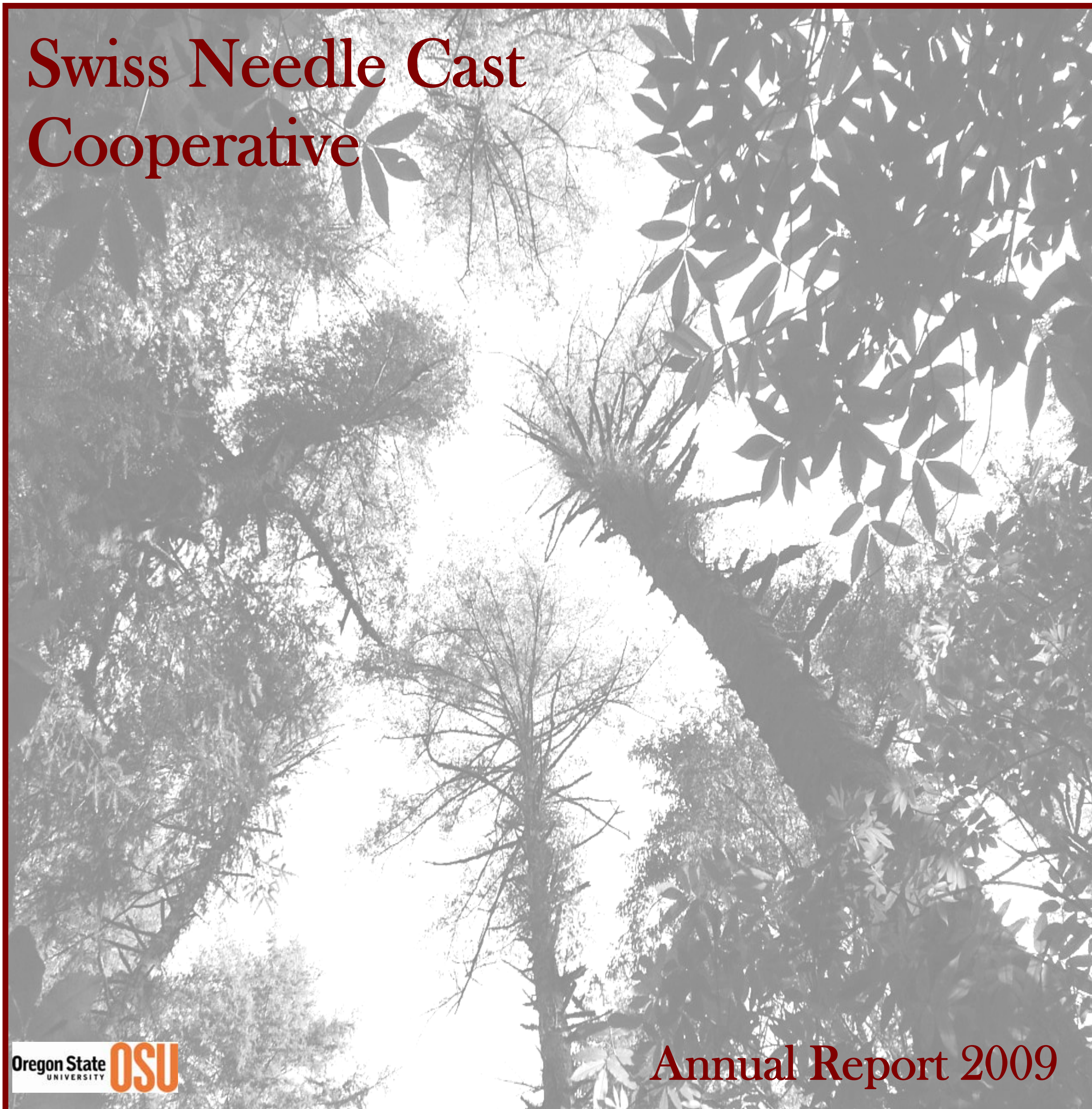
Swiss Needle Cast Cooperative



Oregon State University OSU

Annual Report 2009

SNCC

Swiss Needle Cast Cooperative
Annual Report 2009

Edited By Dave Shaw, SNCC Director
& Travis Woolley

SNCC Income Sources and Expenditures: 2009

Income

Membership dues	80,000
Oregon State Legislature	95,000
Carry-over	29,057
Total 2009 Budget	**$204,507**

Expenditures

Salaries and wages	123,007
Travel	6,853
Operating expenses	4,221
Contract Work	15,481
Materials and Supplies	2,927
Indirect Costs	19,824
Total 2008 Expenditures	**$172,312**

Contents

SNCC Members Letter

SNCC Members College of Forestry, OSU

Swiss needle cast continues to be a major growth loss agent on the west coast of Oregon. Over the past four years, the annual aerial disease detection survey has estimated over 300,000 acres with visible symptoms (See Kanaskie and McWilliams in this report). Only one year previously had over 300,000, although there was one year with 290,000+ acres. The bottom line however, is that it appears the disease is intensifying within the epidemic area. Current work by Bryan Black and colleagues (See Black et al. in this report) using dendrochronological techniques also estimates that the disease impact on basal area growth is not slowing.

A major question often asked is, "What is the threat to the Douglas-fir region as a whole from SNC". Currently we do not think there is a direct threat to the entire region, as the disease is generally limited by geography and climate. Our Cascades plots show no indication of disease expression. Therefore, unless we see a major shift, it appears the SNC epidemic will not spread inland to influence the entire Douglas-fir region. However, this forest disease is causing the largest conifer foliage disease epidemic in North America; larger than the Dothistroma epidemic in lodgepole pine of British Columbia. In Oregon alone, SNC is influencing forests across a 4 million acre region. Although this disease is limited to the coastal belt, it is not going away, appears to be intensifying, and could in the future pose a threat to the region, or at least expand to influence forests at the margin of the epidemic.

The current focus of the SNCC is 1) Disease distribution and severity, 2) Biology, ecology and epidemiology of *P. gaeumannii*, 3) Effect of silvicultural treatments on disease, 4) Models to predict growth impacts and geographic distribution of disease severity, and 5) Developing an Integrated Pest Management (IPM) strategy for SNC. The SNCC supports research and outreach with funds from members and the state legislature of Oregon, through the College of Forestry, Forest Sciences Laboratory, and Department of Forest Engineering, Resources and Management.

Perhaps most important at this point in time is the integrated pest management strategy for SNC. The foundation of an effective IPM strategy is knowledge of the distribution and severity of disease. We currently have this with our Annual Aerial Survey and the Growth Impact Plots (GIS). These complimentary monitoring programs allow us to base our management recommendations on a sound and quantitative footing. The aerial survey provides knowledge of distribution, while the GIS plots allow for a quantitative measure of growth impacts across a range of disease severity.

Douglas-fir is the most important timber species in the Pacific Northwest. It is also a very important ecological element of Pacific Northwest forests. There are numerous compelling reasons to be concerned about Swiss needle cast in the Pacific Northwest. The SNCC is leading the way to a better and more informed future for Northwest forests and continued Douglas-fir productivity.

David Shaw, December 2009

2009 Projects

- Aerial Survey. ODF/USFS Cooperative Survey
- Weather relationships to Aerial Survey Results
- Relationship of SNC disease severity to soil amendments
- Sulfur Project, remeasurement of Sulfur treatments
- Impacts of Swiss Needle Cast on Timber Harvest, Forest Products Output and Timber Markets in the Pacific Northwest
- Additional needle retention plots
- Landscape needle retention maps and growth loss
- Crown distribution of needle retention
- Pre-commercial thinning and disease severity
- Mycorrhizae and SNC
- Dendrochronology methods to understand the history of SNC impacts

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

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

Disease Distribution and Severity, Epidemiology

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Manter, D.K., Reeser, P.W., and J.K. Stone. 2005. A climate-based model for predicting geographic variation in Swiss needle cast severity in the Oregon coast range. Phytopathology 95: 1256-1265.

Rosso, P.H., Hansen, E.M. 2003. Predicting Swiss Needle Cast Disease Distribution and Severity in Young Douglas-Fir Plantations in Coastal Oregon Phytopathology 93:790-798.

Stone, J.K., Hood, I.A., Watt, M.S., and J.L. Kerrigan. 2007. Distribution of Swiss needle cast in New Zealand in relation to winter temperature. Australasian Plant Pathology 36: 445-454.

Stone, J.K., B.R. Capitano, J.L. Kerrigan. 2008. The histopathology of *Phaeocryptopus gaeumannii* on Douglas-fir needles. Mycologia 100: 4310444.

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Genetic Resistance/Tolerance in DF

Kastner, W., Dutton, S., and D. Roche. 2001. Effects of Swiss needle cast on three Douglas-fir seed sources on a low-elevation site in the northern Oregon Coast Range: Results after five growing seasons. West. Jour. of Ap. For. 16(1):31-34.

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Winton, L.M., E.M. Hansen, J.K. Stone. 2006. Population structure suggests reproductively isolated lineages of *Phaeocryptopus gaeumannii*. Mycologia, 98(5), 2006, pp. 781-791.

Winton. L.M., Stone, J.K., and E.M. Hansen. 2007. The systematic position of Phaeocryptopus gaeumannnii. Mycologia 99:240-252.

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Maguire, D.A. and A. Kanaskie. 2002. The ratio of live crown length to sapwood area as a measure of crown sparseness. For. Sci. 48: 93-100.

Weiskittel, A.R., Garber, S.M., Johnson, G.P., Maguire, D.A., and R.A. Monserud. 2007. Annualized diameter and height growth equations for Pacific Northwest plantation-grown Douglas-fir, western hemlock, and red alder. Forest Ecology and Management 250: 266-278.

Weiskittel, A.R., Maguire, D.A., Garber, S.M., and A. Kanaskie. 2006. Influence of Swiss needle cast on foliage age class structure and vertical distribution in Douglas-fir plantations of north coastal Oregon. Canadian Journal of Forest Research 36, 1497-1508.

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Weiskittel, A.R., Maguire, D.A., and R.A. Monserud. 2007. Response of branch growth and mortality to silvicultural treatments in coastal Douglas-fir plantations: Implications for predicting tree growth. Forest Ecology and Management 251:182-194.

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Nitrogen and soils interactions

Waring, R.H., J. Boyle, K. Cromakc, Jr., D. Maguire, and A. Kanaskie. 2000. Researchers offer new insights into Swiss needle cast. Western Forester 45 (6): 10-11.

El-Hajj,-Z., Kavanagh,-K., Rose,-C., and Z. Kanaan-Atallah. 2004. Nitrogen and carbon dynamics of a foliar biotrophic fungal parasite in fertilized Douglas-fir. New Phytologist. 163: 139-147.

Perakis, S.S., D.A. Maguire, T.D. Bullen, K. Cromack, R.H. Waring, and J.R. Boyle. 2005. Coupled nitrogen and calcium cycles in forests of the Oregon Coast Range. Ecosystems 8: 1-12.

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Manter, D.K., Winton, L.M., Filip, G.M., and J. K. Stone. 2003. Assessment of Swiss Needle Cast Disease: Temporal and Spatial Investigations of Fungal Colonization and Symptom Severity. Phytopath-Z. 151:344-351.

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Winton, L. M., Stone, J.K., Watrud, L.S., and E.M. Hansen. 2002. Simultaneous one-tube quantification of host and pathogen DNA with real-time polymerase chain reaction. Phytopathology. 92: 112-116.

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Grotta, A.T., Leichti, R.J., Gartner, B.L., and G.R. Johnson. 2004. Effect of growth ring orientation and placement of earlywood and latewood on MOE and MOR of very-small clear Doulgas-fir beams. Wood and Fiber Science 37: 207-212.

Johnson, G.R., Grotta, A.T., Gartner, B.L., and G. Downes. 2005. Impact of the foliar pathogen Swiss needle cast on wood quality of Douglas-fir. Can. J. For. Res. 35: 331-339.

In Press:

Black, B.A., D.C. Shaw, and J.K. Stone. In press. Impacts of Swiss needle cast on overstory Douglas-fir forests of western Oregon Coast Range. Forest Ecology and Management.

Swiss Needle Cast Aerial Survey, 2009

Alan Kanaskie and Michael McWilliams, Oregon Department of Forestry

Introduction

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.

Aerial surveys to detect and map the distribution of SNC damage have been flown annually since 1996. 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.

Methods

The Oregon Coast Range survey was flown from May 7 to May 16 and covered approximately 4.2 million acres of forest. The observation plane flew at 1,500 to 2,000 feet above the terrain, following north-south lines separated by 2 miles. Observers looked for areas of Douglas-fir forest with obvious yellow to yellow-brown foliage, a symptom of Swiss needle cast. Patches of forest with these symptoms (patches are referred to as polygons) were sketched onto computer touch screens displaying topographic maps or ortho-photos and the position of the aircraft. Each polygon was classified for degree of discoloration as either “S” (severe) or “M” (moderate). Polygons classified as “S” for discoloration had very sparse crowns and brownish foliage, while those classified as “M” were predominantly yellow to yellow-brown foliage with slightly denser crowns than those classified as “S”. The survey area extended from the Columbia River south to Brookings, and from the coastline eastward until obvious symptoms were no longer visible. We did not survey the Cascade Range in 2009, but Swiss needle cast does occur at damaging levels in some areas.

Results and Discussion

The 2009 survey mapped 302,028 acres of Douglas-fir forest with obvious symptoms of Swiss needle cast. This is a slight decrease in the area with SNC symptoms compared to the previous 3 years (figure 1). As has been the case for the past several years, the easternmost area with obvious SNC symptoms was approximately 28 miles inland from the coast in the Highway 20 corridor, but most of the area with symptoms occurred within 18 miles of the coast. Figures 2 and 3 show the distribution of symptoms from selected surveys conducted from 1996 through 2009. Note: last year’s survey (2008) was not fully completed because of weather and aircraft availability. Data from three sample blocks were used to estimate overall survey results for 2008.

The Swiss needle cast aerial survey provides a conservative estimate of damage because observers can map only those areas where disease symptoms have developed enough to be visible from the air. Permanent plot data and ground checks show that Swiss needle cast occurs throughout the survey area, but that discoloration often is not severe enough to enable aerial detection. The total area of forest affected by Swiss needle cast is far greater than indicated by the aerial survey. The aerial survey does, however, provide a reasonable depiction of the extent of moderate and severe damage, and coarsely documents trends in damage over time.

The survey was conducted by the Oregon Department of Forestry Insect & Disease and Air Operations sections, and was funded by the Oregon State University Swiss Needle Cast Cooperative, the USDA Forest Service Forest Health Monitoring Program, and the Oregon Department of Forestry. Trevor Courtney (ODF) piloted the plane. Mike McWilliams (ODF) is the survey coordinator and primary aerial observer; Ben Smith (USFS) and Rob Flowers (ODF) were the other aerial observers. The 2009 survey cost $10,238 (plane and pilot only). Salary for the aerial observers and costs associated with data processing and map production were contributed by ODF and the USDA-Forest Service.

The GIS data and a .pdf file of the map can be accessed via the ODF web page at: http://oregon.gov/ODF/PRIVATE_FORESTS/fh.shtml#Survey_Maps___Data

Additional Notes:
We appreciate any information regarding the accuracy or usefulness of the maps. Please call Alan Kanaskie (503-945-7397) or Mike McWilliams (503-945-7395) if you have questions, suggestions, or comments.

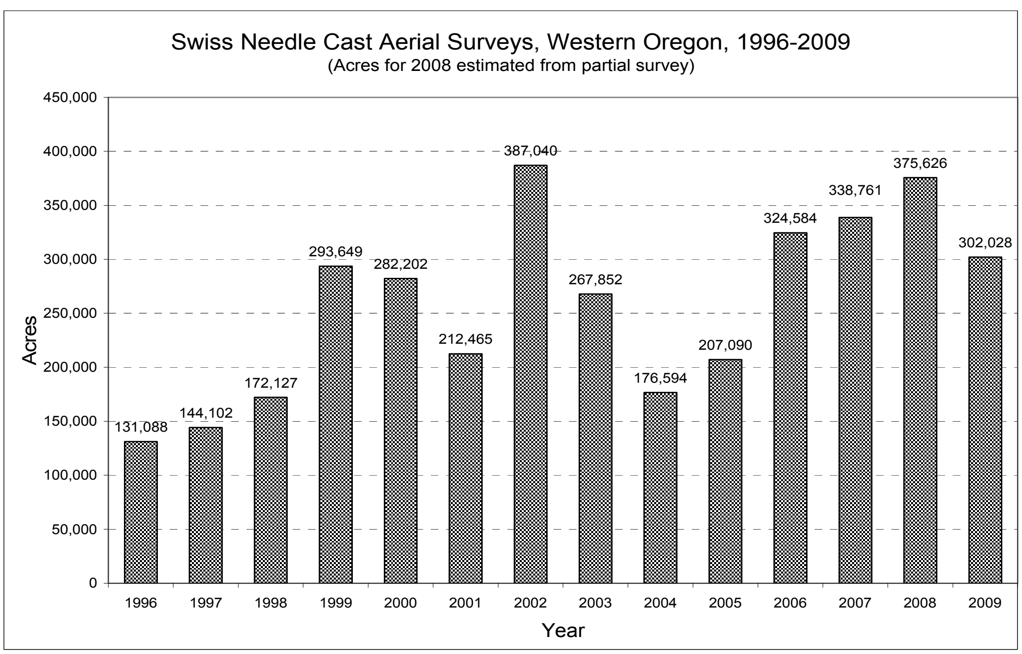

Figure 1. Trend in area of Douglas-fir forest in western Oregon with symptoms of Swiss needle cast detected during aerial surveys in April and May, 1996-2009. Results for 2008 were estimated by extrapolating from 3 sample survey blocks.

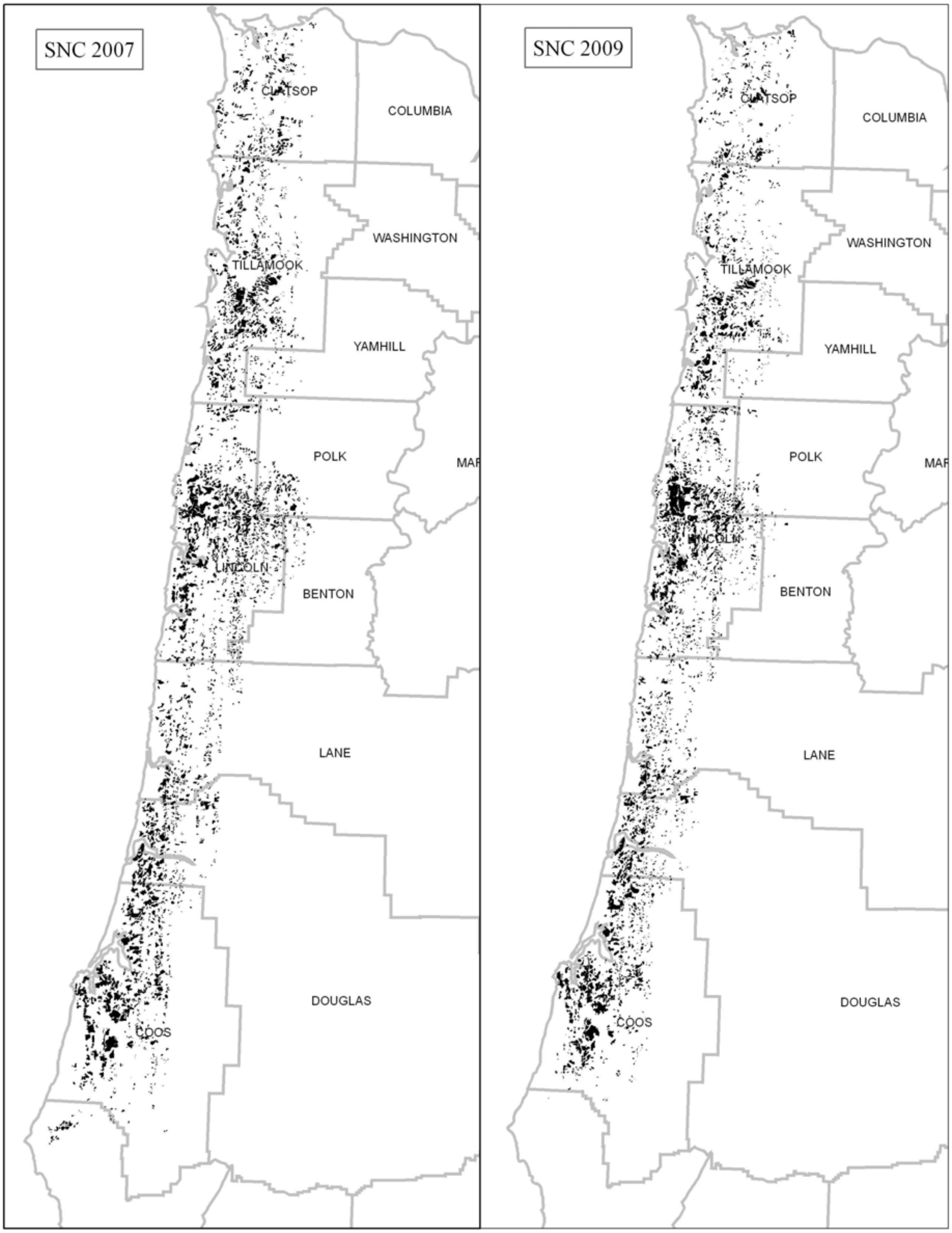

Figure 2. Swiss Needle Cast (SNC) aerial survey: areas of Douglas-fir forest with symptoms of Swiss Needle Cast detected in the 2007 and 2009 surveys. Solid black polygons (blotches) depict areas with severe or moderate damage from SNC.

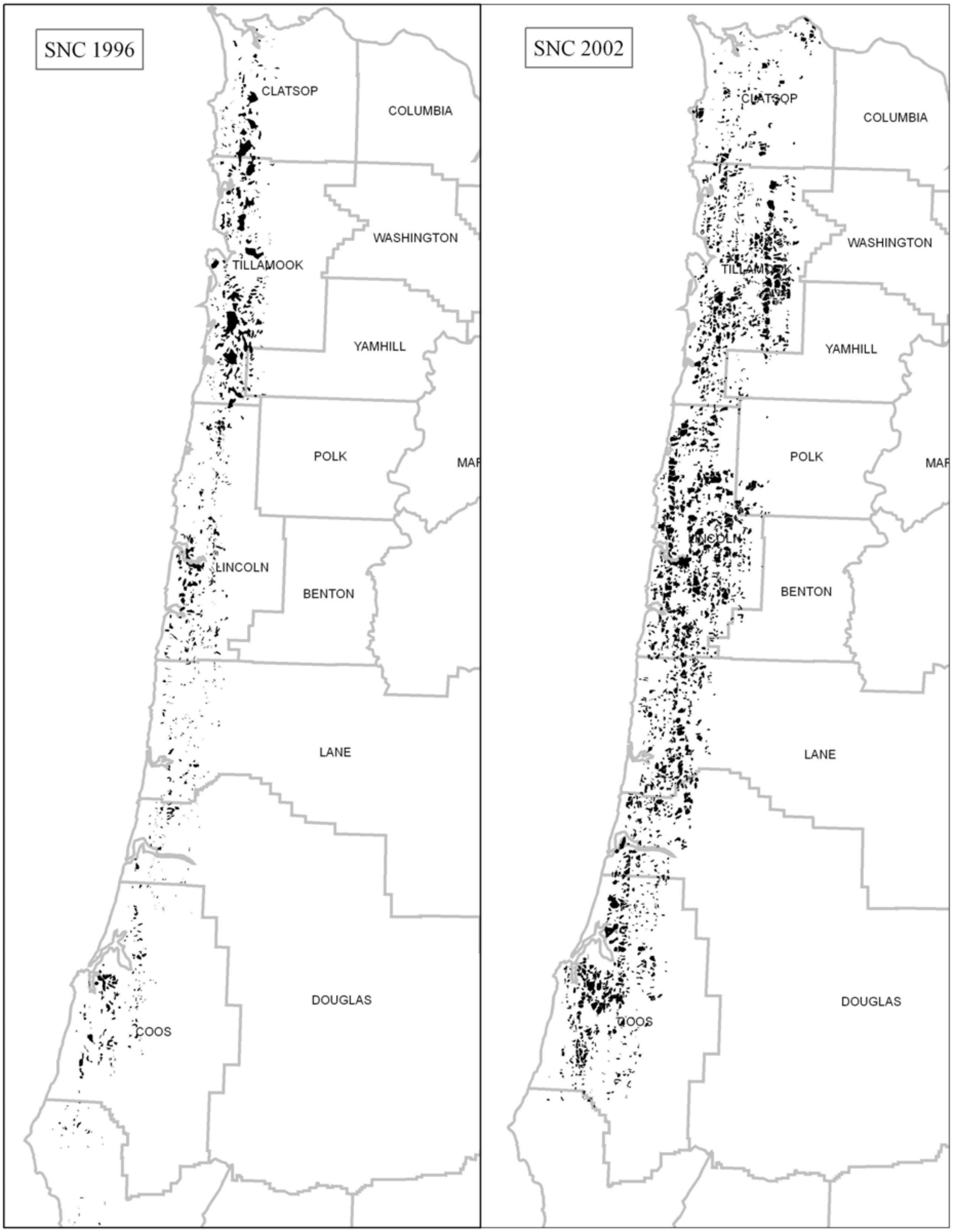

Figure 3. Swiss Needle Cast (SNC) aerial survey: areas of Douglas-fir forest with symptoms of Swiss Needle Cast detected in 1996 (the first aerial survey) and 2002 (survey that mapped the most acres). Solid black polygons (blotches) depict areas with severe or moderate damage from SNC.

Preliminary Analysis of relationships between Swiss Needle Cast Aerial Survey acreages and weather and climate variables

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Abstract

Acreage of severely and moderately classified Swiss needle cast (SNC) foliage disease impacted stands was calculated from GIS data obtained from the Oregon Department of Forestry annual aerial surveys (1996-2009). Oregon coastal monthly average precipitation, average monthly temperature and monthly precipitation/drought indices (Palmer Drought Severity Index (PDSI), Standard Precipitation Index (SP01-09)) Pacific Decadal Oscillation (PDO) were acquired for the years (1993-2007) preceding and overlapping with the aerial survey data (1996-2007) and were compared to the aerial survey results to see if there was a relationship with climate variables and disease occurrence and severity. We also check relationships with previous one, two and three year weather data correlations with SNC. The take home messages appear to be that moderate acres were positively related to colder and drier late winter weather last year and were generally positively correlated to temperature in the 12-15 months prior to the survey. It also seems that symptoms of SNC respond negatively to low temperatures in previous December months. From this preliminary analysis, it appears that the amount of moderately affected acres is driving the total number of acres affected by SNC, as moderate makes up the majority of the total acres affected. Severely affected acres are not correlated with moderate and total acres, while it seems to be related to distinctly different weather patterns and lag periods.

Introduction

The Swiss needle cast (SNC) epidemic on the Oregon coast has been surveyed using aerial detection methods from 1996 to present (Kanaskie and McMilliams 2008). The aerial survey specialists denote visible plantations/stands/forests infected with SNC as moderately impacted or severely impacted. Currently, the aerial survey has indicated an intensifying disease epidemic as the 2006, 2007, 2008, 2009 years all had over 300,000 acreas of visible disease. Only one year in the previous record had over 300,000 acres. Because SNC the epidemiology of SNC and Douglas-fir is closely tied to climate and weather (Manter et al. 2005) it is likely the annual variation in disease severity estimated from aerial survey is associated with weather patterns also.

Our objectives were to determine if there were any clear relationships between weather data and annual aerial survey results. We wondered if higher precipitation in the spring of one year, would influence disease in the following year for example. Oregon coastal monthly average precipitation, average monthly temperature and monthly precipitation/drought indices (Palmer Drought Severity Index (PDSI), Standard Precipitation Index (SP01-09)) Pacific Decadal Oscillation (PDO) were acquired for the years (1993-2007) preceding and overlapping with the aerial survey data (1996-2007) and were compared to the aerial survey results to see if there was a relationship with climate variables and disease occurrence and severity.

Methods

Acreage of severely and moderately classified stands was calculated from GIS data obtained from the Oregon Department of Forestry. The details of the aerial survey are described in previous annual reports (Kanaskie and McWilliams 2008). Aerial survey values for 2008 were not included because a restricted portion of the area was flown and estimated to the entire area. GIS data for 2009 was not available at the time of analysis. Oregon coastal monthly average precipitation, average monthly temperature and monthly precipitation/drought indices (Palmer Drought Severity Index (PDSI) and Standard Precipitation Index (SP01-09)) were acquired for the years (1993-2007) preceding and overlapping with the aerial survey data (1996-2007) from the National Oceanic and Atmospheric Administration (NOAA) National Environmental Satellite, Data and Information Service (NESDIS) (http://www7.ncdc.noaa.gov/CDO/CDODivisionalSelect.jsp). The monthly Pacific Decadal Oscillation (PDO) values were obtained from the NOAA Physical Sciences Division Time Series data site (http://www.esrl.noaa.gov/psd//data/climateindices/List/). Daily and monthly minimum and maximum temperature estimates from Portland and Astoria were obtained from The National Weather Service (NWS) Forecast Office local climate data and observed weather reports (http://www.wrh.noaa.gov/pqr/pdxclimate/, http://www.weather.gov/climate/index.php?wfo=pqr).

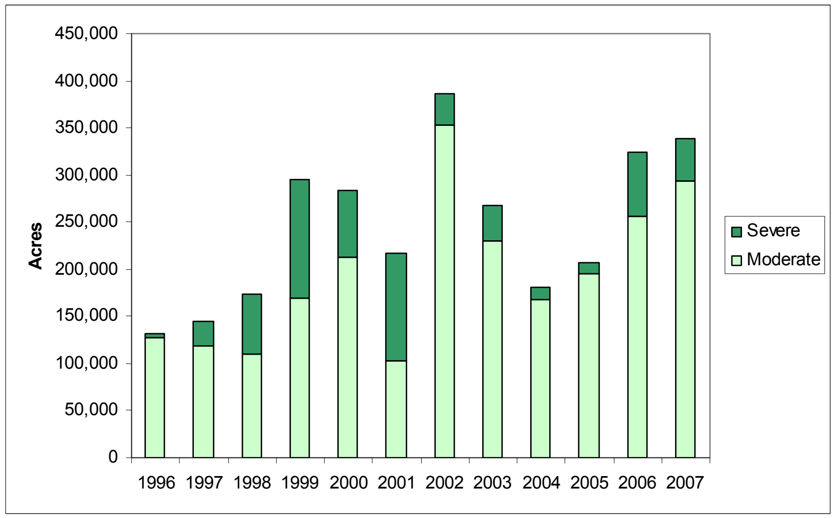


Figure 1 Aerial Survey data illustrating the acres affected by SNC along the coast of Oregon from 1996 to 2007.

