November 2002

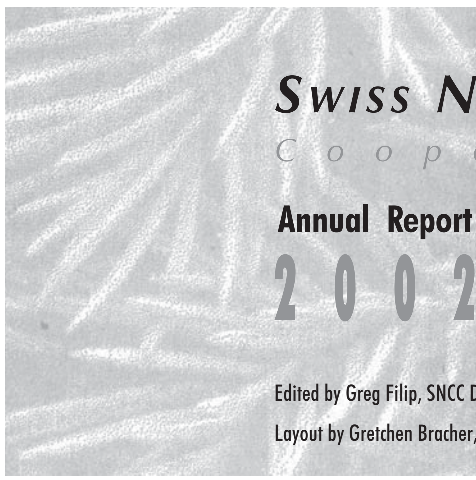
Swiss Needle Cast Cooperative

Annual Report 2002

Gregory Filip, Director

SNCC

OREGON STATE UNIVERSITY
COLLEGE OF FORESTRY



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Edited by Greg Filip, SNCC Director

Layout by Gretchen Bracher, Forestry Communications Group

SNCC Income Sources and Expenditures 2002

Income	
Membership Dues	$270,700
Oregon State Legislature	$120,000

Expenditures (as of 9/02)	
Salaries and Wages	$218,878
OPE	43,042
Supplies and Services	85,354
Travel	4,243
Indirect Costs	35,152
Total Expenditures	$386,669

Contents

To: SNCC Members
From: Greg Filip
Date: September 2002
Subject: 2002 Annual Report

SNCC is now six years old, and I thank the members for all of the support that they have given SNCC this year. For four years we were fortunate to receive $480,000 from the Oregon State Legislature to support projects for 2000 to 2003. This year's annual report contains summaries on the progress made on our 9 projects. We had an aerial survey this year in Oregon that shows a continuing increase in Swiss needle cast. Information continues to be collected on the permanent growth impact and precommercial thinning plots. Progress continues on the basic infection biology research that is summarized in this report. Projects are continuing in tree physiology, soil and foliage nutrition, Bravo and sulfur application, wood quality, and tree genetics, and progress reports are contained in this report. Several publications concerning SNC were written this year based on results obtained through SNCC.

I would like to especially thank this year's project investigators for their fine efforts in generating new information concerning Swiss needle cast: Alan Kanaskie, Doug Maguire, Katy Kavanagh, Jeff Stone, Dan Manter, Randy Johnson, Scott Ketchum, Floyd Freeman, Robin Rose, Cathy Rose, Barb Gartner, Diane Haase, and Gary Chastagner. And thanks to the many graduate students and research assistants who do so much of the work; Lori Winton, Julia Kerrigan, Paul Reeser, Wendy Sutton, Gabe Crane, and Fatih Temel. I would also like to thank the members of the SNCC executive committee who's enthusiasm and creativity keep this cooperative moving in the right direction: Mark Gourley, Charlie Moyer, John Trobaugh, Greg Johnson, Jim Carr, Mari Kramer, Will Littke, and Alan Kanaskie. We have at least 10 projects planned for 2003; it should be another exciting and productive year.

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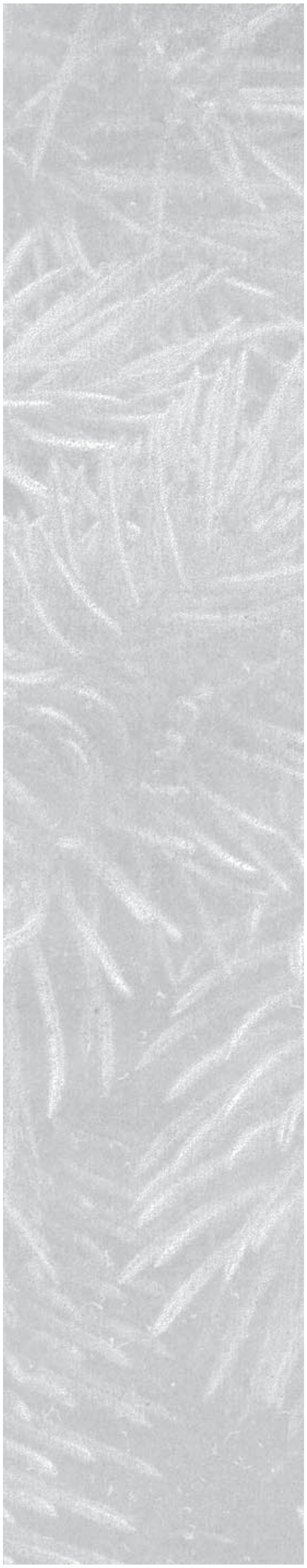
Highlights of 2002

This report presents the Swiss Needle Cast Cooperative activities in Swiss needle cast research. Highlights for 2002 include:

- An aerial survey was conducted over 3 million acres in western Oregon. A total of 387,000 acres of Douglas-fir had obvious symptoms on Swiss needle cast. In general, symptoms of Swiss needle cast increased in 2002 compared to 2001. Survey maps can be obtained from Alan Kanaskie, Oregon Department of Forestry in Salem.
- Research continues on 9 different projects in 2002 including: aerial and ground survey, growth impact studies, tree physiology, infection biology, tree genetics, precommercial thinning, nutrient imbalances, sulfur/tree growth, sulfur efficacy, Bravo/tree growth, and fertilizer and vegetation control.
- Fatih Temel completed his PhD dissertation: "Early testing of Douglas-fir (*Pseudotsuga menziesii* var. *menziesii* (Mirb.) Franco for Swiss needle cast tolerance" and Gabe Crane completed his MS thesis: "Effects of fertilization, vegetation control, and sulfur on Swiss needle cast and growth of Coastal Douglas-fir seedlings."
- Doug Maguire, Alan Kanaskie, Randy Johnson, and Greg Johnson published their research in the journal *Western Journal of Applied Forestry* with the title "Growth of young Douglas-fir plantations across a gradient in Swiss needle cast severity" and also in the journal *Forest Science* entitled "The ratio of live crown length to sapwood area as a measure of crown sparseness."
- Dan Manter, Jeff Stone, and Rick Kelsey published their research in the journal *Forest Pathology* as "Quantification of *Phaeocryptopus gaeumannii* colonization in Douglas-fir needles by ergosterol analysis."
- Lori Winton, Jeff Stone, Lidia Watrud, and Everett Hansen published their research in *Phytopathology* entitled "Simultaneous one-tube quantification of host and pathogen DNA with Taqman real-time PCR."

Plans for 2003

- Continue aerial survey to monitor SNC in Oregon
- Continue to monitor plots in the Cascade foothills
- Monitor permanent plots from the growth impact study Phase III
- Continue with tree physiology studies and develop a user-friendly process model
- Conduct infection biology studies: Factors affecting colonization rate and foliage retention; *P. gaeumannii* infection, development, and reproduction; aerobiology and epidemiology; and population biology of *P. gaeumannii*.
- Examine SNC race populations among seed sources and nurseries



- ▼ Characterize the role of nitrogen in SNC; modifying foliar N to improve needle retention
- ▼ Determine impacts of SNC on wood quality of Douglas-fir
- ▼ Determine growth response to precommercial thinning in Douglas-fir stands with varying intensity of SNC in the Coast Range of Oregon
- ▼ Continue to monitor the effects of fertilization and vegetation control on SNC infection and growth of coastal Douglas-fir

Background and Organization

The Swiss Needle Cast Cooperative (SNCC) was established in January 1997. Damage caused by Swiss needle cast, a native foliage disease that affects Douglas-fir, has made it imperative that new research be conducted to learn practical methods of disease detection and management to maintain the health and productivity of Douglas-fir plantations. A well-run cooperative is an efficient means of increasing and accelerating the level of forest disease research in the region. Because members participate directly in problem identification and research solutions, communications of results is speeded and results are applied more rapidly and effectively.

SNCC is located in the College of Forestry at Oregon State University. The Membership is comprised of private, county, 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.

Purpose

The focus of SNCC will be Swiss needle cast research for forestland owners in western Oregon and Washington. The purpose of SNCC is to provide the following services:

1. Conduct research on the biology, detection, and management of Swiss needle cast in coastal Douglas-fir as related to basic infection biology and genetics, tree physiological dysfunctions, aerial and ground survey technology, disease hazard and risk rating, growth and yield impacts, and strategies for control.
2. Conduct training and workshops on research and survey results
3. Provide newsletters and reports on research and surveys, and
4. Serve as a focal point for information on Swiss needle cast.

Swiss Needle Cast Aerial Survey, 2002

Alan Kanaskie, Mike McWilliams, Dave Overhulser, ODF

Survey Procedures

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 (the patches are referred to as polygons) were drawn onto computer touch screens displaying topographic maps 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 more dense crowns than those classified as "severe". The computer touch screen technology allows observers to spend less time navigating and more time mapping, and generally increases precision and accuracy compared to surveys prior to 2000, which used 1:100,000 scale paper sketch maps.

The Coast range was surveyed on May 1, 15, 16, 24, 31, 2002. The area surveyed extended from the coastline eastward until obvious symptoms were no longer visible, and from the Columbia River south to Brookings.

We did not survey the Cascades in 2002, but Swiss needle cast does occur at damaging levels in some areas.

Results and Discussion

Figure 1 shows the approximate size and location of areas of Coast range Douglas-fir forest with symptoms of Swiss needle cast detected during the survey conducted in 2002. Figures 2 - 7 show survey results for 1996-2001.

The 2002 Coast Range survey covered about 3 million acres of forest. Approximately 387,000 acres of Douglas-fir forest had obvious symptoms of Swiss needle cast; 252,000 north of the Lincoln-Lane county line, and 135,000 acres south of the Lincoln-Lane county line. This is an increase of about 166,000 acres compared to the 2001 survey (table 1, figure 8), and represented the largest number of acres with Swiss needle cast symptoms ever mapped.

