns of elemental distribution in Douglas-fir.

Potassium

Potassium concentration was negatively correlated with age class, relative crown height and relative branch length (figure 8). Potassium concentrations tended to be greater on the south sides of crowns, though this depended on the relative crown depth. As with phosphorus, the absolute difference between the north and south side was inconsequential. Fertilizer treatment of trees with urea or lime was related to greater relative concentration of potassium at the top of the crown.
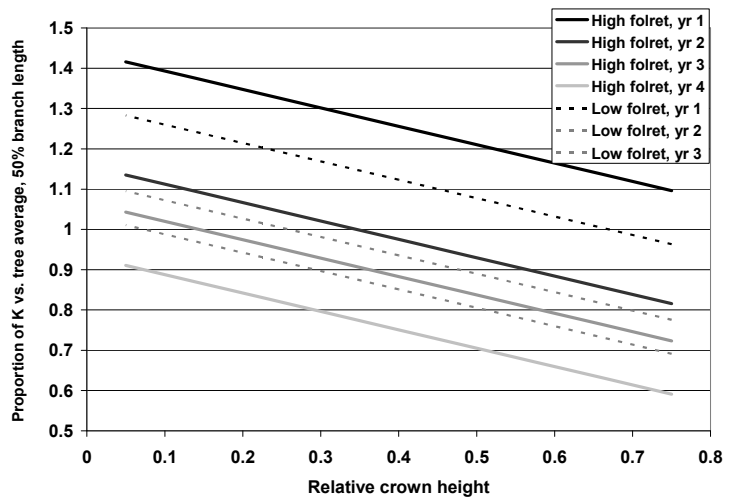
Lavender and Carmichael (1966) reported results from trees sampled at four different sites, with some exhibiting a negative correlation between crown height and K concentration, and some exhibiting a positive correlation. Their average correlation was positive, contrasting with these results. They report numerous other studies with results similar to those reported here.

Figure 8 Relative nutrient concentration of potassium versus relative tree height, high folret=3.5 yr, low folret=1.8 yr

Calcium

Calcium concentration was negatively correlated with age class, relative crown height, and relative branch length (figure 9). Because of a positive interaction between relative crown height and foliage retention, the gradient of calcium concentration was greater as foliage retention diminished, suggesting that within SNC-infected trees, calcium content is even more heavily weighted toward the lower part of the crown.

The negative correlation between calcium and age class and calcium and crown height was not surprising given the relative immobility of calcium (Marschner 1995). This result is nearly universal for evergreen conifers (as reported in Lavender and Carmichael 1966).
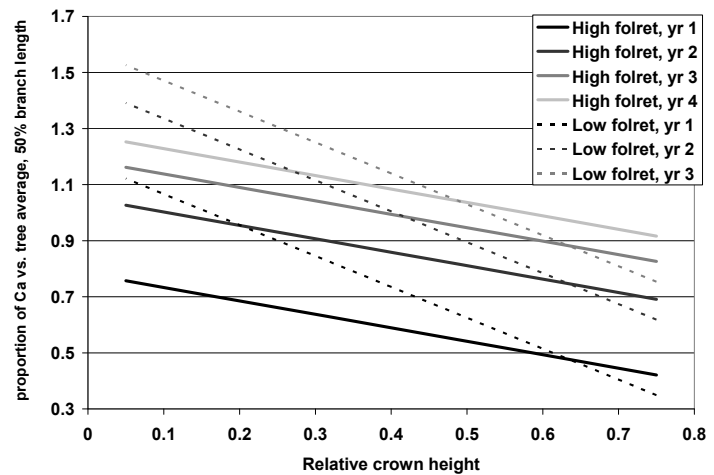

Figure 9 Relative nutrient concentration of calcium versus relative tree height, high folret=3.5 yr, low folret=1.8 yr

Magnesium

Magnesium concentration was negatively correlated with relative crown height but was uncorrelated with relative branch length (figure 10). Magnesium was greater on the south side of crowns, though this depended on crown height. As with other elements, the absolute difference in concentration was inconsequential. As with potassium, Lavender and Carmichael (1966) report different patterns of magnesium concentration with crown level for trees sampled in different sites. Their average trend is positive, while that reported for this study is a negative correlation.
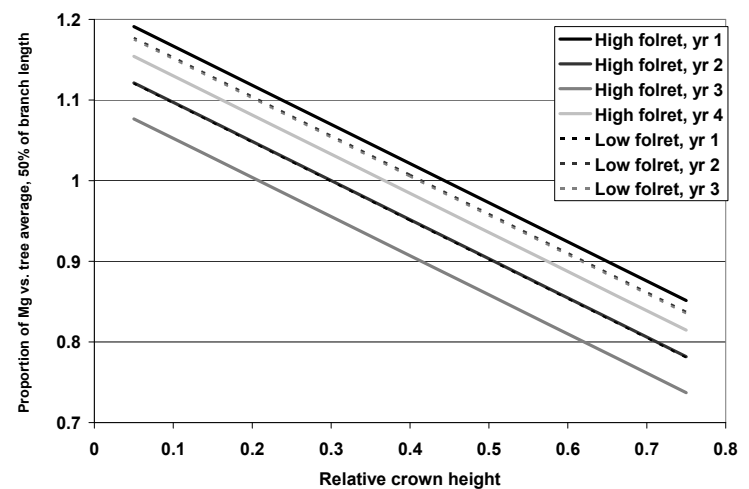

Figure 10 Relative nutrient concentration of magnesium vs relative tree height, high folret=3.5 yr, low folret=1.8 yr

Sulfur

Sulfur concentration is positively correlated with both relative crown height and relative branch length. There is also a positive trend between sulfur concentration and age, a trend previously reported by Beaton et al. (1965a). There was no significant relationship between sulfur concentration and foliage retention.

Iron

Iron concentration was positively correlated with both relative crown height and negatively correlated with relative branch length. The association of concentration with relative crown height depended on both needle age class and foliage retention. Iron concentrations were generally positively correlated with age class. This correlation with age was previously reported by Beaton et al. (1965b).

Boron

Boron concentration was positively associated with relative branch length, but correlation with relative crown height depended on age class. Differences in concentration with cohort age were variable, with no distinct pattern discernable, similar to the result reported by Beaton et al. (1965b). Concentration differences did not depend on foliar retention.

Copper

Copper concentration was negatively correlated with age class and relative crown height, but was unrelated to relative branch length. The gradient of the relationship with relative crown height depended on foliage retention: at low levels of foliage retention the negative relationship essentially disappears, with implied copper concentration for a given age similar throughout the crown.

Zinc

Zinc concentration is positively correlated with both relative crown height and relative branch length. Concentrations within the different age classes were significant, but were variable, exhibiting no obvious trend. Foliage retention was not a significant factor.

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One Year response to fertilization on the Beyond Nitrogen Plots
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Introduction

In 2006, the SNC Coop provided funds to augment the costs of a six-year fertilization trial aiming to test whether specific nutritional amendments might diminish or offset the effects of SNC. A second aim of this project is to test the growth response of individual trees to fertilization, whether or not they are infected with SNC: of the twelve forestland-owning participators, five have little or no SNC problems on their land base.

This report presents the one-year response of foliage retention, and foliar and soil chemistry to fertilization.

Methods

Sites

Sixteen sites ranging from Coos Bay, Oregon to Mineral, Washington (figure 1), were established and measured during the winter of 2006-07. The target population was specified by total age (20 ± 5 yrs), stand density (300 ± 100 trees/ac), time since thinning (7 yrs), and past fertilization (none). Selected stands met the age and stand density criteria, with only a few exceptions. Elevation ranged from 200 to 3100 ft, and slopes were all mild (≤35%). Soil texture ranged from silty clay loam to loam, and parent material on most sites was shale or sandstone, with five sites on volcanic rock or ash.

Foliar and soil sampling

All sites received five standard treatments, and twelve of the sites received two additional site-specific fertilizer blends; two additional treatments were included, but each was applied at only one site (tables 1-3). Each treatment was randomly assigned to ten 0.025-acre (18.6 ft radius) plots centered on an undamaged dominant or codominant tree. These "measurement" trees were located on a ~ 1 chain grid, located to take advantage of road access and to avoid undesirable stand features.

Between September and November of 2006 and 2007, all trees were climbed, and the most foliated four-year-old lateral from the southernmost fifth whorl branch was collected for a foliage retention rating and a foliage sample. An equivalent sample of one-year-old foliage was collected from all trees similarly treated and composited for chemical analysis. In addition, two, three, and four year old foliage was collected and similarly composited in 2007.

Figure 1: Locations of 16 study sites

From October to December of 2006 and 2007, two soil cores (12.5 cm) were collected from opposite sides of each tree, perpendicular to slope. At each tree, once these 2 core

samples were fully mixed, a small quantity was subsampled and combined for all trees within a given treatment.

Initial sampling took place during the fall of 2006, immediately prior to fertilization, and again during the fall of 2007. Fertilization was conducted from February-April 2007.

Chemical analysis
Chemical analysis was performed by the Central Analytical Laboratory at OSU. All foliar samples were dried and ground. Total nitrogen was determined by a LECO CNS-2000 analyzer (combustion). All other element concentrations were determined using a Perkin Elmer Optima 3000DV ICP optical emission spectrometer following an extraction by 5% HNO3.
All soil samples were dried and ground. Total nitrogen was determined using the Kjeldahl method, extractable phosphorus using a dilute acid-fluoride method (Bray-P1), and calcium, magnesium, potassium and sodium using an ammonium acetate method.

Results and Discussion

Foliage retention
Across all 16 sites, foliage retention decreased for each of the seven primary treatments. However, none of the six non-control treatments differed significantly from the control (fig. 2). Only the NP treatment, applied at the OSU site only, resulted in significantly greater foliage retention than the control.

If the analysis was limited to the eight sites with the lowest foliage retention (average retention of 2.7 yrs and lower (GDH, ODF, WW, WE, HAK, HAGR, MNN, MNS)), results were generally similar (fig. 3). One notable difference was the marginally significant gain of 0.2 yrs of foliage in trees receiving a urea treatment (p=0.068).

The general lack of improvement in needle retention one year after fertilization is not surprising. An earlier study testing the efficacy of Bravo fungicide in decreasing SNC symptoms found that growth improved only after multiple years of treatment had been completed. Results from that study implied that increases in growth didn't occur until older cohorts were made up of relatively uninfected fungicide-treated needles (Mainwaring et al. 2002). Likewise, any positive effect of nutritional amendments would presumably take multiple years of crown development. Any improvement in needle retention resulting from fertilization is more likely to be seen during the three year remeasurement in the fall of 2009.

The improvement in foliage retention seen on the NP treatment on the OSU site and the marginal improvement with urea on the high SNC sites is probably explained by the retention of needles otherwise dropped—sometimes called crown densification—typically found with nitrogen fertilization (Brix and Ebell 1969). That said, other studies have found that nitrogen-fertilized Douglas-fir typically hold equivalent lengths of foliated branches, but fewer years of needles as a result of increased branch elongation, and subsequent self-shading (Balster and Marshall 2000). However, the Balster and Marshall results were measured four years post-fertilization, after nutrition amended branch elongation was significant improved. Although previous research has linked nitrogen fertilization to increased levels of fungal fruiting (El-Hajj et al. 2004) and reduced needle retention (Rose and Rosner 2004), these results were based on longer periods of exposure to elevated nitrogen levels.

Soil chemistry

Significant decreases in pH were measured on each of the plots that received nitrogen (urea, Fenn, and NP) while increases were measured on the lime and phosphorus plots (fig. 4). Decreases in pH following N fertilization are typical due to nitrification (Otchere-Boateng and Ballard 1978). In the case of phosphorous fertilization, although mono-sodium phosphate is acidic in solution, large amounts of sodium has been shown to increase pH when sodium carbonate is hydrolyzed to sodium hydroxide, though this tendency is more common in arid soils where sodium is not leached (Foth 1978). Nevertheless, the continued presence of large amounts of sodium on the phosphorus treatment points to this explanation (fig. 5).

Soil nitrogen levels were not significantly different following treatment, though elevated levels were apparent at the single site receiving 400 lbs/ac (fig. 6). Phosphorus levels were significantly greater on the plots receiving phosphorus fertilization, with an apparent though non-significant increase on the site receiving 100 lbs/ac of P as mono-ammonium phosphate (fig. 7). Significant increases in potassium were apparent on the two treatments receiving potassium (fig. 8)—6 of 12 Kinsey treatments receiving an average of 258 lbs/acre of potassium sulfate and 8 of 12 receiving an average of 409 lbs/ac of potassium-magnesium-sulfate. Eleven of twelve Fenn sites averaged almost 400 lbs/acre of potassium-magnesium-sulfate.

Soil calcium levels were significantly greater than control following liming, while they did not differ from zero following the calcium chloride treatment (fig. 9), likely due to the large difference in amount of applied calcium for those two treatments. The significant decrease in calcium following nitrogen fertilization is a typical response to elevated levels of coupled nitrate-cation leaching. It also explains the similarly significant drop in magnesium following urea fertilization (fig. 10). Increases in magnesium levels with the Fenn treatment probably result from the generally high levels of potassium-magnesium sulfate applied.

An important fact for this analysis is that the Kinsey treatments had not received any lime as of the soil sampling in the fall of 2007. The procedure for the Kinsey treatment was to apply all non-lime fertilizers during the first year, and all lime during the second year—lime was applied to the Kinsey treatments in the fall of 2008.

Foliar concentration

Significant increases in foliar nitrogen concentration were apparent on the three treatments receiving nitrogen, with the size of the increase corresponding to the amount of N received (fig. 11). The smallest increase was for the Fenn treatment, where treatment averaged about 90 lbs of slow release N per acre. The increase was largest for the treatment receiving 400 lbs N/acre, with foliar N% on those trees averaging 2.36%.

Phosphorus decreased significantly on the two treatments receiving calcium, though P decreases following lime addition were not significantly different from the control (fig. 12). This was despite the fact that phosphorous generally becomes more available as pH increases across the ranges measured on these sites (Foth 1978). Interestingly, there was no significant difference in foliar P with phosphorus treatment, though soil P greatly increased.

With only one exception, the change in potassium concentration was not significantly different from zero (fig. 13). The one exception was on the single site receiving the NP treatment, and this drop may be the result of dilution.