The PDSI index indicates the severity of a dry (negative values) or wet (positive values) period and the larger or more negative the value, the more severe of a wet or dry period. The PDO index averages the monthly sea surface temperatures (SST) of the Pacific Ocean relative to the global average anomaly. Positive PDO values indicate warm waters along the west coast of North America and generally correlate with lower than average rainfall and higher than average air temperatures. Negative PDO values indicate cooler waters along the coast and indicate higher than average rainfall and lower temperatures.

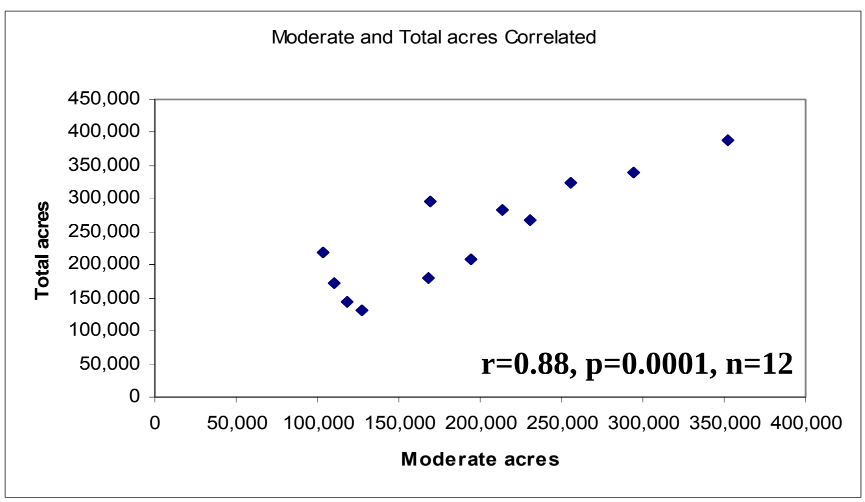
Yearly total and average precipitation and temperature values were calculated from the NESDIS Oregon coastal data. The minimum and maximum temperature from each month was assigned to each month in the time period from the NWS data to try to identify cold or hot periods within months that might be hidden in average temperature data.

A number of climate and PDSI related indices were considered and rejected for this analysis. This preliminary analysis was targeted at variables that we anticipated would directly influence the life history of Swiss needle cast (*Phaeocryptopus gaeumannii*). To limit the number of variables, we included only early spring precipitation (when the ascospores are released and dispersed by wind and rain), winter temperature variables (because there is some anecdotal evidence of cold spells influencing the fungus), indices of wet or dry weather spells in spring to winter months, and monthly PDSI and PDO values. One, two and three-year lags were incorporated into the dataset, in addition to variables from Jan-May of the current survey year, to account for any lag in relationships between climate and area affected by SNC. In addition, incorporating this lagged data might account for time between infection and expression visible to the aerial survey.

Unusual or 'farther from average' values of all variables were identified to approximate unusual or potentially influential events in the 13 year window of interest. Those values (i.e., acreages affected, precipitation, temperature and SST) greater or less than the mean plus or minus two standard deviations were considered unusual and noted. Pearson correlation coefficients were calculated between moderate, severe and total acres affected, and precipitation, temperature and SST (PDO) variables. Significant correlations were synthesized to assess what might be most important based on multiple relationships for precipitation, temperature or SST variables.

Results

Moderate acres were significantly positively correlated with total acres, (r=0.88) which may indicate that the number of moderate acres is largely driving the total number of acres. This is further supported by the fact that, on average, moderate acres made up 80% of the total acres each year.



The number of severe acres was not correlated with moderate or total acre values, which is further evidenced by different relationships to precipitation, temperature and SST variables witnessed in further correlation work. A number of unusual or 'farther from average' precipitation, temperature and SST events, as well as acres affected, appeared in our analysis and can be seen in Table 1.

An increase in total affected acres was negatively correlated (*r* = -0.71) with average annual temperature overall the previous year, specifically the prior February (*r* =0.60) and late summer months of last year (*r* =0.68, 0.70, 0.58 - July, Sept and Oct respectively).

Higher moderate acres were observed in years with drier (*r* = -0.60 to -0.65 - Jan-Mar PDSI) and colder *(r* = -0.65, Feb. temperature*)* late winter months one year ago. In addition, warmer temperatures in the 12-15 months prior to the aerial survey were negatively correlated (*r* = -0.60, average temperature) to the number of moderate acres. That is, colder average annual temperatures related to higher acres moderately affected by SNC. In contrast, moderate acres were positively correlated with having no or very few cold days in December, 3 years prior to the survey (*r* = 0.65).

The number of severely affected acres was positively correlated to wetter Jan-May and Aug-Nov months two years ago (*r* =0.59-0.64). Warmer temperatures in November were also positively related to the number of severe acres 2 years later (*r* =0.89). Overall drier Feb, Mar and April months were related to higher numbers of severe acres three years later *(r* = 0.60-0.66 - PDO*).* However, wetter months in March through December (*r* =0.72-0.74), especially November and December (*r* =0.66-0.68) 3 years prior to the survey, were related to a higher number of severe acres. The number of acres severely affected by SNC is also significantly correlated with a 3 year lag of summer precipitation and average precipitation (*r* = 0.86)

Table 1 - Unusual or 'farther from average' precipitation, temperature and SST events for the time period of 1993 to across the SNC aerial survey of the Oregon Coast Range.

	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
moderate acres	.	.	.			low			low	very high					high
severe acres	.	.	.	low			high		very high			low	low		
total acres	.	.	.	low	low					very high				high	high
percent severe	.	.	.	low		high	high		very high				low		
January								wet, cool	dry						
February			warm				wet								
March							wet		dry						
April	wet														
May	wet				wet										
June	wet				dry, warm						dry				
July	wet										dry				
August	dry, warm				dry, warm						dry	wet, warm			
September					wet, warm										
October					wet						warm				
November														wet	
December				wet						dry, warm					

Discussion

Based on these preliminary results, the relationships appear to underscore a few key relationships with climate and weather variables, and may give us insight into how aerial survey results may relate to on the ground information about SNC. Nearly all of the logical and well supported relationships had time lags built in and suggest that the aerial survey collects data that has responded to prior weather conditions, instead of the current year's weather. Given the fungus' life history and the lag between infection and needle loss, this is not surprising. The take home messages appear to be that moderate acres were positively related to colder and drier late winter weather last year and were generally positively correlated to temperature in the 12-15 months prior to the survey. It also seems that symptoms of SNC respond negatively to low temperatures in previous December months.

Severe acres do not appear to respond to the same variables that moderate (total) acres do. Severe acres were positively correlated to wetter than average weather for most of the year in prior years and may respond positively to warm temperatures in prior November and early spring months.

The most apparent limitation of the approach used in this analysis is that we are unable to say anything about causal relationships, we can only determine that there is a relationship between two time series of data, not that one actually causes the other. Another limitation is that we have little to no information about how level of occlusion, needle retention, tree yellowing and symptom visibility from the plane are related to each other.

Conclusions and Future Work

It appears that the amount of moderately affected acres is driving the total number of acres affected by SNC, as moderate makes up the majority of the total acres affected. Severely affected acres are not correlated with moderate and total acres, while it seems to be related to distinctly different weather patterns and lag periods.

Future work could include more indices and additional variables related to coastal information and additional analytical approaches to assess relationship (e.g., sign test, model building). A number of variables, like fog levels, a distinct record of extreme freezing events, relative humidity levels were not readily available from coastal weather stations but would have been excellent additions to this preliminary analysis.

Spatial information has been neglected completely in this analysis and spatial maps of severity through time could be very helpful. In addition, looking at just the 3 'severe blocks' might be extremely illuminating if similar results are found, or if these blocks really are responding differently than the rest of the coast. Comparisons of other SNCC studies with needle occlusion, needle retention measurements and crown color estimates to aerial survey classifications through time could help us sort out time lags and how these relationships are actually working.

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Pseudothecia density for Growth Impact Study and Pre-commercial Thinning Plots

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Introduction

The severity of the foliage disease Swiss Needle Cast (SNC), caused by the fungus *Phaeocryptopus gaeumannii*, is often reported as the years of needle retention on subsets of Douglas-fir (*Pseudotsuga menziesi*) tree branches. Previous work has shown that the abundance of the fungus is directly related to needle retention. However, much of this work has been done on a small number plots in a small geographic range. Measures of disease severity (i.e., fungal biomass, or density of fruiting bodies) that are much more directly related to the actual abundance of the fungus can provide insight not only to the relationship between needle retention and fungal abundance, but can provide a higher degree of certainty regarding the effects of the fungus on productivity. We used branch samples from the Growth Impact Study (GIS) and Pre-commercial Thinning (PCT) plots to measure pseudothecial abundance on 1 and 2 year old needles obtained from 4-year old lateral branches. We asked the following questions; 1) Is pseudothecia density on needles related to needle retention and how strong is this relationship? 2) Are there differences between both needle retention and pseudothecia density on the north and south sides of Dougla-fir crowns (GIS plots)? And 3) Do different thinning treatments (200 and 100 tpa) change the abuundance of pseudothecia? Some preliminary results for the GIS plots (questions 1 and 2) are shown in this report.

Methods

Study Sites and Branch/Needle Sampling

During the 2008 re-measurement of the GIS plots, a subset of 50 stands was randomly selected for disease severity sampling. Within these 50 stands 10 trees were selected and further sampled for lab analysis of pseudothecia density. On both north and south aspects of the tree canopy, one secondary branch on the fifth branch whorl from the top of the tree was removed. This branch was examined for estimation of foliar retention, placed in a plastic bag, stored on ice and subsequently frozen in the lab.

Branch sampling for the PCT study was conducted in spring of 2008. The fifth whorl branch from the south side of each of 5 randomly selected trees was collected from each thinning treatment at each study site. The branch was placed in a bag and returned to the lab for processing.

Pseudothecia Counts

Ten needles were then randomly selected from both 1 year and 2 year old needles and affixed to cards for assessment of pseudothecia. For each needle 3 randomly located points were chosen to count stomata occluded by pseudothecia. At each point 100 stomata were observed using a dissecting microscope and the number of stomata occluded by pseudothecia was recorded. The proportion of stomata occluded was averaged across the three random points on each needle and then averaged for all 10 needles for each age class; resulting in an average proportion of stomata occluded for age class 1 and 2 needles on both the north and south side of each tree. This same procedure was conducted on needles collected from the PCT plots, only the south side of each tree, resulting in an average proportion of stomata occluded for age class 1 and 2 needles.

Results

GIS

We found that the relationship between pseudothecia density on stomata and needle retention, although significant) was not very strong (Figure 1). The strongest relationship was that of needle retention and 1 year old needles from both sides of the tree crown. There appears to be significant differences in pseudothecia density between needle age classes, but no apparent differences between crown aspects (Figure 2). We found a similar result for needle retention (Figure 3).

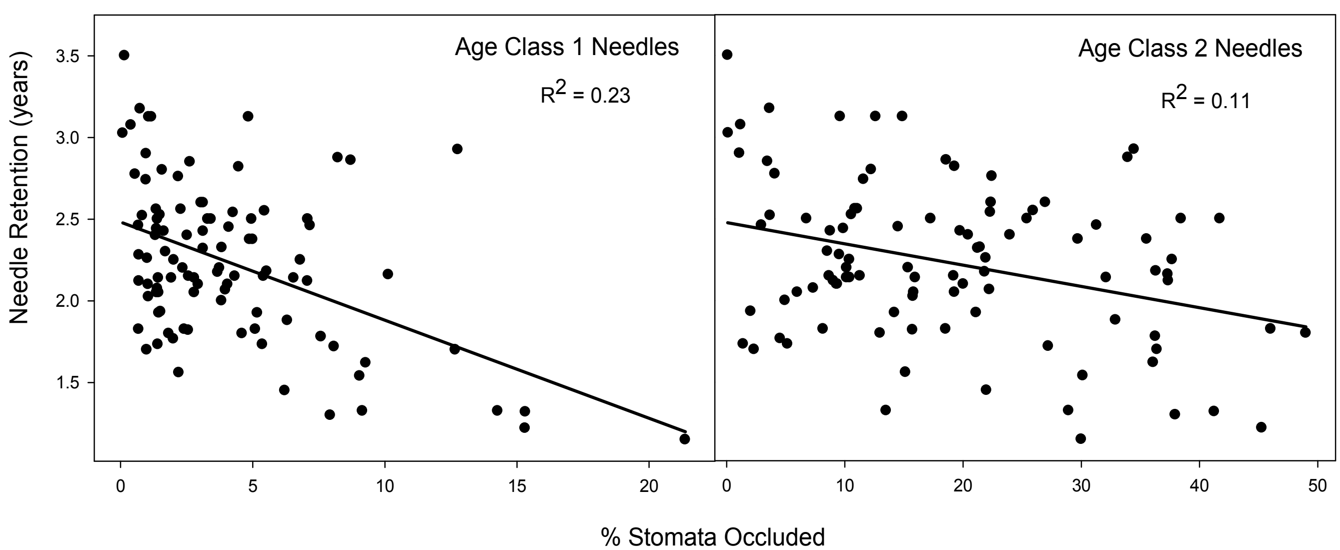

Figure 1. The relationship between pseudothecia density (% occlusion) and needle retention for 50 GIS plots in the Oregon Coast range.

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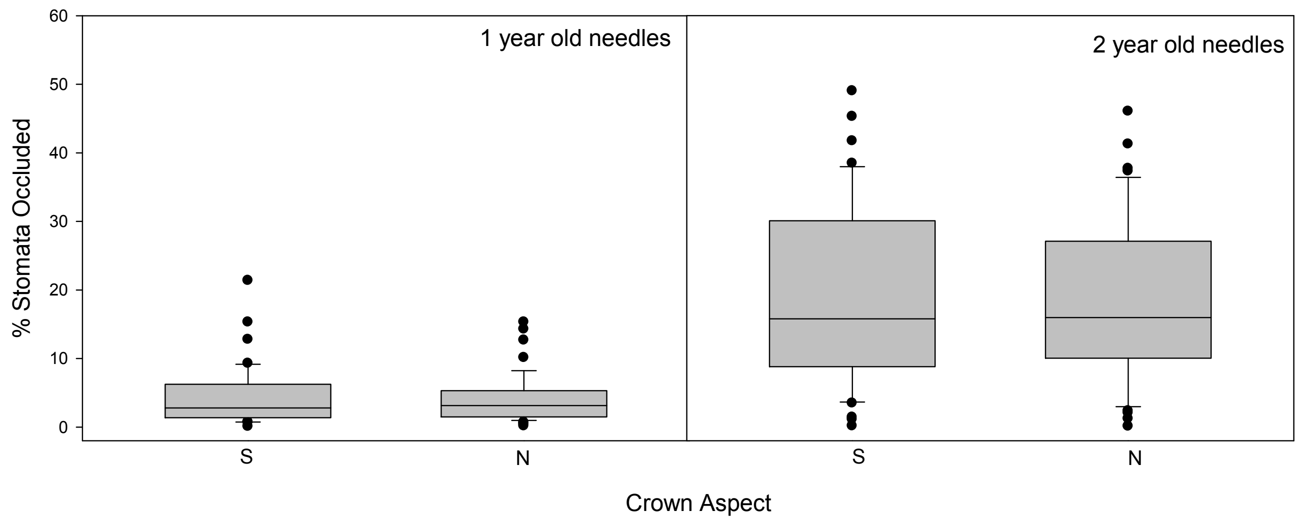


Figure 2. Comparison of pseudothecia abundance between north and south crown aspects, for both 1 and 2 year old needles.

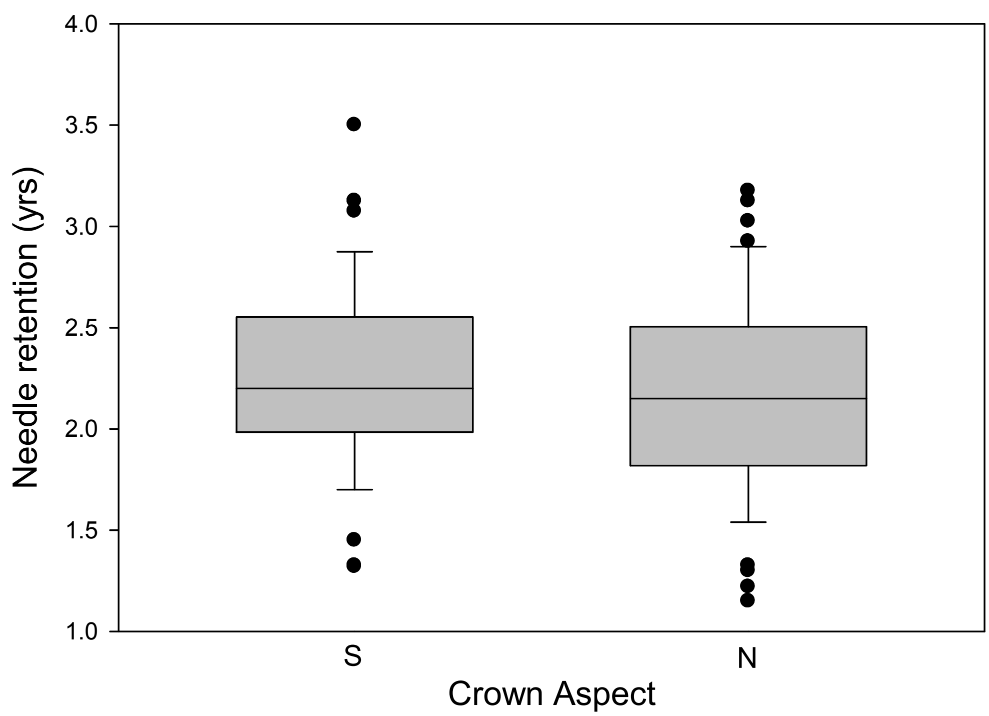
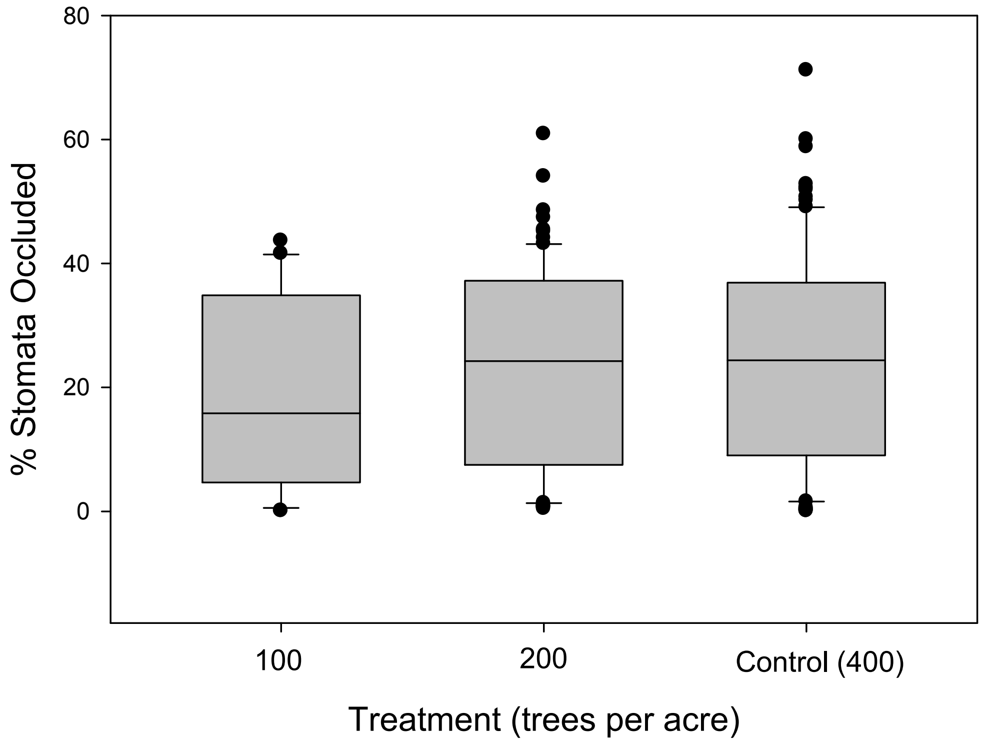


Figure 3. Comparison of needle retention between north and south crown aspects.

PCT

There appears to be no pre-commercial thinning treatment effect of pseudothecia density on needles (Figure 4), other than a slightly lower mean density for the 100 tpa treatment. However, this figure does not account for any stand differences, and when are included in the statistical analysis, these factors may affect the result.



Conclusions and Further Analysis

Given previous work many of these findings are surprising. However, given the results of Weiskittel et al. (2006) for foliage distribution, it is not surprising we found no crown aspect influence.

These data will be used for further statistical analysis to better understand the distribution of disease within Douglas-fir canopies (GIS data) and the effects of pre-commercial thinning treatments on disease abundance (PCT).

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Vertical foliage retention in Douglas-fir trees and stands across a gradient of Swiss Needle Cast disease in coastal Oregon

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Abstract

Swiss needle cast (SNC) foliage disease of Douglas-fir,(*Pseudotsuga menziesi*) 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. Initial observations of the SNC epidemic showed that in heavily infected plantations near the coast the upper crowns were most severely infected and showed more severe symptoms than the lower crowns. This is contrary to the previous understanding of the SNC disease. We investigated the pattern of vertical foliage retention and hypothesized that: 1)in areas high symptom severity, SNC will be most expressed (i.e, foliage retention) in the upper crown, while in areas of light symptom severity, SNC will be most expressed in the lower crown, and 2) foliage retention will increase with distance from coast and elevation, and will be higher on north facing slopes. Foliage retention increased with increasing distance from the coast, which is consistent with our current observations and understanding of disease severity. The vertical pattern of foliage retention stayed the same throughout the study area; lowest retention in the upper crown, highest retention in the lower crown. As foliage retention increases in the upper crown, it also increased in the lower crown. There was no switch in which position of the crown was most impacted. Our hypothesis that in areas of lower disease severity there would be greater impacts in the lower crown relative to the upper crown was not supported by this analysis. Nor were aspect effects significant. Swiss needle cast foliage disease vertical impacts are consistent throughout the current epidemic area.

Introduction

Swiss needle cast (SNC) foliage disease of Douglas-fir,(*Pseudotsuga menziesi*) 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, Hansen and Rosso 2003, Manter et al. 2005). Swiss needle cast disease is expressed as early loss of foliage, thin crowns, chlorotic (yellow) crowns, and reduced tree growth. Tree growth has been directly linked to foliage retention, which can be expressed as the number of years of foliage retained on a branchlet. Maguire et al.

(2002) found that foliage retention in years is directly linked to tree growth, and subsequently adapted this knowledge to forest growth models (ORGANON, see annual reports:). Hansen et al. (2000), Manter et al. (2001), Winton et al. (2003) have shown that foliage retention is linked to biological severity assessments (counts of plugged stomates by fungal tissue, ergosterol measurements of fungi within needles, and molecular biomass estimates) and can be used as a surrogate for disease severity. Therefore, within the epidemic area, foliage retention within Douglas-fir trees is thought to be directly effected by *P. gaeumannii*.

Initial observations of the SNC epidemic showed that in heavily infected plantations near the coast the upper crowns were most severely infected and showed more severe symptoms than the lower crowns. This is contrary to the previous understanding of the SNC disease. Typically, SNC causes foliage loss in the lower and inner portion of the crown, where humidity is higher (Merrill and Longenecker 1973, Chastagner and Byther 1983). Hansen et al. (2000) compared foliage from branches that were from 5-7 years old whorls to foliage from 3 year old whorls from 7 sites near Tillamook, Oregon. They concluded that pseudothecia density was greater, and foliage 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 SNC impacted sites near the coast. Highest pseudothecia density and lowest foliage 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.

There appears to be an apparent ‘switch’ in symptom expression from lower and north side crowns in drier, interior habitats to the upper and south sides of crowns 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 (Crane 2002, Mainwaring et al. 2005). Similar insights have been gained in studies of SNC in New Zealand (Hood and Sandberg 1979). 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. (2002) from a limited number of research sites is consistent across the environmental and biotic gradient of the western Oregon Coast Range. We hypothesize that: 1)in areas high symptom severity, SNC will be most expressed (i.e, foliage retention) in the upper crown, while in areas of light symptom severity, SNC will be most expressed in the lower crown, and 2) foliage retention will increase with distance from coast and elevation, and will be higher on north facing slopes.

Methods

Study Sites and Data Collection

In a retrospective study assessing SNC growth impacts (Maguire et al. 2002), 76 permanent 0.02 ha plot was established and annually re-measured (1998-2003) for tree diameter (all trees), height (subset of trees), height to live crown base (subset of trees), and foliage retention. These plots were located in Douglas-fir (*Pseudotsuga menziesii*) plantations between 10 and 30 years of age, located north of Newport, OR, south of Astoria, OR, and within 31 km of the coast (Figure 1). These plantations were randomly selected from a large database containing all possible Douglas-fir plantations within the given geographic and age ranges.

Estimates of foliage retention (FR) were obtained by dividing the live crown into thirds (lower, upper, middle) and examining secondary or lateral branches on a primary branch in each crown third. The average number of foliar age classes present was determined to the nearest 0.1 year. For further information regarding site characteristics and tree growth responses to SNC see Maguire et al. (2002). As noted, FR is related to disease severity caused by *P. gaeumannii* in this geographic area (Hansen et al. 2002, Manter et al. 2005)

Data Analysis

Differences in (FR) by canopy position (lower, middle, upper) were examined using hierarchical models (Singer 1998) with tree and stand level predictors. This method accounts for multi-level variation due to measurement of explanatory variables at different scales than the response variable. Two-level models that regressed NR against canopy position (tree level) while exploring trends in this relationship with covariates at the tree and stand scale were developed. Tree level covariates included diameter at breast height (DBH) and canopy position (CP). Stand level covariates were elevation, aspect, and distance from coastline. Aspect was measured as an azimuth (0-360) and transformed for analysis using a cosine transformation (equation 1) resulting in values from 1 (0º) to -1 (360º). Values of DBH, elevation, and distance from coast were centered to either the mean values within a stand (DBH), or the mean values across all stands (distance and elevation). This approach provides more interpretable model coefficients (Singer 1998).

<u>Equation 1:</u>
cos-aspect= cosine((aspect/360)*2*pi)
pi=3.14

Explanatory variables at the tree (canopy position and DBH) and stand (elevation, distance from coast, and cos-aspect) levels were used to develop 18 *a priori* candidate models. These models were then compared using Akaike's Information Criterion (AIC) to select the best model (Burnham and Anderson 2002). Models were ranked by the change in AIC (Δ_i) and Akaike's weights (W_i). W_i is the weight of evidence in favor of a model being the best model within the entire set being tested given the data (Burnham and Anderson 2002). In addition, the proportion of variance accounted for (Singer 1998) within and between stands relative to both a null model and a model with only tree level CP and DBH is considered.

Models included combinations and interactions of explanatory variables at both the tree and stand level, based on *a priori* hypotheses. All regression analyses were performed using the MIXED procedure with maximum likelihood estimation methods in SAS v9.2 (SAS Institute Cary, NY). The CORR procedure was also used prior to model selection to determine correlation between explanatory variable. Variables with significant correlations were not included in the same model. Stand age and tree DBH were highly correlated (r=0.57; p< 0.0001). Due to the desire to include tree level effects (i..e., having DBH in the model) and the correlation with DBH (r =0.57). stand age was not used as a stand level variable in model selection Following analysis of outliers, two sites were excluded from the analysis due to their high values of elevation and foliage retention compared to the remaining sites, and thus their extreme influence on the results of the analysis. Several plots were also removed from the analysis due to insufficient replication at the tree level. The analysis was conducted and results are reported for a total of 70 stands and 485 trees.

Results

- Take home messages
    - Foliage retention in canopies of Douglas-fir in 10-30 year old stands on the Oregon coast range varies by canopy position (lower, middle, and upper positions). The lowest foliage retention occurs in the upper canopy and the highest in the lower third of the canopy. Variation in NR is lowest in the upper canopy and highest in the lower canopy.
    - At the tree level dbh, in addition to canopy position, are significant factors explaining foliage retention patterns.
    - At the stand level, distance from coast is the most important factor of the stand variables. Elevation is also a potential factor that can alter foliage retention estimates, and estimates of foliage retention for lower, mid, and upper canopy positions can change as distance from the coast changes.
    - With DBH effects held constant, foliage retention changes with distance from the coast as follows:
        - Lower - Every 10 km from the coast FR increases by 0.40
        - Mid - Every 10 km from the coast FR increases by 0.33
        - Upper – Every 10 km from the coast FR increases by 0.25
    - Holding the other model variables constant, foliage retention changes with tree diameter as follows:
        - For a 10 cm increase in DBH, FR increases by 0.1 yrs (95% CI: 0.04 – 0.17).

- Model selection indicated that the best models to estimate foliage retention included canopy position, tree DBH, and distance from coast (Table 2).
    - 99% of cumulative weight ($\boldsymbol{W}_{\mathbf{aic}}$) was given to the 10 models, which all included position, dbh, and distance. All models with distance as an explanatory variable were included in this top 10.
    - Delta AIC values ($\Delta_{\mathbf{aic}}$) showed that there was little difference between the top 8 models.
    - The best ranked model among the pool of possible models in the analysis included canopy position, dbh, distance, and an interaction of canopy position and distance from coast.
    - The 2nd ranked and simplest model includes only canopy position, dbh, and distance from coast.
    - The model including canopy position, dbh, distance from coast, and elevation was ranked 3rd among the pool of possible models.

Discussion

Foliage retention increased with increasing distance from the coast, which is consistent with our current observations and understanding of disease severity. The vertical pattern of foliage retention stayed the same throughout the study area; lowest retention in the upper crown, highest retention in the lower crown. As foliage retention increases in the upper crown, it also increased in the lower crown. There was no switch in which position of the crown was most impacted. Our hypothesis that in areas of lower disease severity there would be greater impacts in the lower crown relative to the upper crown was not supported by this analysis. This may be because water is not limiting fungal colonization of host foliage during spore dispersal throughout the study area. In addition, our sample plots did not pick up the dry eastern margin of the Coast Range, and only occurred on the western slope up to the crest of the Coast Range.

Elevation is known to influence foliage retention of conifers , as needle retention decreases with increasing elevation (Reich et al. 1992, 1996), and in our study areas, elevation increases with distance from the coast, and is slightly correlated (r =0.36). The biological basis of *P. gaeumannii* impacts on Douglas-fir in the epidemic area are thought to be closely related to winter temperature (Manter et al. 2005), and therefore, one would also expect that as elevation increases mean winter temperature would decrease, reducing impacts of disease. Separating out the interaction between elevation increase and disease severity is therefore, very difficult.

The relationship of DBH to foliage retention was unexpected, in that environmental factors are thought to be the most important epidemiological factors influencing foliage retention. DBH was a highly significant variable explaining foliage retention at the tree level in all models.