Increases in acres mapped occurred throughout the survey area. Most noteworthy is the continual increase in acres in the southern part

Figure 1. Areas of Douglas-fir forest in western Oregon with symptoms of Swiss needle cast detected during an aerial survey in May, 2002.

of the survey area. The north coast trend line appears to have flattened, which could partially reflect on the inherent variability of symptom development from year to year, and the conversion of severely damaged stands to species other than Douglas-fir. Trends for individual counties appear in figure 9.

The easternmost area with obvious SNC symptoms was approximately 25 miles inland from the coast, which is slightly less than observed in 2001. Most of the areas with symptoms that could be detected from the air occurred within 18 miles of the coast.

Figure 2. Areas of Douglas-fir forest in western Oregon with symptoms of Swiss needle cast detected during an aerial survey in April and May, 2001.

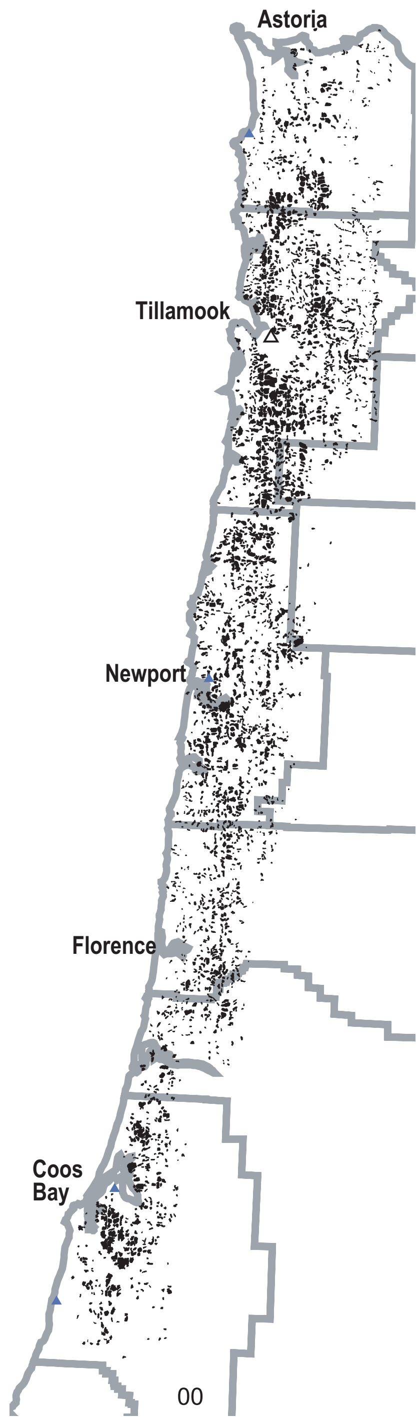


Figure 3. Areas of Douglas-fir forest in western Oregon with symptoms of Swiss needle cast detected during an aerial survey in April and May 2000.

Figure 4. Areas of Douglas-fir forest in western Oregon with symptoms of Swiss needle cast detected during an aerial survey in April and May, 1999.

Because symptoms develop rapidly during April and May, later surveys (late May) usually detect more areas with symptoms than surveys conducted earlier (late April or early May). Most of the 2002 survey was completed during the last two weeks in May, while the 2001 survey was completed during the first two weeks in May. This difference in timing of the survey, coupled with weather-driven tree phenological development, could account for much of the variation between the two years.

Of possible significance is the fact that most acres mapped in 2002 were classified by observers as "mod-

*Figure 5. Areas of Douglas-fir forest in western Oregon with symptoms of Swiss needle cast detected during an aerial survey in April and May, **1998** (does **not** include re-fly of Nehalem and Yamhill quadrangles).*

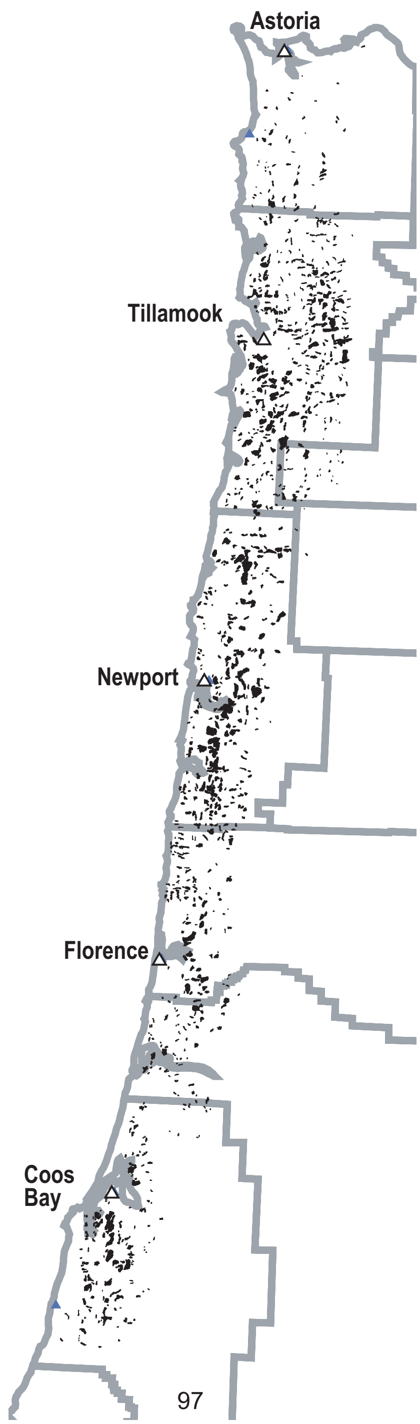


Figure 6. Areas of Douglas-fir forest in western Oregon with symptoms of Swiss needle cast detected during an aerial survey in April, 1997.

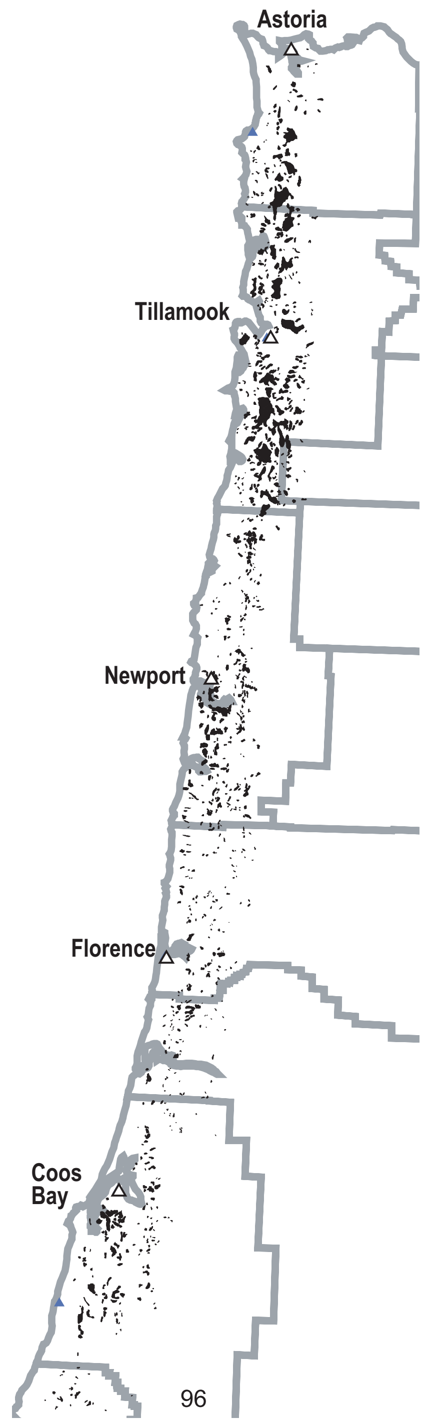


Figure 7 Areas of Douglas-fir forest in western Oregon with symptoms of Swiss needle cast detected during an aerial survey in April, 1996.

Table 1. Area of Douglas-fir forest in western Oregon with symptoms of Swiss needle cast detected during aerial surveys in 1996-2002.

Region	1996	1997	1998	1999	2000	2001	2002
	acres						
North	106,000	130,000	135,000	259,000	226,000	160,000	252,000
South	24,000	30,000	38,000	36,000	57,000	61,000	135,000
TOTAL	30,000	160,000	173,000	295,000	283,000	221,000	387,000

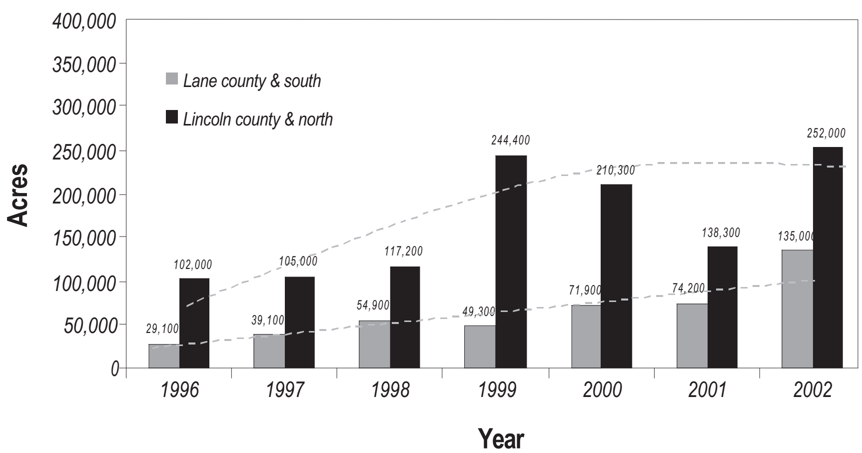


Figure 8. Trend in area of Douglas-fir forest in western Oregon with symptoms of Swiss needle cast detected during aerial surveys in April and May, 1996-2001.