Table 1: Treatment types and quantities

Treatment #	Material	Source	Per acre quantity (lbs.)	Per acre quantity, lbs. A.I.
1	Control			
2	Nitrogen	Urea	440	202.4
3	Calcium	Lime	2600	910
4	Calcium	CaCl2	260	94
5	Phosphorus	Mono-sodium p	2000	500
6	Kinsey	see table 2	see table 2	
7	Fenn	see table 3	see table 3	
8	Starker	See Gourley	See Gourley	See Gourley
9	NP	Urea/MAP	750/475	400/100

Table 2: Fertilizer types and quantities, Kinsey treatment

Material	WF	CTC	HAGR	STR	GDE	GDH	PB	OSU	ODF	MNN	MNS	HAK
MAP	250	250	250		250	250	250	250	250	250	250	250
K2SO4	200	500	125			125	175	425				
Sulfur	95	105	90	95	90	95	95	95	90	85	95	80
Boron	15	15	15	15	10		15	15	10		5	7
ZnSO4	20		20	20	15	20	10	10	20	20		
CuSO4	20	10	10	20	30	20	20	20	25	25	25	25
FeSO4		400	325		400		400	425	400	400	400	400
K-Mag	400		300			300	750		400	324	400	400
MnSO4							100					
MgSO4					300							
Calcium lime	350	4850	1900	2800	1200	1200	950	2100	2250	950	2250	1500
Dolomitic lime	1200	4150	2700	2500	3000	3100			2150	3200	1700	2100

Table 3: Fertilizer types and quantities, Fenn treatment

Material	WF	CTC	HAGR	STR	GDE	GDH	PB	OSU	ODF	MNN	MNS	HAK
Nitroform	476	29.6	169.6	138.4	297.5	297.5	169.6	59.6	59.6	536.1	700.3	169.6
K-Mag	568		340.9	341	681.7	681.7	340.9	227.6	227.6	399.6	214.3	340.9
Gypril			249.9	104	624.8	624.8	249.9	312.8	312.8	74.9	476.4	249.9
Ammonium sulfate		416.8	41.6				41.6					41.6
ZnSO4										273.5	139.9	

**Shaded columns significantly different from zero.
Columns with different letters significantly different from
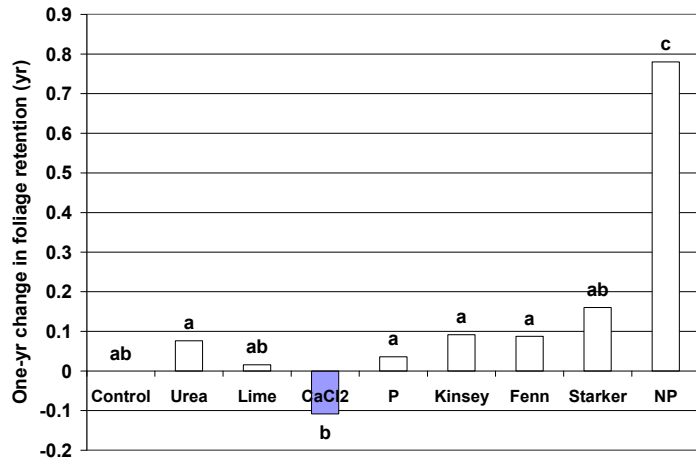each other.**

Figure 2: Change in foliage retention by treatment, all sites,
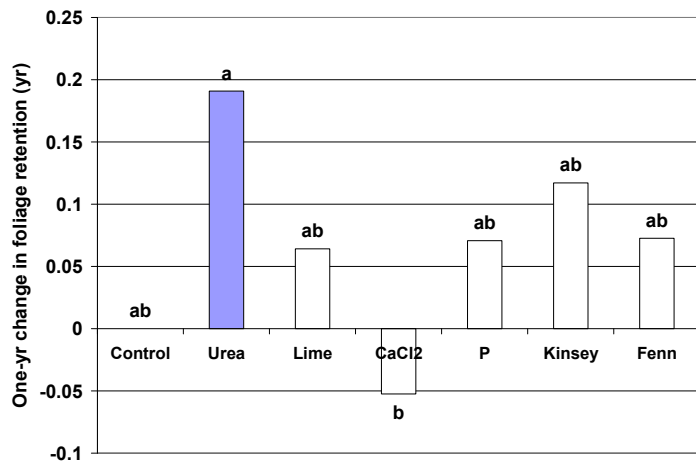adjusted for control

Figure 3: Change in foliage retention by treatment, SNC-
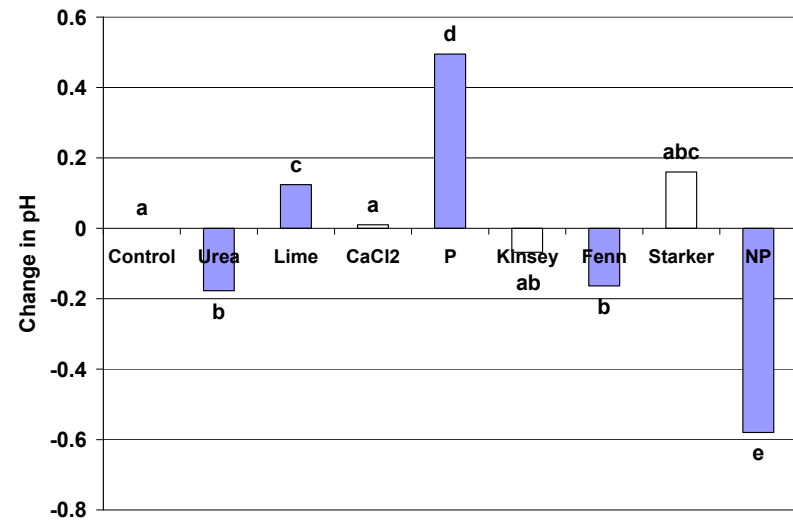infected sites, adjusted for control

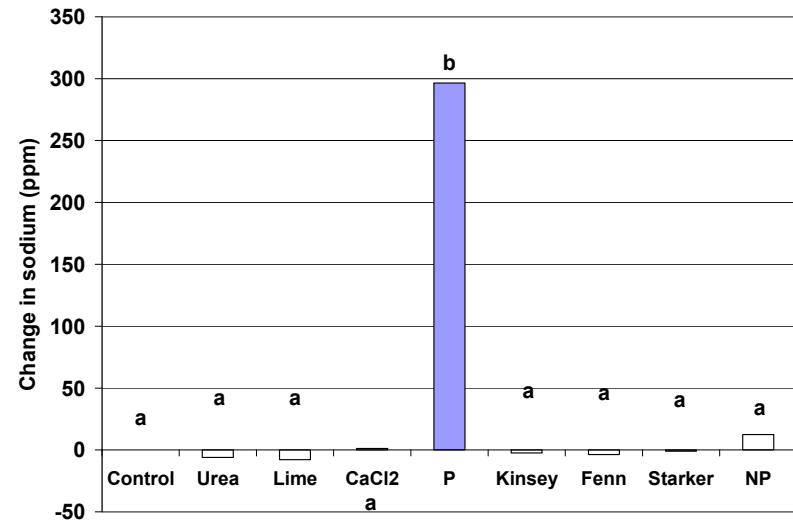Figure 4: Change in soil pH, adjusted for control

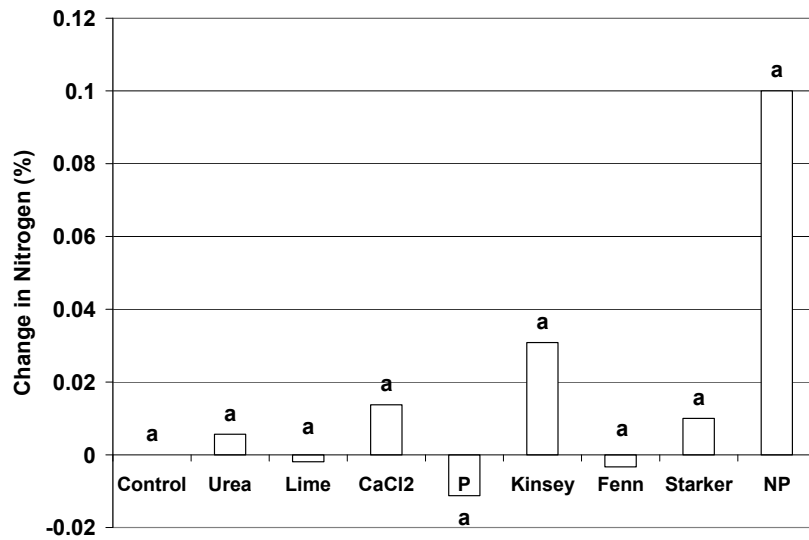Figure 5: Change in soil sodium, adjusted for control

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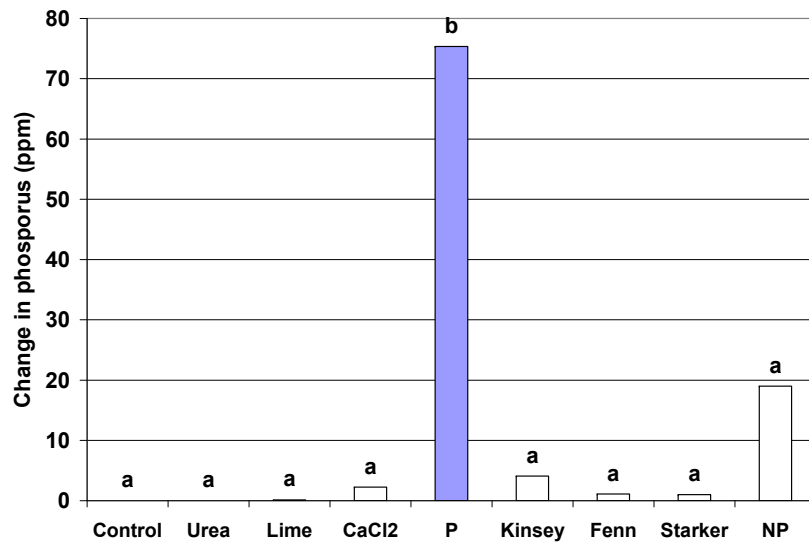*Figure 6: Change in soil nitrogen, adjusted for control*

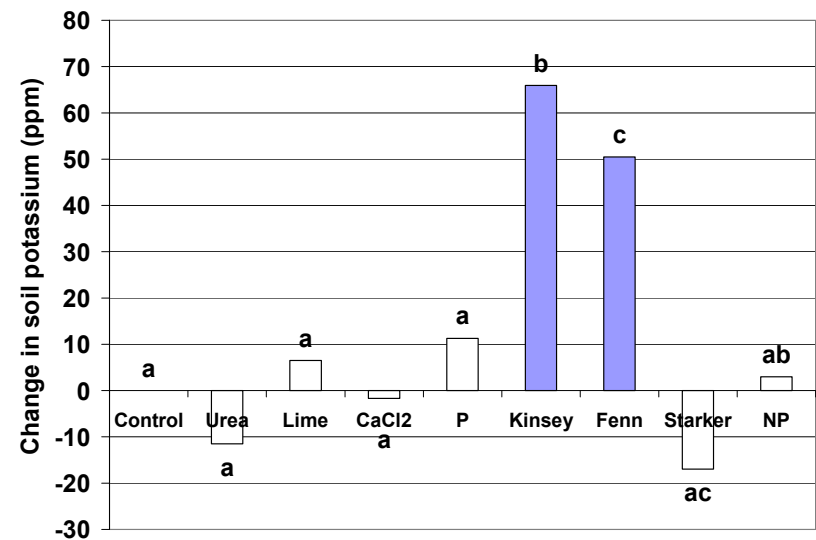*Figure 8: Change in soil potassium, adjusted for control*

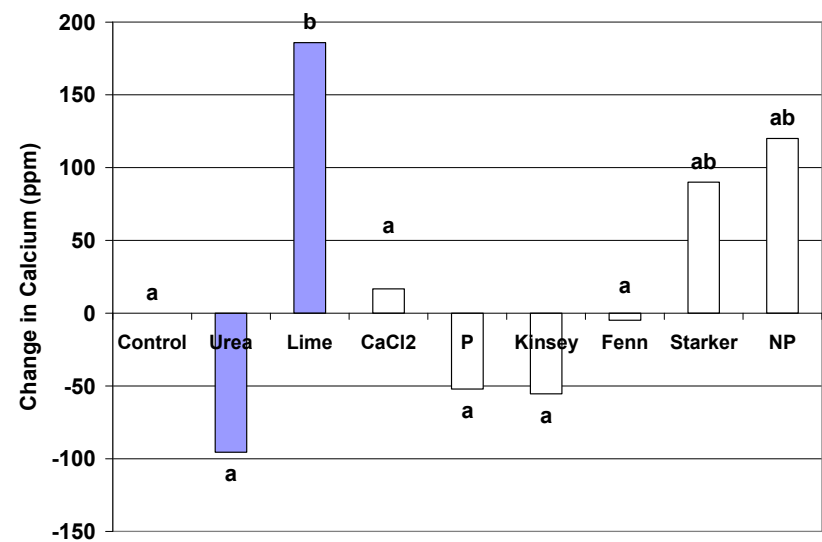*Figure 7: Change in soil phosphorus, adjusted for control*

Figure 9: Change in soil calcium, adjusted for control

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Figure 10: Change in soil magnesium, adjusted for control