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Table 1 - Mean and range of stand attributes for 76 permanent growth impact study plots in the northern OR coast range mountains. Two outlier plots were removed from the analysis reducing the maximum elevation to 518 m.

Stand Attribute	Mean	Range
DBH (cm)	14.8	0.4 – 40.3
Average Breast-height age (yr)	12.2	3.3 – 28.33
Douglas-fir Density (trees/ha)	688	148 – 1,927
Douglas-fir Basal Area (m^2/ha)	15.77	2.03 – 37.24
Total Basal Area (m^2/ha)	19.25	2.84 – 54.97
Site Index (Height at 50 yr, m)	41.0	24.4 – 52.1
Average Foliage retention (yr)	2.21	1.09 – 3.65
Elevation (m)		45-931*

Table 2 – Rankings based on AIC values for the top three hierarchical models and both the level 1 model (no stand level covariates) and the NULL model (intercept only). ***T*** estimates from the covariance matrix reflect variance ratios (variance explained) when ***T's*** are compared between models. Variance ratio= $T_1 - T_2 / T_1$.

Rank	**Variables**	**AIC**	Δ_{aic}	W_{aic}	*T*(Crown Position)	**Variance Ratio vs. NULL**	**Variance Ratio vs. Level 1**
1	CP, DBH, DIST, CP*DIST	2835.2	0.0	0.23	0.27 (Upper) 0.14 (Mid) 0.07 (Lower)	0.89 0.87 0.50	0.23 0.26 0.36
2	CP, DBH, DIST,	2835.8	0.528	0.18	0.28 (Upper) 0.14 (Mid) 0.07 (Lower)	0.88 0.87 0.50	0.20 0.26 0.36
3	CP, DBH, DIST, ELEV	2836.4	1.156	0.13	0.28 (Upper) 0.14 (Mid) 0.07 (Lower)	0.88 0.87 0.50	0.20 0.26 0.36
15	CP, DBH (Level 1)	2852.1	16.8	0.00	0.35 (Upper) 0.19 (Mid) 0.11 (Lower)	0.82 0.87 0.21	NA
19	NULL	3022.2	187.0	0.00	2.35 (Upper) 1.07 (Mid) 0.14 (Lower)	NA	NA

Table 3 - Model coefficients for the top ranked model. Mode is in the form of: NR=B_0 (position) + DBH + Distance*position.

Canopy Position	Intercept	DBH	Distance
Lower	2.8519 (0.05799)	0.01062 (0.00341)	0.03961 (0.008037)
Middle	2.3735 (0.03084)	0.01062 (0.00341)	0.03277 (0.004269)
Upper	1.602 (0.03776)	0.01062 (0.00341)	0.02458 (0.005265)

Figures

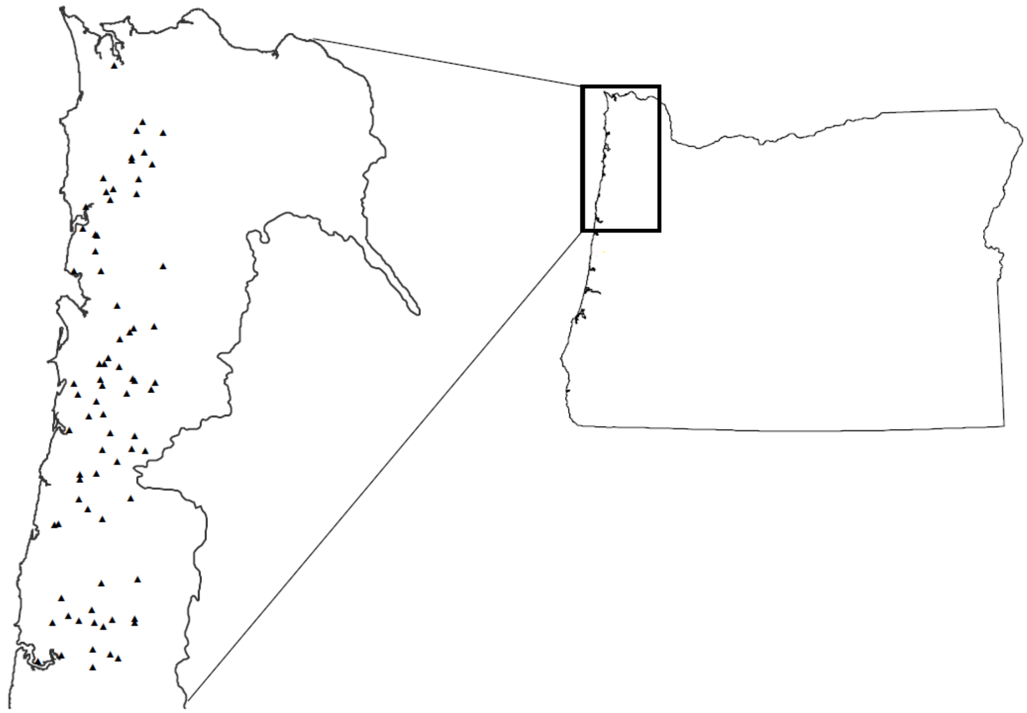

Figure 1 - Map showing Growth Impact Study field sites (triangles) used to obtain needle retention. Plots are located in the northern half of the Oregon coastal ecoregion between Newport, OR and Astoria, OR.

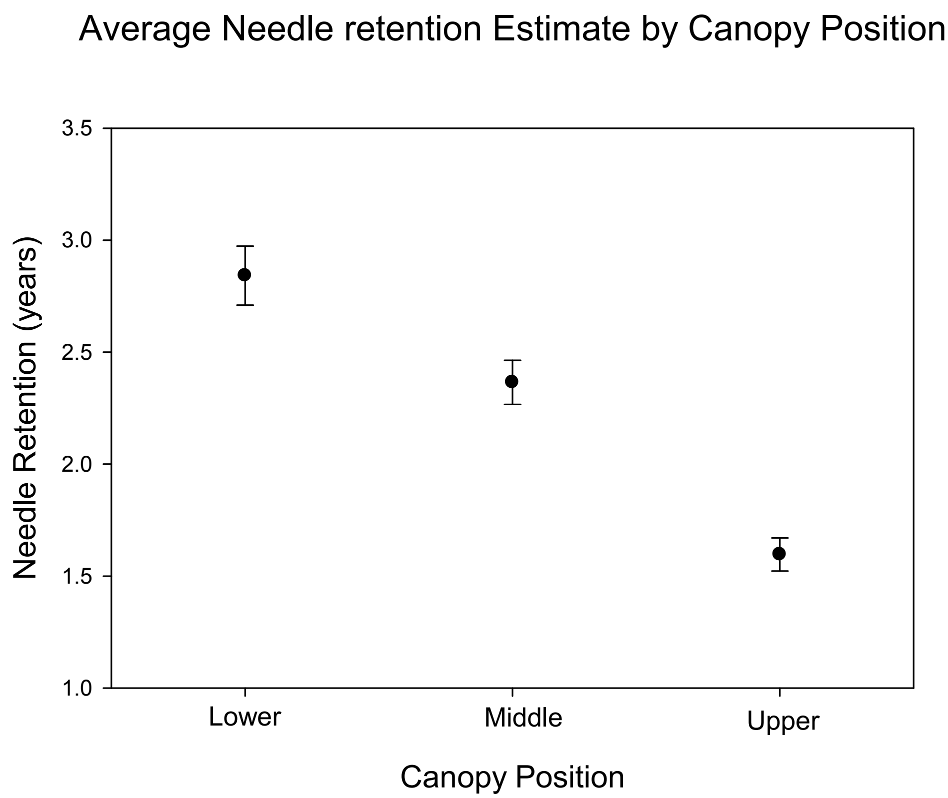

Figure 2 – Mean needle retention estimates by canopy position in the Oregon coast range. Error bars indicate 95% confidence interval.

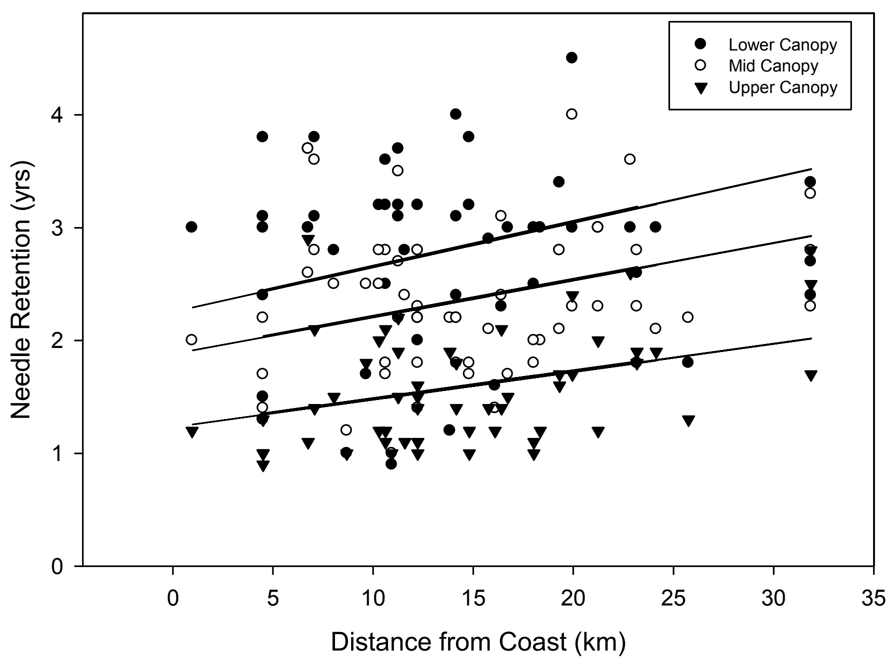

Figure 3 – Predicted values of needle retention for lower, middle, and upper canopy positions illustrating the relationship of needle retention and distance from the coastline for trees of average dbh.

Needle Retention Estimates of the southern Oregon Coast and southwest Washington

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Introduction

Estimates of needle retention for Douglas-fir (*Pseudotsuga menziesii*) have been extensively used in previous studies of Swiss Needle Cast (SNC) in relation to growth impacts Maguire et al.2002; Garber et al. 2007), validation of aerial survey data (Kanaskie and McWilliams 1998-2008), and most recently to develop landscape models of needle retention and climatic drivers. Much of the data available for these pursuits were obtained from the Growth Impact Study (GIS; Maguire et al.2002), Commercial and Pre-Commercial thinning (Mainwaring et al. 2005), and Cascades (Filip et al. 2006) study plots. These plot systems have been limited in geographic scope and primarily focused on the high impact zone between Astoria and Newport, OR. Current modeling efforts have shown a need for a wider geographic range of needle retention estimates. The following briefly describes the methods and results of an effort to expand these estimates geographically.

Methods

Site Selection and Locations

In 2009, it was determined that more estimates of needle retention were needed across the impact zone of Oregon and Washington. In particular there was a lack of data for the southern OR coast and SW Washington. Selection of needle retention sites was focused from Newport, OR south to Bandon, OR and portions of southwest WA approximately 25 miles north of the Columbia River. An additional set of plots were measured by Oregon Department of Forestry field crews in Curry County, OR. As with the GIS study plots, all sites were within 31 km of the coastline and stand ages were restricted to between 10 and 30 years of age. Due to the desire to cover a large geographic area, limited time and resources, and the landscape scale at which estimates were needed, one site was chosen in every Township/Range that occurred within the geographic constraints listed above. These site selection criteria resulted in selection of 61 sites, 10 in southwest WA, and 51 along the southern OR coast. See Figure 1 for map of plot locations.

The following ownerships, with the number of stands sampled in parentheses, were included in the study: Bureau of Land Management (1), Coos County Fortests (2), Elliot State Forest (4), Kingset (1), Menasha-Campbell (14), Plum Creek (4), Siuslaw National Forest (16), South Coast Lumber (10), The Nature Conservancy (1), Washington Department of Natural Resources (5), Weyerhauser Co. (4).

Data Collection

Ocular estimates of needle retention were obtained similar to the methodology used in the initial phases of the GIS plot installations (see Kanaskie and Maguire - Field Specifications and Manual for Rating Swiss Needle Cast in Douglas-fir). For a given stand, one transect with 5 points spaced 50 feet apart was established. A random distance along the road adjacent to the stand was chosen for the beginning of each transect. This point was flagged and the nearest tree was painted with a large orange dot. At this starting point a random azimuth was used for the direction of the transect and 50 feet was paced between each sampling point and blue flagging was used to mark each point. For each stand the following was recorded (stand #, ownership, UTM coordinates, distance and azimuth of transect, overall stand color 1-4, stand SNC rating1-6, and whether there was evidence of dieback from SNC). At each point the nearest dominant or co-dominant tree on each side of the transect was selected (i.e., 2 trees were sampled). Each tree was measured for diameter at breast height (DBH), given a crown color classification (1 to 4), and rated for needle retention in the lower, middle, and upper thirds of the crown. Secondary lateral branches were examined in the center of each third and the average number of annual needle compliments present was estimated. Excessively shaded or damaged branches were avoided whenever possible.

In addition to needle retention estimates a general disease presence and severity check was performed by pruning a secondary lateral branch from the mid crown and examining 2-year old cohort needles for presence of pseudothecia. A range of percent stomata occluded was given for each stand based on this simplistic survey.

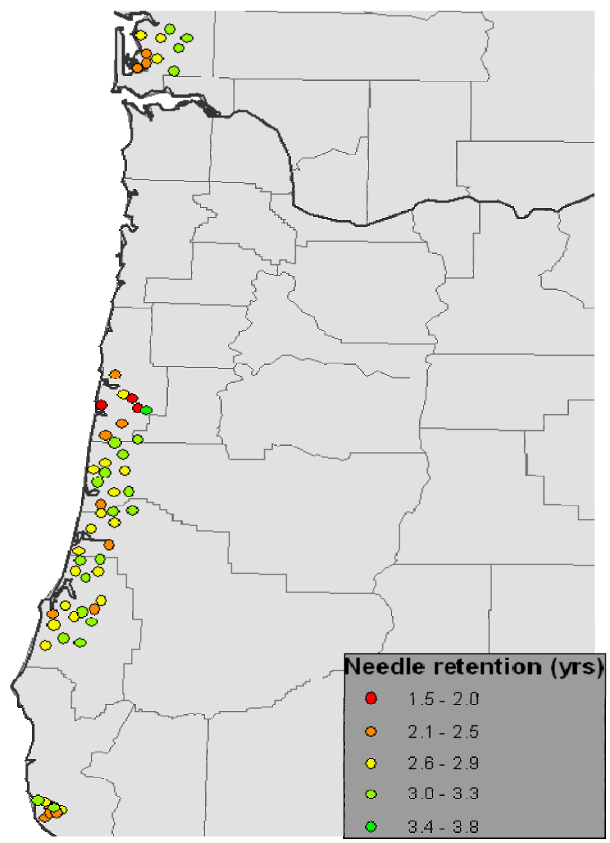

Figure 4. Needle retention plots (61) sampled in spring 2009. Color indicates stand level estimate of needle retention in years.

Results

Stands sampled ranged in age from 9-30 years, and averages DBH ranged from 7.6 to 37.4 cm. SNC disease was present in all stands sampled. SNC disease was present in all stands sampled. However, the degree to which it was present varied widely. Disease severity assessments ranged from approximately less than 1% to 30% of stomata occluded on 2 year old needles from mid-crown secondary=y lateral branches.

Across all stands sampled in 2009 the lowest stand level needle retention was 1.5 years (North of Waldport) and the highest estimate was 3.8 (Curry county). Figure 1 illustrates the range in needle retention estimates across the stands sampled in Oregon and Washington.

Brief examination of the data indicated similar needle retention estimates on average for Curry county, Coos County, North of Coos County to Newport, and southwest WA (Figure 2).

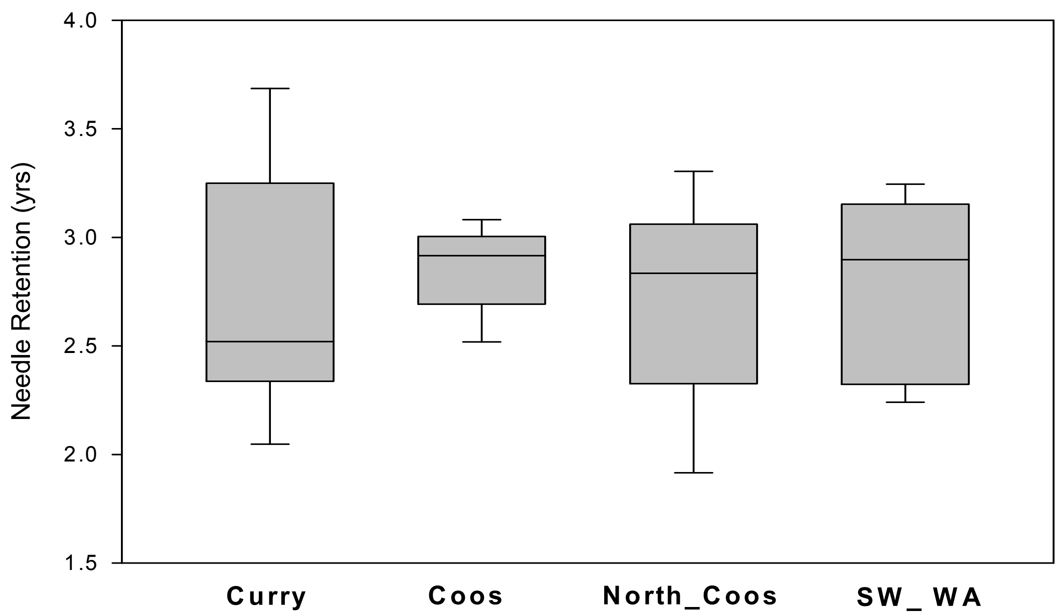

Figure 2 - Needle retention estimates for 4 geographic in 2009.

Sampled plots in Coos County showed the least variation in Needle Retention (2.4-3.1 yrs) and Curry county expressed the highest variation (2.0 to 3.8 yrs). The area spanning from Waldport to North of Coos county contained the stand with the lowest retention (1.5 yrs) and was very similar in needle retention to stands sampled in southwest WA (2.3 to 3.3 yrs).

Conclusions

The needle retention data collected from this project is currently being used for several ongoing analyses for the SNCC. Projects include improving existing needle retention estimates to incorporate into ORGANON growth and yield estimates for market modeling. In addition, a re-examination of needle retention modeling is being undertaken and will use this data to revisit methodologies for modeling of needle retention across the landscape in order to gain further information for managers. In addition, these sample stands provide potential sites in the future for addition to permanent plot networks such as the GIS plot network.

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Mapping western Oregon Douglas-fir foliage retention with a simultaneous autoregressive model

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Abstract

Douglas-fir needle retention along the Oregon and SW Washington coasts is directly related to tree productivity, and also reflects severity of Swiss needle cast foliage disease. Using data gathered on 295 plots in western Oregon and southwestern Washington along with PRISM climate we estimate Douglas-fir needle retention via a simultaneous autoregressive model. Years of needle retention, is explained using January temperature and precipitation in excess of evapotranspiration in the month of July. The predictive ability of the model was tested by randomly dividing the data into 148 reference plots and 147 target plots two hundred times. Each imputation method was evaluated by calculating the correlation of actual and predicted values, bias, and root mean square error of both the target and reference data set. We also test for evidence of spatial autocorrelation. The model was then used the generate maps of Douglas-fir needle retention for forestland in western Oregon.

Introduction

Douglas-fir in western Oregon and SW Washington is currently experiencing foliage loss and growth impacts from a foliage disease known as Swiss needle cast, caused by *Phaeocryptopus gaeumannii* (Hansen et al. 2000, Maguire et al. 2002). The disease causes occlusion of the stomates, resulting in carbon starvation and subsequent foliage loss (Manter et al. 2003a). Disease severity has been measured as the amount of foliage retained, fungus fruiting body numbers, biomass of fungus within the needle, and molecular quantification (Winton et al. 2003, Manter et al. 2003b, Maguire et al. 2002). . All these factors are closely correlated in the zone of the SNC epidemic.

Foliage retention in years is directly related to tree growth in Douglas-fir of coastal Oregon (Maguire et al. 2002). If a tree has 3 years of foliage or more, it is likely growing at expected productivity. However, as needle retention decreases below 3 years, growth declines proportionally. Significant growth losses, over 50%, occur when foliage retention is less than one year. This fact has been used to simplify stand examination when determining the impact of disease on a forest plantation. Foliage retention is now an input for the ORGANON growth model (Hann 2006, Garber et al. 2007), and has been used to develop a spreadsheet tool for assessing stand impacts from Swiss needle cast disease (Mainwaring, SNCC Website, Stand Assessment Tool: http://www.cof.orst.edu/coops/sncc/Stand%20Growth%20Assessment%202.81.xls).

Foliage retention is the primary predictive tool used to estimate growth loss due to foliage disease in coastal Douglas-fir. Therefore, developing a needle retention landscape predictive model as a substitute for Swiss needle cast disease severity has been a goal of the Swiss Needle Cast Cooperative, a research and management cooperative housed in the Department of Forest Engineering, Resources and Management at Oregon State University (with members from forest landowners, Oregon Department of Forestry, US Forest Service, and Bureau of Land Management) (Website: http://www.cof.orst.edu/coops/sncc/index.htm)

Needle retention is influenced by a range of factors, especially site productivity and elevation (Reich et al. 1995). Fertilizers also may influence needle retention, with additions of N decreasing foliage retention in one Douglas fir study (Brix 1983). The Oregon coast range has a steep gradient of nitrogen and calcium (Perakis et al. 2005). Calcium is adequate on the eastern slopes and deficient at the coast, while N is less than adequate on the eastern slope and more than sufficient near the coast. Precipitation is high on the coast, peaks at the coast range crest, and declines on the east slope to the treeless valley.

The objective of this work was to create a foliage retention landscape map to predict the distribution of disease impacts from Swiss needle cast, a foliage disease of Douglas-fir. The model is quite important as a qualitative tool to understand whether a particular forest stand is at risk from disease. However, it also allows a quantitative assessment of landscape growth impacts for productivity, economic and market analysis, while this type of map can also provide the basis for climate change modeling.

Methods

Plot data

Needle retention was assessed by visually estimating the number of years of foliage retained to the nearest 1/10th of a year. In Douglas-fir, each annual cohort of needles is distinct, and careful examination of the branchlet allows an assessment of whether foliage has fallen off. A branch from the south aspect of the tree, and in the middle to upper third (at least the 5th whorl down however) was examined, using a > 3yr old lateral branch, not the apex. This was either from collecting the branch with climbers or observing with binoculars from the ground.

The datasets used included;

Maguire et al. (2002) growth impact study (GIS) plots which were established in XXXX, and used to determine the growth impacts of SNC. 74 plots established by randomly choosing plantations from a possible list of all plantations between 10 and 30 years old and > 80% DF. 77 plots were used.

Mainwaring et al. (2005) commercial thinning plots established as a retrospective study as well as treatment and controls to determine impacts of commercial thinning on DF. ODF and OSU collaborated on the project and the assessment was done mostly on state lands on the Tillamook State Forest. 77 plots were used.

Mainwaring and Maguire (2008) precommercial thinning plots were established on private lands to determine whether precommercial thinning influenced disease severity and tree growth. 23 plots were used.

Filip et al. (2006) USFS Cascades plots that were established in XXXX, and remeasured in 2006. Plots are used to assess whether SNC is causing problems in the west slope of the Oregon Cascades mountains. 55 plots were used.

Mainwaring (1)

Woolley et al. (2009) needle retention plots were specifically designed to fill in geographical gaps in the distribution of known foliage retention. We attempted to place plots in each XXXX in the regions within 20 miles of the coast. 62 plots were used (Table1, Summer09).

This analysis used 295 plots total, and we averaged needle retention for each location. That would mean for some plots with multiple years, we used a simple average. For others such as the CT plots we averaged NR across years and treatments.

Climate Data

We used monthly minimum, maximum, and dewpoint temperature along with precipitation data for the period 1996-2007 produced by the Parameter-elevation Regressions on Independent Slopes Model (PRISM) (Daly et al., 2000). The PRISM data is provided on a 4 kilometer grid which produced differences between measured plot elevation and overlaid PRISM grid elevation of as high as 350 meters in the mountainous areas of Oregon. To account for changes in climate due to these elevation differences

We utilized a process similar to Wang et al. (2006) where we created a scale free interpolation process using a 90 meter digital elevation model and PRISM temperature/elevation gradients of the larger 4 kilometer grid. The gradients are the first derivative of a geographically weighted regression relating temperature to elevation at each PRISM cell. Distance weighted elevation and temperatures are determined for each 90 meter cell and are then adjusted by the gradient which is also weighted by distance from the PRISM cell center. The result is a 90 meter monthly climate grid. Like Wang et al. (2006) we used this procedure for temperature (T) and used a simple distance weighting method for precipitation (P).

As another measure of site moisture we used Climate Moisture Index (CMI) which is a measure of precipitation in excess of evapotranspiration (ET). Hourly short wave incoming solar radiation (SR) was calculated based on Coops et al. (2000) utilizing latitude, longitude, slope, aspect, elevation and the PRISM monthly maximum and minimum temperatures. These hourly values were then used to create monthly averages. The daily evapotranspiration in month *m*, ET_m, was calculated using the Hargreaves method as presented in Narongrit and Yasuoka (2003) as:

$$ET_m = 0.0135 * (T_m + 17.78) * SR_m * \left(\frac{238.8}{595.5 - 0.55 * T_m} \right) \qquad (1)$$

CMI is then calculated using the following equation:

$$CMI = \sum_{m=1}^{12} \left[P_m - \left(days_m * ET_m / 10 \right) \right] \quad (2)$$

where P_m the precipitation in month *m*, $days_m$ are the number of days in months *m*, and ET_m the daily evaporation in month *m*.

Descriptive statistics for the geographic variables along with the climatic variables used in the models are given in Table 2 and maps are provided in Figure 1. Correlation coefficients between selected variables are given in Table 3.

Needle Retention Model

A linear regression model was generated relating needle retention to January average temperature, July climate moisture index.

$$NR_i = \beta_0 + \beta_1 JanTemp_i + \beta_2 JulCMI_i + e_i \quad (3)$$

Statistics for the least squares (OLS) estimation of the model given by Equation 3 can be found in Table 4. Figure 2a show the difference between actual and predicted values for the OLS model. The residuals display visible evidence of clustering of residuals which is confirmed by the positive and significant values for the Moran's I statistic shown in Table 4. Given the spatial bias indicated by the error maps and Moran's I statistic the model was structured as a simultaneous autoregressive (SAR) model. The resulting model is described in equation 4.

$$NR_i = \beta_0 + \beta_1 JanTemp_i + \beta_2 JulCMI_i + \rho u_i + e_i \quad (4)$$

where the autoregressive error term, u_i, is determined by the weighted values of the nearby plots as given in equation 5.

$$u_i = \frac{\sum_{j \neq i} w_{ij} NR_j}{\sum_{j \neq i} w_{ij}} - \left[\beta_0 + \beta_1 \frac{\sum_{j \neq i} w_{ij} JanTemp_j}{\sum_{j \neq i} w_{ij}} + \beta_2 \frac{\sum_{j \neq i} w_{ij} JulCMI_j}{\sum_{j \neq i} w_{ij}} \right] \quad (5)$$

Given the lack of uniformity and gaps in the underlying plot data a simple inverse distance weighting scheme like Latta et al 2009 was deemed inappropriate. A negative exponential with parameters that determine both the slope of the weighting function and how far from the plot the downward slope begins was chosen. The slope of the weighting function is also adjusted by the average distance of the ten closest plots. This has the effect of creating a flatter slope when plots are scattered and a steeper slope when plots are dense. The flexible weighting function is given by equation.

$$w_{ij} = e^{\left(-0.5 \left(dist_{ij} \alpha_0 d10_i \right)^{\alpha_1} \right)} \quad (6)$$

where $dist_{ij}$ is the Euclidian distance between plots *i* and *j*, $d10_i$ is the average Euclidian distance of the ten closest plots to plot *i*, and the values of α_0 and α_1 are 0.979 and 2.565 respectively. The resulting model is then solved using nonlinear least squares.

Results

Table 4 has the parameter estimates, asymptotic t ratios, coefficient of determination and spatial autocorrelation statistics for the model. The use of an autoregressive model improved the standard error by 16% (0.51 years for OLS and 0.43 years for SAR) while at the same time improving the r-squared of the model by 19% (0.61 for OLS and 0.72 for SAR). More importantly though, the SAR model shows no significant signs of spatial autocorrelation when evaluated either using a simple 0.25 decimal degree window (Moran's I #3), inverse distance weighting (Moran's I #2), or the exponential function of Equation 6 (Moran's I #1). This can be seen in Figure 2b as the clustering of residuals of the OLS model in Figure 2a are no longer evident. Given the use of SAR model for needle retention maps which will then be used to estimate or impute needle retention for sites outside of the original dataset, the elimination of spatial bias is a primary goal.

Validation

To examine the usage of the methodology described above in imputing needle retention outside of the data used to derive the model we conduct an experiment where we randomly split the dataset into two groups of roughly 50%. The first set of 148 plots, reference plots, will be used to estimate the model using equations 4 – 6. That model will then be used to impute needle retention for the rest of the 147 plots, target plots. The r-square, bias, root mean square error, and spatial autocorrelation statistics will then be calculated as described in Latta etal (2009). This experiment was replicated 200 times and the results are presented in Table 5. In general the model tends to perform nearly as well with respect to r-square, bias, and root mean square error as the full dataset results of Table 4. In the two hundred replications, there were cases where there was significant clustering of residuals (positive Moran's I with a Z-score greater than 2.0) however the clustering of residuals was not significant.

Needle Retention Map

In a similar process to that used in validating the model, we calculate needle retention for western Oregon forested land using data at a 90 meter pixel resolution. The base 90 meter digital elevation model is used to calculate slope and aspect at each pixel. The same process used to interpolate climate data to the plots is then used to get monthly temperature maximum and minimum values as well as precipitation. Solar radiation, evapotranspiration and CMI is then calculated for each pixel given its temperature, precipitation, slope, aspect and elevation. The 295 needle retention plots provide the neighborhood values for the autoregressive error term and the retention for each plot is calculated using Equation 4. The completed western Oregon needle retention map is presented in Figure 3.

Discussion

Needle retention on an individual tree is a result of many complex factors (Reich et al. 1995), but in the zone of the SNC epidemic on the west slope of the Oregon coast range, it appears that needle retention is closely associated with disease severity (Hansen et al. 2000, Maguire et al. 2002, Manter et al. 2003b). However, disease severity on the landscape is worse in low elevation sites, and impacts decrease with increasing elevation. Elevation is known as a major influence on needle retention of conifers as a general principle (Reich et al. 1996). Therefore both disease severity and elevation are interacting to influence needle retention in the zone of the SNC epidemic.