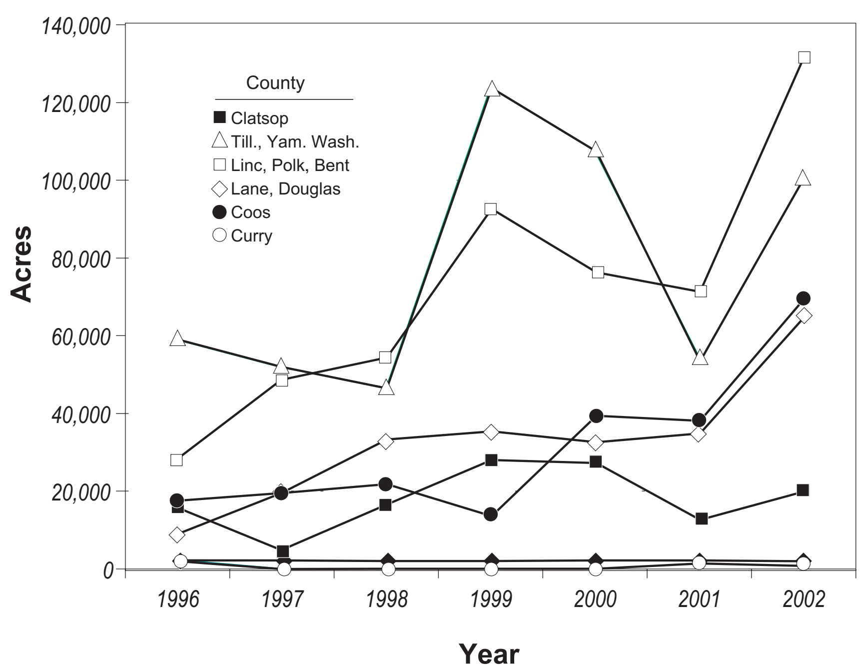


Figure 9. Area of Douglas-fir forest in western Oregon with symptoms of Swiss needle cast detected during aerial surveys in April and May, 1996-2001, by county.

erate", and very few acres were classified as "severe". Although this distinction in degrees of discoloration often is fickle, the difference between the 2002 survey and previous surveys is notable.

Aerial survey results are conservative estimates of damage because observers map only those areas where disease symptoms have developed enough to be visible from the air. Permanent monitoring plots and ground checks have shown that Swiss needle cast occurs throughout the survey area, but that symptoms often are not developed enough to enable aerial detection. Because the survey detects discoloration and does not describe needle retention (which is correlated with growth loss), estimates of disease impact on tree growth should not be made from the aerial survey alone. However, the aerial survey does provide a broad picture of the area significantly impacted by Swiss needle cast, which from a practical point of view establishes a zone in which forest management should take into account the effects of the disease.

Acknowledgments

The survey was conducted by the Oregon Department of Forestry Insect & Disease and Air Operations sections, and was funded by the USDA Forest Service Forest Health Monitoring Program and the Oregon Department of Forestry. Jack Prukop (ODF) piloted the plane. Mike McWilliams (ODF), and Dave Overhulser (ODF) were the aerial observers.

Swiss Needle Cast Monitoring in the Oregon Cascades

Floyd Freeman, Salem BLM; Field Crews from Salem BLM, Mt Hood NF, Willamette NF, Eugene BLM; SNCC staff.

Abstract

In addition to the well documented Swiss needle cast (SNC) infestations in the Oregon Coast Range, there is a light to moderate infection level of SNC in the Oregon Cascades and other parts of the Pacific Northwest. There have been past episodes of SNC events in the Cascades but little monitoring. This project has installed 57 transects in 2 sampling strata according to the same protocol Oregon Department of Forestry has used in the Oregon Coast Range. Transects were located on BLM, USFS and cooperating private industrial landowners from the Columbia Gorge south to Oakridge and from the Willamette Valley margin east to the upper elevation extent of the Pacific Silver fir zone. The 2001 observations indicated a 3.5 year average needle retention and 3.75 years for 2002 in the Oregon Cascades as compared to the 2001 observed 2.5 year average needle retention for the Oregon Coast Range. This is in contrast to a slight increase in severity of SNC rating. Analysis of pseudothecia counts, climatic, needle retention and DNA analysis is continuing.

Objective

To provide baseline information on Swiss needle cast (SNC) in selected stands in the Oregon Cascades and monitor SNC infection levels on an annual basis for up to 5 years.

Importance and History

In addition to the well documented SNC infestations in the Oregon Coast Range, the Cascade Range in Oregon is also experiencing SNC of various ranges of severity. Other areas in the Pacific Northwest may also have observable infestations; SNC may be present any place in the world that Douglas-fir has been out-planted. There have been past episodes of SNC in the OR and WA Cascades but there had not been any systematic study or analysis.

Project Objective

Install sampling transects in 60 stands (one transect per stand, some large stands had two) according to SNCC protocol developed by Alan

Kanaskie and Doug Maguire. This monitoring project is comparable to the array of transects established by ODF in the Oregon Coast area in both numbers of stands sampled and the area sampled. Stands to be sampled were 10 to 20 years old and more than 50 % Douglas-fir.

The area sampled ranges from the Columbia Gorge south to Oakridge and from the Willamette Valley eastern margin to the upper elevations that Douglas-fir is found on the west side of the Cascades. I did not include the high elevation Douglas-fir dominated stands in the mountain hemlock zone because I didn't think there would be any SNC symptoms. Oakridge was the farthest south extent of this project for both climatic and logistical reasons. There is a large rain shadow ridge in this area where the climate is much dryer to the south, the western hemlock zone becomes fragmented and appears primarily on the north side of ridges. SNC is a moisture-loving organism. The area sampled is the most likely place in the Oregon Cascades to find it. Extending the monitoring south of this area would also become progressively more difficult to coordinate.

The decision to limit the sampling to stands of 10 to 20 years of age is that below 10 years of age the disease may not be well expressed; stands older than 20 years have trees large enough that middle and upper crown needle retention is difficult to see from the ground. If I were designing this project today I would further limit this to 10 to 15 year stand ages.

There are two strata in the sample design; 20 stands systematically sampled within 5 townships that were known to have SNC infestation in Spring 2000, and 40 stands systematically sampled over the entire sampling area of about 123 townships or 2 million acres. Sampled stands were located within lands managed by SNCC members for access and cooperation. I didn't sample townships with less than 1 section per township managed by SNCC members because of the low probability of finding suitable candidate stands. SNCC members provided stand mapping of candidate stands and information on stand size, age and past cultural treatments.

The dual strata sampling design was done primarily for funding related reasons. Our BLM office was prepared to fund SNC monitoring in the 20 stand localized area because this is within our office's operating range and small enough scale that we could absorb the cost without adversely affecting our program of work. Beyond that we did not have the resources to establish and monitor SNC infection levels and required outside assistance in funding and monitoring crews.

This monitoring is being done with support of SNCC and ODF in conjunction with the aerial surveys done by ODF.

What has been accomplished for 2002:

Training of all Cascade crews was done by Alan Kanaskie and his staff on April 3, 2002. This was done in the Oregon Coast Range at the Siuslaw National Forest's Hebo Ranger Station between Beaver and Tillamook. Because most crews had some experienced members and lack of ODF personnel we did not do any on-site training with individual crews as we did in 2001.

In 2001 all crews were finished by mid May. In 2002 both Eugene and Salem BLM crews finished by mid May, however, Forest Service crews were hampered by snow and blowdown that blocked access. Forest Service crew production was only about 1 stand per day because they had many walk-ins. Limited resources for road maintenance are exacerbating access problems on Forest Service and to a lesser extent on BLM managed lands; this is increasing the amount of time to do these surveys because there is more walk-in time required.

In 2001 it was apparent that there were other factors besides SNC causing poor needle retention. These included ridges exposed to winds and ice storms and insects such as Cooley spruce gall adelgids. Silver striped tiger moth and tent caterpillar type structures were also seen. Although Douglas-fir is described as having 5 to 8 years of needle retention, westside of Cascade stands may have less than that because rapid abundant needle growth shades older needles faster than where growing conditions are more severe.

Will Littke offered to provide pseudothecia counting on about 200 trees; 5 trees in each of the 37 stands in the extensive strata. The first of each pair of trees at each point per transect was selected. This step would validate the presence of SNC in our samples and provide some measure of quantitative amounts of infection. These collections were from the north and south sides of the middle 1/3 of the crown for sampled trees. The middle 1/3 of the crown is the best part of the tree to collect foliage from because it is usually well exposed to light; the upper 1/3 may be too battered by winter storms to have good needle retention and may be difficult to reach on tall trees; lower 1/3 branches are usually easy to reach but often shaded. Only the last two years of needles were collected. Branchlets were sealed into zip lock bags and stored in beverage coolers while in the field, placed in refrigerators at the end of the day and mailed to Will's Centralia Pathology Lab weekly. Telescoping pole pruning saws and clippers were used on almost all trees. According to Will Littke, needles damaged by adelgids were not used.

Ten of the 37 stands in the extensive group of stands were selected by Lori Winton for DNA studies. One branch from the south side of the middle crown was collected from 20 trees of each stand. These were the same 10 trees being maintained for needle retention observations in the established transects plus another 10 trees selected in the same manner. Lori requested branches having the entire complement of needles to ensure enough fungus to analyze. Even with that measure she still had to grow the fungus from spores becausether was not a sufficient quantity extracted from needles.

Some stands had laminated root rot and Armillaria. In root disease areas we attempted to locate plots outside of infections. New trees were to be selected when the tree being studied died from disease, weather or was purposely cut. One of Eugene BLM stands had a PCT contractor cut some of the 10 trees in one stand. New trees can be selected because we are looking at representative stand conditions rather than following symptoms in individual trees.