Figure 12: Change in foliar phosphorus, adjusted for control

Figure 11: Change in foliar nitrogen, adjusted for control

Figure 13: Change in foliar potassium, adjusted for control
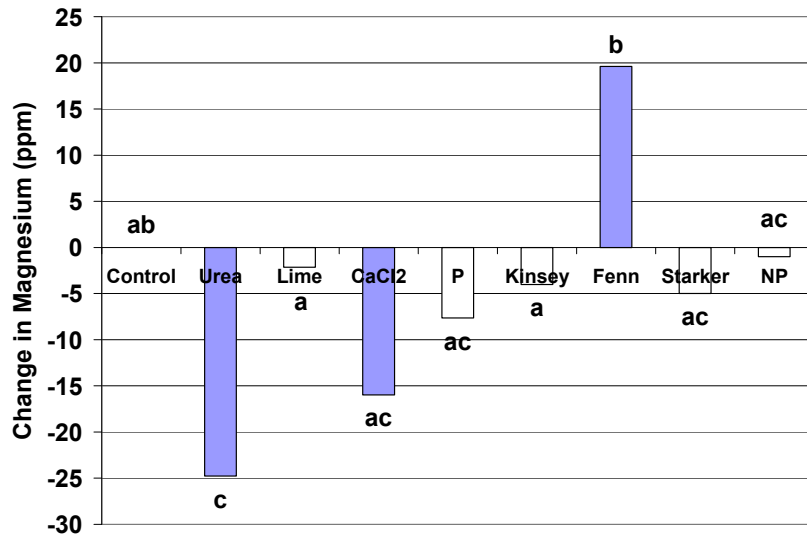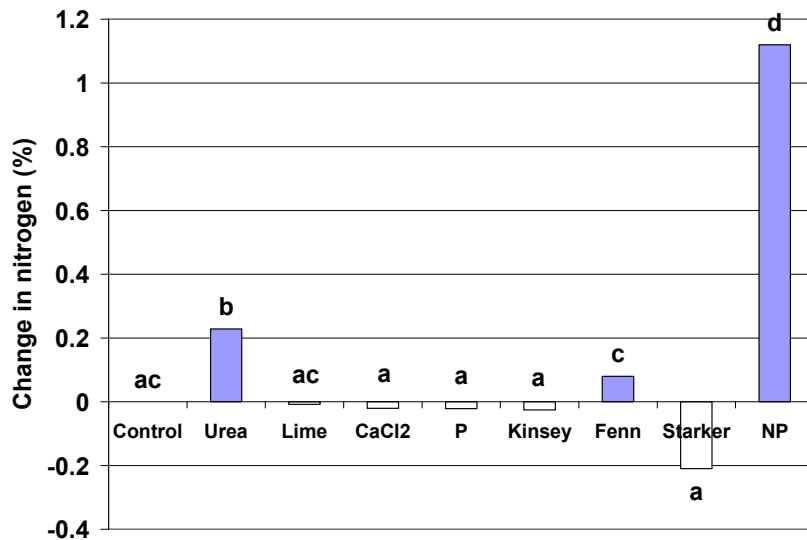
Figure 14: Change in foliar calcium, adjusted for control

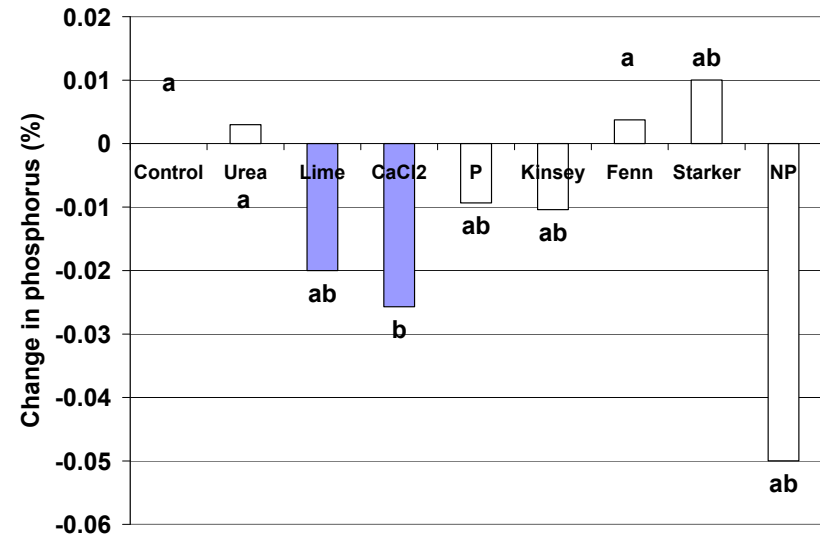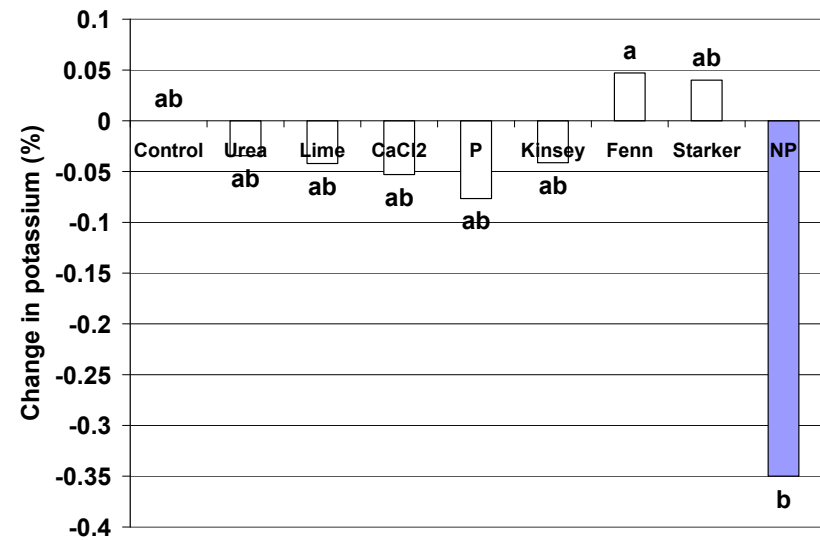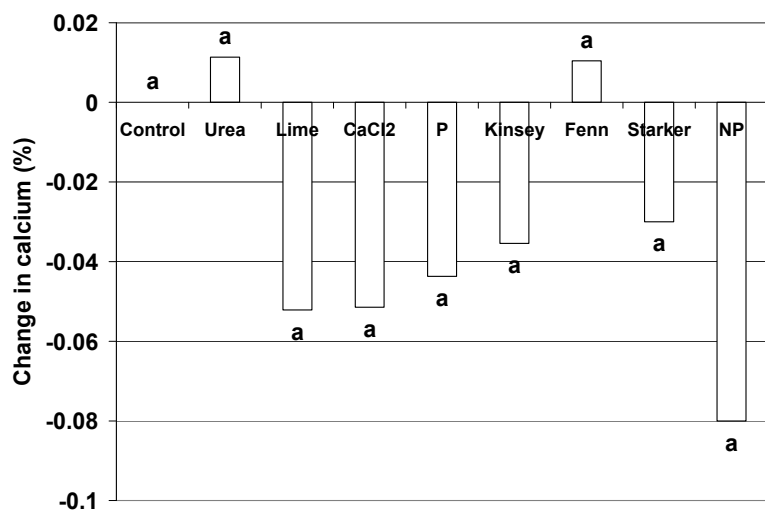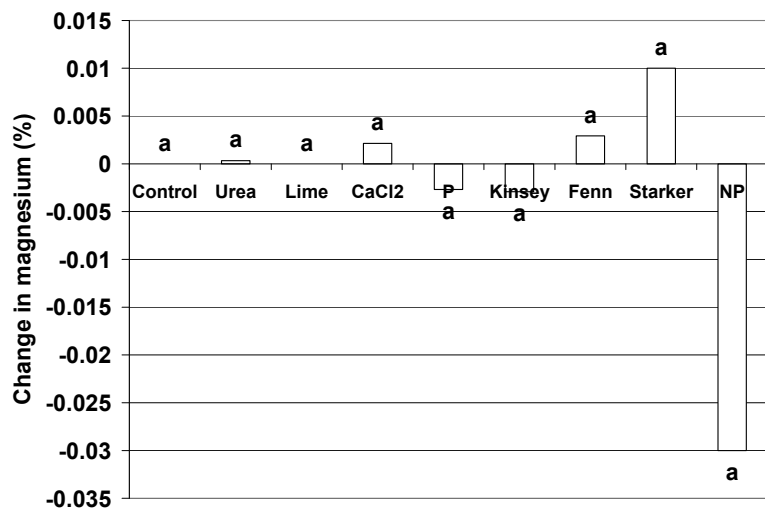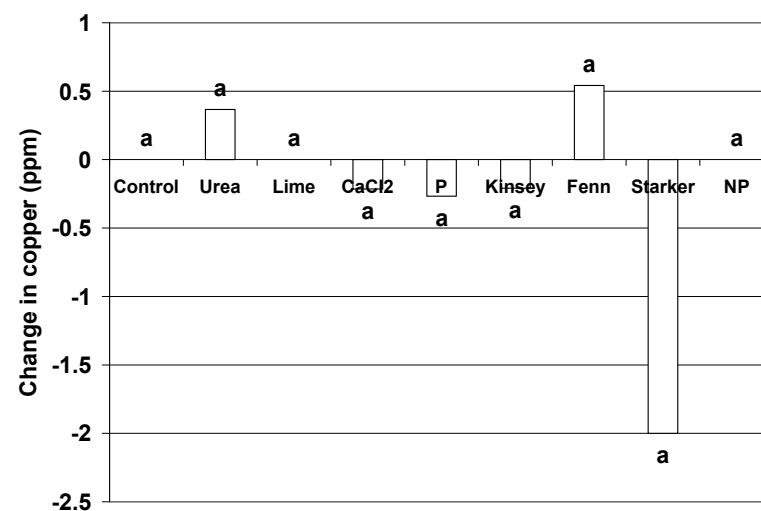*Figure 16: Change in foliar copper, adjusted for control*

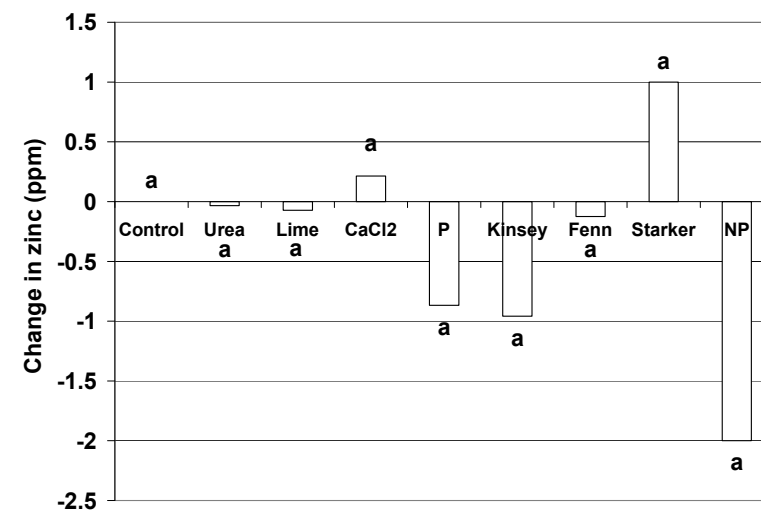*Figure 15: Change in foliar magnesium, adjusted for control*

Figure 17: Change in foliar zinc, adjusted for control

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No significant differences were apparent in the change in foliar calcium (fig. 14) or magnesium (fig. 15). Even with the large addition of calcium with lime treatment, the lack of change in foliar calcium is not surprising given the relative immobility of calcium within the tree. Foliar calcium concentration is positively correlated with foliar age class and negatively associated with height in the crown (Lavender and Carmichael 1966). The decrease in foliar calcium and magnesium on the NP treatment is likely to be a dilution effect.

The change in foliar copper (fig. 16) and zinc (fig. 17) were not significantly different from zero on all treatments in spite of the fact that copper was prescribed for each of the Kinsey treatments and zinc was included in all but three of the Kinsey treatments. In contrast, boron concentration increased significantly on the Kinsey treated plots (fig 18).
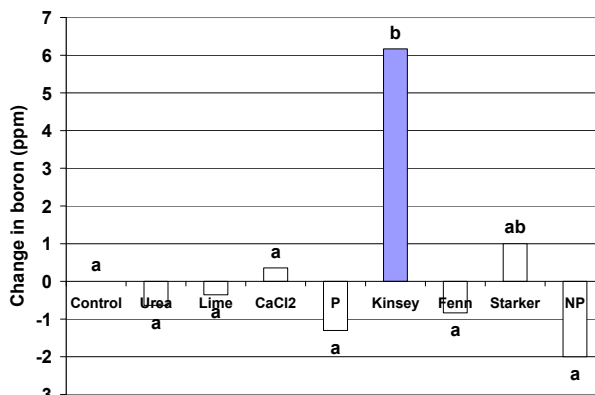

Figure 18: Change in foliar boron, adjusted for control

Vector diagrams
One of the shortcomings of monitoring changes in foliar nutrient concentration is that treatment response is difficult to infer without also accounting for changes in needle size. For example, a treated tree may have a similar nutrient concentration to an untreated tree, suggesting no response. However, the treated tree may have produced significantly greater numbers of larger needles. The two trees have the same concentration, but very different absolute nutrient contents. Vector diagrams provide a way to exhibit this graphically, in this case monitoring shifts in nutrient concentration and content relative to the control treatment for all treatments (fig. 19, Haase and Rose 1995). Data points on the attached vector diagrams have been relativized to the control treatment (trt=1), which on all graphs is at the reference point of 100% relative concentration, and 100% relative content, and on the diagonal representing 100% relative needle weight—thus representing zero change. The diagonal lines represent relative needle weights, with greater relative needle weight represented by a shift to the right. For example, in figure 20, the NP treatment has had a large relative increase in concentration and content, but only a minor change in relative needle weight. This suggests significant uptake, but an as of yet luxury consumption of nitrogen. Increases in needle weight with a non-negative change in concentration and content imply a positive response, and therefore a pre-treatment deficiency.
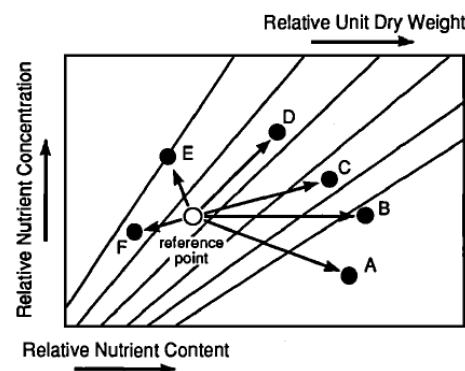
Direction of shift	Response in			Interpretation	Possible diagnosis
	Dry weight	Nutrient			
		Conc.	Content		
A	+	−	+	Dilution	Non-limiting
B	+	0	+	Sufficiency	Non-limiting
C	+	+	+	Deficiency	Limiting
D	0	+	+	Luxury consumption	Non-toxic
E	−	++	±	Excess	Toxic
F	−	−	−	Excess	Antagonistic

Figure 19 Interpretation of directional shifts in nutrient concentration, nutrient content, and dry weight. From Haase and Rose (1995)

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Nitrogen

Not surprisingly, the urea and NP treatments exhibit the most obvious changes in N, though the shifts suggest that the uptaken nitrogen constitutes luxury consumption (fig. 20). The Fenn and Kinsey treatments exhibit similar shifts, though only in specific age classes: both received N, in the form of slow release N and MAP respectively.

Phosphorus

The phosphorus treatment showed consistent increases in P concentration and content, with small increases in needle weight, suggesting that P may have been slightly limiting (fig. 21). The urea treatment showed decreases in P concentration and content without changes in needle weight. Although this scenario has been implicated as possibly an antagonistic excess (fig. 19), a more likely explanation is dilution due to a general increase in tree foliage, a common occurrence in response to N fertilization.