Since needle retention is a useful estimator of tree growth, a needle retention map can be used to predict landscape level growth impacts. If one assumes the reason that foliage retention drops below 3 along the Oregon coast is from Swiss needle cast disease, then calculating impacts is possible. Needle retention maps may provide an important aid in determining the severity of Swiss Needle Cast for specific areas, yet they do not provide an assessment of the volume growth impacts of disease to trees. Garber etal. 2006 estimated equations using needle retention to predict growth impacts of Douglas-fir. Figure 4 presents the diameter and height growth reductions from Garber etal. 2006 for a range of needle retention levels. When coupled with data from the Figure 3 map it becomes possible to examine the extent of potential growth reduction spatially. Table 6 shows the acreage and percentage of forest land by county for five percent diameter growth reduction classes. From this table it is evident that Tillamook and Clatsop county have the most acreage with greater than 25% diameter growth losses with twenty and thirteen percent respectively in this class.

Table 7 shows the acreages and forestland proportions of each western Oregon county by height growth loss classes. Given the more gradual decline of the height growth loss function in Figure 4 there isn’t substantial acreage that could expect height growth losses of more than twenty percent. Figure 5 maps the extent of the area that would receive diameter or height growth losses in excess of five percent and ten percent. These maps show that the largest area that would expect growth losses from swiss needle cast is along the northwestern coast of Oregon. There is another area with less dramatic losses where Douglas County reaches the Pacific Ocean and Northwestern Coos County. The last area expected to experience growth losses in excess of five percent is the coast fringe of Curry County.

Conclusion

Needle retention has become an important tool to assess growth in Douglas-fir influenced by Swiss needle cast foliage disease along the west slope of the Oregon Coast Range.

Our needle retention map coupled with a growth model modified with a disease growth loss estimator (ORGANON with SNC modifier, Garber et al. 2006) allowed for prediction of spatially distributed growth losses. This can be used in Integrated Pest Management strategies, economic and market analysis.

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Table 1. SNC Data sources and plot count

	Number of Plots
CT_Perm	33
CT_Retro	44
Filip	55
GIS	77
Mainwaring	1
PCT	23
Summer09	62

Table 2. Summary statistics for the SNC data

Variable	**Mean**	**Median**	**Maximum**	**Minimum**	**Std. Dev.**
Needle Retention (years)	2.9	2.7	5.3	1.2	0.82
Geographic					
Latitude (°)	44.9	45.1	46.6	42.1	0.93
Longitude (°)	-123.5	-123.7	-122.0	-124.3	0.59
Elevation (m)	369	306	1280	9	258.79
Climatic					
Annual Temperature (°C)	10.5	10.5	12.8	6.8	1.05
Annual Precipitation (cm)	243.6	237.1	449.9	130.9	60.73
January Temperature (°C)	5.5	5.6	9.0	0.6	1.62
July CMI (cm)	-12.4	-12.6	-7.7	-15.7	1.65

Table 3. Correlation matrix for the SNC data

	NR	Lat	Lon	Elev	T_{ann}	P_{ann}	T_{Jan}	CMI_{Jul}
Needle Retention (NR)	1							
Latitude (Lat)	-0.15	1						
Longitude (Lon)	0.69	0.18	1					
Elevation (Elev)	0.60	-0.04	0.67	1				
Annual Temperature (T_{ann})	-0.37	-0.57	-0.64	-0.70	1			
Annual Precipitation (P_{ann})	-0.39	0.44	-0.26	0.08	-0.28	1		
January Temperature (T_{Jan})	-0.61	-0.43	-0.82	-0.78	0.91	-0.07	1	
July CMI (CMI_{Jul})	-0.53	0.65	-0.30	-0.35	-0.19	0.59	0.08	1

Table 4. Correlation matrix for the SNC data

	OLS	SAR
Parameter Statistics		
ρ		0.97 (15.0)
β_0	1.44 (5.6)	4.38 (1.4)
β_1	-0.29 (-15.6)	-0.26 (-5.9)
β_2	-0.24 (-13.3)	-0.09 (-3.3)
Equation Statistics		
r^2	0.61	0.72
S.E.	0.51	0.43
Spatial Autocorrelation Statistics		
Moran's I #1	0.27 (4.3)	-0.05 (-0.8)
Moran's I #2	0.17 (2.8)	-0.01 (-0.2)
Moran's I #3	0.19 (3.0)	-0.02 (-0.4)

Notes: t statistics in parentheses. Moran's I #1 is with exponential weighting, Moran's I #2 is inverse distance weighting, and Morans I #3 is no wieghting, but within a distance of 0.25 degrees

Table 5. Statistics from 200 replications

Statistic	Mean	Median	Maximum	Minimum	Std. Dev.
r^2	0.70	0.70	0.57	0.79	0.04
RMSE	0.45	0.45	0.39	0.52	0.02
Bias	0.00	0.01	-0.16	0.15	0.05
Moran's I	0.10	0.10	-0.01	0.28	0.06
Moran's I SE	0.09	0.09	0.09	0.09	0.00
Moran's I Z	1.04	1.02	-0.23	3.05	0.69

Table 6. Extent of Douglas-fir diameter growth reduction by county

County_Name	Percentage of Diameter Growth Reduction > 25	20 - 25	15 - 20	10 - 15	5 - 10	1 - 5	0.1 - 1	< 0.1	Total
	acres								
Benton	-	-	-	12	2,376	67,855	231,846	14,942	317,030
Clackamas	-	-	-	-	-	-	112,798	854,976	967,773
Clatsop	66,658	42,541	42,655	42,247	54,991	114,471	93,995	43,031	500,589
Columbia	-	-	-	-	-	7,384	226,566	142,847	376,796
Coos	939	-	36	2,770	66,468	534,891	278,927	27,834	911,864
Curry	1,001	4	568	26,120	118,114	247,258	393,287	159,836	946,188
Douglas	975	-	10	1,958	51,136	258,453	1,096,805	1,626,977	3,036,313
Hood River	-	-	-	-	-	-	6	244,204	244,210
Jackson	2	-	-	-	-	-	20	1,661,556	1,661,578
Josephine	-	-	-	-	-	278	85,018	885,177	970,473
Lane	596	-	-	46	8,030	291,596	346,371	1,892,121	2,538,761
Lincoln	23,654	19,417	56,444	102,488	147,242	218,518	22,497	14	590,274
Linn	-	-	-	-	-	-	1,479	1,095,484	1,096,963
Marion	-	-	-	-	-	2	11,765	342,080	353,847
Multnomah	-	-	-	-	-	122	53,241	95,954	149,318
Polk	-	-	20	324	8,040	99,547	188,700	1,737	298,370
Tillamook	134,458	75,188	74,306	87,114	116,576	109,743	32,107	45,850	675,342
Washington	-	-	-	-	-	2,252	85,494	166,313	254,059
Yamhill	-	-	-	12	7,882	157,907	87,502	596	253,899
Total	228,283	137,150	174,039	263,090	580,855	2,110,276	3,348,425	9,301,528	16,143,647
	percent								
Benton				0.0	0.7	21.4	73.1	4.7	
Clackamas							11.7	88.3	
Clatsop	13.3	8.5	8.5	8.4	11.0	22.9	18.8	8.6	
Columbia						2.0	60.1	37.9	
Coos	0.1		0.0	0.3	7.3	58.7	30.6	3.1	
Curry	0.1	0.0	0.1	2.8	12.5	26.1	41.6	16.9	
Douglas	0.0		0.0	0.1	1.7	8.5	36.1	53.6	
Hood River							0.0	100.0	
Jackson	0.0						0.0	100.0	
Josephine						0.0	8.8	91.2	
Lane	0.0			0.0	0.3	11.5	13.6	74.5	
Lincoln	4.0	3.3	9.6	17.4	24.9	37.0	3.8	0.0	
Linn							0.1	99.9	
Marion						0.0	3.3	96.7	
Multnomah						0.1	35.7	64.3	
Polk			0.0	0.1	2.7	33.4	63.2	0.6	
Tillamook	19.9	11.1	11.0	12.9	17.3	16.3	4.8	6.8	
Washington						0.9	33.7	65.5	
Yamhill				0.0	3.1	62.2	34.5	0.2	
Total	1.4	0.8	1.1	1.6	3.6	13.1	20.7	57.6	

Table 7. Extent of Douglas-fir height growth reduction by county

County_Name	Percentage of Height Growth Reduction								Total
	> 25	20 - 25	15 - 20	10 - 15	5 - 10	1 - 5	0.1 - 1	< 0.1	
	acres								
Benton	-	-	-	-	270	97,452	219,308	-	317,030
Clackamas	-	-	-	-	-	38	380,185	587,550	967,773
Clatsop	2,006	1,153	42,605	76,107	91,615	177,015	108,232	1,855	500,589
Columbia	-	-	-	-	-	38,350	337,818	628	376,796
Coos	939	-	-	-	12,119	698,580	200,225	-	911,864
Curry	1,001	-	-	24	71,491	389,971	483,459	242	946,188
Douglas	975	-	-	-	7,954	408,135	1,556,258	1,062,991	3,036,313
Hood River	-	-	-	-	-	-	5,825	238,385	244,210
Jackson	2	-	-	-	-	-	330,068	1,331,508	1,661,578
Josephine	-	-	-	-	-	1,645	768,422	200,406	970,473
Lane	596	-	-	-	689	357,602	361,114	1,818,760	2,538,761
Lincoln	1,853	386	13,895	39,248	203,744	322,520	8,627	-	590,274
Linn	-	-	-	-	-	-	306,522	790,442	1,096,963
Marion	-	-	-	-	-	146	139,556	214,144	353,847
Multnomah	-	-	-	-	-	3,857	104,071	41,390	149,318
Polk	-	-	-	2	1,783	197,095	99,489	-	298,370
Tillamook	4,445	14,125	68,932	145,501	188,426	184,855	60,605	8,453	675,342
Washington	-	-	-	-	-	9,515	236,448	8,096	254,059
Yamhill	-	-	-	-	522	197,749	55,627	-	253,899
Total	11,817	15,664	125,431	260,882	578,615	3,084,526	5,761,860	6,304,850	16,143,647
	percent								
Benton					0.1	30.7	69.2		
Clackamas						0.0	39.3	60.7	
Clatsop	0.4	0.2	8.5	15.2	18.3	35.4	21.6	0.4	
Columbia						10.2	89.7	0.2	
Coos	0.1				1.3	76.6	22.0		
Curry	0.1			0.0	7.6	41.2	51.1	0.0	
Douglas	0.0				0.3	13.4	51.3	35.0	
Hood River							2.4	97.6	
Jackson	0.0						19.9	80.1	
Josephine						0.2	79.2	20.7	
Lane	0.0				0.0	14.1	14.2	71.6	
Lincoln	0.3	0.1	2.4	6.6	34.5	54.6	1.5		
Linn							27.9	72.1	
Marion						0.0	39.4	60.5	
Multnomah						2.6	69.7	27.7	
Polk				0.0	0.6	66.1	33.3		
Tillamook	0.7	2.1	10.2	21.5	27.9	27.4	9.0	1.3	
Washington						3.7	93.1	3.2	
Yamhill					0.2	77.9	21.9		
Total	0.1	0.1	0.8	1.6	3.6	19.1	35.7	39.1	

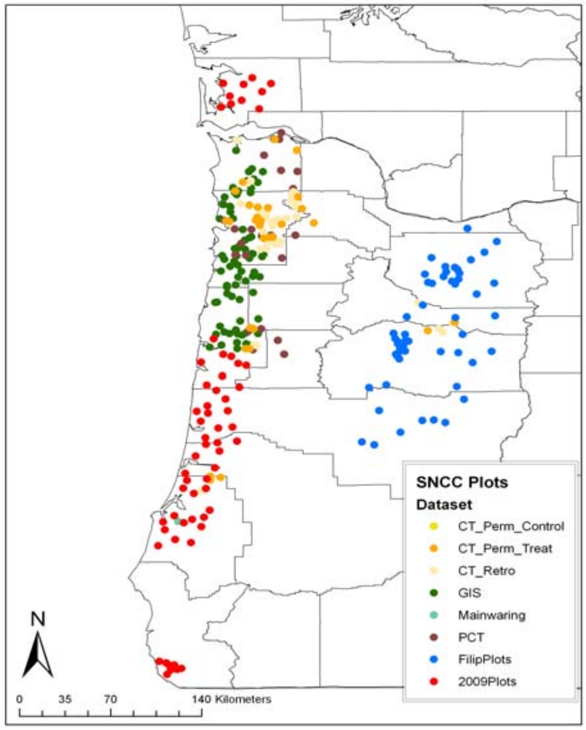

Figure 1. SNC Plot Location

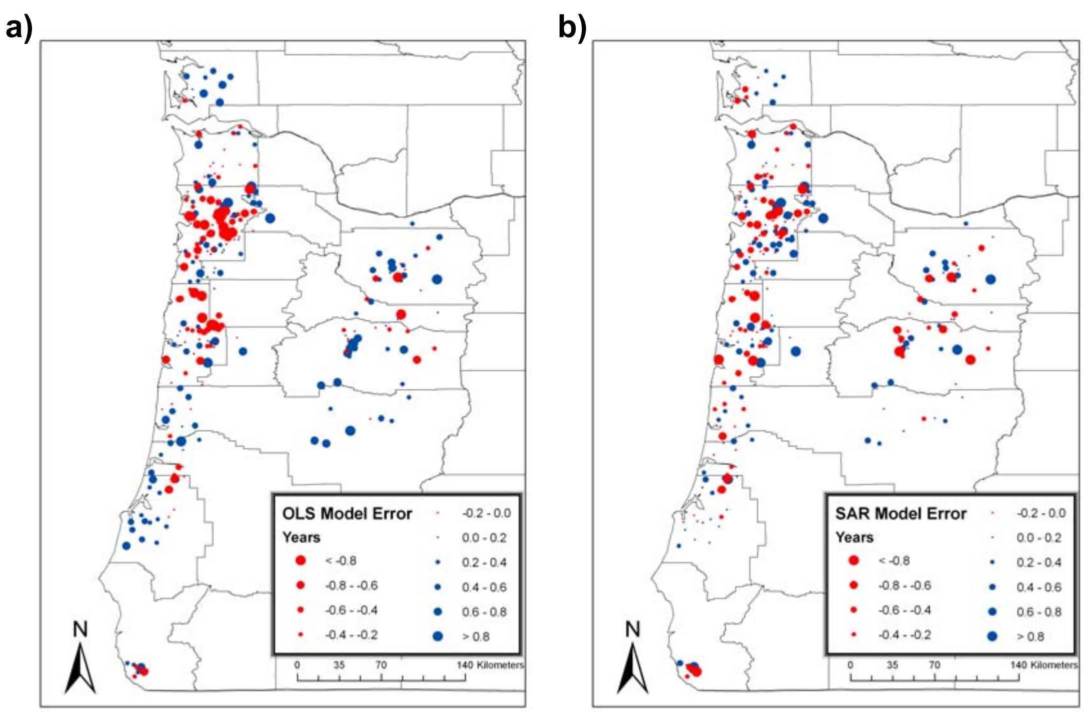

Figure 2. Model error maps (Error = $NR_{Actual} - NR_{Estimated}$) in years

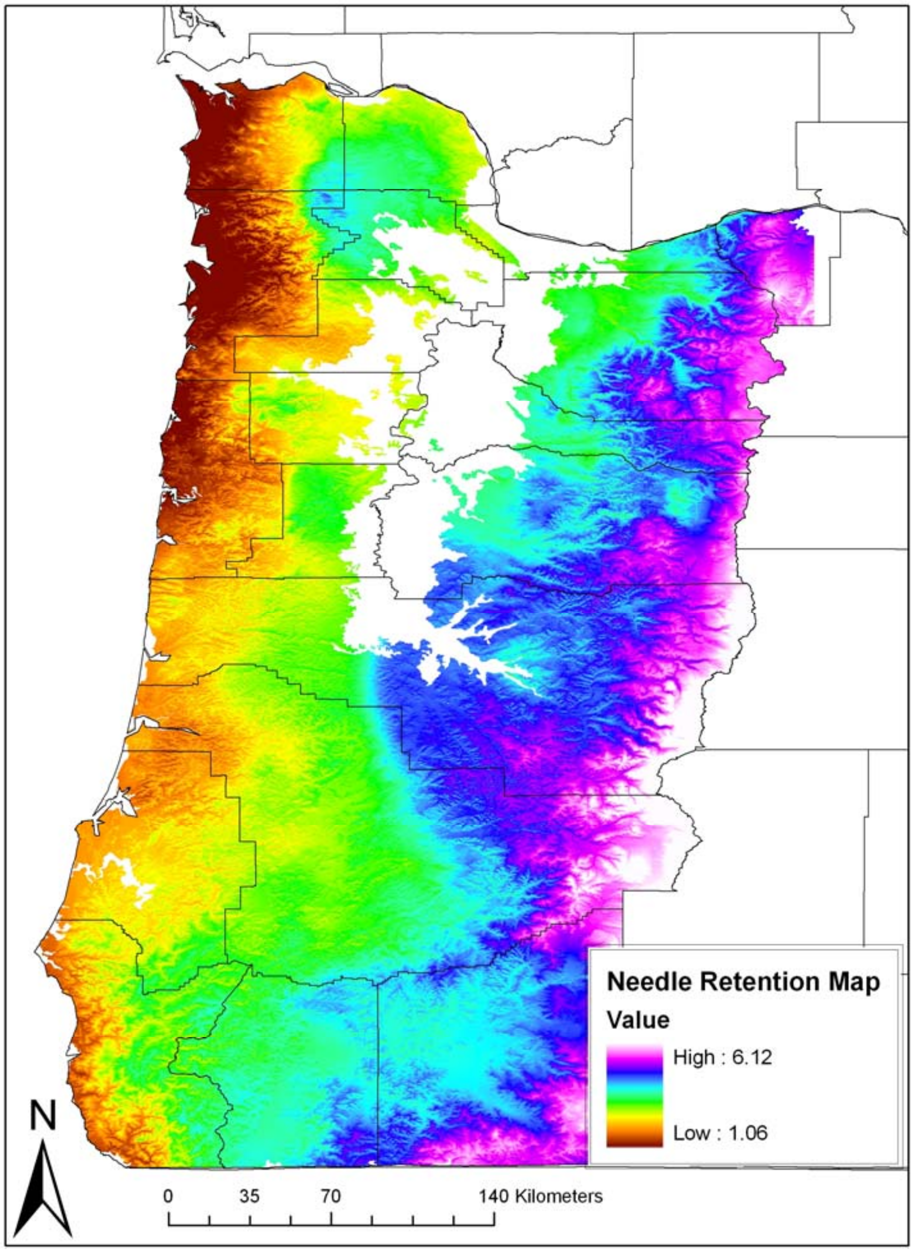

Figure 3. Douglas-fir needle retention map for forested land in western Oregon

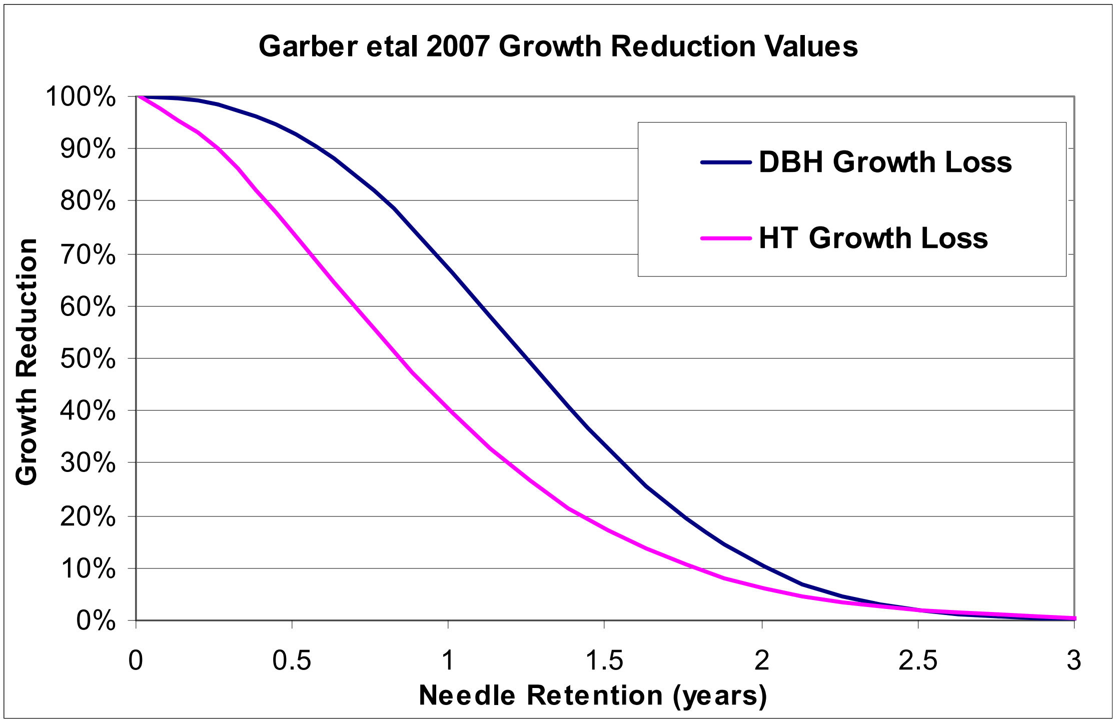

Figure 4. Growth reduction related to needle retention

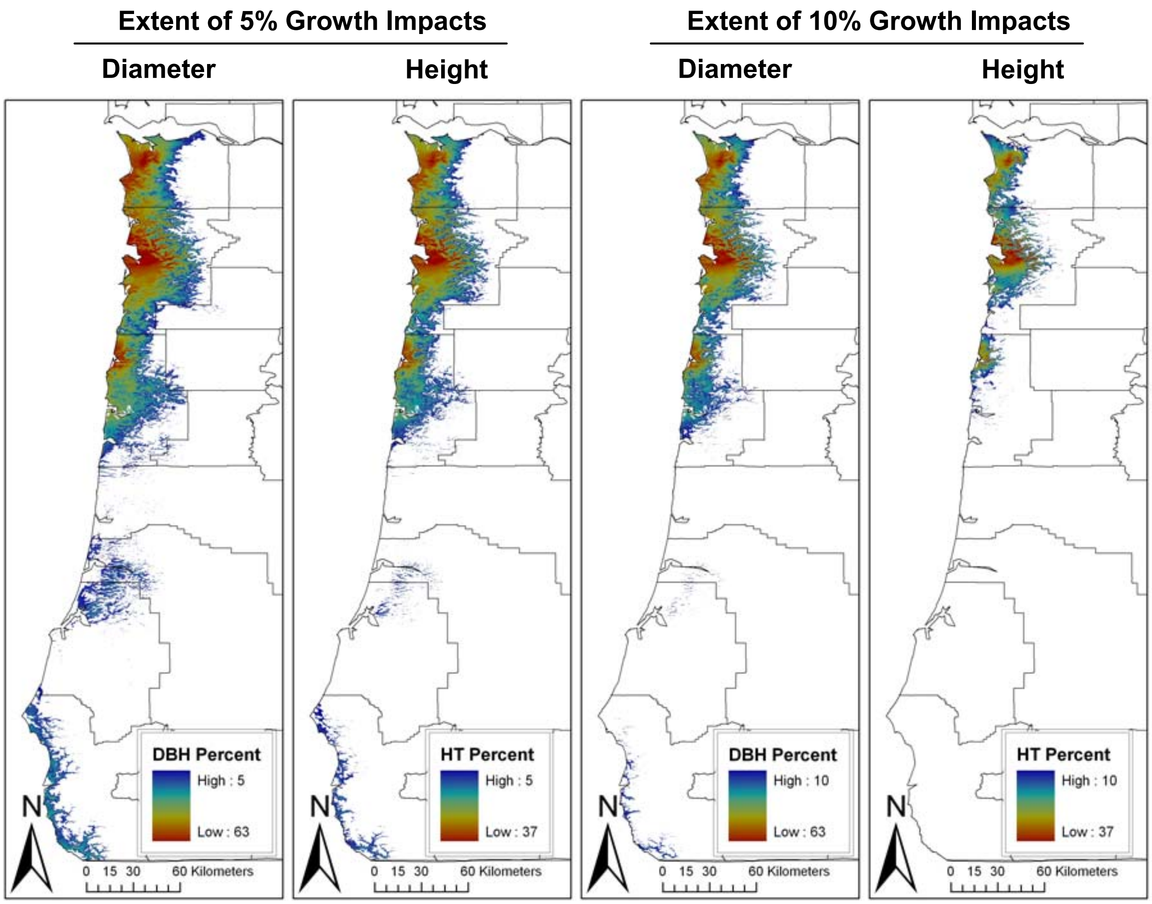

Figure 5. Maps of 5 and 10 % growth impact zones.

Three year response of young Douglas-fir to fertilization treatments on the Beyond Nitrogen plots

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Abstract

Seven fertilizer treatments were tested within young Douglas-fir stands for their ability to improve the growth of SNC-infected trees. The 16 study sites provided both a good SNC gradient and a representative regional distribution. Three years after fertilization, none of the treatments improved foliage retention. Positive improvements in volume growth and leaf area, and reductions in taper depended on both site and treatment, with none of the treatments showing universal effectiveness. Site factors associated with fertilizer response have been identified.

Introduction

In 2006, the SNC Coop provided funds to augment the costs of a six-year fertilization trial aimed at testing whether specific nutritional amendments would be effective in diminishing or offsetting 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.

Methods

Sixteen sites ranging from Coos Bay, Oregon to Mineral, Washington (fig. 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). Elevations 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.

Sites received either 5 (four sites), 7 (10 sites) or 8 (2 sites) treatments, based on landowner interest (table 1). The five basic treatments were control, nitrogen, lime, calcium chloride, and phosphorus. Sites with 7 treatments received these 5 and two additional site-specific blends, the components of which were based on site soil and foliar chemistry. The eight-treatment sites received an additional treatment of interest to that landowner only. The treatments were randomly assigned to 0.025-acre (18.6 ft radius) plots centered on an undamaged dominant or codominant tree (fig. 2). These “measurement” trees were located on a ~ 1 chain grid, located to take advantage of road access and to avoid undesirable stand features. Sites were fertilized in February-April 2007. Due to concern over excess material application, Kinsey treatments were fertilized over two years:

Figure 5 Approximate locations of the 16 sites

non-lime materials were applied during February-April 2007, and all lime was applied during the winter of 2007-2008.

Measurements

Plot centered subject trees were measured for dbh, height, height to lowest live branch, sapwood width, and diameter at 18 ft of height. The largest four year old lateral of the southernmost fifth whorl branch was removed from each tree for both a foliage retention estimate and a sample for foliar chemical analysis. Foliar chemical analyses were obtained from a composite of all similarly treated trees per treatment. All trees within each plot were measured for diameter.

Two soil cores (10 cm) were collected from opposite sides of each subject tree, containing mineral soil only. Once these 2 core samples were fully mixed, a small quantity was subsampled and combined for all trees within a given treatment.

All measurements were made prior to fertilization in the fall of 2006, and in the fall of 2009. Additional foliar and chemical analyses were made one growing season after fertilization.

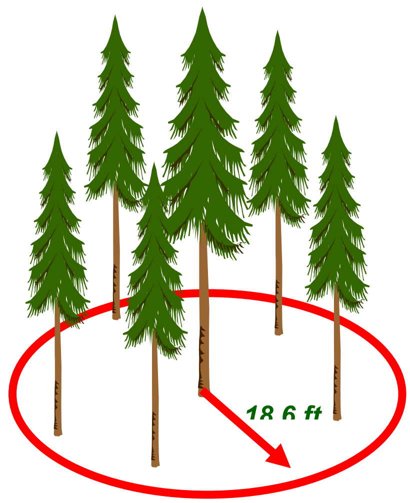

Figure 6 Graphical representation of a treatment plot

Table 1 Treatment types and quantities

Treatment #	Treatment type	Source	per acre quanity	per acre active ingredient
1	Control			
2	Nitrogen	Urea	440	202.4
3	Lime	CaCO3	2600	910
4	Calcium	CaCl2	260	94
5	Phosphorus	mono-sodium phosphate	2000	500
6	Kinsey	various	various	various
7	Fenn	various	various	various
8	Starker (STR only)	various	various	various
9	NP (OSU only)	Urea/MAP	825/190	400 N, 100 P

Analysis

Four different variables were computed to assess the efficacy of fertilizer treatments: 1) three-year change in foliage retention; 2) three-year volume growth; 3) Form quotient (d(18ft)/dbh) and changes in form quotient since treatment; and 4) Change in sapwood area at crown base (CBSAP). Crown base sapwood areas were calculated by applying a sapwood taper equation to estimates of breast height sapwood area (Maguire and Batista 1996). Changes in foliage retention were assessed using ANOVA (analysis of variance). Regression equations were used to assess volume growth, form quotient, and change in crown base-sapwood area. Numerous covariates were included in exploratory equations to account for differences between treated trees including diameter, height, crown ratio, crown base sapwood area, and plot-level basal area.

Volume growth, form quotient, and CBSAP were assessed at both the site level and regional level. Analyses on the site-level were based on the 10 replications per treatment at each individual site, with equations taking the general form shown below:

[1] $Y = TRT + a_1X_1 + a_2X_2 + a_iX_i$
where Y is the response variable, TRT is the treatment effect, the a_i's are parameters to be estimated from the data for the covariates (X).

When assessing volume growth on the regional level, data from all 16 sites was used simultaneously. Regional treatment effects were assessed two ways: 1) inclusion of site as a class variable as shown in equation [2]; and 2) use of site-level covariates (site index, soil nutrients, foliar nutrients) to distinguish between influential site-level factors, using a model form similar to equation [1].

[2] $Y = SITE + TRT + b_1 X_1 + b_2X_2 + b_iX_i$
When testing the significance of specific treatments, analysis datasets were limited to only those sites containing the specific treatments of interest. With the exception of a very few influential covariates, variables were included in the final model only if they were significant at α=0.05. Marginally significant differences were considered those with α<0.10.

Results and Discussion

Foliage retention

Of the 14 sites completed to date, average foliage retention has generally decreased, dropping from an average of 2.72 to 2.39 years. All but two sites (WE, WW) experienced a decrease.

After adjusting for the control trees, average foliage retentions decreased regardless of treatment. Nitrogen, $CaCl_2$, and Kinsey treatments were all associated with a significant decrease in foliage retention, each approximately 0.18 yrs lower than the control (fig. 3). Foliage retention was marginally lower following phosphorus treatment (p=0.057). When the analysis was limited to the eight sites with the lowest foliage retention (average 2006 retention of 2.7 yrs and lower (GDH, MNN, MNS, HAK, HAGR, ODF, WE, WW)), results were generally similar, though foliage retention following lime treatment increased incrementally, though not significantly (fig. 3). Changes in retention at each of the SNC-infected sites differed by site and treatment (fig. 4).