Analysis is ongoing. All information is being input into Excel spreadsheets so sorts can be made.

The two strata are being kept separately because they are different samples.

Analysis is ongoing. Little work has been done on this set of data between the July 11 Project Proposal meeting and mid September because of work commitments not related to this project. What I hope to have accomplished prior to the November 8th SNCC Annual meeting is:

- Comparison between 2001 and 2002 data
- Pseudothecia counts from Will Littke's lab correlated with needle retention
- Elevation and climatic data for Cascade samples compared with needle retention and pseudothecia counts.
- Fertilizer related to with needle retention and pseudothecia counts.

Preliminary analysis of Extensive strata:

This strata of 37 stands had the following SNC rating:

Below is a brief description of the SNC rating criteria, rating 5 and 6 are not described because they have not been reported in the Cascades thus far.

SNC Rating	
1	Healthy normal-appearing Douglas-fir stand, 3.5 years of needle retention at mid crown
2	Almost normal but showing slight yellowing, 3.5 years of needle retention at mid crown
3	Yellowing obvious, most trees retain 2.5 to 3 years of needles
4	Yellowing obvious, most trees retain 1.5 to 2 years of needles, a few trees have 25% reductions in height growth the last 1 to 3 years
5	Very Yellow, most trees retain 1 to 1.5 years of needles, >50 % of trees have 25% reductions in height growth the last 1 to 3 years
6	Yellowish brown, with very sparse foliage, most trees retain 1 or years of needles, Obvious height reduction the last 4 plus years

The average SNC rating as compared to last year by unit are as follows:

	2001	2002	
Salem BLM	2.54	2.31	Salem had 3 SNC rating No. 1's this year, eleven No. 2's, eight No.3's. Last year there was a No. 4 that was rated a 3 this year and two 3's that became 2's.
Eugene BLM	1.33	1.8	Eugene had three SNC rating No. 1's this year, two No. 2's, one No. 3. One of last years No. 1's became a No. 2 and one of last years No. 2's became a No. 3.
Mt Hood NF	1.5	1.5	Mt Hoods stands did not change SNC ratings from 2001 to 2002.
Willamette NF			
N. End Crew	1.875	2.375	Willamette NF North End Crew (Detroit, Sweet Home, north part of Blue River) had one SNC rating No. 1, three No. 2's and four No. 3's. Two of last years No. 1's became No. 2's and two of last years No. 2's became No. 3's.
S. End Crew	1.25	1.5	Willamette NF South End Crew (south part of Blue River and Middle Fork) had two No. 1's and two No. 2's. One of last years 1's became a No. 2.

Overall average of all the extensive strata stands SNC ratings was:

1.89 in 2001 and 2.0 in 2002 which is a slight increase. Mid-year needle retention averages have improved slightly from 3.5 to 3.75 years of needle retention.

Relative infection levels appear to be decreasing in the lands surveyed by Salem BLM and increasing for all other land managers.

Note: Stands surveyed by Salem BLM included private industrial lands in both strata.

Preliminary analysis of Intensive Strata of 20 stands in 5 townships the results are as follows:

As a contrast Salem BLM is the only unit that has any stands in the Intensive strata.

	2001	2002	
Salem BLM	2.41	2.23	There are 22 transects in 20 stands, a couple of large stands have 2 transects each. There are three SNC rating No. 1's, eleven No. 2's and eight No. 3's. One of last years No. 2's became a No. 1 and three of last years No. 3's became No. 2's.

Plans for Next year

I plan on remeasuring the transects next spring. Funding is not certain but I expect that we will get it. I won't know for sure until January 2003.

Next year is the last year that Forest Health Monitoring funding money will be available since it is only for 3 years. Beyond 2003 this project will cease unless the SNCC or possibly some other funding source emerges.

Will Littke appears to support some measure of pseudothecia counting for 2003, perhaps only the more severely infected stands. DNA work by Lori Winton is probably not going to be continued.She has not done the analysis on the samples we collected last spring although she has assured me that the cultures of SNC are growing well and, hopefully there will be some results by annual meeting time.

I will prepare a budget for 2003 later this year when I have to resubmit this project proposal to the Forest Service's Forest Health Monitoring program. I will add more time for Forest Service crews because of the access problems experienced this past winter.

Trends in Damage from Swiss Needle Cast in Permanent Plots in 10- to 30-year-old Douglas-fir Plantations, November 2002

Alan Kanaskie, ODF; Doug Maguire, OSU; Jon Laine, ODF; John Beeson, ODF; Rick Christian, ODF; Mike McWilliams, ODF

Background:

The Permanent plot network was established in 1997 to provide a basis for monitoring Swiss needle cast (SNC) damage and for quantifying impacts of SNC on tree growth. This paper describes only the results of monitoring various indicators of SNC damage. Growth impacts are discussed in a separate paper.

Objectives:

1) To describe the trends in the severity of damage from Swiss needle cast in randomly chosen 10- to 30-year-old Douglas-fir plantations in the Coast Range of western Oregon;
2) to estimate the area (acres) affected by SNC, and;
3) to ground-truth areas mapped by aerial survey.

Methods

In 1997, 77 Douglas-fir plantations in the northern Coast Range of Oregon were randomly chosen for monitoring trends in damage from Swiss needle cast. The target population was all Douglas-fir plantations between 10 and 30 years total age (1996 age) and located within 18 miles of the coast, north of Newport and south of Astoria. With much cooperation from landowners, a list of plantations meeting these criteria was assembled. Plantations were selected from this list with probability proportional to size (area). The target population included 4,504 plantations covering 187,545 acres. The initial sample included 77 plantations covering 6,873 acres (figure 1). One plantation was lost from the study in 1999 due to cutting.

Swiss needle cast damage was assessed in April and May of each year since 1997. The 1997 assessments were based on a sample of ten trees per stand (two trees at each of five points along a transect). Beginning in 1998, assessments were made on ten trees per stand located in the 1/

5-acre permanent growth monitoring plots (Phase III) located at point 5 of the 1997 transects. The same ten trees in each plot were assessed each year unless mortality or breakage necessitates substitution.

Stand Ratings.

Stand ratings were designed to provide a quick method of estimating Swiss needle cast severity by making a general assessment of average stand condition during a brief walk-through of the stand. All ratings refer to the Douglas-fir component of the stand in the vicinity of the permanent plots. Overall stand discoloration was rated on a scale of 1 to 4 for as follows: **1** = normal green color, with Douglas-fir similar in color to healthy hemlock; **2** = slight yellowing; **3** = moderate yellowing, and; **4** = severe yellowing and/or browning.

The Swiss Needle Cast Severity Rating for the stand was described according to the following 6-class system (needle retention was assessed on unshaded secondary laterals in the upper middle crown, usually whorl 5 to 7 from the tree top):

1 = *Healthy, normal-appearing Douglas-fir stand*. Typical of the east-slope Coast Range stands that are dark green, growing normally, and with normal needle retention (3.5 years or more mid-crown). Douglas-fir and hemlock of the same size will not differ appreciably in color. Swiss needle cast may be present, but causing symptoms only on 3 year-old and older needles.

2 = *Almost normal, but showing slight yellowing*. Needle retention normal (3.5 or more years present on most trees) Douglas-fir will appear slightly more yellow than hemlock or spruce. Crown still appears full and dense. No reduction in height growth increment.

3 = *Yellowing obvious*. Most trees retaining 2.5 to 3 years of needles. No obvious height increment reduction.

4 = *Yellowing obvious*. Most trees retaining 1.5 to 2 years of needles. Reduction in height growth increment by 25% of normal for one or more of the last three years will <u>not</u> be obvious, but may occur on a few trees only.

5 = *Very yellow stand*. Most trees retaining 1 to 1.5 years of needles. Height growth increment is reduced by at least 25 percent of normal for one or more of the last 3 years on at least 50% of trees, but not as much as described in "6" below.

6 = *Stand is extremely yellow to yellow-brown, with very sparse foliage*. Most trees retaining 1 year of needles or less in upper crown. Obvious height growth reduction for 4 or more years. These are the most severely damaged stands, typical of the Juno Hill, Beaver, and Hebo areas.

Individual tree Assessments on plots.

Ten codominant or dominant trees in each 1/5-acre permanent plot were assessed for damage from Swiss needle cast. Sample trees were permanently tagged so the same trees could be assessed each year.

Needle Retention was estimated for the middle of each third of the live crown (upper, middle, lower) by examining secondary lateral branches and estimating the average number of annual needle compliments present (a *secondary lateral* is a branch that originates on the side of the main lateral branch). Sample branches were chosen to represent the average condition in the part of the crown being examined. The number of annual needle compliments present for each third of the live crown was estimated to the nearest 0.1 year as follows:

0.5 = 50 % of one-year-old needles (1998) remain, all older needles gone

1.0 = All one-year-old needles remain, older needles gone

1.2 = One-year-old needles plus 20 % of two-year-old needles remain

1.6 = One-year-old needles plus 60 % of two-year-old needles remain

2.0 = One- and two-year-old needles remain, older needles gone

2.5 = One- and two-year-old needles remain, plus 50% three year old needles remain

3.0 = All one-, two-, and three-year-old needles remain....

...and so on up to 6.0.

Whorl-5 needle retention was estimated by examining branches in the whorls fifth whorl (occasionally the sixth or seventh whorl) from the top of the tree. Needle retention, i.e., percentage of the full compliment of needles remaining on the branch at the time of the assessment, was estimated for each of the four most recent internodes of shoot growth on secondary laterals according to the following “0 to 9” scale:

0 = 0 to 10 percent of full compliment present;

1 = 11 to 20 percent of full compliment present;

2 = 21 to 30 percent of full compliment present;…..