The Fenn and Kinsey treatments show the same general shift. Fenn treatments generally received slow release N, possibly explaining its negative shift, though Kinsey treatments generally received phosphorus (MAP). The shift in the NP treatment across all age classes suggests that on that single site, 100 lbs P is enough to keep phosphorus from becoming deficient when added with 400 lbs N.

The shift of the lime and calcium chloride treatments are relatively small (and perhaps non-significant) though they are lesser versions of the treatment 5 shift. It is unknown whether these constitute significant changes or natural variability.

Potassium

Shift in potassium content and concentration are more apparent in older needle age classes than younger (not shown here). Needles on the Kinsey treatment increased in concentration, content and needle weight, suggesting that potassium may have been limiting. Potassium was added in significant quantities on that treatment, both in the form of potassium magnesium sulfate and potassium sulfate. Similar changes in content and concentration without changes in needle weight, however, suggest luxury consumption. Especially because many of these sites are also experiencing annual variation in Swiss needle cast, and, because this can affect needle weight, conclusions about treatment effects due to minor changes in needle weight should be made with caution.

The substantial change in potassium concentration and content on the Starker treatment (trt 8) is difficult to interpret given the content of the material applied.

Calcium

Three of the treatments received calcium in the first year: lime, calcium chloride, and Fenn (gypsum)). The Kinsey treatment received significant quantities of lime, but that didn't take place until year 2, after foliage was sampled. Neither the lime nor calcium chloride treatments show any signs of increased foliar calcium (fig. 23). Only the one year-old foliage from the Fenn and Kinsey treatments show signs of increases in foliar calcium after one year, with increases in both concentration and content. With needle weights unchanged, this normally is suggestive of luxury consumption. However, it appears that calcium increases in
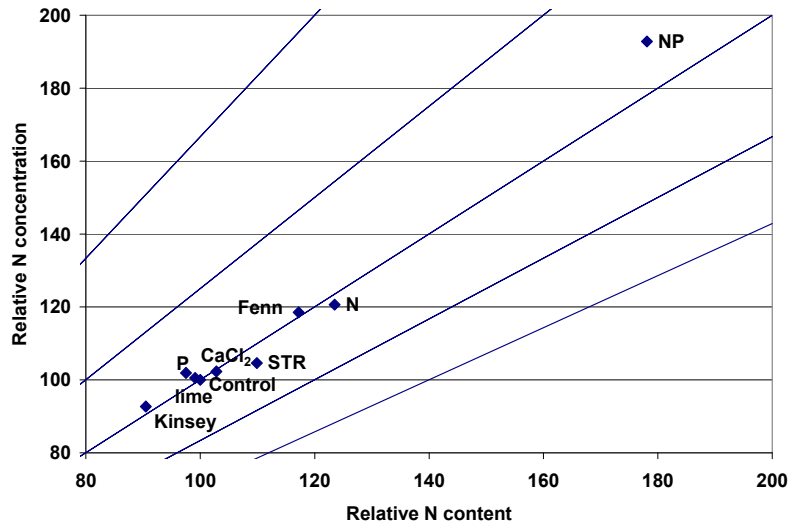
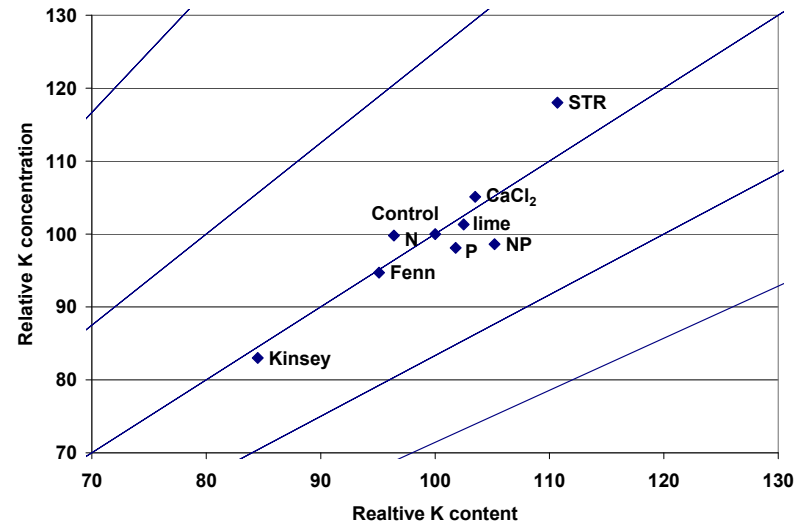*Figure 20 Vector diagram for first year foliage, nitrogen*

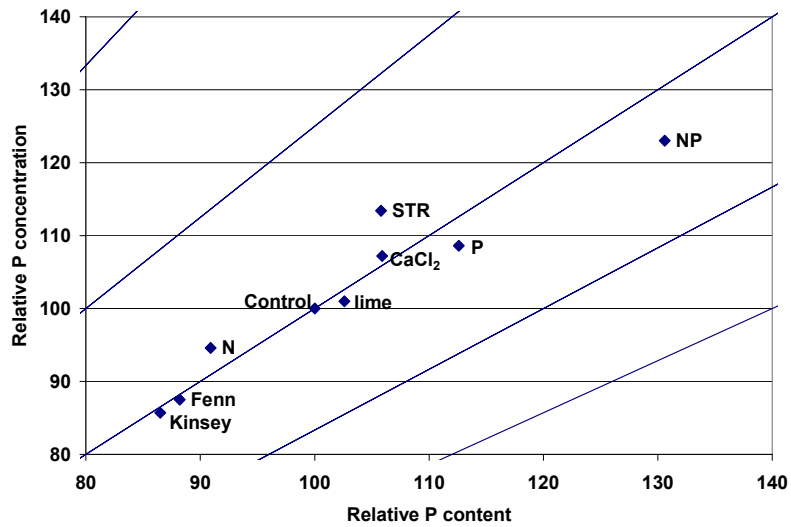*Figure 22 Vector diagram for first year foliage, potassium*

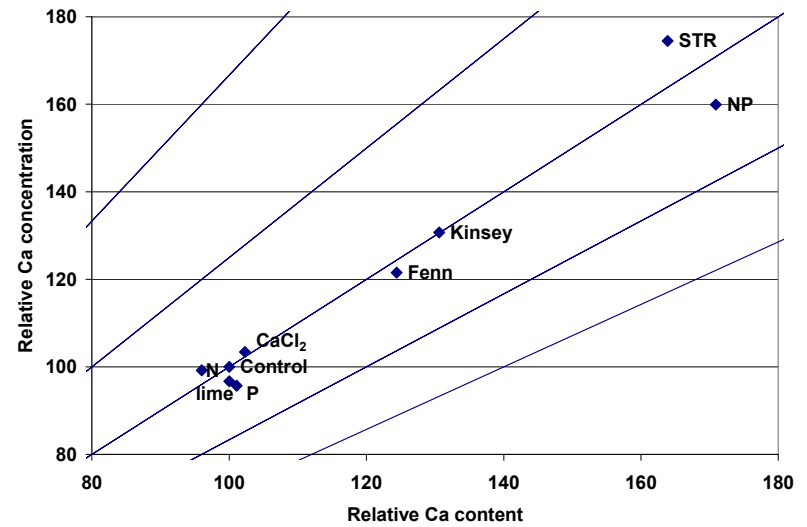*Figure 21 Vector diagram for first year foliage, phosphorus*

Figure 23 Vector diagram for first year foliage, calcium

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year 1 needles come at the expense of those in year 2 and 4, where the Fenn and Kinsey treatments show declines in concentration and content. Reasons for this shift are unknown, with the only consistency between the two treatments are large quantities of potassium-magnesium sulfate.

The two non-standard treatments, applied only at one site each, show increases in foliar calcium in each needle cohort. The NP treatment received 400 lbs N and 100 lbs P (MAP) per acre, which don't suggest an explanation for calcium increases. That said, soils at that site contain high levels of calcium.

Conclusions

One year after treatment, analysis shows evidence of increased presence and/or uptake of specific nutrients. The link between this uptake and growth will not be known until after the first post-treatment measurement of the trees next fall. Whether treatments will have any impact on foliage retention will be unknown until next fall at the soonest, and three years following at latest.

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Refining Techniques for Detecting Swiss Needle cast Outbreaks in Tree-ring Records fro the Oregon Coast Range

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Introduction

Over the past fifteen years, the incidence and severity of Swiss needle cast disease has greatly increased in the Oregon Coast Range, significantly lowering productivity in affected Douglas-fir forests. Caused by the fungal pathogen *Phaeocryptopus gaeumannii*, Swiss needle cast disease interferes with gas exchange by physically blocking Douglas-fir stomata, thereby reducing or halting photosynthesis. Indeed, cubic volume growth loss ranges from 23-50% in epidemic stands with an estimated loss of 34 million board feet for the region in 1996 alone. Though *P. gaeumannii* is endemic to the Pacific Northwest, no previous outbreaks have been recorded, and until recently the disease was not known as a source of significant tree injury. The environmental conditions that facilitated the current outbreak are not clearly understood, but appear to be linked with climate. In particular, warm winter temperatures and spring precipitation are strongly associated with the development of Swiss needle cast disease. Increasing winter temperatures and springtime precipitation since the 1960s suggest that Swiss needle cast disease will only worsen in the Pacific Northwest if climatic trends continue.

To date, studies related to Swiss needle cast disease in the Pacific Northwest have been limited in scope to the current outbreak. Given that the pathogen is presumed to be native to the Pacific Northwest and to have long been associated with Douglas-fir, similar outbreaks of Swiss needle cast probably have occurred in the past. Such outbreaks could have escaped notice or comment if they were of relatively brief duration or in unmanaged forests. One approach to assess the history of Swiss needle cast disease in the Oregon Coast Range is tree-ring analysis (dendrochronlogy). Dendrochronology has been widely applied in a variety of forest types to reconstruct insect and pathogen outbreaks as well as climate and disturbances such as windstorms, fires and floods. In the Oregon Cascades dendrochronology has proven particularly useful in quantifying the dynamics of the western spruce budworm and Pandora moth outbreaks over the past several centuries. Surprisingly no similar studies have been conducted in the Coast Range, even though Swiss needle cast disease is a strong candidate for dendrochronlogical analyses. Severe outbreaks result in significant growth reductions that would almost certainly be translated to ring width. Thus the objectives of this study are to *i*) assess the impacts of Swiss needle cast disease on radial growth, and *ii*) use any growth signatures to develop techniques for detecting Swiss needle cast disease in the tree-ring record.

Methods

For this study we selected a 100 year-old Douglas-fir -western hemlock stand near Euchre Mountain in the Oregon Coast Range east of Lincoln City, Oregon (Figure 1). The forest was located along the top of a ridge and ranged from approximately 1200-1250 ft in elevation. Slopes varied from 10% at the top of the ridge to 30% at mid and lower elevations in the study area (Figure 1). In September 2008, six circular, 0.02 ha plots were located along a transect through the forest interior at approximately 20 m intervals. Species, diameter, and crown class were recorded for all trees > 10.0 cm dbh (diameter at breast height). Crown class was partitioned into four categories (dominant, codominant, intermediate, and suppressed) according to the amount of intercepted light (Smith 1986). For each tree species, a relative importance value was calculated as the average of the relative frequency (presence or absence in plots), relative density (number of individuals), and relative dominance (basal area). (Cottam

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and Curtis 1956). Using a 32" and an 18" increment borer, we cored at breast height all dominant and codominant trees within each plot. One core was taken per tree and breast height was used to avoid rot and buttressing. Saplings and seedlings were counted within nested circular plots of 9 m^2 and 5 m^2, respectively. Saplings were classified as tree species > 1.5 m in height but < 10.0 cm dbh and seedlings were < 1.5 in height. To increase the sample size, we also collected cores from several dominant or codominant western hemlock located just outside the boundaries of the plots.
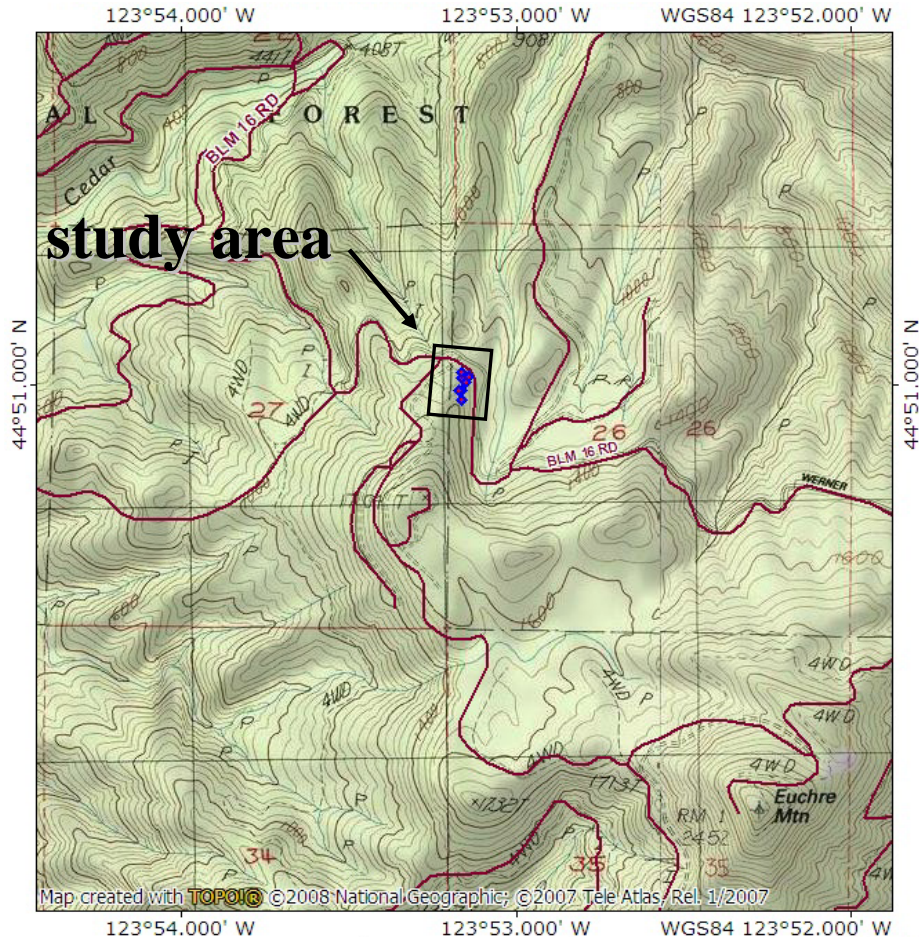
Figure 1. Map of the study area. Blue squares within the study area are locations of six fixed-radius plots.