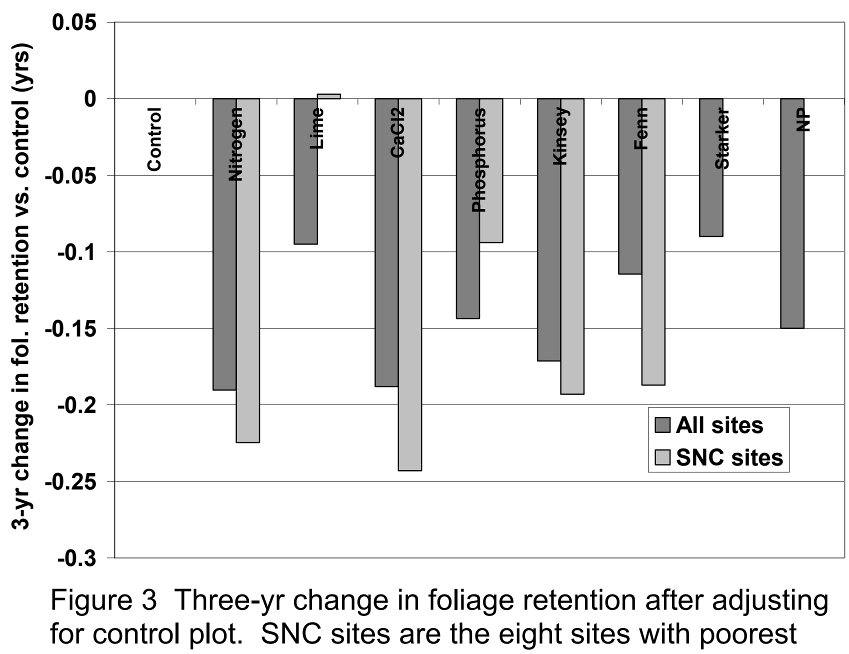

Figure 3 Three-yr change in foliage retention after adjusting for control plot. SNC sites are the eight sites with poorest foliage retention (2006 foliage retention <2.7 yrs)

After a single growing season following fertilization no significant increases in foliage retention were apparent, an unsurprising result given the limited time that any potentially positive effect of fertilization would have had on new needle cohorts. If it can be assumed that any positive effect of fertilization with respect to SNC infection is manifest in the newly emerging shoots (as with Bravo), three years should be sufficient time for any differences to emerge. These results imply that these fertilizers are not effective at increasing the number of years of foliage retention at the top of the crown. It does not answer the question as to whether treated trees have more needle biomass as a result of increased retention in the lower crown, increased branching, longer shoots, and larger and/or more needles. For example, studies have found that increased shoot growth of nitrogen-fertilized Douglas-fir typically result in fewer cohorts of needles, but equivalent lengths of foliated branches (Balster and Marshall 2000).

It should be noted that the estimate of foliage retention on these sites is based on the foliage retention of a four year old lateral: maximum foliage retention is thus 4 years, which is almost certainly an underestimate for the healthy stands in this study. It also means that fluctuations in foliage retention in healthy stands may be more influenced by annual variation rather than a specific treatment effect.

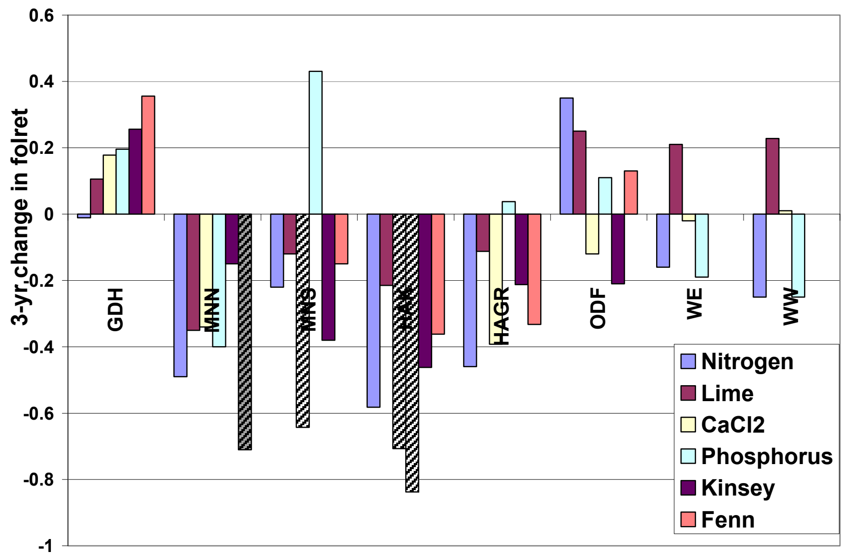

Figure 4 Three-yr site-level change in foliage retention after adjusting for control plot for SNC plots. Hatching signifies a significant difference from control.

Site-level volume growth

Volume response to treatment varied by site (table 2). Significant covariates also varied by site, but included combinations of diameter, height, crown base sapwood area or crown ratio, and plot level basal area (table 2).

Very few of the treatments resulted in significant gains in volume growth. Nitrogen treatment increased growth significantly at two sites (CTC, WW). Although all the sites in this study were chosen to be relatively N-rich so as to ensure that any responses to other nutrients wouldn't be limited due to nitrogen deficiency, the WW site was an exception, with an initial average foliar N concentration of 1.14%.

None of the sites responded significantly to lime treatment, though increased growth at two sites was of marginal significance (MNS, WE). Calcium applied as calcium chloride increased growth significantly at WE but decreased growth significantly at HAGR, and was marginally associated with a decrease at LRT. With one notable exception (MNS), responses to calcium chloride and lime were similar (fig. 5), suggesting that where calcium deficiencies exist, short term growth may be improved with a non-lime treatment, operationally preferable due to the smaller quantity of material applied. Whether or not the two treatments would have similar long-term potential is unknown.

Phosphorus increased growth significantly at CTC and MNS, both of which increased in growth by ~ 20%. None of the sites responded significantly to the Kinsey treatment, while only one (GDE) had a significant response to the Fenn treatment. The lack of a positive response to the Kinsey treatments may be partially due to the delayed application of lime, which was delayed until the second growing season.

Table 2: Three-yr tree level volume growth responses to treatment. Shaded boxes represent a significant change relative to control. Bold only represents a marginal difference.

	N	Lime	$CaCl_2$	Phos	Kinsey	Fenn	STR	NP	R2	Covariates
CTC	**36.2**	8.8	12.5	**20.6**	14.6	3.1			0.58	dbh, cbsap, pba
GDE	11.5	6.4	10.9	-3.6	4.3	**16.1**			0.69	dbh, ht, cbsap
GDH	-12.2	4.6	2.8	-10.5	-5.7	-9.4			0.56	dbh, ht, cbsap
GPH	5.6	2.6	6.9	11.5					0.36	dbh, ht
HAGR	-9.8	-6.1	**-14.9**	1.6	-4.6	1.6			0.61	dbh, ht, cbsap
HAK	6.2	4.2	7.2	10.2	12.8	9.1			0.58	dbh, ht, cbsap, pba
LRT	0.3	-1.3	**-7**	-3.2					0.63	dbh, ht
MNN	-4.5	4.9	3.9	-2.5	-12.2	2.6			0.58	dbh, ht, cbsap
MNS	6.7	**13.3**	-10.1	**18.5**	5.5	8.5			0.6	dbh, ht, pba
ODF	1.4	-0.9	-5.5	10.6	7.6	5.7			0.56	dbh, ht, folret
OSU	1.1	6.2	6.2	5.7	3.9	7.2		1.9	0.57	dbh, ht, cr
PB	-5.9	-0.8	5.9	7	-2.5	3.2			0.34	dbh, pba
STR	-1.1	-10.1	-8.4	-0.2	-10.7	-8.1	**-12.2**		0.65	dbh, ht, cbsap
WE	3.3	**17.2**	**19.2**	11.2					0.65	dbh, ht, pba
WF	5.9	-6	-11.1	-7.1	-0.4	-1.9			0.41	dbh, ht, cbsap
WW	**23.9**	14.6	10.3	0.6					0.55	dbh, ht, cr

Regional responses

After accounting for SITE (equation 2) differences in initial tree diameter and initial leaf area (crown-base sapwood area), only 3 of the 7 primary treatments showed a marginally significant positive response: nitrogen (p=0.066), lime (p=0.078), phosphorus (p=0.060), corresponding to average volume growth increases of 2.7, 2.8, and 3.9%.

When the SITE variable from equation [2] was replaced with site index and variables representing various soil and foliar nutrient concentrations, the variables of significance depended on treatment type. Treatment responses of the seven primary treatments were all positively associated with soil calcium:soil nitrogen (sCasN) ratio (fig 6). This association can be rationalized for nitrogen treatment due both to the ratio's correlation to low foliage retention (Maguire et al. 2000) and the general lack of response of SNC-infected stands to N fertilization, and the inverse relationship between these two soil

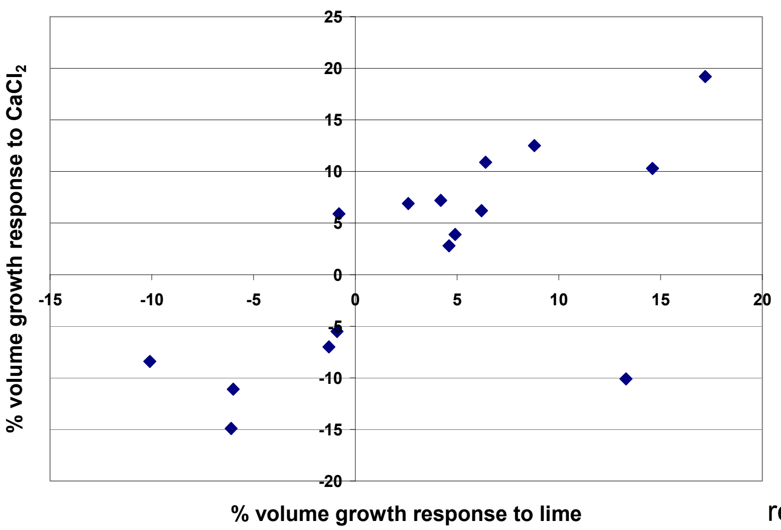

Figure 5 Correlation between volume growth response to lime and response to calcium chloride

variables in the coast range (Perakis et al. 2006) and the implied abundance of nitrogen at low values of the ratio. However, the positive association of the ratio to lime and calcium chloride treatment are difficult to explain, given the relatively high soil (and foliar) calcium concentrations found at sites with a high sCasN ratio. One explanation may be the general association of sCasN ratio with distance from the coast. Distance from the coast has been identified as being positively associated with response to nitrogen. This nebulous variable may be related to any number of site factors related to climate, moisture holding capacity, or mineral nutrition that haven't as yet been significantly correlated with fertilizer response. This rationalization may also explain the response of phosphorus and the two site specific blends.

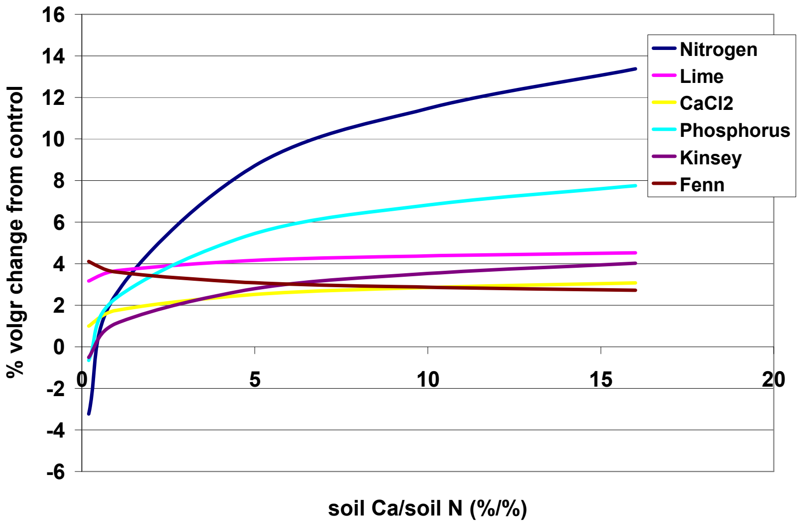

Figure 6 Change in tree level 3-yr volume growth vs. control for the six primary treatments

Further explorations between specific treatments and site-specific factors revealed significant correlations between volume response to N and site index (fig. 7), which has been previously reported (Carter et al. 1998); volume response to lime and initial foliar calcium (fig. 8), suggesting deficient calcium levels; and volume response to phosphorus and soil pH (fig. 9), related to the increasing availability of phosphorus as soils become less acidic (Marschner 1995).

Foliage retention was generally not a significant covariate within these regression models. When it was significant, the parameter estimate was almost always negative, suggesting that after adjusting for other model covariates, increased foliage retention results in lower growth. Foliage

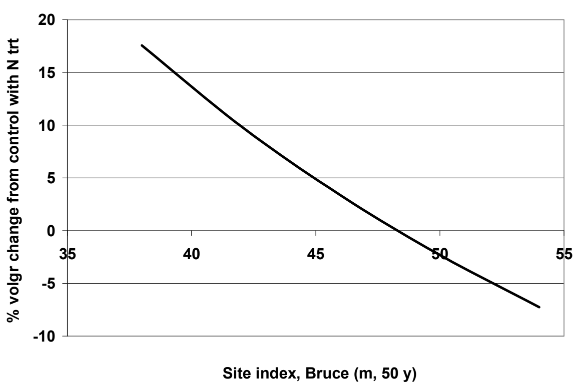

Figure 7 Percent change in tree level 3-yr volume growth from control with N treatment

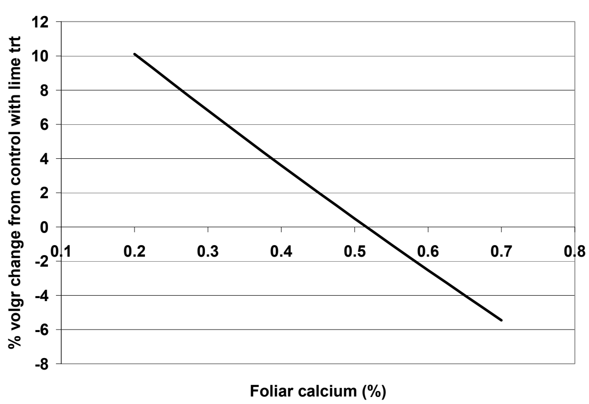

Figure 8 Percent change in tree level 3-yr volume growth from control with lime treatment

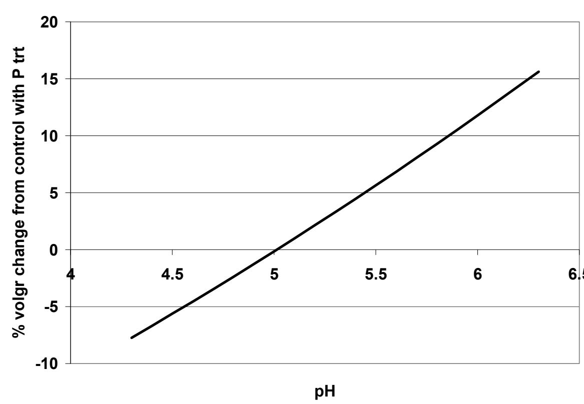

Figure 9 Percent change in tree level 3-yr volume growth from control with P treatment

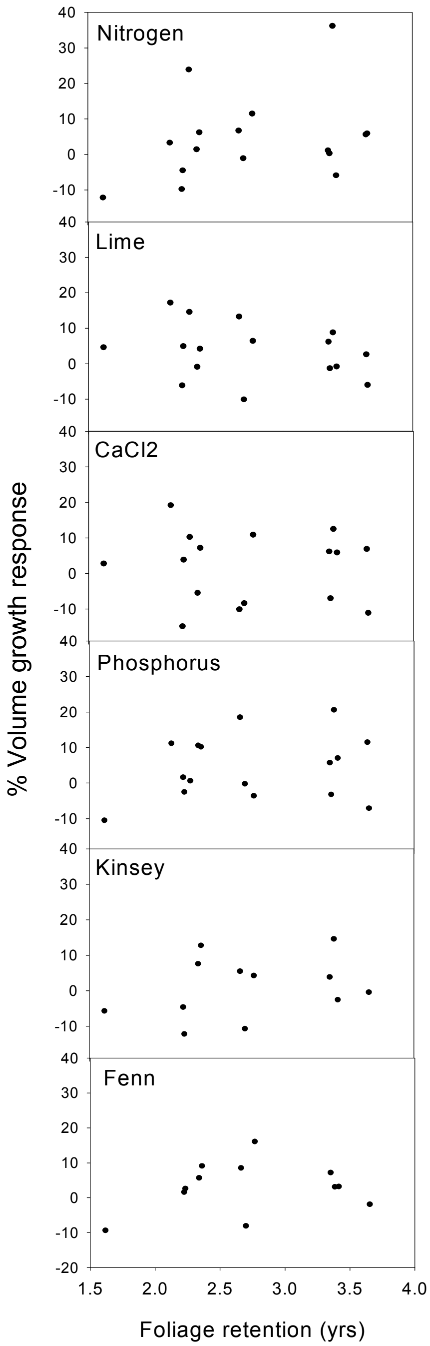

Figure 10 Site x treatment volume growth response versus foliage retention

retention was thus not included in any of the models, being counterintuitive both biologically and based on previous experience. One explanation for the general insignificance of foliage retention may be that the trees in this study were limited to the dominants and codominants. Previous work in commercially thinned stands found that for a given level of foliage retention in an infected stand, the large, and by implication, the dominant trees within that stand suffered a smaller relative volume growth loss due to SNC than did small trees (Mainwaring et al. 2005). On a courser scale, patterns between volume growth response and foliage retention appear to have limited practical correlation and large variability at all levels of foliage retention (fig 10).

Form quotient

Initial form quotient in 2006 did not differ between treatments after accounting for SITE (ANOVA). The form quotient of treated trees did not differ from the controls at the regional level. The change in form quotient at the regional level was significantly lower than control with phosphorus treatment only.

On the site-level, treatment differences depended on site and treatment (tables 3-4). Significant or marginally significant treatment differences in the two FQ variables were found for each of the treatments, though differences within a given treatment could be positive or negative depending on site.

Changes in form quotient were negatively related to volume growth response (fig. 11). Sites that responded positively to fertilizer treatment tended to have no change or a negative change in form quotient. A negative change in form quotient means that trees have more dbh growth or less upper stem growth relative to the control i.e. they are becoming more tapered. Conversely, a positive change in form quotient, found mostly where there was no change or a negative change in volume growth, suggests a less tapered tree. This relationship appears to be independent of treatment type.

Previous studies looking at effect of fertilization on taper have shown similar results: with N- and P- fertilized slash pine (Jokkela et al. 1989); with N-, P-, and blend-fertilized Norway spruce (Mead and Tamm 1988); and N-fertilized Douglas-fir (Mitchell and Kellogg 1972). Other studies have found increases in upper stem growth relative to dbh: with N-fertilized Scots pine (Valinger 1992) and sulfur-treated and blend-fertilized Douglas-fir (Younger 2007).

Table 3: Form quotient (d18ft/dbh) by site and total. Values in shaded boxes are significantly different from the control. Bold numbers are of marginal significance.

	Control	N	Lime	$CaCl_2$	Phos	Kinsey	Fenn	STR	NP
CTC	0.908	0.898	0.911	0.897	0.894	0.903	0.907		
GDH	0.8229	0.8422	0.8369	0.8282	0.8514	**0.8549**	0.827		
GPH	0.8494	0.842	0.856	0.859	0.833				
HAGR	0.8232	0.8373	0.815	0.8064	0.8238	0.8348	0.8318		
HAK	0.885	0.867	0.882	0.87	0.876	**0.857**	0.891		
LRT	0.8554	0.8817	0.8577	**0.8996**	0.8707				
MNN	0.7903	0.8004	**0.818**	**0.8199**	0.8002	0.8094	**0.8367**		
MNS	0.8465	0.8592	0.8462	0.8739	0.8371	0.8382	0.8512		
ODF	0.8281	0.8214	0.8482	0.818	**0.8003**	0.8191	0.8218		
OSU	0.8356	0.8256	0.8337	0.8379	0.8256	0.8338	0.8316		0.8275
PB	0.9267	0.9214	**0.9003**	**0.8947**	**0.9043**	0.9164	0.9127		
STR	0.8707	0.8702	0.8588	0.8569	**0.8429**	0.8633	0.8339	0.8556	
WE	0.8041	0.7759	0.7894	0.7802	0.7964				
WF	0.8212	0.8333	0.8352	0.8235	0.8074	0.8284	0.8269		
WW	0.8994	0.8935	0.8992	0.8989	0.8915				
all sites	0.8486	0.8528	0.8523	0.8495	0.8448	0.8515	0.8523		

Shaded boxes represent a significant change relative to control.

Table 4: Change in form quotient, adjusted for control plot, by site and total. Values in shaded boxes are significantly different from the control. Bold numbers are of marginal significance.

	N	Lime	$CaCl_2$	Phos	Kinsey	Fenn	STR	NP
CTC	-0.0063	-0.0062	0.0042	-0.0002	0.0046	0.0089		
GDH	0.001	-0.0101	**-0.0177**	**-0.0128**	0.0042	0.0001		
GPH	-0.0074	-0.0038	0.0038	-0.0159				
HAGR	**0.0205**	**0.0178**	0.01	0.0137	**0.031**	**0.0202**		
HAK	0.0012	-0.0034	-0.0042	-0.0081	0.0046	-0.0014		
LRT	0.0001	0.0015	**0.0271**	-0.0102				
MNN	-0.0137	0.0014	0.0076	0.0052	0.0035	**0.0174**		
MNS	0.0009	0.0083	0.0026	-0.0026	-0.006	-0.0061		
ODF	-0.0083	-0.0023	-0.0099	**-0.0368**	-0.0116	-0.0065		
OSU	0.0028	-0.0016	-0.0036	-0.0008	-0.0033	-0.0017		0.0018
PB	-0.0063	**-0.0163**	**-0.0169**	-0.0079	0.0018	**-0.0164**		
STR	-0.0033	-0.0002	-0.0009	-0.0024	-0.0019	-0.0039	0.0155	
WE	-0.0033	-0.0096	-0.0107	-0.0077				
WF	-0.0008	0.0104	0.0025	-0.0004	0.0003	0.011		
WW	-0.0059	0.0038	-0.0041	-0.0127				
all sites	-0.0013	0.0013	0.0005	**-0.0056**	-0.0005	-0.0021		

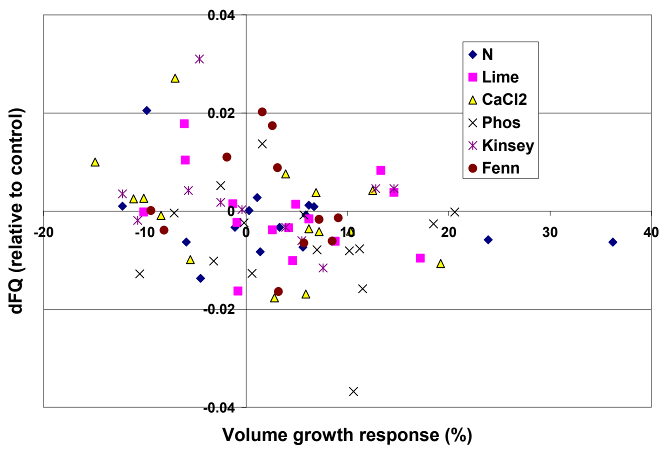

Figure 11 Change in form quotient vs. volume growth response

Crown base sapwood area

Previous work has shown that growth responses of Douglas-fir to nitrogen fertilization are the result of both increased leaf area and improved physiological efficiency (Brix and Ebell 1969, Brix, 1981, Brix 1983). The correlation between leaf area and sapwood area (Waring et al. 1982) provides a simple means to estimate the effect of fertilizer treatments on changes in leaf area per tree.

Crown base sapwood area increased at all sites; Increases in site-level averages ranged from a low of 5% to a high of 60% (average ~33%). While some of this is the result of the relative and enhanced dominance of subject trees in these well stocked, differentiating stands, some of the increase is probably due to the fact that pre-treatment sapwood widths were estimated in the spring

Table 5 Change in crown base sapwood area (cm^2), adjusted for control plot, by site and total. Values in shaded boxes are significantly different from the control. Bold numbers are of marginal significance.

	N	Lime	$CaCl_2$	Phos	Kinsey	Fenn	STR	NP	R^2	Covariates
CTC	**68.9**	**58.3**	6.4	**41.2**	28.8	14.7			0.31	dbh
GDE	-19.4	-63.5	33.6	-12.7	-52.1	-7.5			0.16	dbh, cr18
GDH	-26.1	**39.8**	26.4	2.7	-4.4	-9.4			0.34	ht
GPH	-14.9	-1.9	-14.6	-7.9					0.13	ht
HAGR	-27.2	4.9	-34.8	-8.4	**-43.7**	-20.7			0.28	ht, cr
HAK	-9.8	14	3.4	-15.7	33.8	-4.4			0.37	d18, cr18, cbsap, pba
LRT	-62.8	-1.3	-5.8	-57.8					0.27	ht
MNN	21.5	34.4	-6.8	30.2	0.4	16.4			0.31	ht, cr, pba
MNS	36.8	15	-25.7	47.7	23.7	28.7			0.54	ht, cr18, pba
ODF	15.1	18.4	-9.1	24.5	6.5	19			0.16	ht
OSU	-18.9	**51.8**	9.6	3.4	35.7	11.4		4.5	0.2	(None)
PB	-12.3	-6.3	36.2	**56.5**	24	15.7			0.44	dbh, pba
STR	-15.8	**-52.3**	-26.5	-6.3	-23.8	-9.8	-9.3		0.32	d18, pba
WE	5.2	**27.1**	13.9	15.7					0.4	cr18, cbsap
WF	**65.5**	-1.5	**-52.6**	-43.7	10.2	30.1			0.47	ht, cbsap
WW	**83.1**	**57.5**	48	36.9					0.14	
all sites	2.2	9.7	-4	4.8	5.1	1.4			0.2	dbh, ht, cr, pba

of 2007 (after the period of significant needle loss) and the 2009 measurements were made in September and October of this year.

On a regional level, there was no significant treatment-related changes in CBSAP (table 5). On the site level, significant changes in CBSAP depended on treatment. Of the thirteen significant or marginally significant changes in CBSAP, only four corresponded to significant changes in volume growth: CTC and WE (nitrogen), WE (lime), and CTC (phosphorus). Nevertheless, the changes in CBSAP are correlated with volume growth responses, though with significant variability (fig. 12). Although increases in leaf area from nitrogen fertilization are well known for numerous species (Brix 1969, Vose and Allen 1988, Heilman and Xie 1994), increases resulting from non-nitrogen fertilizers are poorly understood for Douglas-fir. Increases have been documented for non-nitrogen fertilization of other species, including phosphorus (Herbert and Fownes 1995), potassium (LaClau et al. 2009), and by implication, calcium (Long et al. 1997).

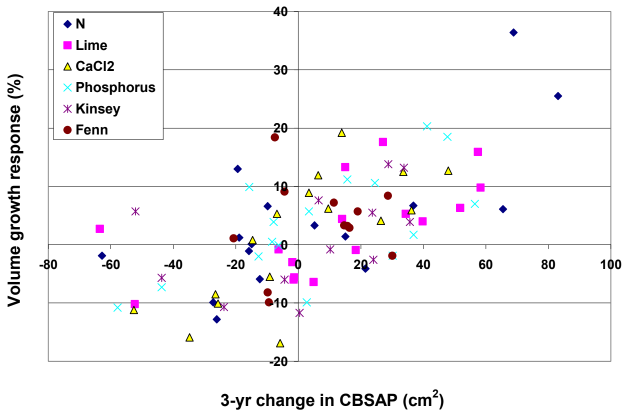

Fig. 12 Change in CBSAP vs. % volume growth response by treatment

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Growth Responses to Sulfur Application in Douglas-fir Stands with Swiss Needle Cast

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Abstract

Volume growth was assessed within five young Douglas-fir plantations following two consecutive years of aerial sulfur application. In the three year period 5-7 growing seasons following initial application, volume growth of treated trees was marginally improved (p=0.103) by 9.8%. This is essentially identical to the results for the growth period 3-4 growing seasons after initial application, implying that the growth improvements have been sustained during the last 5 years.

Introduction

Because sulfur has shown potential for controlling Swiss needle cast infection (Stone et al. 2001), an experiment was initiated in spring of 2002 to test the effect of aerial application of sulfur on Swiss needle cast symptoms, the abundance of the causal fungus, and the growth of Douglas-fir (Stone et al. 2003). Two growing seasons after the initial application, growth analysis determined that treatment did not affect either basal area or height growth (Maguire et al. 2004). During the second two-yr period following application, a marginally significant positive effect of sulfur application on volume growth (9.6%) was detected (p=0.11). The objective of this report is to present the results for volume growth during the three-year period 5-7 growing seasons following initial sulfur application (2006-2008).

Methods

Five-acre experimental units were chosen in pairs, with one unit serving as control and the other treated by aerial application of micronized sulfur (Stone et al. 2003). Within each experimental unit, a 0.5-ac measure plot was established. All trees were tagged and measured for dbh (nearest 0.1 cm) before the growing season in 2002, and a subsample of at least 40 Douglas-fir trees was measured for total height and height to crown base (nearest 0.1m). The experimental units were treated aerially with micronized sulfur, twice during June in each of the 2002 and 2003 growing seasons. Five plot pairs established in the Coast Range of Oregon were available for analysis. Prior to this third remeasurement in the fall of 2008, previous remeasurements were made in the spring of 2004, after two growing seasons, and again in the spring of 2006, after four growing seasons. Treatment effects on periodic annual volume growth were tested by ANCOVA consistent with the randomized block design.

Results and Discussion

Analysis of covariance with initial Douglas-fir basal area as a covariate indicated that sulfur treatment was associated with a marginally positive volume growth response (p=0.103) (figure 1,2). After adjusting for initial Douglas-fir basal area, the average difference in growth between the control and treatment plots was ~9.8%. These results are essentially the same as for the second two-yr period (Mainwaring et al. 2006), suggesting that any effect of treatment is relatively consistent for 3-7 years after treatment. Given the relatively high p-value, this conclusion should be viewed with caution. Nevertheless, these results are very different from the clear insignificance of treatment observed during the first two growing seasons (p=0.61).