9 = 90 to 100 percent of full compliment present.

Crown indicators.

From 1998 to 2000 inclusive, observers estimated the following four indicators, based in part on the US Forest Service Forest Health Monitoring protocols: 1) *Crown Color* - discoloration of the upper 1/2 to 1/3 of crown, near whorls 5 to 7 from the top, using the 1 to 4 scale previously described for stand color; 2) *Crown Density* - estimate the percentage of sunlight being blocked by all parts of the crown, in 5% classes; *3) Foliage Transparency* - estimate the percentage of sunlight being transmitted through the foliage, in 5% classes; 4) *Crown Dieback* - estimate the percentage of the total crown area that has dieback, in 5% classes. For the 2001 and 2002 assessment, all USFS crown condition variables except color were dropped because they had not proven very useful in previous analyses.

Results and Discussion:

The mean SNC stand rating (1 to 6 scale) increased gradually by nearly one rating class between 1997 and 2002 (figure 2). This trend suggests a general increase in SNC damage over the period based on subjective overview ratings. Although the SNC rating for 2002 was not significantly different from the 2001 rating, the ratings for these two years were significantly greater than in previous years.

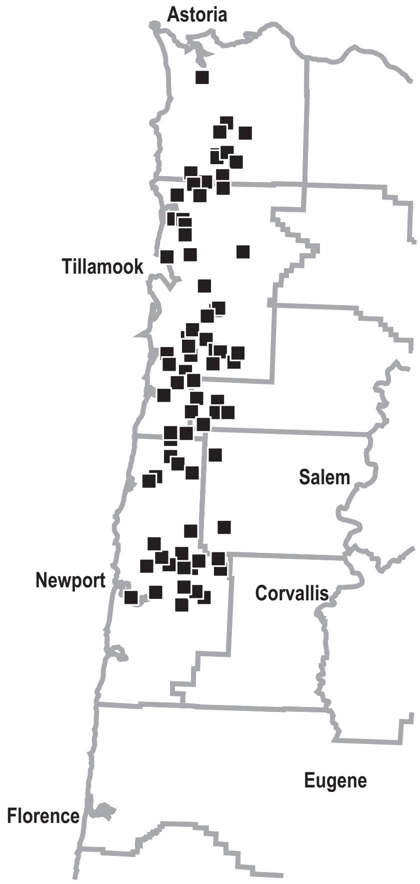


Figure 1. Location of 76 permanent plots for monitoring Swiss needle cast and tree growth in 10- to 30-year-old Douglas-fir plantations, Coast Range, Oregon.

In contrast, the mean stand discoloration rating did not differ consistently during the same period, suggesting a trend of slightly improving stand color between 1997 and 2001, then an increase in 2002 to 1997 levels in 2002 (figure 3). One explanation for the discrepancy between these two stand ratings is that the SNC rating incorporates both needle retention and color into the rating. A stand that is very yellow but with good needle retention could lead to different relative ratings on each scale. The SNC rating (1-6) is the preferred method for overview rating stands because it incorporates many indicators of Swiss needle cast damage. The stand color rating was originally conceived as a link to aerial survey and remote sensing applications. In practice, the stand discoloration rating has proven very difficult to determine with consistency because of the influence of sunlight, cloud cover, and observer subjectivity.

Mean needle retention (whole crown) for all plots increased slightly from 1997 to 1999, decreased from 1999 to 2001, then increased to the highest level (2.47 annual needle compliments) since measurements began. Although the differences were significant (Analysis of variance, .05 significance level), they were very small (figure 4).

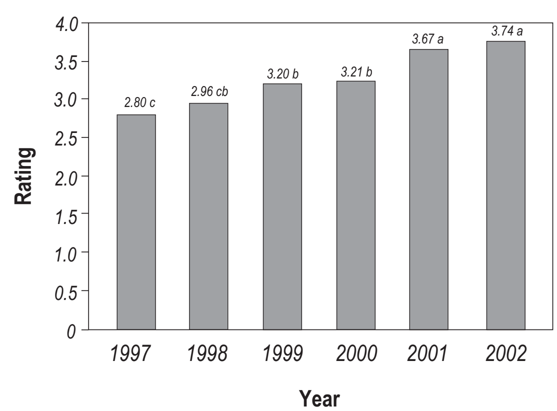


Figure 2. Mean SNC Stand Rating for 76 permanent plots in 10- to 30-year old (1996 age) Douglas-fir plantations. Swiss needle cast severity increases as SNC Stand Rating increases. Means with same letter within a data series are not significantly different (analysis of variance, Fisher’s LSD, a=.05).

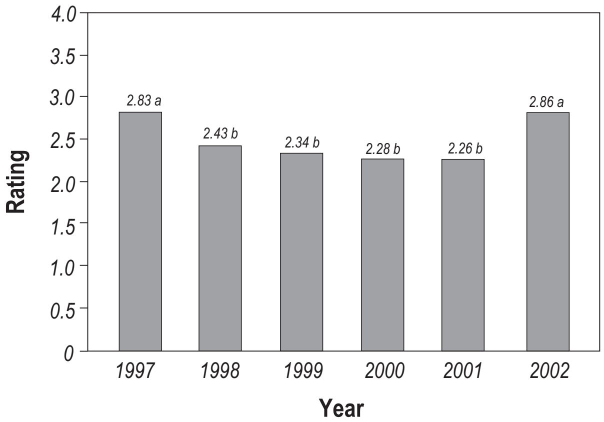


Figure 3. Mean SNC Stand Discoloration Rating for 76 permanent plots in 10- to 30-year old (1996 age) Douglas-fir plantations. Stands become more discolored (yellow) as Stand Discoloration Rating increases. Means with same letter within a data series are not significantly different (analysis of variance, Fisher's LSD, a=.05).

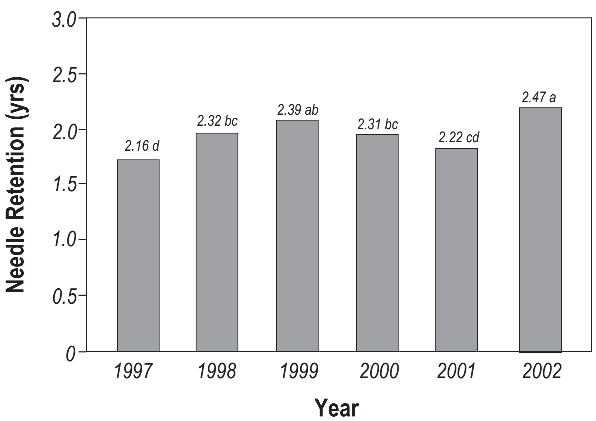


Figure 4. Mean needle retention for 76 permanent plots in 10- to 30-year old (1996 age) Douglas-fir plantations. Means with same letter are not significantly different (analysis of variance, Fisher's LSD, a=.05).

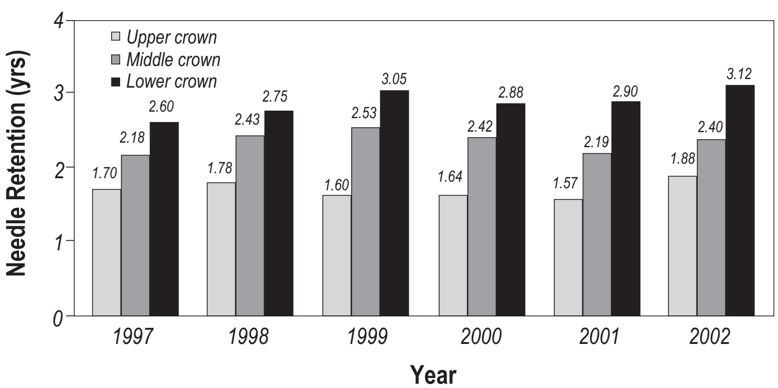


Figure 5. Mean needle retention for 76 permanent plots in 10- to 30-year-old (1996 age) Douglas-fir plantations, by crown thirds.

Analysis by crown thirds revealed that mean needle retention was lowest in the upper third of the tree crown and greatest in the lower third of the tree crown. Mean needle retention in the upper third of the crown showed a noticeable but slight decrease from 1998 to 1999, probably reflecting the interaction of Swiss needle cast with the high frequency of severe windstorms and a period of very cold weather that occurred during the winter of 1998-1999 (Figure 5). Slight improvements in needle retention in 2001 and 2002 could be due to recent relatively mild winters, and increasing tree size and subsequent crown sheltering, both of which could reduce foliage loss.

Mean needle retention for each permanent plot appears in figure 6. Mean needle retention (whole crown) differed significantly (analysis of variance, paired t-tests, a=.05) between 1998 and 2002 on 17 (22 percent) of the plots. During this period, mean needle retention increased on 8 of the plots, and decreased on 9 of the plots (figure 7). We chose 1998 as the reference year rather than 1997 because the 1997 data were from transect trees, while all subsequent data was from permanent plot trees, with the same trees being measured each year. The largest improvement in needle retention for an individual stand during this period was 0.73 annual needle compliments; the largest decrease in retention was 0.68 annual needle compliments. We did not observe any geographic pattern to the changes in needle retention.

Mean needle retention ratings were expanded to estimate the number of acres in each needle retention class for the 187,545-acre population. Since 1997, there has been a general increase in the estimated number of acres with needle retention of at least 2.25 annual compliments, and a general decrease in estimated acres with less than 2.25 annual compliments (figure 8).