Cores were dried, mounted, and sanded with increasingly fine sandpaper to reveal the cellular structure. Within each species, all cores were then crossdated to identify and missing or false rings in the data set and ensure that all growth increments were assigned the correct calendar year. The procedure is based on the principles that at least one climatic variable limits growth and values of these climatic variables fluctuate over time. Under these conditions, climatic variability induces synchronous growth patterns in all individuals within a given region. These synchronous growth patterns, much like bar codes, can then be matched among all individuals to verify that all growth increments have been identified. If a ring has been missed, the growth patterns in the tree will be offset relative to the growth patterns in all other trees, and the first year of the offset indicates where the error occurred. All samples were first visually crossdated using the "list year" technique in which common growth patterns were identified by

noting growth increments that were conspicuously narrow or wide relative to surrounding increments (Yamaguchi 1991).

Once visual crossdating was complete, we measured all growth increments to the nearest 0.002 mm using a Unislide "TA" tree-ring measuring system (Velmex, Inc., Bloomfield, NY). Following measurement, crossdating was statistically verified using the International Tree-Ring Data Bank Program Library program COFECHA, available thorough the University of Arizona Laboratory of Tree-Ring Research http://www.ltrr.arizona.edu/pub/dpl/ (Holmes 1983, Grissino-Mayer 2001). To statistically validate crossdating, COFECHA removed long-term trends in each measurement time series via the process of detrending, then cross-correlated all detrended time series to verify that common growth patterns aligned. In COFECHA, detrending was accomplished by fitting each set of otolith measurements with a flexible cubic spline. Each set of tree-ring measurements was divided by the values predicted by the spline, thereby removing low-frequency variability, homogenizing variance, and equally weighting each set of measurements to a mean of one (Holmes 1983, Grissino-Mayer 2001). Detrended time series were tested for autocorrelation, which if present was removed to ensure that all detrended time series met the assumptions of serial independence. Each detrended set of tree-ring measurements was then correlated with the average of all other detrended sets of tree-ring measurements in the sample. To facilitate finding potential errors, correlations were performed in sequential 25-year windows along the length of each set of detrended tree-ring measurements. For example, correlations between a set of tree-ring measurements and the average of all other tree-ring measurements between 1900 and 1925, then from 1925 to 1950, 1950 to 1975, and so forth. These windows were then lagged by plus and minus zero to ten years. If lagged segments correlated more strongly with the average growth patterns of all other tree-ring measurements, the number of lags indicated the number of rings missed or falsely added, and the window at which the correlation statistic first decreased indicated the approximate location of the error.

Following crossdating, we developed a master chronology for each species using the original tree-ring measurements. First, we detrended all measurement time series with a negative exponential function to remove age-related growth trends and standardize each set of tree-ring measurements to a mean value of one. Exceptions were made for those series that followed a positive trend. Positive slopes do not reflect age-related trends and could instead remove valuable climate-induced trends. Therefore we chose to detrend all positively-trending measurement time series with the series mean (a horizontal line). By detrending with the most rigid functions possible, we attempted to preserve long-term variability, including disturbance events. For each species, all detrended series were averaged into a master chronology using a biweight robust mean to reduce the effects of outliers (Cook 1985). All chronology development was conducted using the program ARSTAN developed by Ed Cook and Paul Krusic and is available at http://www.ldeo.columbia.edu/res/fac/trl/public/publicSoftware.html (Cook 1985). Detrending with negative exponential functions or horizontal lines removed only age-related growth trends but otherwise preserved all other patterns of variability. This chronology would capture all processes that lasted from one or two years to those that lasted from one or more centuries.

To establish the effects of climate on growth, we obtained monthly averages of precipitation, temperature, and Palmer Drought Severity Index (1895 – present) for Oregon Region 1 (Coastal Oregon) at the NOAA NCDC website http://www7.ncdc.noaa.gov/CDO/CDODivisionalSelect.jsp# . We also obtained instrumental temperature and precipitation records (1910-present) for Newport, OR through NOAA NCDC. Monthly averages were used to determine those periods of the year in which environmental

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variability most strongly affects growth. For example, a warm March often favors growth by allowing photosynthesis to begin early in the season. Also, given the proximity to the Pacific Ocean, we obtained several indices of ocean circulation to relate to tree growth including the Pacific Decadal Oscillation (PDO) and the Northern Oscillation Index (NOI). The NOI is the anomaly sea level pressure difference between the North Pacific High and Darwin, Australia. The index captures the strength of atmospheric circulation between the tropics and the north Pacific, particularly with respect to the El Niño Southern Oscillation on the north Pacific. High values occur during La Niña years while negative values occur during El Niño events (Schwing et al. 2002). In addition to these basin-wide variables, we also obtained monthly averages of local sea surface temperature, and upwelling. NOI (1948-present), and upwelling (1946-present) records were obtained through the Pacific Fisheries Environmental Laboratories live access server at http://www.pfeg.noaa.gov/ . We then correlated monthly environmental variables with each master chronology to determine the impacts of climate on tree radial growth.

Results and Discussion

The stand was dominated exclusively by Douglas-fir and western hemlock, and Douglas-fir had the greater density, dominance, and importance value (Table 1). In Douglas-fir tree cores the synchronous growth pattern among samples was strong, facilitating crossdating. Particularly prominent signature years included 1991, 1984, 1974, 1959, 1951, 1947, 1933, 1918, 1908, 1895, and 1889. The common climate signal was not as strong in western hemlock, though 1989, 1958, 1953, 1933, and 1912 were consistently narrow. Locally absent or partial rings occurred in several of the Douglas-fir samples during periods of extreme slow growth.

Table 1. Results of the overstory tree survey at the Euchre Mountain study site

Species	Frequency (6 plots)	Density (stems / ha)	Dominance (m^2 / ha)	Relative density	Relative frequency	Relative dominance	Relative importance
Douglas-fir	6	208.3	343.6	50.0	69.4	81.6	67.0
hemlock	6	91.7	77.7	50.0	30.6	18.4	33.0
Totals	12	300.0	421.3	100.0	100.0	100.0	100.0

The oldest western hemlock sample dated to 1881 and the oldest Douglas-fir dated to 1873. For now, six cores have been measured per species. All Douglas-fir showed strong age-related growth declines, and growth rates varied within and among individuals (Figure 2). Growth rates were, however, much more variable over time for western hemlock, in which growth rate may increase by as much as an order of magnitude in as little as three years (Figure 3). Such variability was consistent with the high levels of understory tolerance characteristic of western hemlock, allowing it to maintain very slow growth rates for prolonged periods and then rapidly exploit gaps following disturbance.
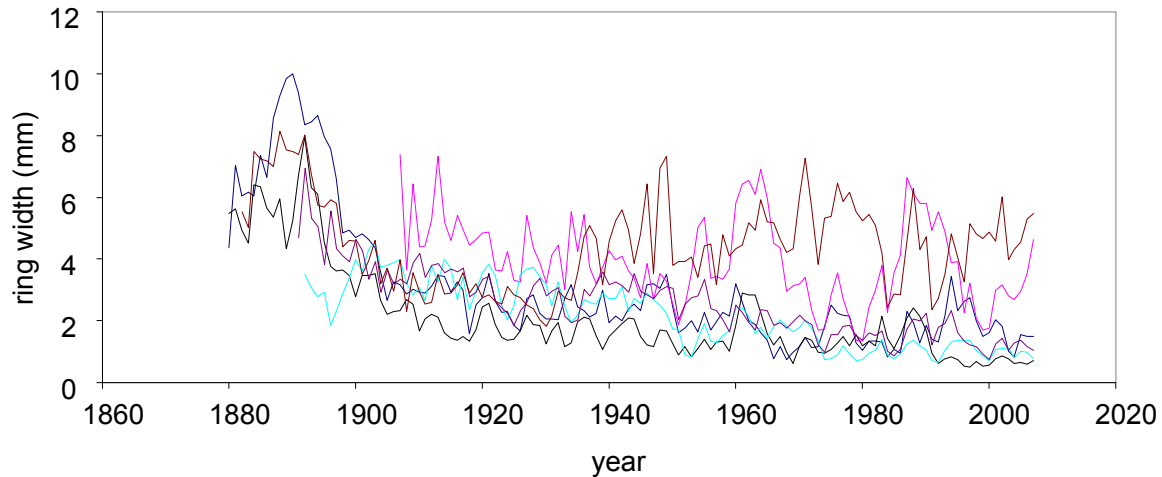
Figure 2. Ring width measurements for six Douglas-fir at the Euchre Mountain study site.
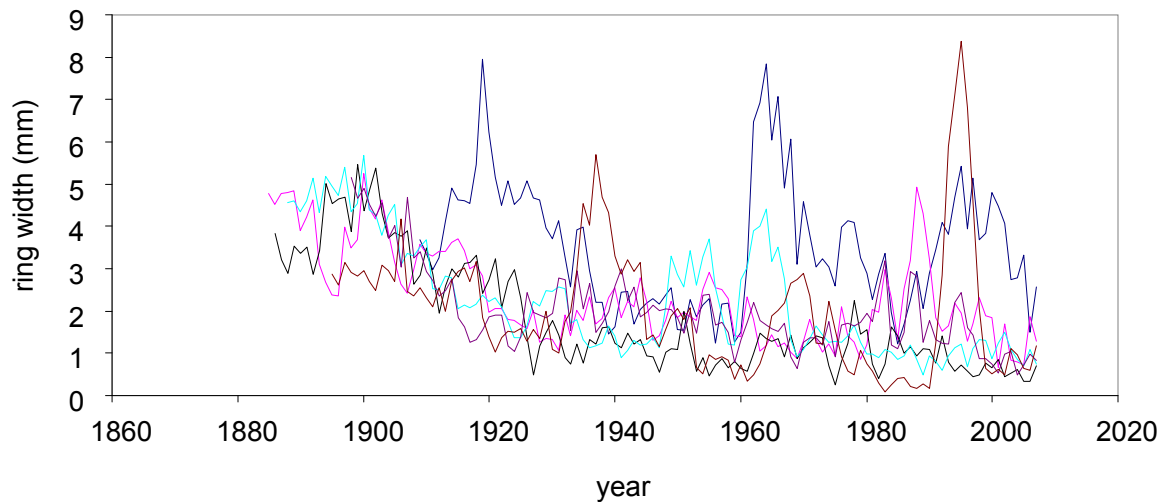
Figure 3. Ring width measurements for six western hemlock at the Euchre Mountain study site.

Master chronologies varied on a range of timescales from interannual to interdecadal (Figure 4). However, both species generally tracked one another, especially with respect to longer-term processes. In particular, western hemlock and Douglas-fir experienced substantial growth increases in the mid-1960s followed by a growth decline for the next thirty years and a sudden increase again around 1990. Since that time, growth has steadily declined for both species (Figure 4). These long-term trends are consistent with competition. This site likely experienced a stand-thinning event around 1960 and again around 1990, both of which released trees from competition, resulting in growth increases. Steady declines in growth indicate rising levels of competition as the freed resources were increasingly exploited by the survivors.

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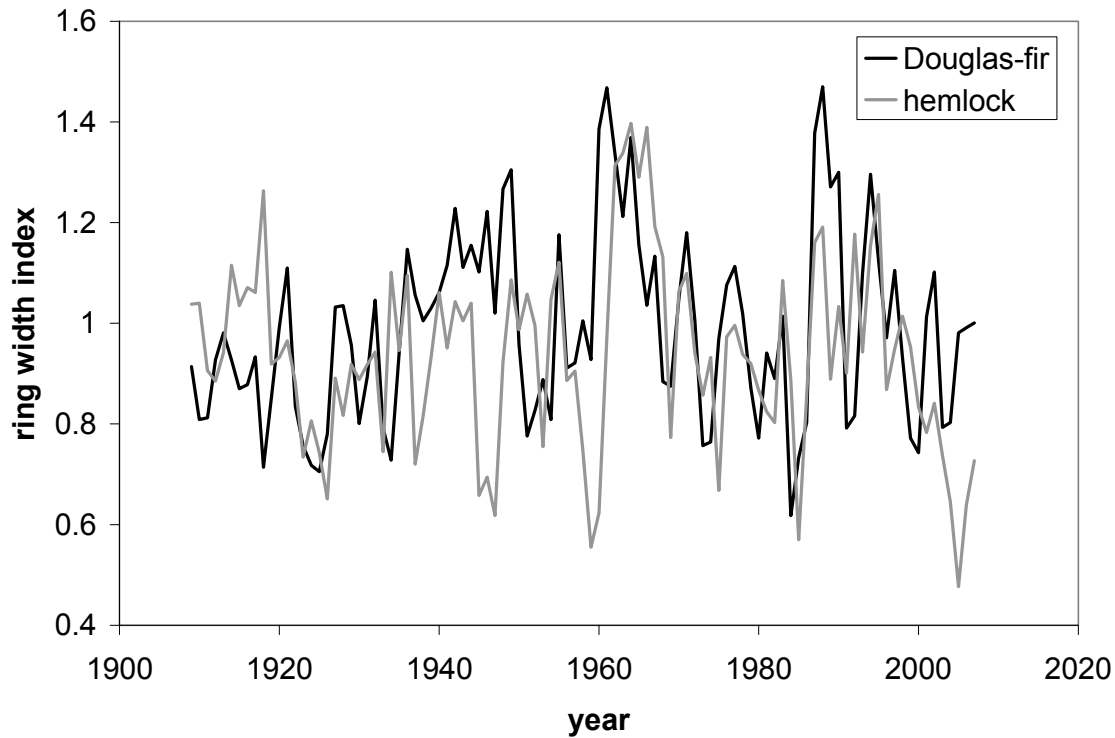
Figure 4. Master chronology for western hemlock and Douglas-fir; measurement time series detrended with negative exponential functions.

The difference between the chronologies underscores the synchrony of growth between these two species (Figure 5). Pronounced departures (greater than ±4) occurred only occasionally, and most fall within ±2. This was especially true for long-term trends whereby differences returned to the mean within a matter of only a few years. Perhaps more importantly, the most pronounced differences tended to be positive, indicating strong growth in Douglas-fir relative to hemlock, especially over the past forty years (Figure 5). These trends did not suggest that Douglas-fir growth has been negatively impacted in recent years, and was instead following or even exceeding the growth rates of western hemlock.