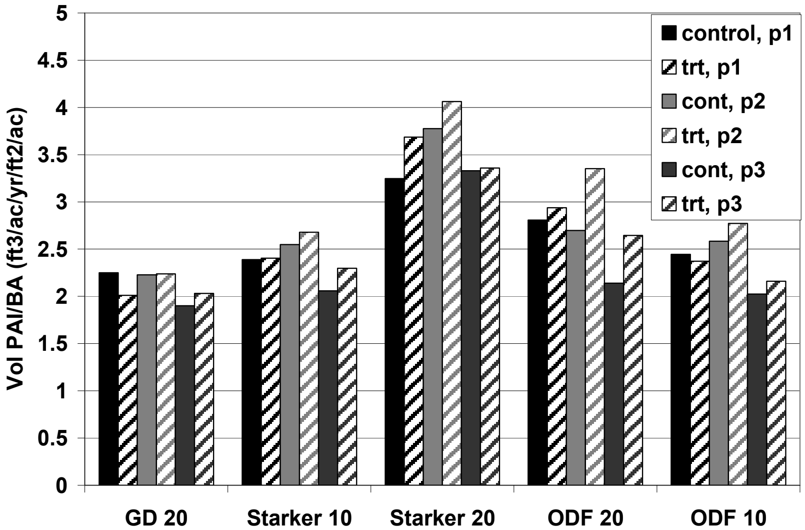

Figure 1 Periodic annual volume growth per unit basal area after sulfur application on five sites. Number after landowner refers to the initial age of the stand. P_i in legend refers to growth period.

The delayed response in growth improvement with treatment is similar to what was found following aerial Bravo fungicide applications (Mainwaring et al. 2002). Over the five year period of Bravo application, the cubic volume growth of treated stands increased ~35% versus untreated stands. In the final three years of application, the growth increase was ~60%, implying a lack of response in the first two years following application. Because fungicides like Bravo and sulfur inhibit fungal infection/germination, and *P. gaeumannii* only infects newly expanding foliage (Stone et al. 2000), the explanation for this delay is that time is required for a tree to develop the uninfected foliage necessary to enhance growth rates. Enhanced growth after a delay was particularly reasonable during the second two-year period, when treated foliage was 3 and 4 years old. During this latest growth period, treated foliage would be 5-7 years old, lower in the crown, and increasingly likely to have senesced for any number of reasons. If sulfur and Bravo act similarly, i.e. to only inhibit infection of first year needles by *P. gaeumannii*, improved growth of sulfur treated trees can be expected to diminish as the protected needles age and senesce.

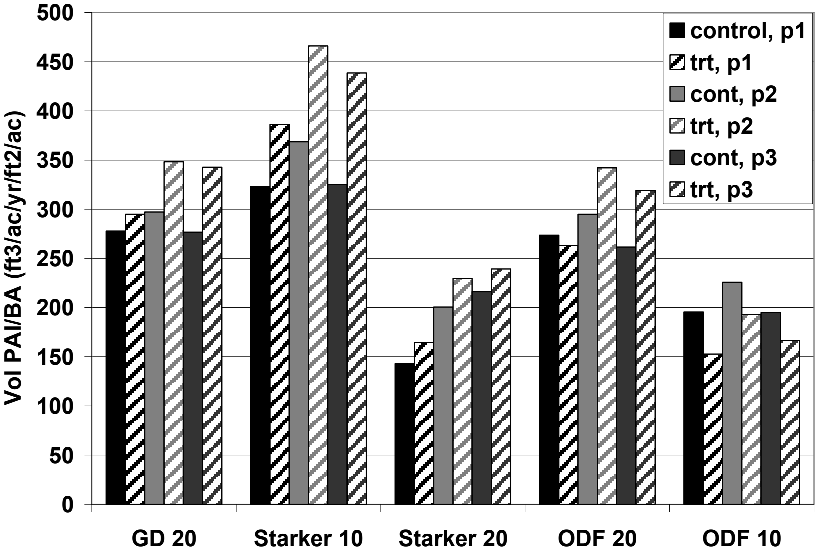

Figure 2 Periodic annual volume growth after sulfur application on five sites. Number after landowner refers to the initial age of the stand. P_i in legend refers to growth period.

In addition to the problem of the relatively high p-value, the question of efficacy of sulfur for inhibiting *P. gaeumannii* infection and improving Douglas-fir growth is compromised due to the relatively unfavorable conditions for SNC infection during the years of treatment. Research has identified a positive correlation between spring wetness and fungal germination rates (Manter et al. 2003). According to regional climate data, there was relatively low spring rainfall in 2002 and 2003, the years of sulfur application. Trees throughout the Coast Range might then be expected to have experienced lower relative infection rates during the 2002-03 period than they would have during most two-year periods in the last 10 years, and this is consistent with subsequent aerial survey results and personal observations of infection levels throughout the region. As a result, it is likely that trees on these study sites retained a greater amount of older foliage during the years following treatment, regardless of treatment type. Unfortunately, the improved conditions of the 2002-03 period coincided with the two years of fungicide application. If infection rates were lower during these treatment years, the positive effects of treatment would be smaller and harder to detect.

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Impacts of Swiss needle cast on overstory Douglas-fir forests of the western Oregon Coast Range

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Abstract

Tree-ring analysis was applied to assess the impacts of the fungal disease Swiss needle cast on the radial growth of mature Douglas-fir (*Pseudotsuga menziesii*) forests in the western Oregon Coast Range. Although endemic to the Pacific Northwest, Swiss needle cast has significantly lowered productivity in Douglas-fir forests only in the past twenty to thirty years. To date, studies on Swiss needle cast impacts have almost exclusively involved young (< 30 yrs) plantation trees. To better describe the history of Swiss needle cast and its impacts on older (> 80 yrs) trees, we extracted tree cores from dominant and codominant Douglas-fir and western hemlock (*Tsuga heterophylla*) in three even-aged stands in western Oregon. In the least affected stand growth rates of both species did not significantly differ, while Douglas-fir radial growth was reduced by as much as 85% at the most severely diseased site. Growth reductions likely associated with Swiss needle cast began as early as 1950, though the most severe impacts occurred after 1984 followed by an apparent worsening of the disease after 1996. An index of Swiss needle cast severity significantly ($p < 0.01$) related to instrumental records of air temperatures such that warm conditions from March through August were associated with reduced radial growth at the most severely affected site. Overall, this study demonstrates that even mature forests of natural origin are susceptible to severe growth reductions by Swiss needle cast, that warmer springtime temperatures are associated with Swiss needle cast impacts, and that the disease appears to be increasing in severity.

Introduction

Over the past twenty years, an epidemic of Swiss needle cast, a foliage disease caused by the native fungus *Phaeocryptopus gaeumannii*, has emerged in the Oregon Coast Range, significantly lowering productivity in affected Douglas-fir forests (Hansen *et al.*, 2000; Maguire *et al.*, 2002). Fruiting bodies of the fungal pathogen interfere with foliage gas exchange by physically blocking Douglas-fir stomata, thereby reducing or halting photosynthesis and leading to premature needle abscission (Manter *et al.*, 2000). Although mortality is rare, cubic volume growth loss ranges from 23-50% in diseased stands (Maguire *et al.*, 2002). The total area of symptomatic forest in coastal Oregon observed in aerial surveys conducted by the Oregon Dept of Forestry annually since 1996 has been gradually increasing; the area reported in 2009 was 163500 ha (ODF, 2009).

A major question associated with the current epidemic is whether the disease is a recent phenomenon, or whether there have been growth declines of Douglas-fir due to foliage diseases along the western slope of the Oregon Coast Range during the past century. Current impacts of Swiss needle cast have been evaluated almost exclusively in relatively young (<30 years in age) Douglas-fir stands, often in plantation settings (Maguire *et al.*, 2002). Impacts of the disease on older, overstory trees, especially in naturally regenerated stands, remain to be described. Also, all assessments of Swiss needle cast severity span the current outbreak, focusing on the years from approximately 1990 to present (Hansen *et al.*, 2000; Maguire *et al.*, 2002; Stone *et al.*, 2008). Little is known about the history of the disease prior to the current outbreak, and whether it significantly affected growth in earlier decades. Moreover, field and laboratory studies indicate that the disease is associated with springtime and summertime needle wetness as well as wintertime temperatures (Rosso and Hansen, 2003; Manter *et al.*, 2005; Stone *et al.*, 2008). A longer time series of Swiss needle cast impacts would better characterize the development of the disease and provide more statistical power to quantify relationships with climate.

Tree-ring data have been widely used to reconstruct the timing, severity, and spatial extent of insect outbreaks in western conifers (references). However, in this study we explore whether related dendrochronology techniques can be applied as a novel means by which to assess the long-term history and impacts of a foliar pathogen, Swiss needle cast, on overstory Douglas-fir in the northwestern Oregon Coast Range. More specifically, our objectives are to *i*) describe the effects of Swiss needle cast on the radial growth of mature (>50-yr-old), naturally regenerated trees, *ii*) reconstruct the history of Swiss needle cast over the past fifty to seventy years, and *iii*) relate multidecadal time series of Swiss needle cast derived from tree-ring data to instrumental climate records.

Methods

Growth-increment analysis was performed on Douglas-fir, the host species for Swiss needle cast, as well as a control species, western hemlock, to better distinguish the impacts of the disease from stand-level disturbances or extreme climate events. Therefore, three even-aged mixed Douglas-fir (*Pseudotsuga menziesii*) -western hemlock (*Tsuga heterophylla*) stands of native origin were selected as study sites in the northwestern Oregon Coast Range (Figure 1). Chosen stands also had no history of logging or thinning, were in excess of 70 yrs in age, and occurred immediately adjacent to younger stands heavily or moderately impacted by the disease. Of the three stands, Tillamook Upper and Lower were located within approximately 3.2 kilometer of one another near Tillamook, OR, while Euchre Mountain was located approximately 70 km to the south, near Lincoln City, OR (Figure 1). At each site, circular, 0.02 ha plots were located along transects 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; 1.3 m). 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 and Curtis, 1956). Within each 0.02 ha circular plot, one core was extracted from all dominant and codominant western hemlock and Douglas-fir trees. All cores were taken at breast height to avoid rot and buttressing. To increase sample sizes, we also collected cores from several dominant or codominant western hemlock and Douglas-fir trees located just outside the boundaries of the plots.

Cores were dried, mounted, and sanded with increasingly fine sandpaper to reveal the cellular structure. Within each species and site, all cores were then visually crossdated using the “list year” technique to identify and missing or false rings in the data set and ensure that all growth increments were assigned the correct calendar year (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).

In COFECHA, measurement time series were detrended using cubic spline set at a 50% frequency response of 32 years. Within each species and site, every detrended time series was correlated with the mean of the all other detrended time series to yield the interseries correlation. Individuals with an unusually low interseries correlation were checked for potential errors such as missed or false rings. Mean sensitivity was also calculated to describe the high-frequency, between-year growth variability, which for any pair of adjacent years ranged from zero (each year is the same width) to two (when a non-zero value is adjacent to a zero value; i.e. a missing increment) (Fritts, 1976).

Once crossdating was verified, original measurement time series were averaged with respect to species and site to produce "ring width" master chronologies. Next, to identify suppressions a running calculation of percent-growth change was applied to each of the original measurement time series. In this "suppression index," percent growth change for a year was equal to $(M_1 - M_2) / M_2$ in which M_1 equals average growth over the prior 5 years and M_2 equaled average growth over the subsequent 5 years. Sudden reductions in growth result in highly positive values. This calculation was also applied to the ring width master chronologies. Each time the suppression index exceeded 100%, the year with the maximum value was recorded as a moderate suppression. If the index exceeded 200%, the year was recorded as a major suppression. No more than one suppression event could be recorded in a ten-year period. As an additional measure, we calculated percent growth reduction in Douglas-fir relative to the control species, hemlock. At each site, the hemlock measurement master chronology (hemlock) was used, and the calculation was repeated for each Douglas-fir (fir) individual using the formula (hemlock – fir) / hemlock. This calculation was performed for the intervals of 1984 through 2007 and 1996 through 2007.

Differences between Douglas-fir and hemlock were useful for quantifying disease-related growth reductions and establishing preliminary Swiss needle cast histories at each site. However, we found that estimates of disease history could be refined by comparing Douglas-fir among sites. None of the three sites appeared to have a substantial disturbance history that would confound such a comparison, and species-specific contrasts would reduce complications if hemlock had experienced positive growth responses to Douglas-fir decline, or experienced radically different climate responses. Overall, comparisons of Douglas-fir across sites would corroborate results from comparisons of Douglas-fir and hemlock within sites.

An analysis of growth among sites was conducted by subtracting mean Douglas-fir growth at the site with the lowest Swiss needle cast influence (Euchre Mountain) from Douglas-fir at the site with the greatest influence (Tillamook Lower). Although each stand was even-aged, tree ages among stands varied by forty to fifty years. Thus, age-related growth declines had to be removed before growth could be compared, accomplished by developing a "detrended" master chronology at each site. First, each measurement time series was detrended with a negative exponential function to remove age-related growth trends and standardize each mean to a value of one. Exceptions were made for those series in which an exponential function followed a positive trend. Positive slopes would not be related to age, and these individuals were detrended using the series mean (a horizontal line). By detrending with the most rigid functions possible, we attempted to preserve as much long-term variability as possible. Within each site, all detrended Douglas-fir time series were averaged to create master detrended chronologies. Chronology development was conducted using the program ARSTAN http://www.ldeo.columbia.edu/res/fac/trl/public/publicSoftware.html (Cook 1985). A detrended master chronology was also developed for western hemlock at Tillamook Lower as well as for Douglas-fir from Cape Perpetua, a site approximately 65 km south of Euchre Mountain. At 400 years in age, these trees were more than four times the age of western hemlock and Douglas-fir at the other three sites. For these reasons Cape Perpetua was not used as a full replicate, but was still useful in comparisons with the other sites. In particular, the Cape Perpetua Douglas-fir chronology was substituted in place of the Euchre Mountain Douglas-fir chronology to further refine a chronology of Swiss needle cast impact.

A complication with this chronology-development procedure was that many Douglas-fir at Tillamook Lower experienced particularly severe growth declines over the most recent twenty to thirty years, and in many cases negative exponential functions predicted values less than zero. To resolve this issue we used a type of regional curve standardization at Tillamook Lower in which a single function was used to detrend every individual. First, a pith locator (a transparency with concentric circles that matched the curvature and growth rate of the core's growth increments) was used to estimate age at breast height. The earliest growth increment in a core was generally within five years of pith date. Next, each measurement time series was normalized to a mean of zero and standard deviation of one, after which all were aligned with respect to cambial age. A single negative exponential function ($y = 5.24*\exp^{-0.04*x}$) was then fit to the pooled data and used to detrend each measurement time series (R^2 =0.81). Detrended measurement time series were then aligned with respect to calendar year and averaged to create the master chronology.

We correlated the chronology of Swiss needle cast impact with monthly averages of precipitation, temperature, and Palmer Drought Severity Index (1895 – present) for Oregon Region 1 (Coastal Oregon), available at the NOAA NCDC website http://www7.ncdc.noaa.gov/CDO/CDODivisionalSelect.jsp# . Monthly averages were used to determine those periods of the year in which environmental variability most strongly affected the Swiss needle cast time series. Given the potentially heavy influence of ocean circulation on the climate of these forests, we also related the Swiss needle cast time series to the Multivariate ENSO Index (MEI) (Wolter and Timlin, 1998). The MEI is the leading principal component of six marine and atmospheric variables in the tropical Pacific, and was obtained (1950-2005) from the NOAA Earth Systems Research Laboratory (http://www.cdc.noaa.gov/people/klaus.wolter/MEI/).

Results

Douglas-fir and western hemlock dominated two of the three study sites with the exception of Tillamook Lower, in which Sitka spruce dominated with the highest importance value (Table 1). Sitka spruce and red alder were minor components of Tillamook Upper and absent from Euchre Mountain (Table 1). Among the three sites, Tillamook Lower supported the smallest total basal area and number of stems per hectare (Table 1). Mean plot elevation ranged from 260 m at Tillamook Lower to 520 m at Tillamook Upper, and slopes were comparable among all three sites at fifteen to twenty percent (Table 2). Aspects at Tillamook Lower and Tillamook Upper were southwest, in contrast to northwest-facing slopes at Euchre Mountain (Table 2). Hemlock and Douglas-fir were even-aged within each site, although trees at Euchre Mountain were approximately forty years older than those at Tillamook Upper or Tillamook Lower (Table 2).

Visual crossdating was verified using COFECHA, and no dating errors were identified. Interseries correlations as calculated by COFECHA, which reflect the degree of synchrony in growth patterns, were lower for western hemlock than Douglas-fir (Table 2). Also, interseries correlations for each species were highest at Tillamook Lower and lowest at Euchre Mountain (Table 2). No clear trends were evident for mean sensitivity, though all species and sites exceeded 0.2 and values for Douglas-fir at Tillamook Lower were relatively high at 0.4 (Table 2). Locally absent rings occurred only rarely (approx. two per thousand) in both species at Euchre Mountain, and none was identified in western hemlock at Tillamook Lower or Tillamook Upper. Locally absent rings did, however, occur with much greater frequency in Douglas-fir at Tillamook Lower (approx. seventy-eight per thousand), and to a lesser extent, in Douglas-fir at Tillamook Upper (approx. twelve per thousand). At these two sites several cores contained a full complement of rings, which facilitated crossdating and identification of locally absent rings.

Hemlock master chronologies all significantly ($p < 0.05$) correlated with one another as did Douglas-fir chronologies, corroborating dating accuracy.

Inter-species differences in growth rates were most strongly pronounced at Tillamook Lower, in which mean Douglas-fir ring width was significantly ($p < 0.05$) less than the control species, hemlock, during 1950-1951, 1961, 1969, 1972-1974, and 1976 through present (Figure 2A). Early in the measurement chronologies, Douglas-fir ring width was significantly greater than western hemlock, although western hemlock growth did eventually exceed Douglas-fir in 1984 and again from 1999 to 2000 (Figure 2B). No significant differences occurred between hemlock and Douglas-fir at Euchre Mountain (Figure 2C). Also, at Tillamook Lower, Douglas-fir experienced severe and widespread suppression events in 1984 and 1996 (Figure 3A). Almost all Douglas-fir individuals experienced a major suppression in those years, a pattern not shared by hemlock (Figure 3A,B). A similar suppression history was also evident at Tillamook Upper, but the severity of the Douglas-fir suppressions was not as pronounced as at Tillamook Lower, and fewer trees were affected (Figure 3C,D). Neither Douglas-fir nor hemlock experienced major or widespread suppressions at Euchre Mountain (data not shown).

As a final indicator of growth reductions, locally absent rings occurred in a large percentage of Tillamook Lower Douglas-fir, especially in three episodes beginning in 1984, 1996, and again in the mid-2000s (Figure 4A). Locally absent rings began to occur with some frequency at Tillamook Upper in 1996 (Figure 4B). Yet at both sites, hemlock did not contain a single locally absent ring, despite comparable sample sizes (Figure 4C). Too few locally absent rings were noted at Euchre Mountain to compare frequencies between species (data not shown). All indices corroborated that growth reductions for Douglas-fir were most severe at Tillamook Lower, and that these reductions were most pronounced after 1984 (Figures 2-4). Indeed, percent-growth reduction relative to hemlock was greatest and highly significant ($p > 0.001$) at Tillamook Lower, at more than 80% between 1984 and 2007 and almost 90% for the interval of 1996 to 2007 (Figure 5). Percent growth reduction for Douglas-fir at Tillamook Upper was less pronounced, and significant ($p < 0.05$) only from 1996 through 2007. No significant reductions were identified at Euchre Mountain (Figure 5).

Three chronologies of Swiss needle cast impact all indicated that the effects of the disease on radial growth have been increasing over the past five decades (Figure 6). Very similar trends were evident whether the Tillamook Lower Douglas-fir detrended chronology was subtracted from the Tillamook Lower hemlock detrended chronology, the Euchre Mountain Douglas-fir detrended chronology, or the Cape Perpetua Douglas-fir detrended chronology (Figure 6). Thus, growth comparisons within sites between Douglas-fir and the control species, hemlock, corroborated growth comparisons between Douglas-fir among sites differentially impacted by the disease. These chronologies of Swiss needle cast impact were calculated such that negative values indicate increasing disease impact and reduced tree growth.

For correlations with climate, the difference between The Tillamook Lower Douglas-fir and Cape Perpetua Douglas-fir detrended chronologies was used due to the fact that Swiss needle cast appeared to have the least effect on trees at the southernmost site, and species-specific growth patterns could be better eliminated using Douglas-fir instead of hemlock. For the Swiss needle cast impact chronology, relationships with climate were negative and strongest from March through August with respect to air temperature and MEI (Figure 7A). High values of MEI indicate warm ocean conditions, such that all correlations suggest that warm temperatures in the spring, summer, and early fall are associated with greater Swiss needle cast severity and reduced radial growth. Thus, the inverse of the Swiss needle cast index (index * -1) was calculated to more clearly illustrate that disease progression was consistent with long-term warming trends in mean March through August temperature (Figure 7B). Even when the Swiss needle cast and temperature time series are detrended using 30-year frequency cutoff splines to remove long-term trends, relationships are still significant ($R^2 = 0.11$; $p < 0.01$).

Discussion

Douglas-fir growth was substantially reduced in comparison to western hemlock at Tillamook Lower, and to a lesser extent, Tillamook Upper. Western hemlock and Douglas-fir were mixed at all three sites, and sampling was spread as evenly as possible across the spatial extent of each stand. Thus, growth differences were not likely due to species-specific differences in disturbance histories. Although western hemlock is a more understory tolerant species than Douglas-fir (Hermann and Lavender, 1990; Packee, 1990), age-specific radial growth rate was comparable for both species, especially at Euchre Mountain. Perhaps the only exception was early in the chronologies at which time Douglas-fir tended to exhibit faster growth rates, particularly at Tillamook Upper. Yet this difference could be explained by the tendency of Douglas-fir to more rapidly colonize the site and outcompete western hemlock, at least in the early phases of stand development. Although differences in the silvics of these two species could complicate direct growth comparisons between these species, much higher frequencies of locally absent rings and severe suppression events corroborate that Douglas-fir growth was differentially affected, independent of differences with hemlock absolute radial growth rates. Moreover, the timing of these growth reductions was consistent across Tillamook Lower and Tillamook Upper, suggesting that the same causal factor affected Douglas-fir at both sites.

Given the timing of growth declines and locations of the most severely diseased stands on the landscape, Swiss needle cast is the most likely explanation for Douglas-fir suppressions. Although Swiss needle cast is believed to be endemic to the Pacific Northwest the disease has not been considered a significant forest health problem until approximately thirty years ago (Hansen *et al.*, 2000). In the early 1980s, Swiss needle cast was suspected as the cause of yellowing and needle loss in young Douglas-fir plantations in southwest Washington and western Oregon from Tillamook to Lincoln City (Hansen *et al.*, 2000). Indeed, in a May 1984 memo to the Bureau of Land Management, the US Forest Service Director of Forest Pest Management for the Pacific Northwest Region noted “extensive foliage discoloration and needle loss” in Douglas-fir near Tillamook, OR. Affected Douglas-fir ranged from young plantations to old growth, and “most” were infected by *P. gaeumannii.* Much milder discoloration was reported for western hemlock and Sitka spruce, leading the author to conclude that adverse environmental conditions, including unusually cold temperatures during the previous winter, were at least in part responsible. According to the tree-ring record, 1984 was the year in which Douglas-fir entered a severe and prolonged period of reduced radial growth. Growth rates were much lower than western hemlock, suggesting that the severity of Swiss needle cast had in fact become much more pronounced (Figures 2, 3, 4).

At Tillamook Lower, the most severely affected site, Douglas-fir growth reductions began in 1950 to 1951 and were associated with locally absent rings by 1969. Foliage yellowing or loss may not have been sufficiently severe or widespread to attract attention prior to 1984. According to the tree-ring record, the most profound impacts did not begin until the mid 1980s, at which time growth reductions also appeared at Tillamook Upper (Figure 2, 4) and presumably also at a much broader spatial scale. Reflective of the tree-ring record, surveys reported that impacts of the disease increased through the 1990s, especially in young plantation stands (Hansen *et al.*, 2000). In an analysis of ten- to thirty-year-old Douglas-fir plantation trees, Maguire *et al.* (2002) found significant losses in cubic volume growth beginning in 1990, consistent with the findings at Tillamook Upper and Lower. In the most severely affected stands, percentage growth loss consistently ranged from thirty to sixty percent, with the greatest losses in 1992 and 1996, the last year included in the study. By 1996 an annual aerial survey of Douglas-fir forests was initiated for the western Oregon Coast Range (Hansen *et al.*, 2000; ODF, 2009). Although the growth reductions captured by the tree-ring records do not strongly correlate with the spatial distribution reflected by the aerial survey, both indicate that Swiss needle cast is becoming progressively more severe. Over the past four years, aerial detection surveys have identified more than 121400 ha of Douglas-fir forests with visible Swiss needle cast symptoms, more than any previous year with the only exception of 2002 (ODF, 2009).

Impacts of Swiss needle cast are by no means homogenous across the landscape and vary at a range of spatial scales. In general, Swiss needle cast tends to be more severe near the coast, especially at low-elevation and south-facing aspects with summer drizzle and exposure to summertime fog (Manter *et al.*, 2003; Rosso and Hansen, 2003). Indeed, Tillamook Upper and Lower were both south-facing, of which Tillamook Lower was most heavily impacted, while Euchre Mountain was relatively high in elevation and north-facing (Table 2). Moreover, Tillamook Lower contained a large component of Sitka spruce and red alder, indicative of a strong maritime influence. However, no evidence of growth decline due to Swiss needle cast was detected in Douglas-fir at Cape Perpetua despite a south aspect, close proximity to the coast, and an elevation (260 m) identical to that of Tillamook Lower. Douglas-fir at Cape Perpetua were four times as old as western hemlock (and trees at any of the other three study sites), preventing direct comparisons between the two species. Yet no growth suppressions equivalent to those at Tillamook occurred in the 400-year tree-ring record (data not shown). Moreover, yellow foliage and *P. gaeumannii* pseudothecia were evident in younger stands immediately adjacent to the Cape Perpetua and Euchre Mountain study sites. Thus, additional microsite variables as well as stand age are almost certainly involved in the observed patterns of Swiss needle cast severity. For example, older stands may have inherent buffers to the disease associated with lower tree densities, trees with deeper, more shaded crowns, and a highly developed overstory that better protects against environmental extremes. It is also notable that not only were basal areas and frequencies of Douglas-fir low at Tillamook Lower, but so were total basal area and tree frequency across all species (Table 1). Indeed, total dominance was half that of Euchre Mountain or Tillamook Upper, suggesting that Tillamook Lower may have been an unusually unproductive site. If this is indeed the case, a combination of particularly unfavorable climatic and edaphic site conditions may help explain the tremendous growth reductions experienced by Douglas-fir over the past thirty years.

To date, analyses of climate and Swiss needle cast have involved laboratory experiments or field studies across broad spatial scales, but over a limited number of years (Rosso and Hansen, 2003; Manter *et al.*, 2005; Stone *et al.*, 2007). By contrast, tree-ring records in this study provided uniquely long time series of growth for comparison with instrumental climate records, but over a limited number of sites. In general, past studies have identified that warmer wintertime temperatures are correlated with greater Swiss needle cast severity, not only in Oregon (Rosso and Hansen, 2003; Manter *et al.*, 2005), but also for Douglas-fir forests in New Zealand (Stone *et al.*, 2007). Spring and summertime needle wetness also appear to favor the disease (Rosso and Hansen, 2003; Stone *et al.*, 2008) as long as summertime temperatures are relatively low (Rosso and Hansen, 2003). Thus, warm winters and cool, wet, and foggy springs and summers should correspond with greater Swiss needle cast severity, and these climate-growth relationships loosely correspond to those identified for tree-ring data.

In this study, an index of the disease was most strongly related to late-winter through springtime temperatures as well as mid-summer temperatures, such that warm temperatures were associated with reduced radial growth and presumably greater disease impact. Notably absent were any relationships with precipitation, PDSI, or wintertime temperatures, and correlations with summertime temperatures were opposite from what was expected. However, the final climate-growth relationships must be interpreted with caution. First, Douglas-fir is moisture sensitive with chronologies that negatively correlate with temperature and positively correlate with precipitation during the dry season, which for western Oregon is the late summer. Differencing the Tillamook Lower and Cape Perpetua Douglas-fir chronologies should have removed such species-specific climate responses, though the negative correlations with July and August temperatures may still be an artifact of Douglas-fir's sensitivity to hot and dry summers. A second consideration is that other studies relating Swiss needle cast to climate have used much younger trees and either relative abundance of *P. gaeumannii* pseudothecia on needles or total foliage retention as metrics of the disease (Rosso and Hansen, 2003; Manter *et al.*, 2005; Stone *et al.*, 2008). By contrast, radial growth is a biological response and an indirect measure of disease in comparison to a direct measure of fungal abundance. Finally, the Swiss needle cast index is based on growth patterns from only two sites, and the climate variables associated with the disease on a landscape scale may not associate as strongly at these single stands. To better address these uncertainties, a larger number of sites must be incorporated to quantify climate influences.

Previous to the current epidemic of Swiss needle cast, another foliage disease of Douglas-fir was considered important; Rhabdocline needle cast, caused by a complex of *Rhabdocline* species (Parker and Reid, 1969; Hansen and Lewis, 1997). Our current understanding of Rhabdocline needle cast is that in western Oregon it is strongly associated with off-site stock, and especially with interior Douglas-fir (*P. menziesii* ssp. *glauca*) seed sources planted in the Oregon Coast Range (Hansen and Lewis, 1997). The disease is also associated with unusually wet spring weather, especially if this continues for several years, and high-humidity micro-sites (Goheen and Willhite, 2006). Although our analysis is focused on impacts from Swiss needle cast, we cannot completely rule out a role from Rhabdocline needle cast in the past. However, growth declines from the early 1980s to present are almost certainly due to Swiss needle cast, given the history of accounts and surveys from the Tillamook study sites and the fact that *Rhabdocline* species infrequently occur in the study area (Hansen *et al.*, 2000).

Conclusion

In conclusion, tree-ring chronologies capture multidecadal, annually resolved growth declines in Douglas-fir associated with Swiss needle cast. Previous studies have almost exclusively involved young plantation Douglas-fir with seed from off-site origin. The results of this study indicate that Swiss needle cast can also substantially impact the growth of naturally regenerated overstory trees, even in mixed-species stands. In comparison with hemlock, these growth reductions have exceeded 80% over the last twenty years. Though this estimate may be somewhat inflated if western hemlock experienced growth releases concurrent with Douglas-fir decline, Swiss needle cast nonetheless appears capable of profound reductions in growth-increment width. Moreover, growth declines at Tillamook Lower began several decades prior to the first records of Swiss needle cast outbreaks in the region, providing a longer history of the disease. In addition, these tree-ring data corroborate that the impacts of Swiss needle cast continue to worsen in the western Oregon Coast Range. They also corroborate that Swiss needle cast is associated with climate, especially long-term warming trends during the late winter and early spring.