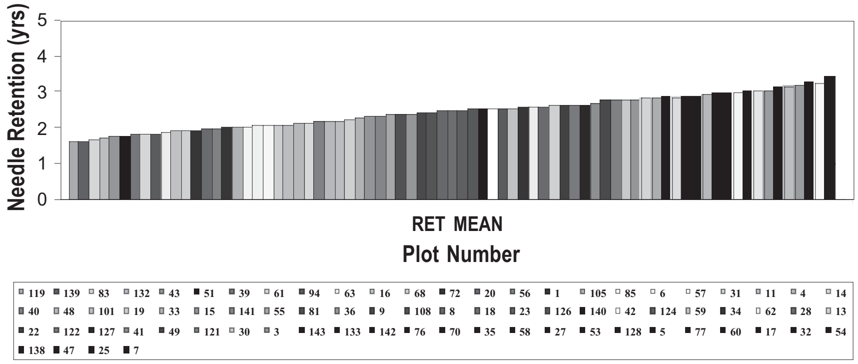


Figure 6. Mean needle retention (whole crown) in May 2002 for each of the 76 permanent plots in 10- to 30-year-old (1996 age) Douglas-fir plantations.

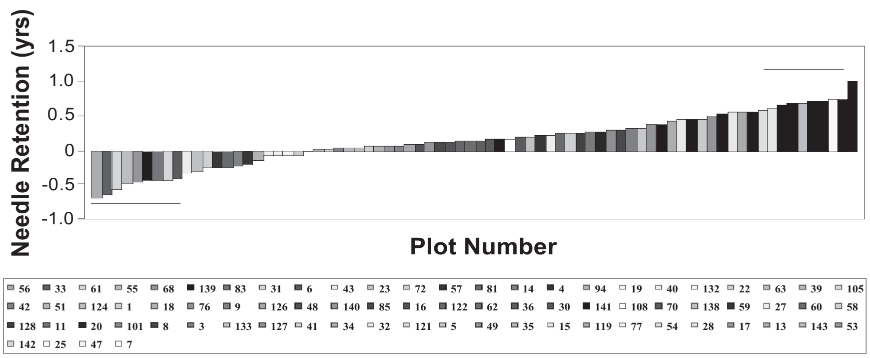


Figure 7. Increase or decrease in mean needle retention between 1998 and 2002 in 76 permanent monitoring plots in 10- to 30-year-old (1996 age) Douglas-fir plantations. Mean needle retention increased significantly on 8 of the plots, and decreased significantly on 9 of the (analysis of variance, Fisher's LSD a=. 05). Horizontal line above or below vertical bars indicates stands with significant differences.

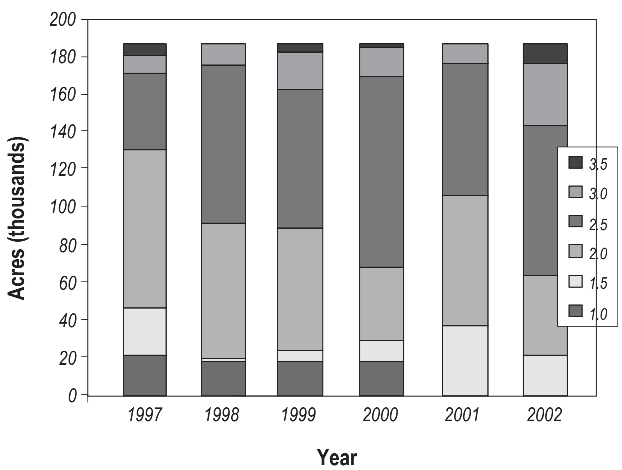


Figure 8. Distribution of Douglas-fir plantation acreage by needle retention class for the 187,545-acre population from which sample plantations were chosen.

Conclusions

Based primarily on needle retention ratings, these results show little evidence of a significant change in damage from Swiss needle cast since 1997. The slight but significant increase in mean needle retention from 2001 to 2002, and the lack of a consistent trend of worsening damage from SNC are encouraging, and are consistent with casual observations in the north coast area. However, the overall poor needle retention in the sample population suggests a continuing severe growth reduction from Swiss needle cast.

Precommercial Thinning of Douglas-fir Stands with Varying Intensity of Swiss Needle Cast in the Coast range of Oregon:

Status Report on Trends in Disease Severity, November 2002

Alan Kanaskie, ODF; Doug Maguire, OSU; Mike McWilliams, ODF; Rick Christian, ODF.

Background

Many young Douglas-fir plantations in coastal Oregon exhibit extreme symptoms of Swiss needle cast, and these symptoms are associated with reduction in tree growth. Observations suggest that thinning stands with severe Swiss needle cast may increase foliage loss and discoloration, and exacerbate thinning shock. Other observations indicate that early thinning to maintain deep crowns may mitigate some of the growth loss attributed to Swiss needle cast. The response of stands to thinning is expected to vary according to the initial severity of Swiss needle cast at time of thinning.

Objectives

The objectives of the study are: 1) to monitor concurrently on permanent plots the course of Swiss needle cast symptoms and the effect of the disease on the growth of individual trees; 2) to measure shifts in SNC infection severity and associated tree growth responses over time, and; 3) to measure differences in disease severity and tree growth in thinned and unthinned plots. This reports focuses on trends in the various indices of disease severity between 1998 and 2002. Tree growth responses to pre-commercial thinning and Swiss needle cast appear in a separate report.

Methods

In April and May of 1998, twenty-three paired 0.2 acre square plots were installed in 10- to 16-year-old Douglas-fir plantations (1997 age) in northwest Oregon. Plot locations were selected across a range of Swiss needle cast severity classes and distributed across different topographic aspects (figure 1). One plot in each pair was precommercially thinned to approximately 200 trees per acre in May 1998 (because of initial stocking levels, at two sites the target residual was 100 trees per acre). At five of the 23 locations, an additional plot was thinned to approximately 100 trees per acre. During thinning, tree spacing was given priority over tree quality. All crop trees were measured for dbh, total height, and height to crown. Swiss needle cast severity (needle retention and discoloration) was assessed annually during April and May each year since plot establishment.

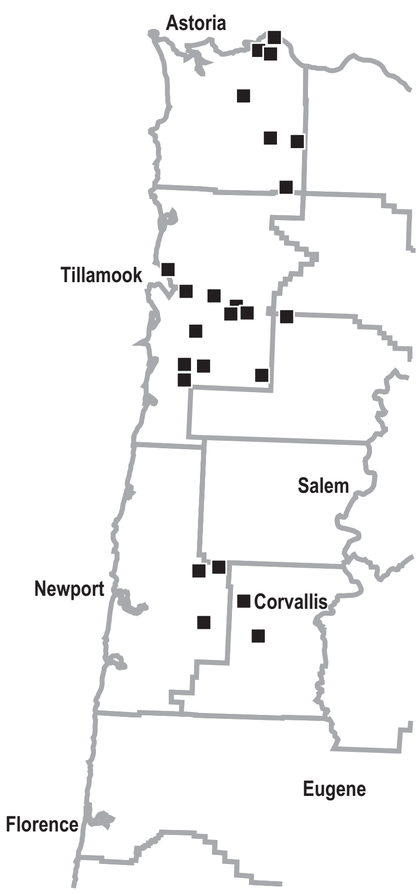


Figure 1. Location of 23 permanent plot sets to monitor disease symptoms and evaluate growth response to precommercial thinning in Douglas-fir plantations with varying intensity of Swiss needle cast in the Coast range of Oregon.

Stand Ratings

Stand ratings were designed to provide a quick method of estimating Swiss needle cast severity by making a general assessment of average stand condition during a brief walk-through of the stand. All ratings refer to the Douglas-fir component of the stand in the vicinity of the permanent plots. Overall stand discoloration was rated on a scale of 1 to 4 for as follows: **1** = normal green color, with Douglas-fir similar in color to healthy hemlock; **2** = slight yellowing; **3** = moderate yellowing, and; **4** = severe yellowing and/or browning.

The Swiss Needle Cast Severity Rating for the stand was described according to the following 6-class system (needle retention was assessed on unshaded secondary laterals in the upper middle crown, usually whorl 5 to 7 from the tree top):

1 = *Healthy, normal-appearing Douglas-fir stand.* Typical of the east-slope Coast Range stands that are dark green, growing normally, and with normal needle retention (3.5 years or more mid-crown). Douglas-fir and hemlock of the same size will not differ appreciably in color. Swiss needle cast may be present, but causing symptoms only on 3 year-old and older needles.

2 = *Almost normal, but showing slight yellowing.* Needle retention normal (3.5 or more years present on most trees) Douglas-fir will appear slightly more yellow than hemlock or spruce. Crown still appears full and dense. No reduction in height growth increment.

3 = *Yellowing obvious.* Most trees retaining 2.5 to 3 years of needles. No obvious height increment reduction.

4 = *Yellowing obvious.* Most trees retaining 1.5 to 2 years of needles. Reduction in height growth increment by 25% of normal for one or more of the last three years will not be obvious, but may occur on a few trees only.

5 = *Very yellow stand.* Most trees retaining 1 to 1.5 years of needles. Height growth increment is reduced by at least 25 percent of normal for one or more of the last 3 years on at least 50% of trees, but not as much as described in "6" below.

6 = *Stand is extremely yellow to yellow-brown, with very sparse foliage.* Most trees retaining 1 year of needles or less in upper crown. Obvious height growth reduction for 4 or more years. These are the most severely damaged stands, typical of the Juno Hill, Beaver, and Hebo areas.

Individual tree Assessments on plots

Ten codominant or dominant trees in each 1/5-acre permanent plot were assessed for damage from Swiss needle cast. Sample trees were permanently tagged so the same trees could be assessed each year.