Figure 5. The difference between the western hemlock and the Douglas-fir master chronologies. Positive values indicate above-average growth for Douglas-fir relative to western hemlock while negative values indicate below-average growth relative to western hemlock.

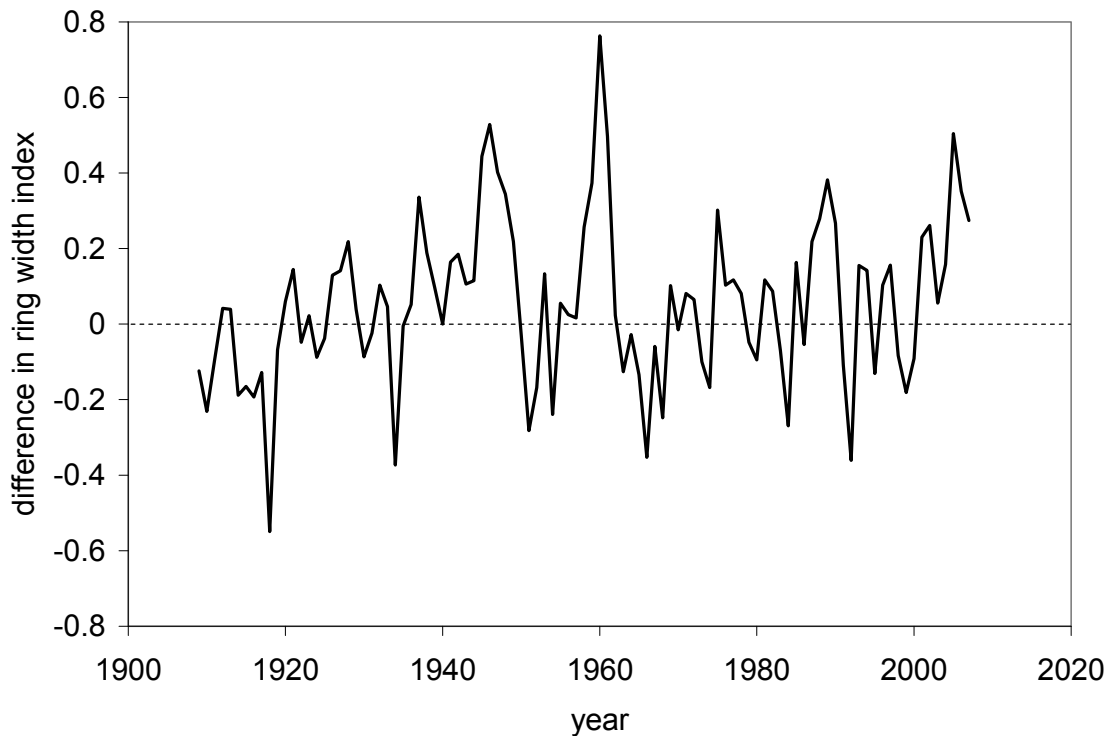Climate only modestly influenced Douglas-fir radial growth in this stand. The master chronology was weakly, yet significantly ($p < 0.05$) correlated with the Palmer Drought Severity Index during May and July of the current year and July of the prior year. Correlations were positive, indicating a moisture limitation during the summer months, as expected given the low levels of precipitation and high evapotranspirative demands the trees experience during this time of the year. The Douglas-fir chronology was also positively correlated with the Pacific Decadal Oscillation (PDO) in January. Positive values of the PDO reflect warm sea surface temperatures along the eastern Pacific and are associated with above-average temperatures and levels of precipitation. A positive PDO during the winter months may recharge soil moisture for the growing season or lessen the number of cold events. Regardless of the exact mechanisms, climate accounts for less than 10% of the variance in the Douglas-fir chronology and no discernable variance in the western hemlock chronology. Thus, climate is not a major determinant of growth patterns at the Euchre Mountain site.

Conclusions

Though the analysis is only partially complete, it indicates that Swiss Needle Cast disease does not appear to have substantially influenced the growth of Douglas-fir in this forest. Over the last 100 years Douglas-fir growth closely tracked western hemlock, including the past twenty years over which Swiss needle cast disease has been observed in the stand. This observation agrees with results from a 400-year-old Douglas-fir stand at Cape Perpetua in which radial growth over the past 100 years did not differ from that of hemlock growing on the same site. More trees will be analyzed from Euchre Mountain, and another site will be sampled

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to confirm the finding. Yet, Swiss needle cast does not appear to influence growth increment widths of these mature Douglas-fir trees. Perhaps older individuals are not as susceptible to the effects of the disease, or as natural regeneration, they are genetically resistant. As for reconstructing the history of the disease, perhaps other anatomical signals such as latewood density will be more effective indicators. Overall, radial growth rate does not appear to capture any effects from Swiss needle cast on older trees.

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Introduction

This study was conducted to further our understanding on the inheritance of Swiss needle cast (SNC) tolerance and its effects on other traits in Douglas-fir. It was done in genetic trials of the 2nd-cycle South Central Coast (SCC) Tree Improvement Cooperative program. Detailed background information and research purposes can be found in the Swiss Needle Cast Cooperative proposal for 2007 and 2008.

Experimental / mating designs and assessments

Three sites were established along the southern Oregon coast in the SNC zone, in areas specifically selected for obvious needle cast symptoms. Each trial contained 50 full-sib families selected for high 1st-cycle gains in growth, 10 from each of the five 1st-cycle programs (i.e., Umpqua Swisshome, Umpqua Coast, Coquille Coastal, Mapleton Low, and Mapleton High). Another six sites were installed as the SCC phase I mainline tests using 284 full-sib families (including the 50 in the SNC sites). Figure 1 shows the geographic locations of all 2nd-cycle testing sites and related 1st-cycle sites. There were also four checklots in each of the nine sites, including two woodsrun lots from the north end and south end of the SCC testing zone respectively, and two seed orchard control lots. The tests were established according to an alpha design, 20 replicates per site and nine (for mainline sites) or two (for SNC sites) blocks per replicate. Each block on average had 23 crosses with single-tree plots. All trees were sown in 2001 as 615A container seedlings and planted in February 2002. These tests were planted at a 9 × 9 ft initial spacing.

Age-7 tree height (HT, cm), diameter at breast height (DBH, mm), number of forks (FORK), number of ramicorns (RAMI), and sinuosity scores (SINU) were assessed at all nine sites for all living trees. For the three SNC sites and three of the mainline sites outside the zone of SNC epidemic, estimated years of needle retention (NR) at age 6 were also recorded on the 50 common families and four controls as an indicator of disease severity. Needle retention was scored in May 2007 on lateral branches close to breast height; the minimum and maximum possible needle retention scores were 0 and 2 years.

Data manipulation / statistical analyses

The data were checked through NWTIC protocols and are currently available in the NWTIC database. Due to the lack of adequate tree volume equation for young Douglas-fir trees from genetically improved materials, we used $HT \times DBH^2/100,000$ as a stem volume index (VOL, dm^3). Our previous studies have showed that the results from using different volume equations are very similar in terms of ranking families or individual trees.

Site variability within a field trial is often spatially continuous. Such spatial variation causes a serious violation of the assumption of independent observations. Thus, spatial analysis, using separable autoregressive processes of residuals, was performed for all growth traits (i.e., HT,

DBH, and VOL) on all living trees at each site (see Ye and Jayawickrama 2008 for detail). The fitted spatial surface was then subtracted from the original data to create de-trended data sets.

For valid inference, many statistical models have required independent and normally distributed errors. This cannot reasonably be assumed for some data sets like form traits (i.e., FORK, RAMI, and SINU)), as they often follow the Poisson distribution. Thus, the square root transformation, $\sqrt{Y+0.5}$, was conducted for the three form traits prior to statistical analyses.

The individual tree data were analyzed for each trial and across trials, using several linear mixed models of the general form (Henderson 1984):

$$\mathbf{y} = \mathbf{Xb} + \mathbf{Zu} + \mathbf{e} \tag{1}$$

where $\mathbf{y}$ is the vector of data, $\mathbf{b}$ is a vector of fixed effects (e.g., site and checklot effects) with its design matrix $\mathbf{X}$, $\mathbf{u}$ is a vector of random effects (e.g., replicate, block, GCA, SCA, GCA × site, and SCA × site effects) with its design matrix $\mathbf{Z}$, and $\mathbf{e}$ is a vector of residuals. Univariate family models were used for estimate variance components and genetic parameters (e.g., heritabilities and genetic correlations). Individual-tree models with heterogeneous residual variances and pedigree information were used for predicting breeding values / genetic gains and for testing statistical significance of fixed effects. Data were standardized by phenotypic standard deviation for each trial prior to any across-trial analyses to remove scale effect. The analytical procedures were detailed in NWTIC's technical document "DA-9: A Data Analysis Protocol for Cooperative Second-Cycle Progeny Tests in the NWTIC".

The results reported here were based on the age-7 data collected from the 50 full-sib families and 4 checklots in the 6 trials (3 SNC sites and 3 mainline sites).
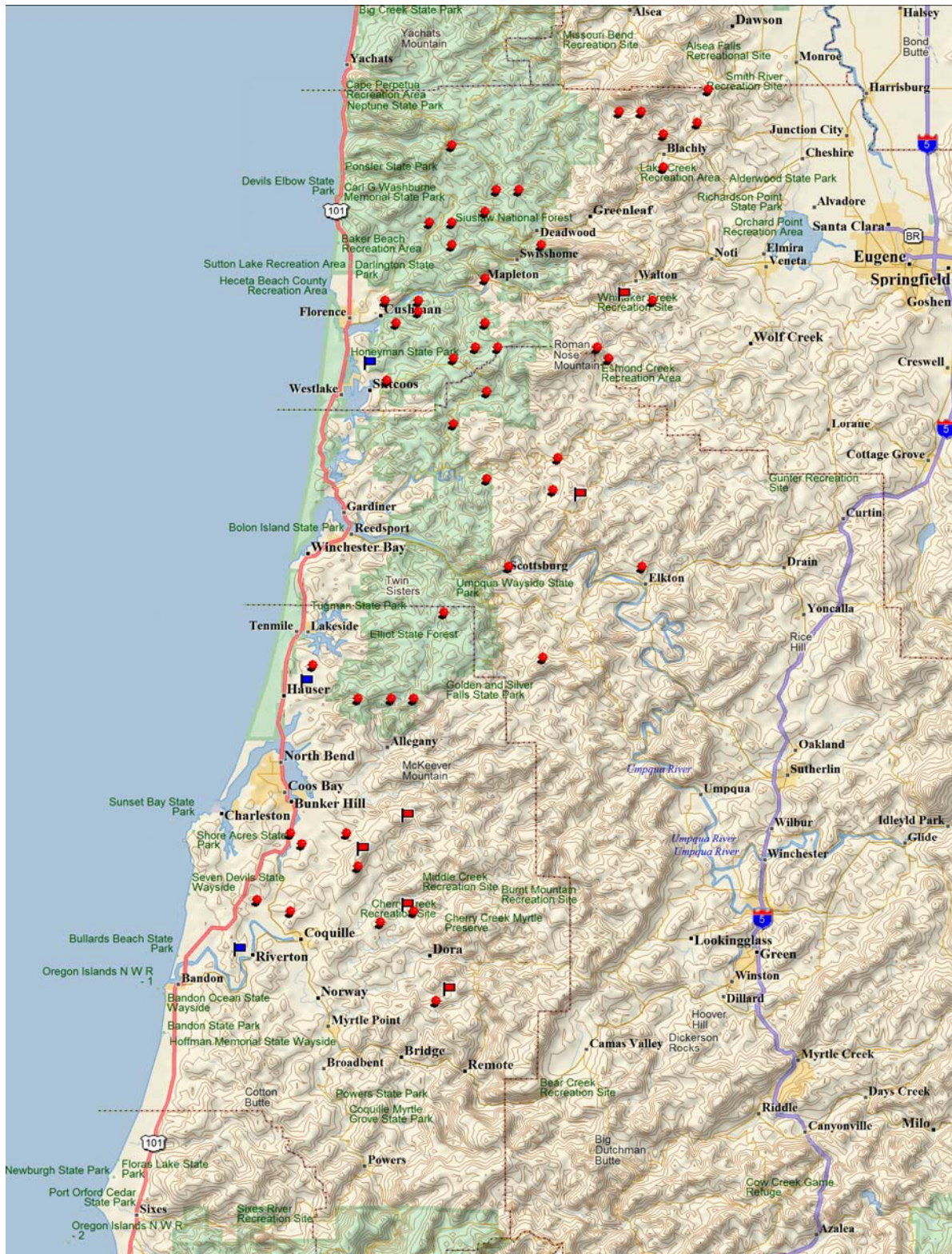
Figure 1 Geographic locations of testing sites in SCC (Red flags – 2nd-cycle mainline sites; blue flags – 2nd-cycle SNC sites; red dots – 1st-cycle sites in Umpqua Coast, Umpqua Swisshome, Mapleton High, Mapleton Low, Reedsport Coast, and Coquille Coastal)

Results

1. *Site productivity and survival rate*

Sites differed greatly in growth rate, especially for VOL (ranging from 4.7 to 33.6 dm^3). Interestingly, one of the mainline sites (572330) on average had low NR, which was even lower than two of the SNC sites. This mainline site also had the largest within-site variation in NR. This site was very intensively prepared prior to planting, including complete slash and stump removal. We can speculate that soil nutrients may have been affected. Apart from that, and its proximity to the Coquille river valley, there are no obvious reasons for low NR since this site is located about 25 miles inland.

The overall mortality, including early mortality which had been inter-planted, differed slightly among the 6 test sites, ranging from 81% to 90%.

2. *Estimates of variance components and heritabilities*

Heritability estimates of growth traits were consistently above intermediate based on either single-site or across-site analyses. The narrow-sense heritabilities of individual-tree from the across-site analysis of all sites were 0.42 for HT, 0.31 for DBH, and 0.36 for VOL; family-mean heritabilities were 0.80 or above. Note that the family-mean heritabilities are highly correlated with number of trees per family, and increase with increasing family size. For the three form traits, i.e., FORK, RAMI, and SINU, heritability estimates at age 7 were much lower than for the growth traits; the across-site individual-tree heritabilities were only 0.10 or below. Their family-mean heritabilities were, however, intermediate (0.45~0.75), suggesting potential genetic improvement via parental selection. The heritability estimate for NR was 0.17, which was smaller than the growth traits but larger than the form traits.