From a management perspective, the results of this study indicate that naturally regenerated older trees are susceptible to Swiss needle cast, and that younger trees will not simply “outgrow” the disease. Growth may be substantially reduced, even in trees more than 100 years in age. From an ecological perspective, coastal forests are among the most productive in the world, and continuing intensification of Swiss needle cast could alter forest composition, dynamics, and carbon sequestration. More replicates will be necessary to better estimate the synchrony of radial growth losses across the landscape, the timing at which significant losses began, and the sites that are most vulnerable. In addition, stands with older trees should be sampled to determine whether declines occurred prior to the 20th century. For now, however, this study demonstrates that Swiss needle cast is a significant pathogen even in mature forests and that tree-ring analysis is an important resource for quantifying the historical dynamics of this disease.

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Table 1. Frequency, density, and dominance values for overstory species at the three study stands

A) Tillamook Lower

Species	Frequency (12 plots)	Density (stems / ha)	Dominance (m^2 / ha)	Relative frequency	Relative Density	Relative dominance	Relative importance
Alnus rubra	1	8.3	1.9	4.2	3.4	1.1	2.9
Picea sitchensis	9	91.7	80.6	37.5	37.9	46.6	40.7
Pseudotsuga menziesii	5	41.7	22.9	20.8	17.3	13.3	17.1
Tsuga heterophylla	9	100.0	67.4	37.5	41.4	39.0	39.3
Totals	24	241.7	172.8	100.0	100.0	100.0	100.0

B) Tillamook Upper

Species	Frequency (5 plots)	Density (stems / ha)	Dominance (m^2 / ha)	Relative frequency	Relative Density	Relative dominance	Relative importance
Alnus rubra	2	30.0	12.2	15.4	6.0	3.6	8.3
Picea sitchensis	2	50.0	38.7	15.4	10.0	11.4	12.3
Pseudotsuga menziesii	4	150.0	154.0	30.8	30.0	45.2	35.3
Tsuga heterophylla	5	270.0	135.6	38.5	54.0	39.8	44.1
Totals	13	500.0	340.5	100.0	100.0	100.0	100.0

C) Euchre Mountain

Species	Frequency (6 plots)	Density (stems / ha)	Dominance (m^2 / ha)	Relative frequency	Relative density	Relative dominance	Relative importance
Pseudotsuga menziesii	6	208.3	343.6	50.0	69.4	81.6	67.0
Tsuga heterophylla	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

Table 2. Site and chronology attributes

	elevation	Aspect	slope	chronology	Interseries correlation[1]	mean sensitivity[2]	number of cores	pith date[3]
Tillamook Lower	260 m	210° (SSW)	15%	Douglas-fir	0.65	0.41	23	1927
				hemlock	0.43	0.26	21	1932
Tillamook Upper	520 m	230° (SW)	20%	Douglas-fir	0.56	0.22	21	1931
				hemlock	0.38	0.22	19	1925
Euchre Mountain	410 m	330° (NNW)	15%	Douglas-fir	0.48	0.21	21	1882
				hemlock	0.35	0.28	19	1887

[1] The average correlation between each detrended measurement time series (using a 22-year cubic spline) and the average of all other detrended measurement time series as output by COFECHA

[2] An index of high-frequency variability that ranges from 0 (no variability) to 2 (highly variable), as output by COFECHA

[3] Mean pith date at breast height

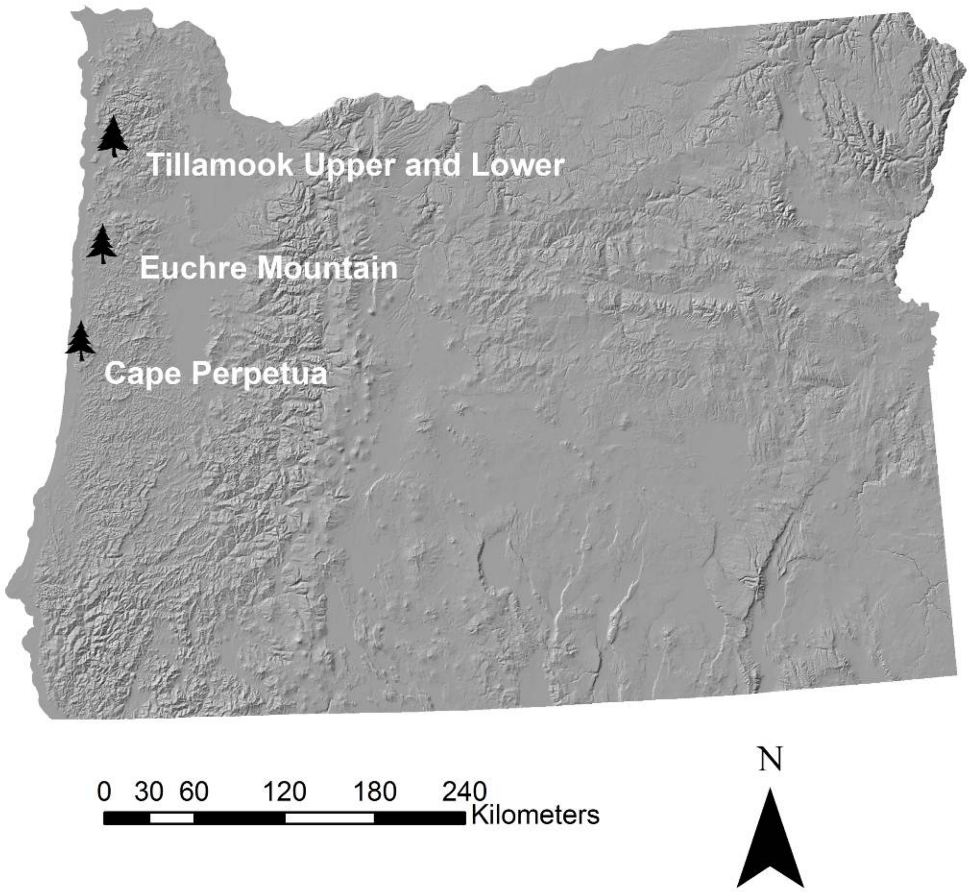

Figure 1. Locations of the three study sites for this analysis, Tillamook Upper, Tillamook Lower, and Euchre Mountain. Tillamook Upper and Lower are only 1 km apart and are not separable at this scale. Cape Perpetua, the location of an additional Douglas-fir chronology, is also noted.

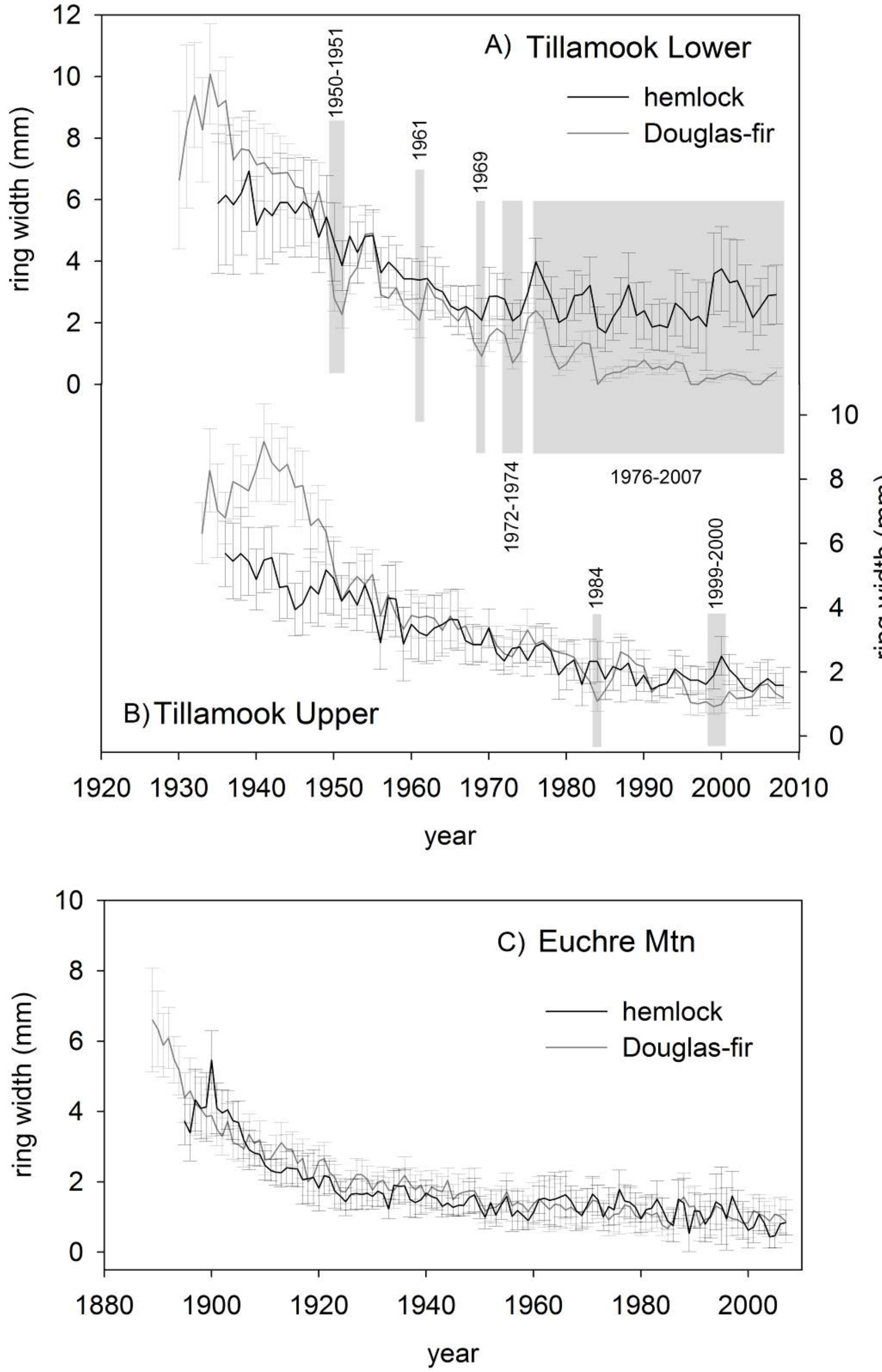

Figure 2. Tree-ring chronologies for each of the three stands. Chronologies were developed by averaging all measurement time series with respect to species and site for A) Tillamook Lower, B) Tillamook Upper, and C) Euchre Mountain. 95% confidence intervals are included. Shaded areas denote years in which Douglas-fir growth is significantly lower than that of hemlock. For all three sites, the only period in which Douglas-fir growth is greater than hemlock was at Tillamook Upper between 1940 and 1948.

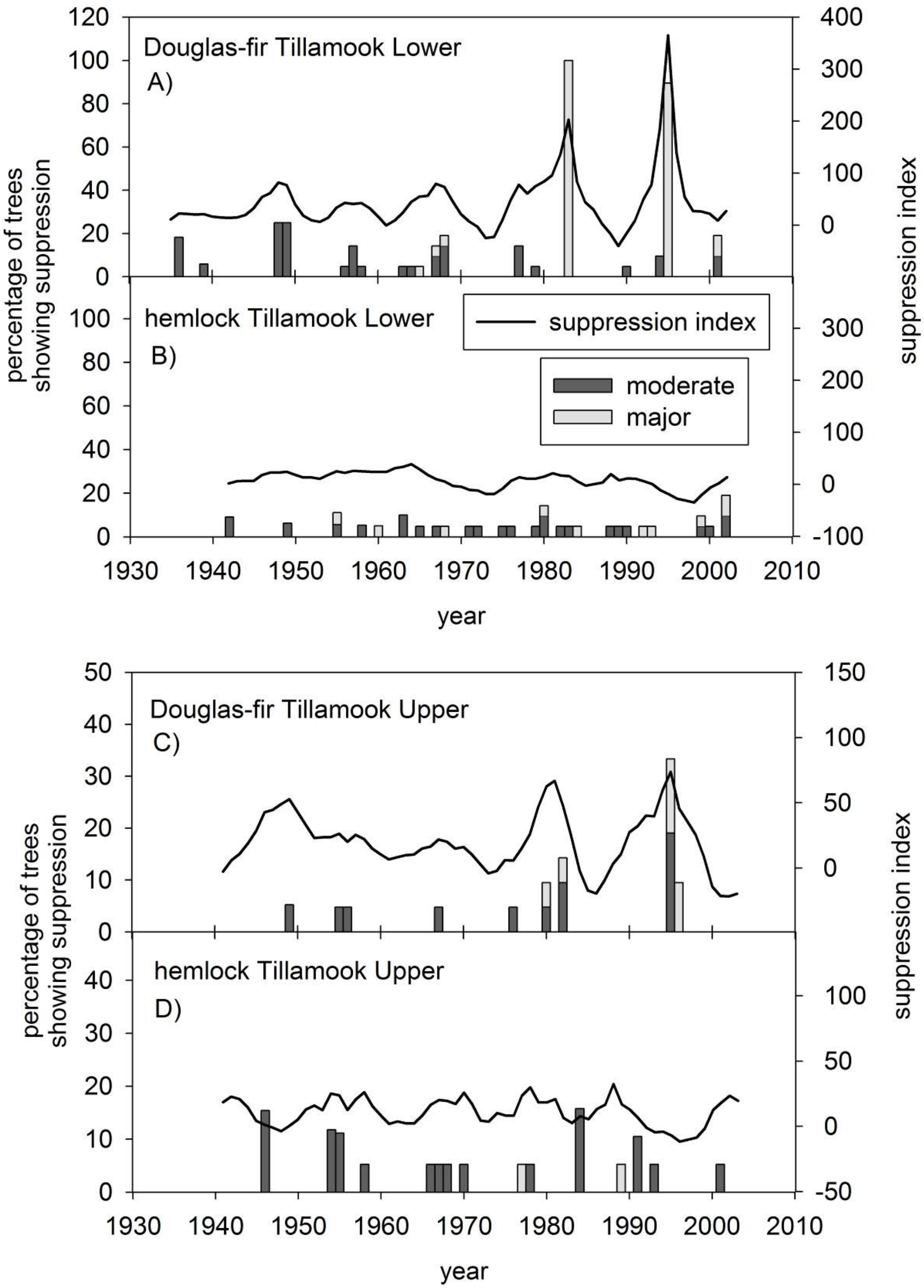

Figure 3. The percentage of trees with a suppression index that exceeded 100% (moderate suppression) and 200% (major suppression) at A) Tillamook Lower Douglas-fir, B) Tillamook Lower western hemlock, C) Tillamook Upper Douglas-fir, and D) Tillamook Upper western hemlock. The suppression calculation was also applied to the master chronologies.

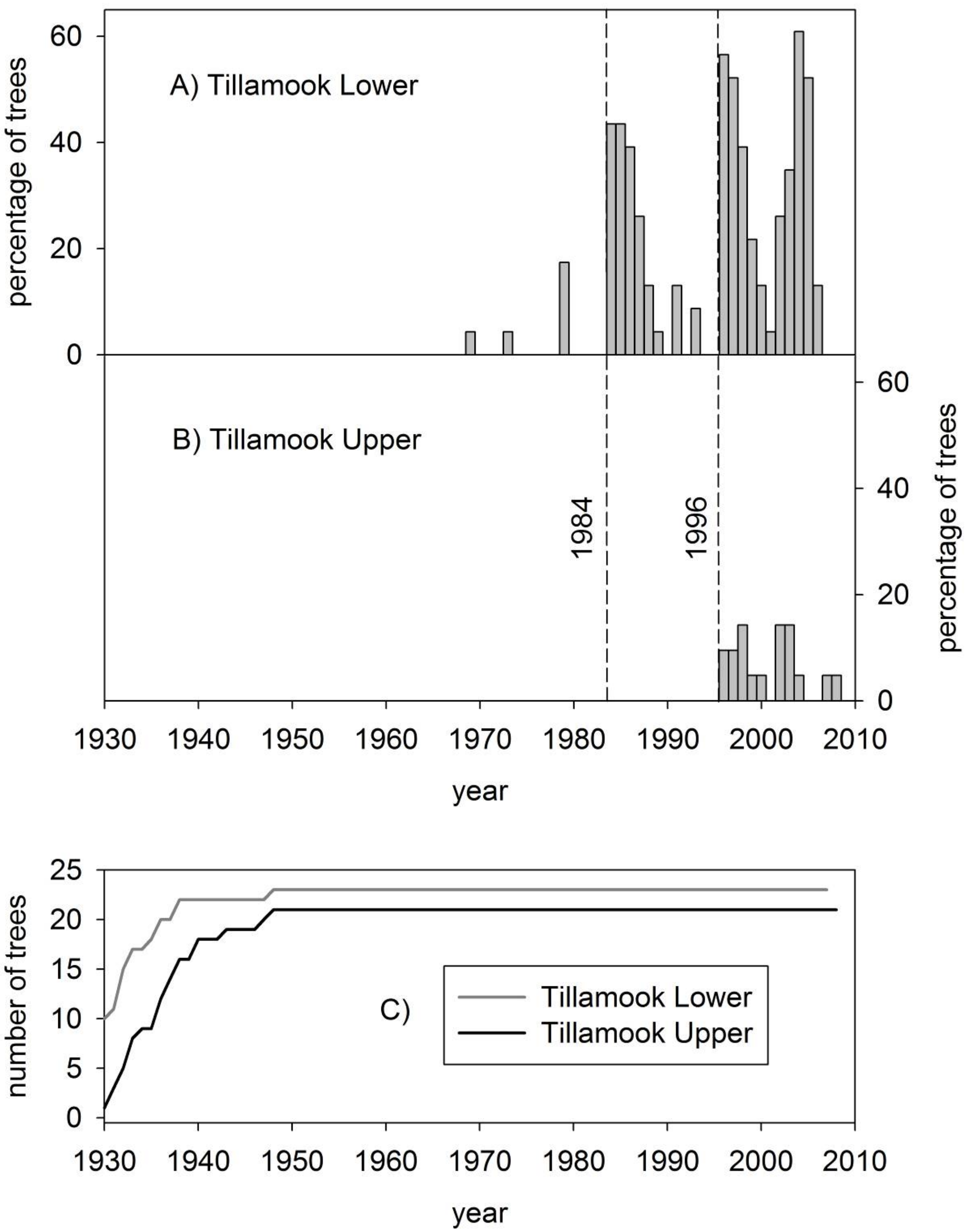

Figure 4. The percentage of Douglas-fir with a locally absent ring at A) Tillamook Lower and B) Tillamook Upper. C) The total number of Douglas-fir trees included in the analysis.

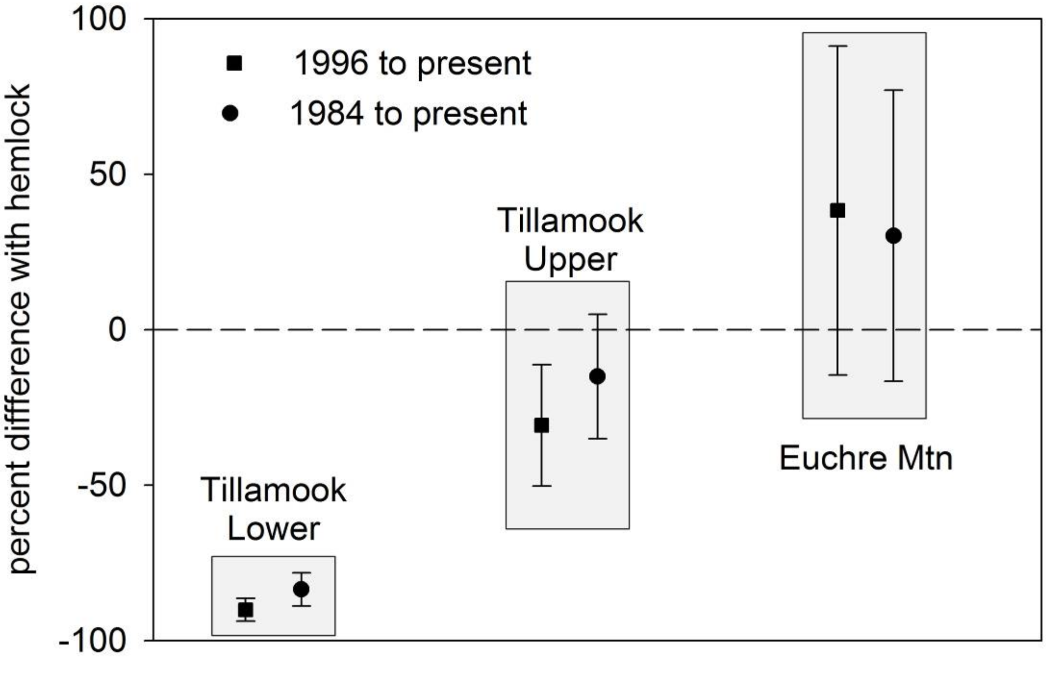

Figure 5. The percent difference between mean hemlock growth (in mm) that of each Douglas-fir (in mm). Percent difference was calculated as Douglas fir minus hemlock, and the difference divided by hemlock. Negative values indicate low growth in Douglas-fir relative to hemlock. Growth was compared over two intervals: from 1984 to 2008 and also from 1996 to 2008. 95% confidence intervals are shown.

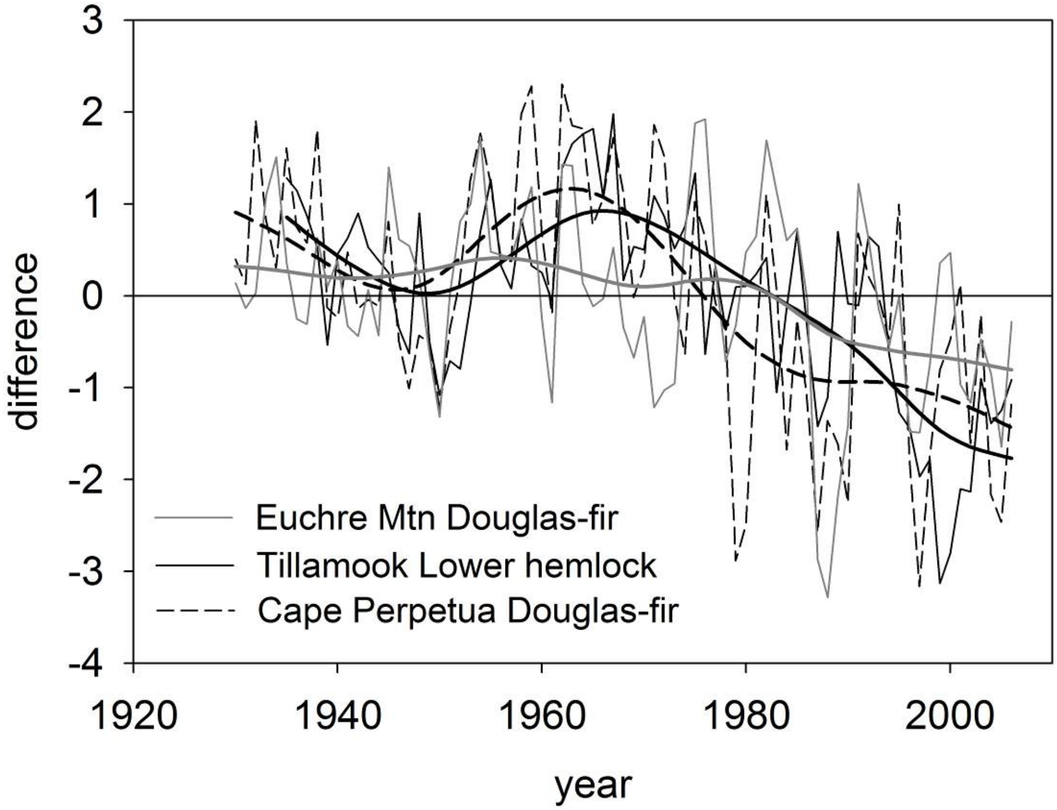

Figure 6. The difference between the detrended master chronology of Douglas-fir at Tillamook Lower and the detrended master chronologies of i) western hemlock at Tillamook Lower, ii) Douglas-fir at Euchre Mountain, and iii) Douglas-fir at Cape Perpetua. All chronologies were first normalized to a standard deviation of one and a mean of zero over the common interval of 1930 to 2006. Negative values indicate low growth for Tillamook Lower Douglas-fir. Heavy lines are smoothing splines to emphasize decadal trends.

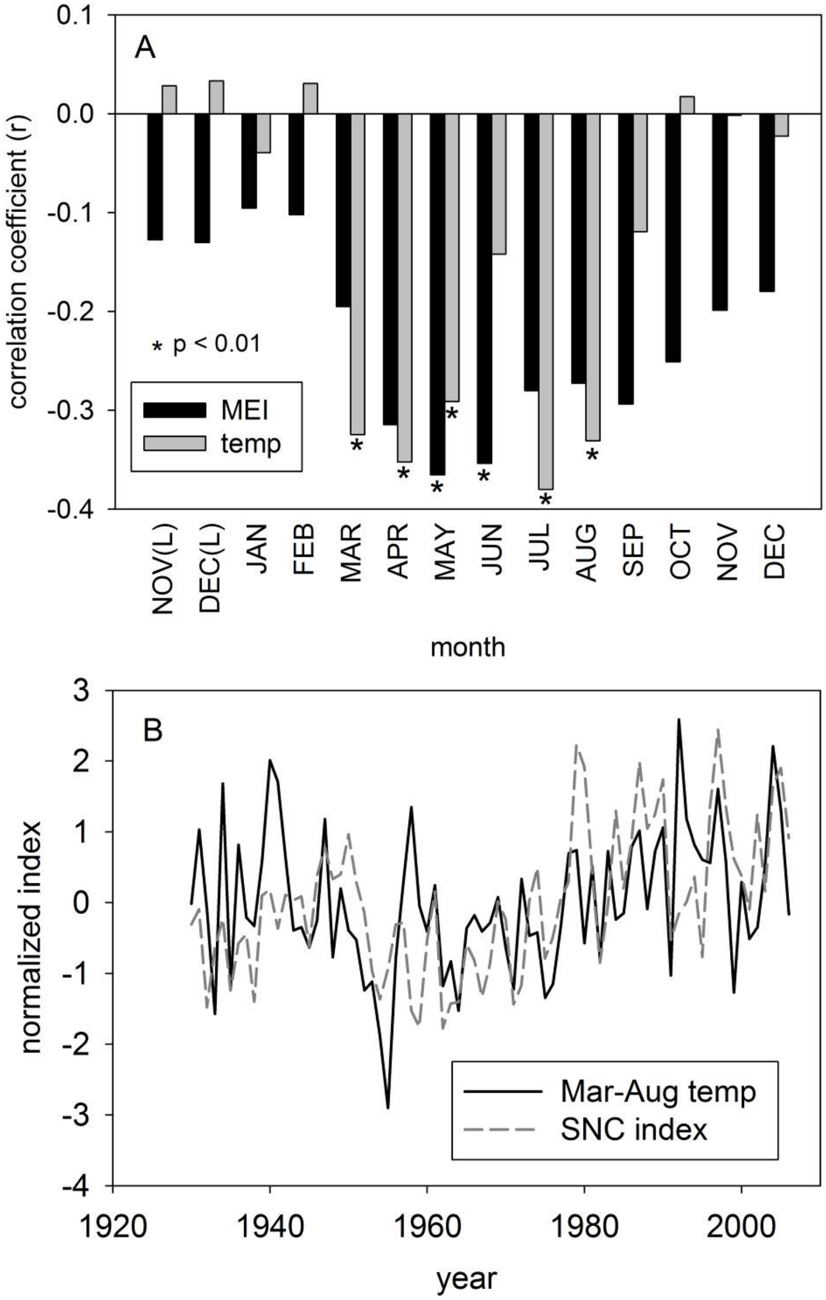

Figure 7. A) Correlations between the Swiss needle cast index (the difference between the Tillamook Lower and Cape Perpetua Douglas-fir chronologies) and monthly-averaged air temperature (temp) and Multivariate ENSO Index (MEI). Months span the prior (lagged) November through current December. * indicates significant correlations ($p < 0.01$). B) Relationship between average March through August temperature and the inverse of the Swiss needle cast index ($R^2 = 0.22$; $p < 0.001$) (both normalized to mean = 0; std dev = 1). Warm temperatures are associated with reduced radial growth and presumably favorable disease conditions.

Second-year Response of Ectomycorrhizae to Soil Nutritional Amendments Across a Gradient of SNC Disease

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Abstract

Across six blocks of the Kinsey treatment, no effects were detected on either feeder-root density (p = 0.84) or ectomycorrhiza type richness (p = 0.96). The effect of block was significant for both variables (p = 0.02 and 0.009, respectively). Within the Giustina block, the phosphorus treatment had no effect on either feeder-root density (p = 0.66) or ectomycorrhiza type richness (p = 0.71). Mean root density varied by nearly 8x among sites while mean EM species richness varied by about 3x.

Ectomycorrhiza species richness was significantly correlated with root density; $R^2 = 0.75$, $p = 0.01$.

Ectomycorrhizal root density was not significantly correlated with Douglas-fir needle retention; $R^2 = 0.41$, $p = 0.12$.

Ectomycorrhiza species richness was significantly correlated with Douglas-fir needle retention; $R^2 = 0.70$, $p = 0.02$.

As was noted previously (Luoma and Eberhart 2007, 2008) some normally common ectomycorrhiza types were reduced in frequency on highly impacted SNC disease sites. The variable responses of EM fungi to carbon availability and soil nutrient status provides context for understanding the strong relationship between EM richness and needle retention and why root density, *per se*, exhibits a less consistent relationship to needle retention. Characteristics of the ectomycorrhiza community can be used to monitor forest health and are useful in predictive models.

Introduction

Ectomycorrhizae and Silvicultural Manipulations

Ectomycorrhizal symbioses are formed on about 8000 plant species (Dahlberg, 2001) and the current estimate of the number of ectomycorrhizal fungus (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, 2008). Douglas-fir has about 2000 EMF symbionts throughout its range (Trappe, 1977). Douglas-fir will not grow in soil without ectomycorrhizal fungi (Trappe and Strand, 1969).

Ectomycorrhizal fungus diversity is an important attribute of forested ecosystems; for instance, stabilizing below-ground processes after disturbances (Perry et al., 1989). Seedlings associated with a high diversity of EMF may be better adapted to disturbance as compared to seedlings with less diversity (Simard et al., 1997). In addition, high EMF diversity seems to increase trees' competitive abilities. A laboratory study supported this hypothesis by documenting that *Pinus patula* seedlings inoculated with two species of EMF grew taller and put on more biomass than seedlings inoculated with only one EMF species (Sudhakara and Natarajan, 1997).

Several small studies have suggested a correlation between Swiss needle cast (SNC) disease severity and the 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 (Berg and Smalla, 2009). Ectomycorrhiza (EM) communities are particularly influential with respect to nutrient availability and tree nutrition (Smith and Read, 2008), so may be influential in predisposition of Douglas-fir to SNC.