Needle Retention was estimated for the middle of each third of the live crown (upper, middle, lower) by examining secondary lateral branches and estimating the average number of annual needle compliments present (a *secondary lateral* is a branch that originates on the side of the main lateral branch). Sample branches were chosen to represent the average condition in the part of the crown being examined. The number of annual needle compliments present for each third of the live crown was estimated to the nearest 0.1 year as follows:

0.5 = 50 % of one-year-old needles (1998) remain, all older needles gone

1.0 = All one-year-old needles remain, older needles gone

1.2 = One-year-old needles plus 20 % of two-year-old needles remain

1.6 = One-year-old needles plus 60 % of two-year-old needles remain

2.0 = One- and two-year-old needles remain, older needles gone

2.5 = One- and two-year-old needles remain, plus 50% three year old needles remain

3.0 = All one-, two-, and three-year-old needles remain....

...and so on up to 6.0.

Whorl-5 needle retention was estimated by examining branches in the whorls fifth whorl (occasionally the sixth or seventh whorl) from the top of the tree. Needle retention, i.e., percentage of the full compliment of needles remaining on the branch at the time of the assessment, was estimated for each of the four most recent internodes of shoot growth on secondary laterals according to the following "0 to 9" scale:

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1 = 11 to 20 percent of full compliment present;

2 = 21 to 30 percent of full compliment present;.....

9 = 90 to 100 percent of full compliment present.

Crown indicators

From 1998 to 2000 inclusive, observers estimated the following four indicators, based in part on the US Forest Service Forest Health Monitoring protocols: 1) *Crown Color* - discoloration of the upper 1/2 to 1/3 of crown, near whorls 5 to 7 from the top, using the 1 to 4 scale previously described for stand color; 2) *Crown Density* - estimate the percentage of sunlight being blocked by all parts of the crown, in 5% classes; *3) Foliage Transparency* - estimate the percentage of sunlight being transmitted through the foliage, in 5% classes; 4) *Crown Dieback* - estimate the percentage of the total crown area that has dieback, in 5% classes. For the 2001 and 2002 assessment, all USFS crown condition variables except color were dropped because they had not proven very useful in previous analyses.

Results and Discussion:

Analysis of data for all 23 sites revealed few trends. Four growing seasons after thinning, mean needle retention did not differ significantly between thinned and unthinned plots (analysis of variance, Fisher's LSD, a=05). Mean needle retention also did not differ significantly among the four annual measurements for any of the treatments (analysis of variance, .05 significance level) (figure 2). There was no significant difference in Stand Swiss Needle Cast Severity or Discoloration Ratings among years or between thinning treatments (figure 3).

Analysis of data from each installation separately revealed that mean needle retention in 2002 differed significantly between thinned and unthinned plots at only 4 of the 23 sites (T100 and T200 treatments were combined for this analysis). At three of these sites (APT4, APT5,APT6 - all in Clatsop county), trees in the thinned plots had greater needle retention than trees in the unthinned plots. At the other site (Powerline - Tillamook County), mean needle retention of trees in the unthinned plot was greater than needle retention trees in the thinned plot (analysis of variance, .05 significance level). The magnitude of difference in needle retention between thinned and unthinned plots on these four sites ranged from 0.5 to 0.8 annual needle compliments (figure 4). Five of the sites received two levels of thinning; 100(T100) and 200 (T200) residual trees per acre. A comparison of mean mid-crown needle retention among treatments at these sites four growing seasons after thinning showed significant differences among thinning treatments at three of the five sites (figure 5). At two sites, APT5 and APT6, mean needle retention was greater in the thinned plots than the unthinned plots, but did not differ between the T100 and T200 treatments. At the other site (Devitt),

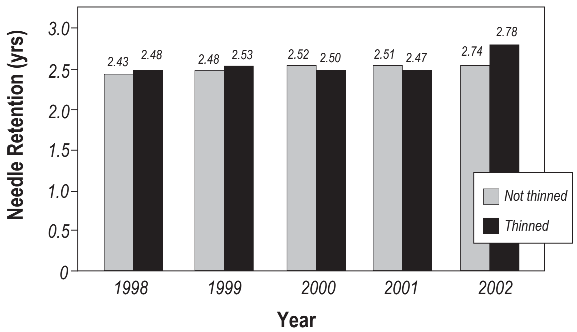

Figure 2. Mean needle retention (whole-crown) in paired thinned and unthinned plots in Douglas-fir plantations affected by Swiss needle cast in the Coast Range of northwest Oregon, 1998 to 2002. Plots were thinned in May 1998. Needle retention was evaluated in May of each year. Mean needle retention did not differ significantly (analysis of variance, a=.05) between thinned and unthinned plots, or among years.

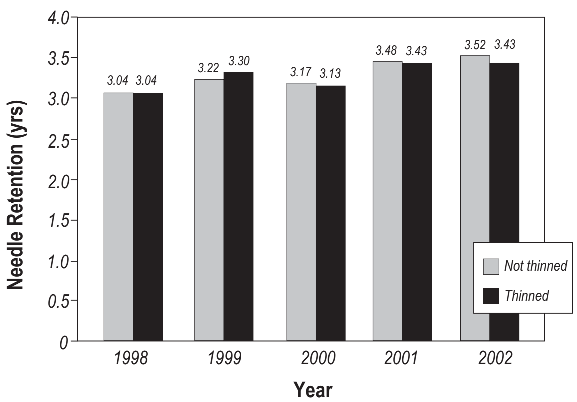

Figure 3. Swiss Needle Cast Stand Severity Rating for paired thinned and unthinned plots in Douglas-fir plantations affected by Swiss needle cast in the Coast Range of northwest Oregon, 1998 to 2002. Plots were thinned in May 1998. The SNC severity rating did not differ significantly (analysis of variance, a=.05) between thinned and unthinned plots, or among years.

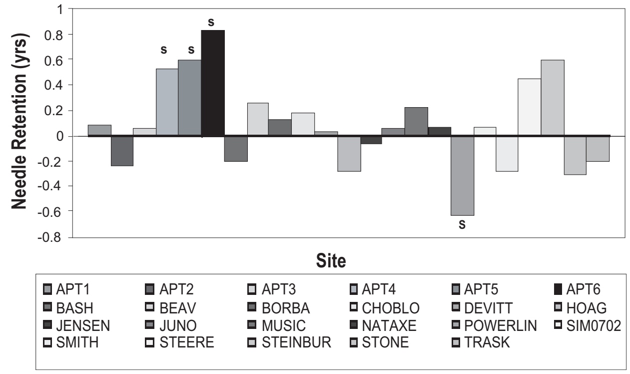

Figure 4. Mean difference in mid-crown needle retention in 2002 for 23 paired thinned and unthinned plots of Douglas-fir affected by Swiss needle cast in the Coast Range of northwest Oregon. Plots were thinned in May 1998. Needle retention was evaluated in May of each year. A vertical bar that extends below the zero line indicates that needle retention in the thinned plot was less than in the unthinned plot; if above the line, needle retention in the thinned plot was greater than in the unthinned plot. Significant differences are indicated by "s" (t-test, a=.05). T100 and T200 treatments were combined for this analysis.

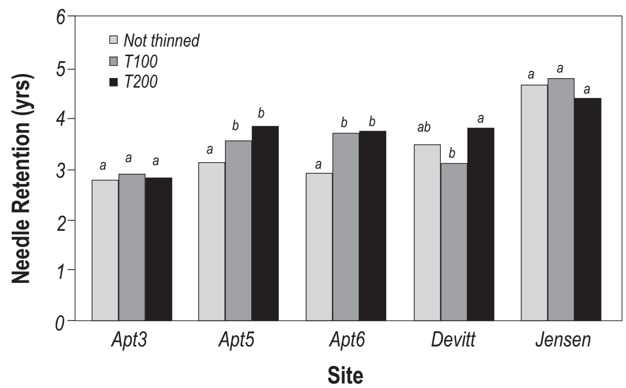

Figure 5. Mean needle retention (mid-crown) in 2002 for sites with three treatments (not thinned; T100 = 100 trees per acre after thinning; T200 = 200 trees per acre after thinning). Means within a site with the same letter are not significantly different (Analysis of variance, Fisher's LSD, a= .05).

mean needle retention in the T100 plot was significantly less than in the T200 plot, but needle retention in neither thinning treatment differed significantly from needle retention in the unthinned plot.

Casual observations have lead to speculation that Douglas-fir plantations with severe Swiss needle cast and poor needle retention will experience more needle loss following precommercial thinning than unthinned plantations. Analysis of the six stands with the lowest needle retention at the time of thinning and the six stands with the greatest needle retention at the time of thinning showed little difference in the effects of thinning on needle retention four growing seasons after thinning. Needle retention was significantly lower in the thinned plot compared to the unthinned plot at only one of the six sites with the poorest initial needle retention (Figure 6), and at none of the six sites with the highest initial needle retention (Figure 7).

Needle retention is not the only measure of the effects of thinning on tree damaged by Swiss needle cast. A small amount of tree fall, top breakage, and branch dieback occurred at low levels in a few of the thinned plots, but not in the

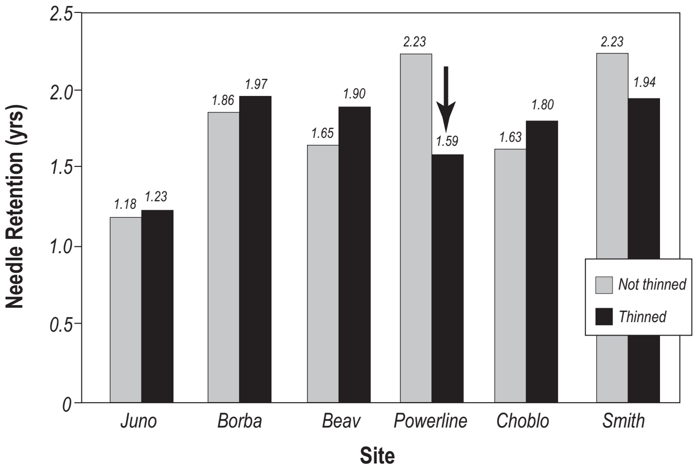

Figure 6. Mean needle retention (mid-crown) in 2002 for paired thinned and unthinned plots with the lowest initial (1998) needle retention. An arrow indicates sites with a significant difference in mean needle retention between thinned and unthinned plots (t-test, a=0.05).