When data were analyzed separately for the mainline and the SNC sites respectively, it is found that the SNC group of sites had higher heritability estimates than the mainline group except for SINU. For example, the heritabilities for SNC group had 37%, 63%, 45%, and 122% higher than that for the mainline group for HT, DBH, VOL, and NR, respectively. This could partially be due to the fact that the SNC sites were much smaller than the mainline sites, and had better local environmental control. Another contributing cause might have been the excess slow-release fertilizer added at the nursery by mistake; during the first year this seemed to cause more problems on the mainline sites than on the SNC sites. The SNC sites had more rainfall in early 2002 possibly diluting the excess fertilizer.

Note that there was still large variation in heritability among sites, and it is possible to find some mainline sites with high heritability.

Except for the site 573313 ("Miller Flyway"), the dominance effect ($4\sigma^2_{cross}$) was close to 0 for growth traits. This suggests that our breeding program could be focused on utilizing additive genetic variations only.

3. *Site-to-site genetic correlations* (*Type-B correlations*)

The average r_B (site-to-site genetic correlations) for age-7 growth traits were intermediate or above (i.e., 0.82 for HT, 0.79 for DBH, and 0.62 for VOL). Interestingly, some pairs of sites had

high r_B for both HT and DBH but had low r_B for VOL (e.g., 572342 vs. 573313). Type-B correlations were calculated based on estimates of variance components, which were subject to the bias of normality assumption. Compared to HT and DBH, VOL data usually showed certain degrees of departure from a normal distribution (Ye and Jayawickrama 2008). This may partially explain why VOL behaved differently from HT and DBH.

As expected, r_B for NR between the SNC sites (0.65~0.90) were much higher than that between the mainline sites (0.21~0.39).

Note that type-B correlation is a measure of genotype-by-environment interaction (Burdon 1977).

4. Genetic correlations between needle retention and growth

From the analysis using data from all 6 sites (mainline + SNC sites), NR had weak but positive genetic correlations with HT, DBH, and VOL. The coefficients ranged from 0.14 (for HT) to 0.26 (for DBH).When analyzed separately, however, the mainline group and SNC group showed two distinct patterns in terms of genetic correlation. For the mainline group, genetic correlations between NR and growth traits were intermediate or above (i.e., 0.44 for HT, 0.76 for DBH, and 0.69 for VOL). In contrast, such correlations were close to zero for the SNC group; this was a surprising and counter-intuitive finding. Whether the same patterns are seen at the second measurement is a matter of considerable interest, since the real impact of SNC on growth is only just beginning in these tests.

While it is not clear why the two groups of sites differed so much in the coefficients of genetic correlation, it is possible that needle loss is caused by different agents within and outside the SNC zones. At these SNC sites, the needle loss may be due to SNC, salt spray, nutrient issues (especially at 572342 which is perhaps more a Port-Orford-Cedar site than a Douglas-fir site). At the mainline it may have been caused by SNC, other needle diseases, and other factors such as drought or nutrient deficiency as well.

5. Is there evidence for difference in NR and other traits between SNC sites and mainline sites?

The Wald F statistics and P values were used for testing statistical significance of contrasts between the SNC and the mainline groups, as well as among all sites. Except for RAMI, highly significant differences were found between the two groups. However, even larger difference was also found among sites within each group. For example, although the mainline group had higher NR than the SNC group (1.72 vs. 1.45) on average, site 572330 had much smaller NR than the other two mainline sites (1.21 vs. 1.90). Figure 2 shows the differences in least-squares means among all sites.

6. Is there evidence for difference in NR and other traits between the full-sib families and checklots?

Similarly, the Wald F statistics, P values, and least-squared means were used for testing statistical significance of contrasts between the full-sib families and checklots. The 50 full-sib families differed from both seed orchard lots and woodsrun lots significantly for growth traits but

insignificantly for NR and form traits. As expected, the FS families were the best for growth, and the worst performers in growth were the two woodsrun lots.

The two woodsrun lots had similar growth performance between the mainline and the SNC sites. Woodsrun South and the full-sib families on average showed a similar NR gain on the mainline sites; the latter had slightly lower NR than the former on the SNC sites (~4.5%). Not much difference in NR was found for Woodsrun North and the two seed orchard lots between the two site groups (< 3%).

7. *Comparisons in predicted breeding values / genetic gains between SNC and mainline groups*

For both mainline and SNC groups of sites, the full-sib families had much higher predicted gains in growth traits than the two woodsrun lots. Not much difference was found between site groups for NR and form traits. Gains for individual parents and crosses are proprietary to the SCC breeding co-op and are therefore not presented.

At the family-mean level, correlations of the breeding values (or genetic gains) predicted from the mainline sites and the SNC sites were high for HT, DBH, and VOL (≈ 0.90), intermediate for NR, RAMI, and SINU (0.57~0.68), and low for FORK (0.29). It should be pointed out that the imperfect correlation between groups is not only caused by infection of Swiss needle cast, but also subject to the effect of genotype-by-environment interaction. These two factors are indistinguishable based on the current experimental design. Nevertheless, it seems that Swiss needle cast does not have great impact on the growth ranking of families and parents.

8. *Relationship between 2nd-cycle age-6 NR and 1st-cycle age 9~20 growth rate*

Relationships of predicted gains between the 2nd-cycle tests and various 1st-cycle programs were examined. Results were mixed, with no consistent pattern across 1st-cycle tests. For example, Mapleton High (MH) and Low (ML) showed completely reversed patterns. In ML, high growth rate was strongly associated with high NR in both site groups. In MH, however, fast-growing parents tended to generate progeny with low NR. In the two Umpqua programs, gains for NR in the mainline group had small correlations (0.2~0.3) with age-15 gains for DBH, indicating that age-15 1st-cycle DBH gains were slightly associated with age-6 NR scores outside SNC zone. This pattern, however, did not exist for HT on the mainline sites and growth traits on the SNC sites.

A map of both first-generation and second-generation tests is shown in Figure 1. The SNC sites were typically further west (and therefore presumably more exposed to SNC) than the first-generation tests.

9. *Will scoring NR at age 6 and using it as a selection criterion improve selection?*

We will have to wait to the second measurement of this test series, to properly answer this question. However the 2nd-cycle/1st-cycle correlations mentioned in section 8 can be also interpreted as some indication of the effectiveness of using NR as a selection trait.

Data

All data referred to in this publication is available from Dave Shaw, SNCC Director. Data will also be made available on the SNCC website: http://www.cof.orst.edu/coops/sncc/index.htm

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Response of Ectomycorrhizae to Swiss Needle Cast Disease

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Introduction

Ectomycorrhizal fungi (EMF) are essential for host plant nutrient uptake and play important roles in nutrient cycling in many forests (Cromack *et al.*, 1979). For example, an estimated 50 to 70 percent of the net annual productivity may be translocated to roots and associated mycorrhizal fungi (Norton *et al.*, 1990; Fogel and Hunt, 1979; Vogt *et al.*, 1982).

Ectomycorrhizal symbioses are formed on about 8000 plant species (Dahlberg and Stenström, 2001) and the current estimate of the number of EMF species is 6000 (Molina et al., 1992). Most of the dominant and economically important timber species in the Pacific Northwest are ectomycorrhiza (EM) dependent including all members of the Pine, Oak, and Birch plant families (Smith and Read, 1997). Douglas-fir alone has about 2000 EM fungal symbionts throughout its range (Trappe, 1977). Douglas-fir will not grow in soil without ectomycorrhizal fungi (Trappe and Strand, 1969).

Several small studies have suggested a correlation between Swiss needle cast (SNC) disease severity and nutrient status of both soil and Douglas-fir foliage. Although preliminary fertilization trials have not found evidence of nutritional amelioration of SNC, it is still plausible that imbalanced nutrition may contribute to the susceptibility of Douglas-fir to SNC. Research and experience in agriculture suggests that nutrients are not as available to plants if the soil microbial community is not in a stable and healthy condition. Ectomycorrhiza (EM) communities are particularly influential with respect to nutrient availability and tree nutrition, so may be influential in predisposition of Douglas-fir to SNC.

Summary of Previous Results

In 2007, mean root density varied by nearly 10x among sites while mean EM species richness varied by about 2.5x. Ectomycorrhiza species richness was significantly correlated with root density; $R^2 = 0.65$, $p = 0.03$. Ectomycorrhiza density was significantly correlated with Douglas-fir needle retention; $R^2 = 0.70$, $p = 0.02$. Ectomycorrhiza species richness was significantly correlated with Douglas-fir needle retention; $R^2 = 0.90$, $p = 0.001$. Characteristics of the ectomycorrhiza community can be used to monitor forest health and have potential to be useful in predictive models. Normally common ectomycorrhiza types were reduced in frequency on SNC disease sites. Ectomycorrhiza types were identified and noted as candidates for future investigation as "stress tolerant" species. See Luoma and Eberhart (2007) for details.

2008 Objectives

Quantify root density by ectomycorrhiza types (species)

Rational: SNC may affect various ectomycorrhizal fungi differentially. This work addresses the hypothesis that "stress tolerant" EMF increase their dominance on roots and may reveal dominance patterns relative to functional roles EM play in nutrient uptake.

Use molecular tools to identify ectomycorrhiza species

Rational: If SNC affects the relative abundance of EM types, then knowledge of which fungal species are most affected may be essential to developing hypotheses regarding functional effects.

Methods

Stands were managed Douglas-fir plantations about 20-25 yrs. old. See Stone et al. (2005) for further site information. We collected 10 soil cores from the previously sampled (Luoma and Eberhart 2007) Green Diamond, Hemlock site. One, 350 cc soil core was taken from beneath the canopy of 10 randomly chosen Douglas-fir trees from the control treatment. We similarly collected 10 soil cores from the nearby Green Diamond Swede Hill site that was used as a control in the 2002 sulfur study. Soil cores were located approximately 1 m from the base of each tree and on the side of the bole closest to the nearest neighboring Douglas-fir, so as to bias for maximum Douglas-fir root density.

Methods for measurement of EM were the same as those used in the previous studies (Luoma and Eberhart, 2006 and 2007). Roots were extracted by wet-sieve washing the soil sample. The contents of the sieve were spread evenly, with enough water to cover, in the bottom of a 38 x 17 x 2 cm tray that was divided into 36 compartments by an inserted Plexiglas partition (Eberhart et al. 1996). Roots were examined with a stereomicroscope at 15-30X magnification Each EM type encountered was classified by morphological characteristics similar to those described in Ingleby et al. (1990) and Goodman et al. (1996) including color, texture, presence/absence of rhizomorphs and emanating hyphae. Morphotype identities were determined by comparison to the EM character database maintained by J. Eberhart. The total number of ectomycorrhiza types per soil core and total number of mycorrhizal root tips in each core were recorded for 10 soil cores from each site. Representative samples of the predominant mycorrhiza types were saved in CTAB buffer for potential molecular analysis of the fungal DNA.

Number of EM types per soil core (species richness) and total number of EM tips per soil core (feeder root density) were used as response variables. The data were used to further characterize this aspect of soil biology and EM responses to SNC disease.

JMP software (SAS, 2002) was used to perform hierarchical cluster analysis. Ward's minimum variance method was used as the clustering distance formula.

Results

A mean of 124 EM root tips/soil core were found at the Green Diamond, Hemlock site and a mean of 118 was obtained from the Green Diamond, Swede Hill site. From the 20 soil cores examined, a total of 31 EM types were identified by use of morphotyping and molecular methods. Both sites had an average of 2.3 EM types per soil core.

Table 1. List of taxa identified from EM by use of DNA "fingerprinting".

Amanita pantherina
Atheliaceae
Clavulina sp.
Hydnotrya sp.
Inocybe sp.
Lactarius luculentus
Melanogaster sp.
Russula nigricans
Sebacina sp.
Thelephoraceae
Thelephorales
Tomentella sp.
Tomentella sublilacina
Tylospora sp.

Cluster analysis showed no difference in community structure between the two sites. In fact, the analysis showed virtually no structure to the EM community due to the high number of single or few occurrences of EM types in soil cores.

Discussion

Our results confirm the findings of the 2007 study of a strong correlation between EM species richness and Douglas-fir needle retention. In fact, the new data strengthen that correlation (Fig. 1) the R^2 value increased from 0.90 to 0.93 (p = 0.0001). It is also notable that EM species richness was less well correlated with root density, at the low levels of each that we observed. Even though 2008 root density was twice that observed in 2007 on the Green Diamond Hemlock site, 2008 species richness was slightly lower. The 31 EM types (species) obtained from 20 soil cores contrasts with an expected number of 60 - 65 species found in 20 soil cores (of the same volume) from mature Douglas-fir stands in the Cascade Range (Luoma et al. 2006 and unpublished data).

Since EM species richness varied somewhat independently of root density (habitat availability) we proposed the existence of stress tolerant EM types (Luoma and Eberhart 2007). Our data revealed only one EM type that was broadly represented in the soil cores (35% constancy). This was the *Cenococcum* type that is found ubiquitously in PNW forests that are dominated by ectomycorrhizal host trees. The next most common EM type (Fig. 2) was identified with DNA sequencing as *Lactarius luculentus* and was found with only 20% constancy

across soil cores. This fungus produces orange milk-cap mushrooms and is particularly reported from Sitka spruce forests (http://www.mushroomexpert.com/lactarius_luculentus_laetus.html).

Neither of the two most common EM types would seem to be good candidates for our concept of a general "stress tolerant" species (*sensu* Grime, 1979) that would come to dominate a SNC site. The *Cenococcum* type has been reported as occurring with 97-100% constancy in soil cores from our region (Kolaczkowski, 2005; Luoma *et al*., 2006). Its presence in this study is greatly reduced from that found in healthy Douglas-fir forests. The *Lactarius* type is likely a holdover from previous site occupancy by *Picea sitchensis*. From a conservation biology perspective, it is of note to see that this fungus is able to persist in symbiosis with Douglas-fir.