Previous Results

In 2006 we determined levels of ectomycorrhizae in forest stands with moderate to high levels of SNC disease (Luoma and Eberhart, 2006). In that pilot study, the levels of EM diversity found indicated that the below-ground ecosystem was strongly affected by SNC, by the previous removal of mature trees during timber harvest, by post-harvest silvicultural practices, or by a combination of all three. Comparison of EM diversity in naturally regenerated young stands following stand-replacing disturbances may help separate harvest or natural disturbance effects from those of post-harvest silvicultural treatments. In short, more work is necessary to establish whether, and under what conditions, EM diversity is most related to cause or effect.

However, there was also indication that some EM fungi may be "stress tolerators" (sensu Grime, 1979). Common Douglas-fir EM types such as *Cenococcum* and *Rhizopogon* were less widespread in SNC stands than they were found to be in other studies (Eberhart et al., 1996; Luoma et al., 2006; Luoma and Eberhart, 2007). Because the trees strongly affected by SNC were mycorrhizal, albeit at low densities, we hypothesized that certain EM fungi had become more predominant on the roots that remain and are filling the important functional roles that EM play in tree nutrition. Studies to examine and test the hypothesis that "stress tolerant" EM fungi are important to keeping Douglas-fir alive in the face of SNC disease were undertaken (Luoma and Eberhart, 2008)

Rather than a few EM species dominating because they are particularly tolerant of a reduced carbon supply on highly impacted SNC sites, Luoma and Eberhart (2008) hypothesized observing a "survival of the survivors" scenario. They found that stand-level aggregate species richness (exhibiting an approximate 50% reduction) was not impacted as severely as species richness at the level of the individual soil core (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). Luoma and Eberhart (2008) demonstrated the potential ecological value conferred by the existence of a 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.

Here, we present two years post-treatment results as part of the “Beyond Nitrogen” fertilization study. Our findings provide an essential component to assess functional fertilizer effects on SNC disease. Ectomycorrhizae are the organs through which any nutritional benefits of fertilization are conferred to Douglas-fir trees.

Methods

Seven blocks of the “Beyond Nitrogen” study (Mainwaring et al. 2006, 2007) were sampled (Table 1). The blocks varied by degree of SNC disease symptoms. Ectomycorrhizal roots of Douglas-fir trees from 3 of the fertilizer treatments were obtained:

1) Unfertilized control (7 blocks)
2) Kinsey site-specific mix (6 blocks, see Table 5, Mainwaring et al. 2007)
3) Phosphorus, as mono-sodium phosphate (1 block).

Table 1. Study sites (blocks) with mean needle retention (2009) of sampled trees and fertilizer plots used.

Landowner	Location	Block code	Retention (yrs.)	Fertilizer treatment
Cascade Timber	Waterloo	CTC	2.29	Kinsey
Giustina	Pleasant Hill	GIU	2.84	Phosphorus
Stimson (Green Diamond[1])	Hemlock	GDH	1.61	Kinsey
Hampton	Grand Ronde	HAGR	2.16	Kinsey
Starker	Burnt Woods	STR	2.62	Kinsey
Oregon Dept. Forestry	Elk City	ODF	2.19	Kinsey
Oregon State University	McDonald Forest	OSU	2.93	Kinsey

[1] Landowner at start of study

In each block, one 350 cc soil core was taken from beneath the canopy of 10 randomly chosen trees prior to, or concurrent with, application of the treatments in 2007. Five of the trees in each block were from the control, while the other 5 were assigned to receive the fertilizer treatments listed in Table 1. A total of 70 soil cores were obtained (10 trees/block x 7 blocks). Two years post-treatment, another set of soil cores was obtained in May, 2009. When possible, soil cores were obtained about 15 cm from the marked 2007 soil core location. In a few instances, the location of the previous core could not be determined, in which case the new core was located the same distance from the base of the tree (1m) and on the side of the tree from which the nearest adjacent trees were at the greatest distance, following the same procedures used in 2007.

Methods for measurement of EM were the same as those used in gathering the pre-treatment data (Luoma and Eberhart, 2007). Roots from the soil cores were extracted by wet-sieve washing the 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.

Feeder root density (total number of EM tips per soil core) and species richness (number of EM types per soil core) were used as response variables. The data were used to test for treatment effects and to test for gradient responses to SNC disease. ANOVA was used to test for effects of the Kinsey treatment across 6 blocks and was used to test for effects of the phosphorus treatment within the Giustina block.

Because no treatment effects were detected, the pooled treatment and control data were tested for among-block differences in the response variables using ANOVA. When appropriate, that was followed by Fisher's protected least significant difference test to determine which study sites (blocks) differed from one another. The change in response variable values between 2007 and 2009 were tested within each block using a paired *t*-test.

Linear regression was used to examine gradient responses in feeder root density and EM species richness to among-block variation in SNC disease. Linear regression was also used to measure the association between feeder root density and species richness. When necessary to better meet the assumptions of normality and constant variance, we transformed the dependent variables (Sabin and Stafford 1990). To test for fertilizer treatment effects, feeder root density was square-root transformed while EM richness was transformed using square-root + 0.5. To test for among-block variation in the response variables and for the linear regression analysis, mean block feeder root density was square-root transformed while mean block EM richness was log transformed.

Needle retention data were provided by D. Mainwaring and were obtained following the methodology described in Mainwaring and Maguire (2008). Mean years needle retention did not require transformation. The change in values between 2007 and 2009 were tested within each block using a paired *t*-test.

Results and Discussion

For the Kinsey treatment, no effects were detected across 6 blocks on either feeder-root density ($p = 0.84$) or species (EM type) richness ($p = 0.96$). The effect of block was significant for both variables ($p = 0.02$ and 0.009, respectively). Within the Giustina block, the phosphorus treatment had no effect on either feeder-root density ($p = 0.66$) or ectomycorrhiza type richness ($p = 0.71$).

Post-hoc tests using Fisher's PLSD revealed significant differences among blocks in feeder root density (Fig. 1) and EM richness (Fig. 2). Ectomycorrhiza species richness was significantly correlated with root density; R^2 = 0.75, p = 0.01 (Fig. 3). Ectomycorrhizal root density was not significantly correlated with Douglas-fir needle retention; R^2 = 0.41, p = 0.12 (Fig. 4). Ectomycorrhiza species richness was significantly correlated with Douglas-fir needle retention; R^2 = 0.70, p = 0.02 (Fig. 5).

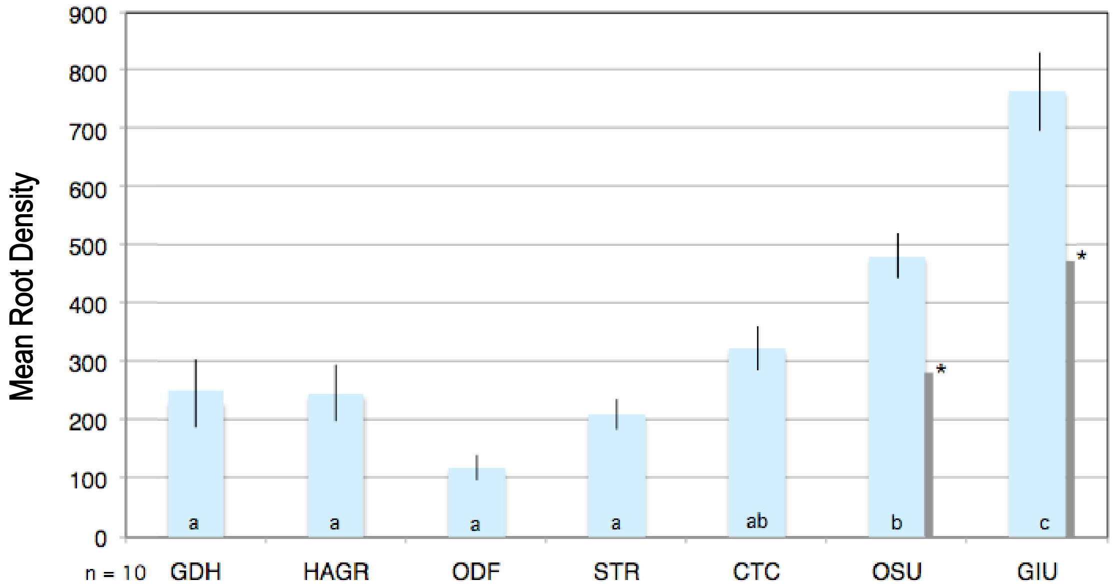

Figure 1. Variation in feeder root density (mean # of ectomycorrhizal root tips/soil core) among study sites (blocks). Site codes are provided in Table 1. Bars not sharing letters are significantly different at $p \leq 0.08$ (based on Fisher's PLSD), vertical lines indicate SE, n = 10. *Narrow gray bars represent significantly different 2007 within-block values.

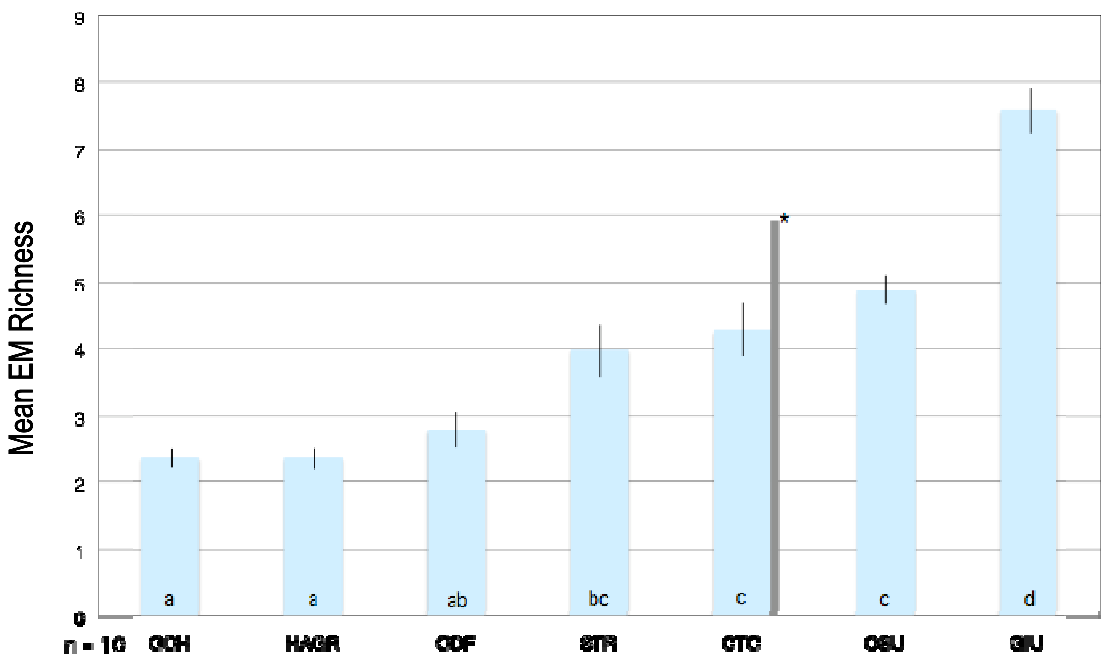

Figure 2. Variation in ectomycorrhiza richness (mean # of EM species/soil core) among study sites (blocks). Site codes are provided in Table 1. Bars not sharing letters are significantly different at $p \leq 0.06$, vertical lines indicate SE, n = 10. *Narrow gray bars represent significantly different 2007 within-block values.

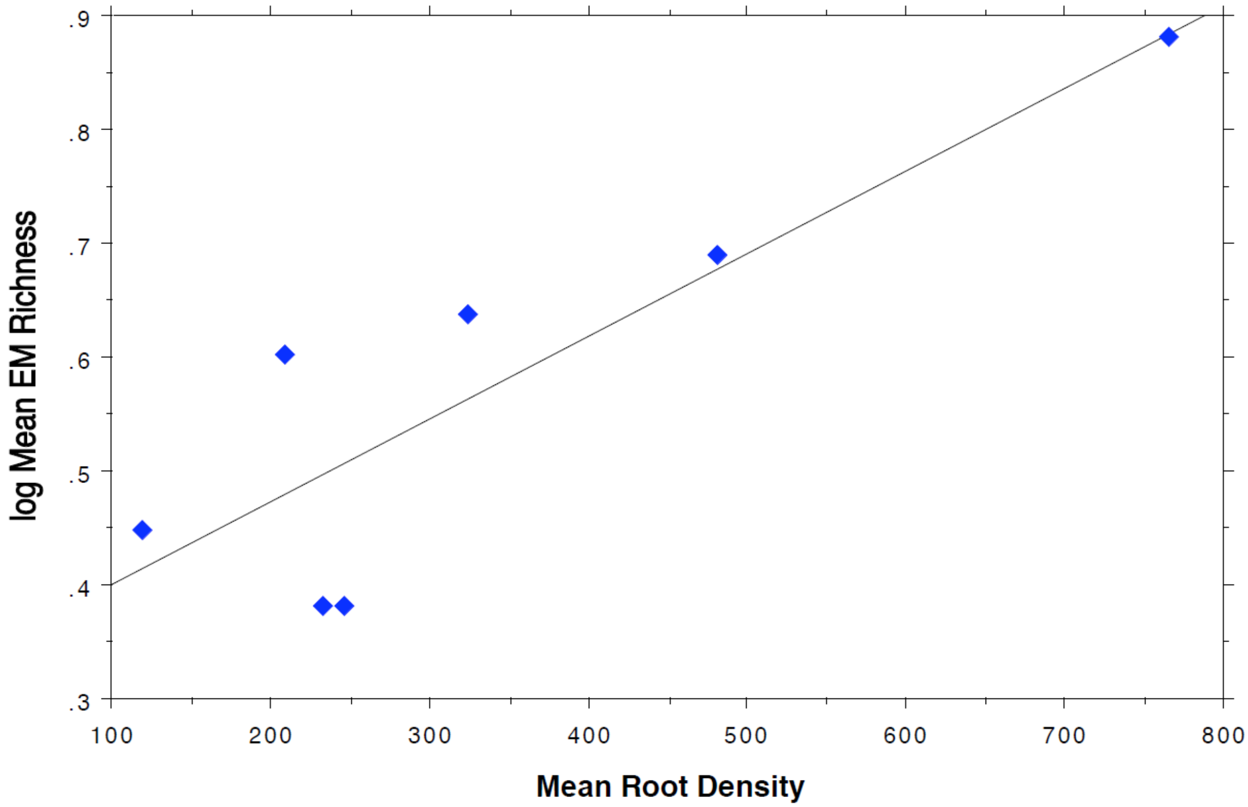

Figure 3. Regression plot of mean ectomycorrhiza species richness (log transformed) against mean root-tip density, Y = .326 + .001 * X; R^2 = .75 (p = 0.01, n = 10).

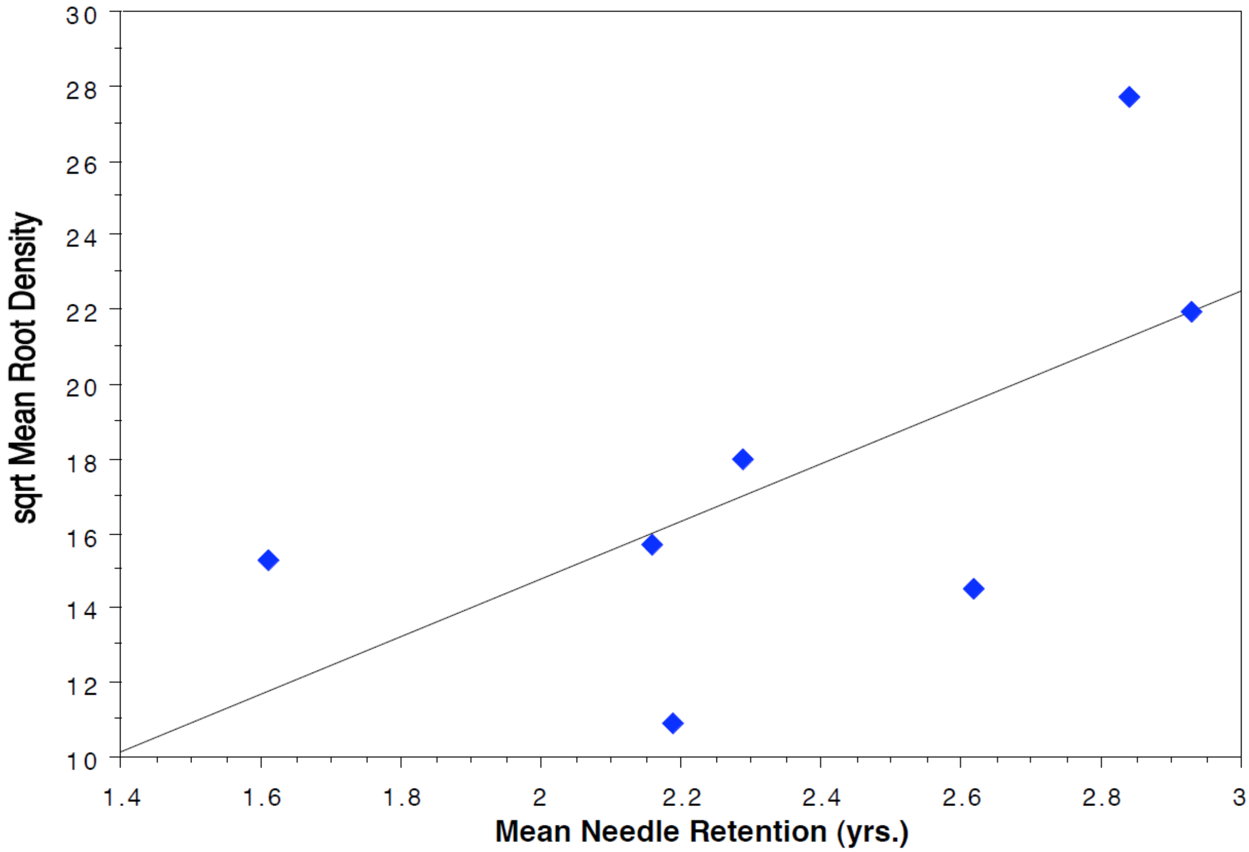

Figure 4. Regression plot of mean ectomycorrhiza root density (square-root transformed) against mean years needle retention, Y = -0.633 + 7.719 * X; R^2 = .41 (*p* = 0.12, *n* = 10).

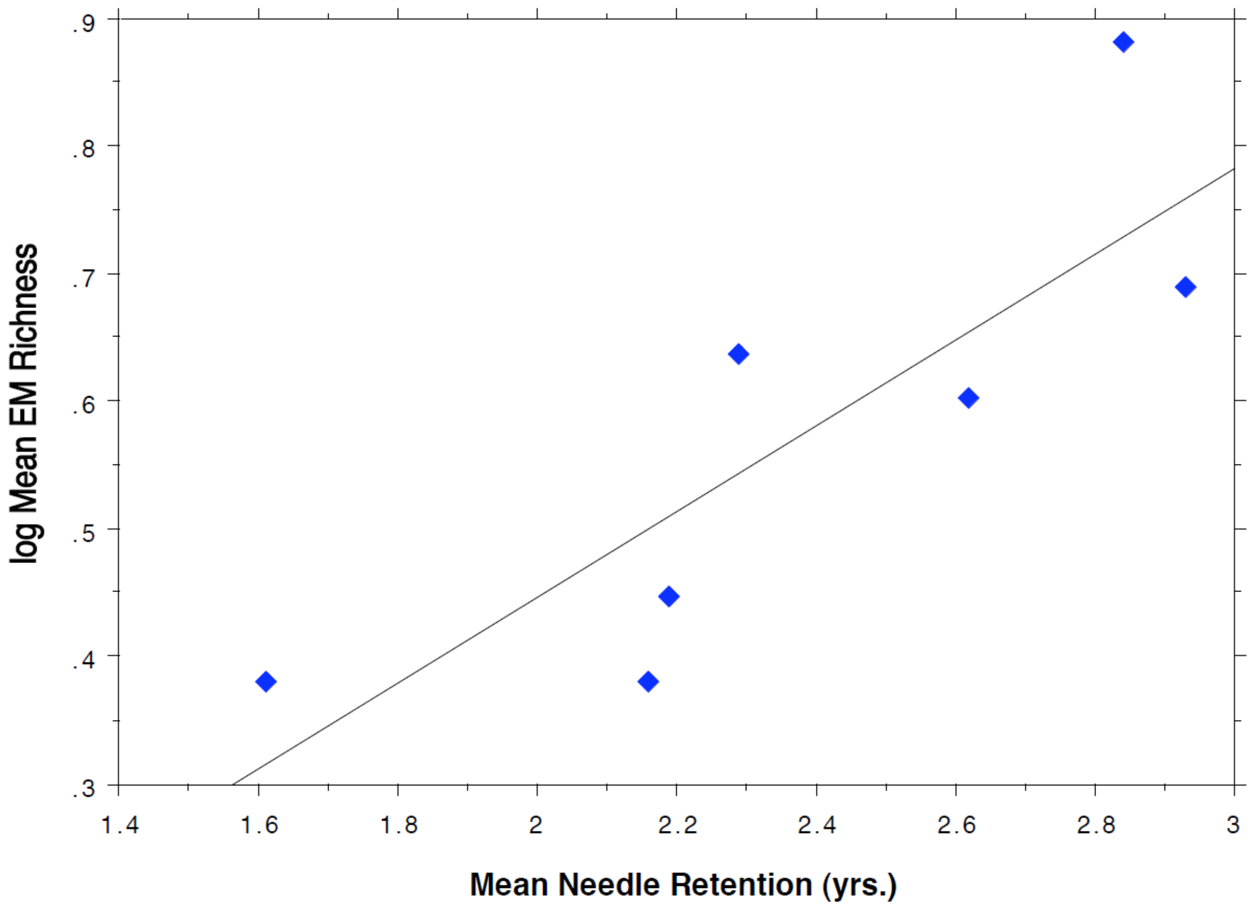

Figure 5. Regression plot of mean EM species richness (log transformed) against mean years needle retention, Y = -.224 + .336 * X; R^2 = .70 (*p* = 0.02, *n* = 10)

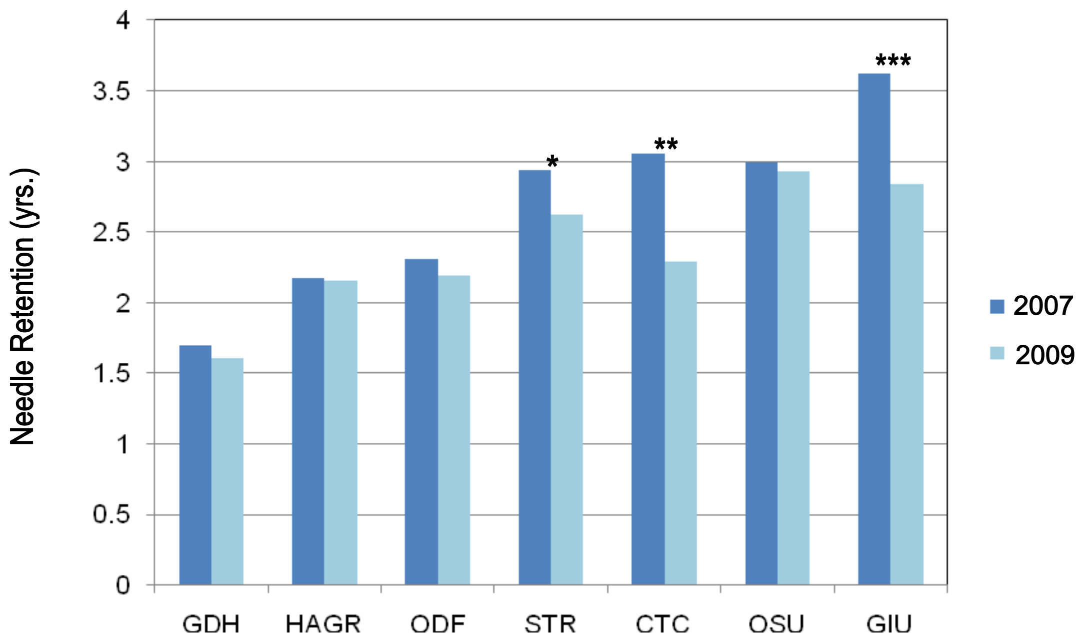

Figure 6. Mean years needle retention of sampled trees by block for 2007 and 2009. Site codes are provided in Table 1. Significant changes are stared; * p = 0.08, ** p = 0.004, *** p = 0.0007.

A significant change in EM richness coincided with a significant reduction in needle retention only at the Cascade Timber site (Figs. 2 and 6). That site bears watching for future corresponding growth reductions. Though the change in EM richness within the Cascade Timber site did not differ by treatment, the reduction in needle retention was significantly greater (for the trees we sampled) with the Kinsey treatment than the control (1.25 yrs. vs. 0.35 yrs., p = 0.004).

The Giustina site also showed a significant reduction in needle retention (Fig. 6), but that was accompanied by an increase in root density (Fig. 1) and no change in EM richness (Fig. 2). The reduction in needle retention on the Giustina site was due in most part to loss of 4th-year needles (D. Mainwaring, pers. com.). We hypothesize that the loss of those older needles was related to unusually heavy low-elevation snows. Though other sites would also have experienced those snows, the trees on other sites did not have as many (or any) 4th-year needles to loose. If our speculation is correct, needle retention at the Giustina site should rebound since our data indicate that the root systems are in healthy condition.

The Starker site showed a smaller, marginally significant decrease in needle retention, but no change in root density or EM richness. The OSU site had increased root density (Fig. 1) but no change in EM richness or needle retention. Pertaining to the parameters we measured for both the Starker and OSU sites, we speculate that little biological change took place.

The regression relationship between EM richness and root density improved from 2007 to 2009 (R^2 = .65 to R^2 = .75, Fig. 3). However, the relationship between root density and needle retention decreased in strength (R^2 = .70 to R^2 = .41) and became non-significant (Fig. 4). High values for root density that were patchy in occurrence were a source of variance. Ten percent of the soil cores contained ramifications of mycorrhizae that produced 500-1000 root-tips of a single EM species.

Ectomycorrhiza type (species) richness was significantly related to needle retention across the blocks (R^2 = .70, Fig. 5) but the strength of the relationship was far less than we found in 2007 (R^2 = .90) or 2008 (R^2 = .93). The main impact to the 2009 relationship between EM richness and needle retention came from the Giustina site where needle retention decreased significantly but EM richness did not change. As noted above, we expect the needle loss will turn out to be a temporary situation that was the result of extreme weather events.

Fertilizer effects on ectomycorrhizal fungi are varied and complex. Arnebrant and Soderstrom (1992) found that a one-time fertilization with 600 kg nitrogen ha^{-1}, 13 years prior to study, produced no difference in the total number of ectomycorrhizal root tips. However, yearly application of 30-80 kg nitrogen ha^{-1} over a period of 15 years, was associated with 20% fewer mycorrhizal roots. Other aspects of fertilization effects on EM were examined by Nilsson and Wallander (2003). They found that the addition of P ameliorated negative effects of N addition alone on mycelia growth of EM fungi. The lack of effects from the Kinsey treatment was consistent with those findings, since the fertilizer was balanced according to a particular soil nutrient optimization formula that included moderate amounts of N and P (as monoammonium phosphate (MAP) at 250 lbs/ac.) except at the Starker site where MAP was not part of the formulation (Table 5 in Mainwaring et al. 2007).

The carbon sink strength of EM fungi varies and is affected by nutrient additions. In a study of four EM fungi, Bidartondo and Wallander (2001) found that response to calcium phosphate addition (as apatite) was reflected in biomass accumulation, while the response to N addition (as ammonium) was associated with increased respiratory activity. They also note that fungi with relatively low carbon sink strength may be poor competitors when carbon is limited. We have shown that the presence of *Cenococcum* (Fig. 7) is reduced on highly impacted SNC sites, which in light of Bidartondo and Wallander's (2001) results, indicates it may be poorly adapted to compete for a greatly reduced carbon supply.

The variable responses of EM fungi to carbon availability and soil nutrient status provides context for understanding the strong relationship between EM richness and needle retention, and illuminates why root density, *per se*, exhibits a less consistent relationship to needle retention. Our finding of mass proliferations of single-species clusters of mycorrhizae provides a good example of how those different responses can be manifested in the soil. Mycorrhizae are a strong carbon sink for recent photosynthate (Norton et al., 1990). Reduced carbon to the roots should result in a shrinking pool of potential EM symbionts that can successfully maintain the symbiosis.

Though the response variables that we measured were not significantly affected by the treatments that we studied, we did further document EM responses to a gradient in SNC disease. Characteristics of the ectomycorrhiza community can be used to monitor forest health and are useful in predictive models. Given the strong potential for the EMF community to respond to reduced carbon supply and soil nutritional amendments in species-specific ways, we hypothesize that knowledge of EMF community structure would reveal patterns associated with particular fertilizer treatments.

Figure 7. A typical ectomycorrhiza of *Cenococcum geophilum* on Douglas-fir.

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2009 Annual Meeting Agenda
DECEMBER 16, 2009
RICHARDSON RM 105
830AM – 430PM

Morning: Science Review

830-845AM. INTRODUCTIONS, 2009 and the SNCC

845-900AM. Alan Kanaskie and Mike McWilliams, ODF. 2009 Swiss Needle Cast Aerial Survey.

900-915AM. Stephanie Hart. Brief Analysis of Climate and Aerial Survey Data

915-930AM. Travis Woolley. Needle Retention Plots 2009.

930-945AM. Greg Latta, Darius Adams, OSU. Needle Retention Prediction Model and coming economic/market analyses.

945-1000AM. Dave Shaw, Travis Woolley, Manuela Huso. Vertical foliage retention in Douglas-fir trees and stands across a gradient of Swiss Needle Cast disease in coastal Oregon.

1000-1015AM. BREAK

1015-1030AM. Dave Shaw/Travis Woolley. GIS and pre-commercial thinning disease severity.

1030-1100AM. Doug Mainwaring/Doug Maguire. Beyond N Studies. AND Results of Sulphur plot remeasurements.

1100-1115AM. Dan Luoma and Joyce Eberhart, OSU. Second-year Response of Ectomycorrhizae to Soil Nutritional Amendments Across a Gradient of SNC Disease.

1115-1135AM. Bryan Black, D. Shaw, J. Stone. Impacts of Swiss needle cast on overstory Douglas-fir forests of the western Oregon Coast Range.

1135-Noon. Steve Perakis. Soil Nutrient Research in the Coast Range

NOON. LUNCH ARRIVES

100 –130PM. Will Littke, John Browning. Weyco Studies on SNC

130-200PM. . Dave Shaw. Integrated Pest Management for SNC

200-430PM. **Afternoon: Business Meeting**

http://www.cof.orst.edu/coops/sncc/