Twenty-four of the 31 EM types found in this study were recorded from one soil core each. An additional 4 EM types were recorded from only 2 soil cores each. Rather than a few EM species dominating because they are particularly tolerant of a reduced carbon supply on highly impacted SNC sites, we may be seeing a "survival of the survivors" scenario. With this concept, the remaining EM species supporting Douglas-fir growth on these sites are able to persist simply because other EM species have dropped out at a locally patchy scale. Stand-level, aggregate species richness (exhibiting perhaps a 50% reduction) has not been impacted as severely as local, soil-core species richness (80% reduction). The highly patchy soil environment may provide opportunities for particular EM species to persist due to each species unique adaptive advantages in a given location. In addition, the pre-stress abundance of particular EM species could induce a founder effect that favors EM species that were already locally dominant (at the scale of the soil core). This study demonstrates the potential ecological value of the high number of EMF that can form mycorrhizae with Douglas-fir. As the stress of reduced carbon flow to the roots asserts it influence, many EMF are available to fulfill the role of "stress-tolerator" in the heterogeneous soil environment.
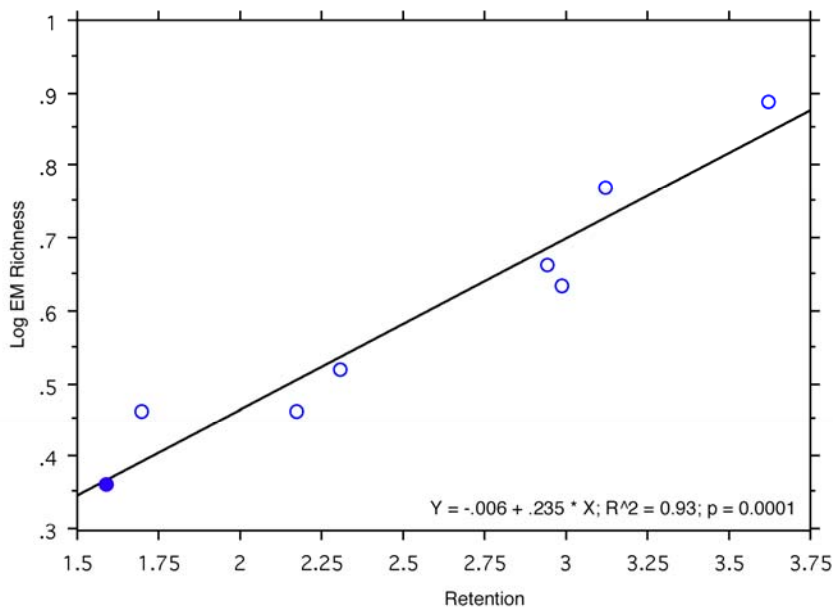

Figure 1. Regression plot of mean ectomycorrhiza root density (log transformed) against mean years needle retention (*p* = 0.0001, *n* = 10). The solid fill symbol represents data from the 2008

sample, other data are from the 2007 effort. The two left-most points represent the Green Diamond, Hemlock site.
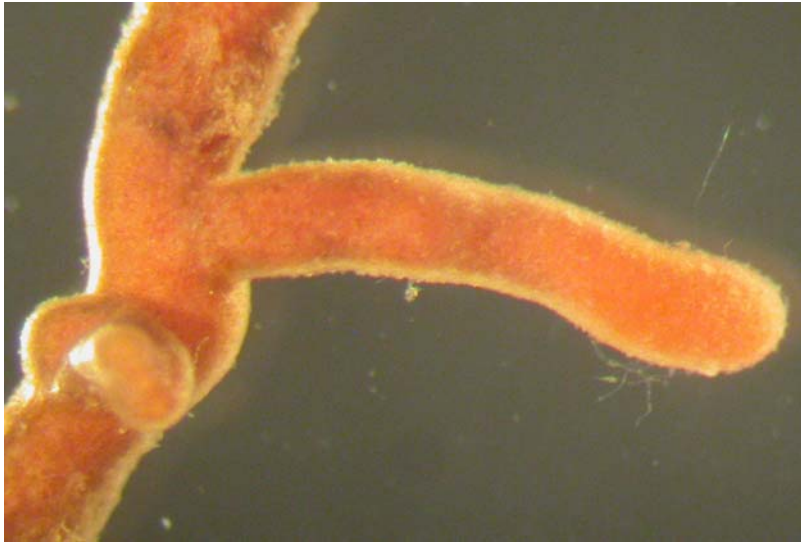

Figure 2. The *Lactarius luculentus* EM type on Douglas-fir roots.

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Crown Expression of Swiss Needle Cast Disease in Douglas-fir Plantations Across a Gradient of Infection

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Introduction

The classic disease triangle of host, pathogen, and environment acknowledges the importance of environmental variables in plant disease epidemics. Plant disease prediction systems mostly rely on the relationship of temperature and moisture to disease development and pathogen reproduction. Fungi that cause foliage diseases in coniferous trees in particular are tightly linked to climate and weather. Spore production, dispersal, and colonization of hosts are life stages that are very susceptible to desiccation, and occur during periods of optimum temperature and moisture conditions. A dominant paradigm in western North America is that wet spring and summer weather, especially warm-wet weather extending into summer, will exacerbate foliage diseases and there is considerable evidence to support this. For example, some fungi such as *Mycosphaerella pini*, cause of Dothistroma foliage disease in pine, can produce conidia whenever conditions are wet, and the current outbreak of this fungus in northern British Columbia is associated with an increase in summer rainfall over the past several decades (Woods et al. 2005).

Within any given plantation or open grown coniferous tree crown, the inner and lower portions of the crown are the most humid. Grasses, shrubs, and other vegetation are thought to increase the humidity around lower branches that mix with this understory. Foliage diseases are often most severe in the lower and inner portions of the crown in plantations and Christmas tree farms, and this is thought to be related to these micro-environmental conditions of increased humidity and prolonged leaf wetness. The upper and outer crowns are desiccated by wind and sunshine, and therefore show less expression of disease due to less successful colonization of host foliage.

Swiss needle cast foliage disease of Douglas-fir, caused by *Phaeocryptopus gaeumannii*, is currently causing an epidemic in Oregon State, USA along the Pacific coast and west slope of the Oregon Coast Range mountains. The disease is most severe near the coast, at low elevations and this is linked to warm winter temperature and consistent spring/summer leaf wetness (Hansen et al. 2000, Rosso and Hansen 2003, Manter et al. 2005). One of the first observations to be made about the epidemic was that, contrary to our understanding of Swiss needle cast disease (Merrill and Longenecker 1973, Chastagner and Byther 1983), in heavily infected plantations near the coast the upper crowns were most severely infected and showed more severe symptoms than the lower crowns. Hansen et al. (2000) used an individual tree from 7 sites near Tillamook, Oregon and compared foliage from branches that were from 5-7 years old whorls to foliage from 3 year old whorls and found that pseudothecia density was greater, and needle retention was less in the foliage higher in the crown (3 year old whorl).

Manter et al. (2003) sampled one branch each from the north-top, north-bottom, south-top, and south-bottom quadrats of the crown on three infected trees from five swiss needle cast infected sites near the coast. Highest pseudothecia density and lowest needle retention was found on the south-top, followed by north-top quadrates. Manter et al. (2003) also compared trees from north aspects to trees from south aspects across three sample sites that represented the gradient from western coast area to the eastern drier Willamette Valley margin. They found that trees growing on south slopes in the west and trees on the north slopes in the east had higher levels of infection and symptom severity.

This apparent 'switch' in symptom expression from lower and north side crowns in drier, interior habitats to the high and south side crown in the coastal epidemic area may provide insight into management of Swiss needle cast disease in Douglas-fir plantations. For example, thinning (density reduction) and vegetation control are suggested as management options to reduce needle disease in Douglas-fir plantations. However, research in the epidemic area has so far shown thinning and vegetation management does not appear to aid control of the disease in the epidemic area (Maguire et al. 2002). However, it may be that this is only the case in this epidemic area and that it should still be suggested for interior habitats where SNC is a factor.

The objectives of this research were to begin examining whether the pattern described by Hansen et al. 2000 and Manter et al. 2003 from limited research sites is consistent across the environmental and biotic gradient of the Oregon Coast Range.

Hypotheses:

1. In areas high symptom severity, SNC will be most expressed in the upper crown, while in areas of light symptom severity, SNC will be most expressed in the lower crown.

2. In areas of high symptom severity, SNC will be most expressed on the south side of the crown, while in areas of low symptom severity, SNC will be most expressed on the north side of the crown.

Methods

We plan to use the GIS and PCT plots of Mainwaring and Maguire (see the papers in this annual report) to test our hypotheses. We initiated studies in 2008 and when trees in the GIS plots were climbed for a south side branch, we had the climber collect a north side branch also. Several datasets are anticipated and analysis has only begun on these two:

1. The GIS study (Mainwaring and Maguire, this report, Figure 1) estimated needle retention in all crown thirds until 2005. We are beginning analysis of pattern across the infection gradient.

2. This field season (2008) we had tree climbers that were already in trees take an additional branch from the north side of the crown as well as the south side of the crown on about 50 plots. Five trees from each plot had branches samples (250 trees). We counted the % of stomates plugged with pseudothecia to determine infection intensity. Although needle retention, pseudothecia density, and fungal biomass are all tightly linked, it is important to check to be sure the effect is on the fungus. This data has not yet been analyzed.
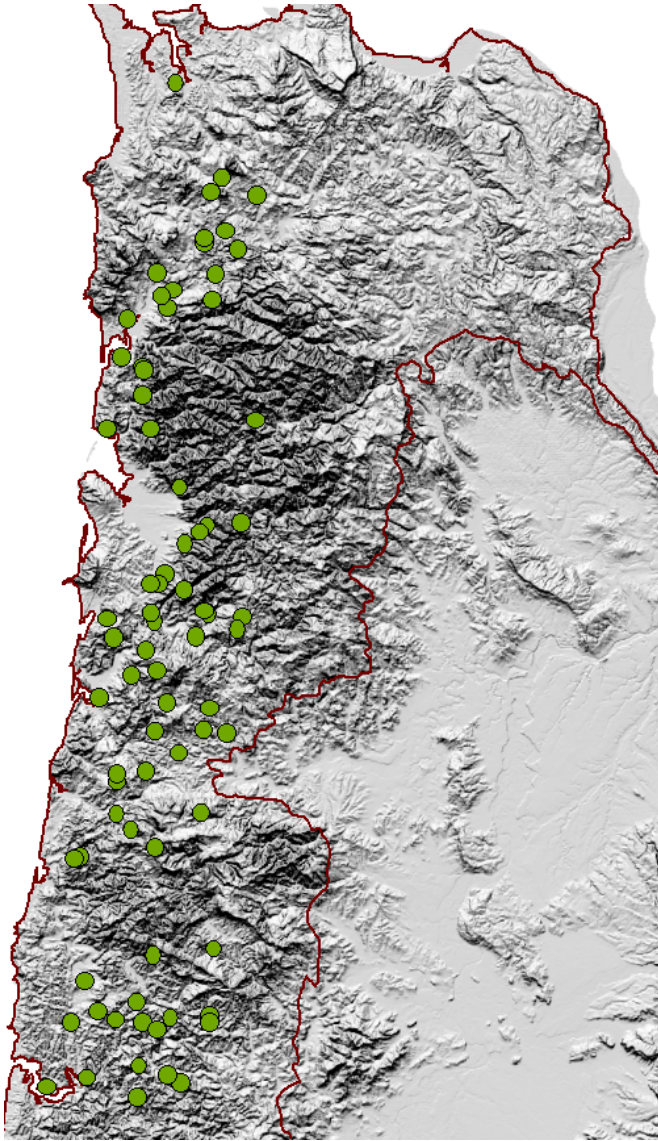
Figure 1. Location of the GIS plots along the north Coast Range, Oregon

Results to date.

We have begun investigating the pattern of vertical needle retention using a hierarchical modeling approach (Singer 1998, SAS-PROC MIXED) at two levels:
1. Tree level, where canopy position and DBH are tested.
2. Stand level, where elevation, aspect, stand age, and the interactions of DBH*aspect, elevation*position, elevation*aspect, elevation*DBH, elevation*DBH*aspect are tested.

Position in the crown (p < 0.0001), DBH (p = 0.0007), and elevation (p=0.004) were significant.

Needle retention vertical crown averages (standard error) (see also Figure 2)
- Lower canopy NR estimate = 2.86 years (0.05)
- Middle canopy NR Estimate = 2.38 years (0.06)
- Upper canopy NR Estimate = 1.62 (0.03)

Needle Retention 2000
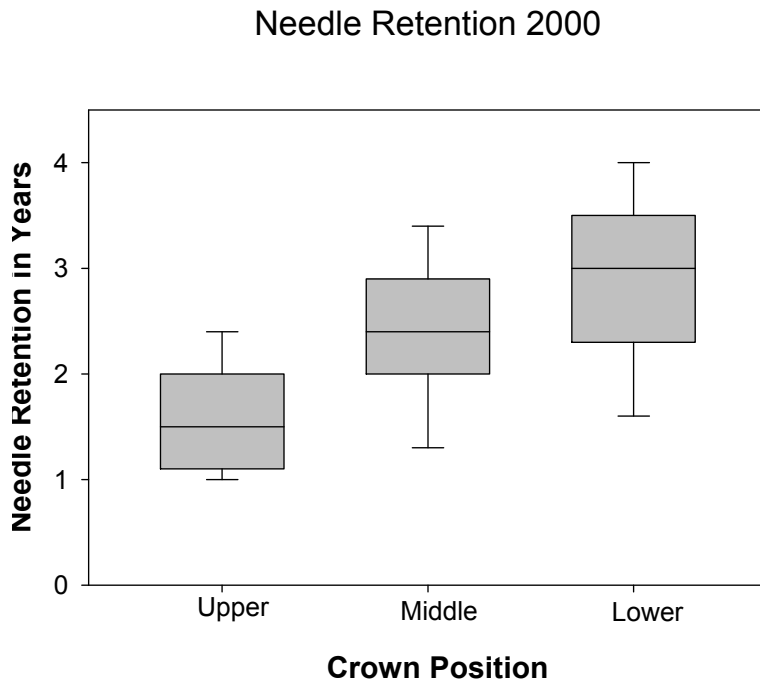

Crown Position

Figure 2. Needle retention in years and crown position during 2000.

The effect of DBH on needle retention was interesting, although it is generally thought that the fastest growing trees are the healthiest, and therefore should have greatest needle retention. The relationship can be conceptualized that for every 1 cm increase in DBH you increase needle retention by 0.16 years.

At the stand level, the only significant variable on needle retention was elevation. For every 1,000 ft of elevation gain, you increase needle retention by 0.3 years.

Summary

Across the gradient of the GIS plots, the canopy needle retention is different in each crown third and this pattern is consistent across the plots (upper least foliage, lower most foliage), although the upper crown is the most variable and the lower crown is least variable. No switch is seen in the retention of foliage, i.e. the lower crown always had the most foliage.

This research is in progress and will investigate north vs. south side crown for disease incidence. It appears that the plot distribution from the crest of the Coast Range to the coast may not go far enough east to capture the entire Coast Range gradient.

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