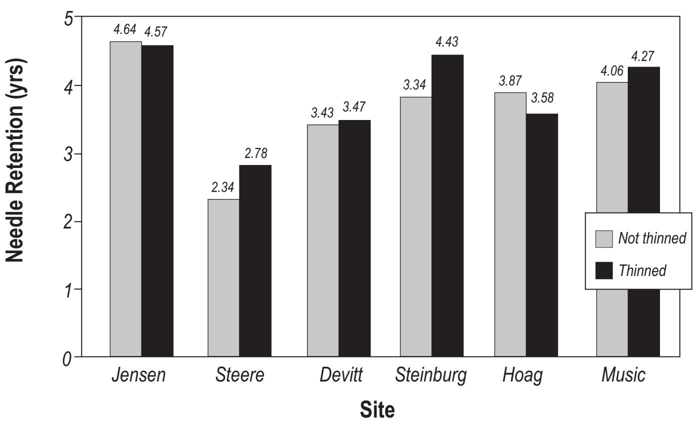

Figure 7. Mean needle retention (mid-crown) in 2002 for paired thinned and unthinned plots of Douglas-fir with the greatest initial (1998) needle retention. No sites had a significant difference in mean needle retention between thinned and unthinned plots (t-test, a=0.05).

unthinned plots, and especially in plantations with the most severe Swiss needle cast.

The expected high loss of foliage following precommercial thinning of stands damaged by Swiss needle cast has not occurred four growing seasons after thinning, nor has there been much improvement in needle retention. Even sites with severe disease (such as Juno Hill and Beaver) showed little difference in mean needle retention between thinned and unthinned plots. Needle retention ratings, although correlated with tree volume growth, likely do not capture the entire the impact of the Swiss needle cast on tree growth. Retention ratings do not account for shoot length, needle size and quality, crown length, or the absolute amount of foliage present, all of which vary considerably in stands affected by Swiss needle cast. A differential tree growth response to thinning across a range of Swiss needle cast damage still is quite possible, despite the inconclusive needle retention results.

The stands in this study were approximate 12 to 16 years old at the time of thinning. Trees of this age typically have deep crowns and are growing vigorously. Older overstocked stands with relatively low crown ratios could respond quite differently to thinning than the stands in this study.

Conclusions

These results suggest that precommercial thinning does not have an obvious detrimental effect on Douglas-fir plantations affected by Swiss needle cast in the Coast range of Oregon, nor do they show an obvious benefit, at least in terms of visible indicators of disease severity. With due attention to reduced volume growth of Douglas-fir caused by Swiss needle cast (discussed in a separate paper), precommercial thinning remains a viable stand management tool in the Coast range in all but the most severely damaged stands.

Acknowledgements

Field work was completed and coordinated by Steve Skinner (ODF Astoria), Matt Howard (ODF Astoria), Steve Dutton (ODF Tillamook), Jim Hines (ODF Tillamook), Dale Anders (ODF Forest Grove), Mike Totey (ODF Philomath), Tom O'Connor (ODF Philomath), Scott Malvitch (ODF Salem), Bryan Capitano (ODF Salem), Chet Smith (ODF Salem), Michael West (ODF Salem), Mark Gourley (Starker Forests), John Washburn (Simpson Timber), Rick Allen (Miller Timer Services), Ted Reiss (Miller Timber Services), Mark Montpas (Miller Timber Services).

Influence of Pre-Commercial Thinning on Swiss Needle Cast Severity and Tree Growth in North Coastal Oregon

Alan Kanaskie, ODF; Doug Maguire, OSU; Doug Mainwaring, OSU

Abstract

A study of paired plots, one thinned and one control, was established in 1998. Plots have now been through their second 2-yr growth period. During this second period, significant block and thinning effects were observed, with thinned plots having lower growth. After accounting for initial basal area of Douglas-fir in an analysis of covariance, the thinning effect became positive. When thinning intensity of Douglas-fir was separated from thinning intensity of other species, the former was correlated with lower growth, probably due to the effect of implied higher pre-thinning stand density on crown size and vigor. As thinning intensity of other species increased, plot growth increased for a given residual basal area in Douglas-fir. Growth responses for the 2000-01 growth period and preliminary analyses of needle retention in year 2000 (2 yrs after thinning) do not seem to indicate that stands decline after thinning; however, analysis of the change in needle retention over the 4-yr period is still ongoing.

Introduction

Concern remains about the effect of thinning on Swiss needle cast (SNC) intensification and the corresponding effect of SNC intensification on growth responses. One initially proposed strategy to thwart SNC was to reduce stand density and thereby maintain growth and vigor of residual trees and stands. Some evidence suggests that thinning will not eliminate or ameliorate the disease, and in fact SNC symptoms may intensify after thinning. In some areas, commercially thinned stands with few SNC symptoms have been clearcut several years after thinning due to their apparently rapid decline and intensification of SNC. Similarly, the lack of thinning response in stands with moderate SNC raises the question as to whether stand management objectives normally attainable by thinning can be met under moderate or severe SNC. If thinning does adversely impact tree condition and growth due to intensification of SNC, then alternative strategies must be explored. The objectives of the ongoing pre-commercial thinning study are: 1) to test whether thinning in pre-commercial stands leads to intensification of SNC symptoms, particularly foliage retention; and 2) to test whether thinning in pre-commercial stands with a given initial intensity of SNC leads to growth rates below those that would be expected under the reduced stand density and initial SNC severity. This report addresses the second objective, and analyses to address the first are ongoing.

Methods

In the late winter/early spring of 1998, 22 sets of plots were established across a range in initial Swiss needle cast (SNC) severity. Most of these sets contained a pair of plots, one thinned and the other a control, but some included a third plot that allowed testing of two different residual densities. The thinning prescription specifically called for leaving 494 tph (200 tpa), but on two installations the target residual was 247 tph (100 tph) because stand densities were already low. In addition, a third plot was established on 5 installations to yield two thinned plots, one with a residual of 494 tph and one with a residual of 247 tph. All control plots and 494-tph plots were square and covered 0.08-ha (1/5-ac; 31.8 x 31.8 m), except for the two installations on which the thinned plot was reduced to 247-tph. These latter two control plots and all 7 plots thinned to 247 tph encompassed an area of 0.16-ha (2/5-ac). On each measurement plot, all trees were tagged and measured for diameter at breast height. At least 40 Douglas-fir trees on each plot were also measured for total height and height to crown base. The treated plots were thinned before the growing season started in 1998. After two and four growing seasons (after the 1998-99 and 2000-01 growth periods), all trees were remeasured for dbh, and all trees from the original height subsample were remeasured for total height and height to crown base. Where necessary, replacement trees for the height subsample were substituted with another tree of the same diameter. Ten dominant or codominant trees on each plot were also scored for SNC at time of plot establishment in 1998 and during annual visits in the spring (1999-2002).

Factors influencing growth responses in 2000-01 are being investigated in three ways: 1) as a randomized block experiment with plot pairs treated as blocks and plots classified as thinned or controls (same as a paired t-test); 2) as a multiple regression problem with a large number of potential predictors such as initial stand density, thinning intensity, and initial SNC severity; and 3) a randomized block experiment with a large number of potential covariates (analyzed with a multiple regression model).

Results and Discussion

A large portion of plot-to-plot variation in Douglas-fir volume growth (81%) was accounted for by block effects, which would include a wide array of factors such as site index, soil type, initial stand density, Swiss needle cast severity, and many others. As a result, much of the block effect could alternatively be explained directly by specific covariates. Initial Douglas-fir basal area (in the year 2000) was also a very strong predictor, alone accounting for 57% of the variability in volume growth. When analyzed as a randomized block experiment, both block and treatment effects were significant ($p<0.001$). As would be expected, thinned plots had lower periodic annual increment (Douglas-fir) than unthinned stands, due to their reduced growing stock not in Fig 1 & 2. The thinning treatment effect was still significant ($p=0.027$) after correcting for initial Douglas-fir basal area in an analysis of covariance, but with this covariate in the model, thinning had a positive effect on Douglas-fir increment. The following model includes the influence of needle retention, in addition to block, treatment, and initial stocking effects:

$$\ln[PAI] = BLOCK + 0.9604 \bullet \ln(BA_{DF}) + 0.1920 \bullet I_{THIN} + 1.03076 \bullet \ln(FOLRET_{00}) \qquad [2]$$

where PAI = plot-level periodic annual cubic volume growth of Douglas-fir for 2000-2001(m^3/ha)

$BLOCK$ = set of indicator variables and associated parameter estimates representing the block effect

BA_{DF} = initial Douglas-fir basal area (m^2/ha in 2000)

I_{THIN} = 1 if plot was thinned; 0 otherwise

$FOLRET_{00}$ = initial (2000) average foliage retention for plot (yrs)

All variables are statistically significant (all $p<0.005$), and 98% of the variation in the logarithm of Douglas-fir volume growth is explained by the model. Foliage retention in 2000 ranged from 1.1 to 4.3 yrs, suggesting that plots with the most severe SNC were growing only 25% of the volume that plots with the greatest needle retention were growing (Fig. 1). The second highest foliage retention was 3.7, so if this was assumed closer to the average maximum, the most severely impacted plots are growing approximately 29% of the best plots. The range in foliage retention does not seem related to thinning because, after block effects are accounted for, foliage retention 2 yrs after thinning (2000) is not significantly related to the treatment. At a given level of the other covariates, thinned plots were growing about 21% more than the unthinned plots.

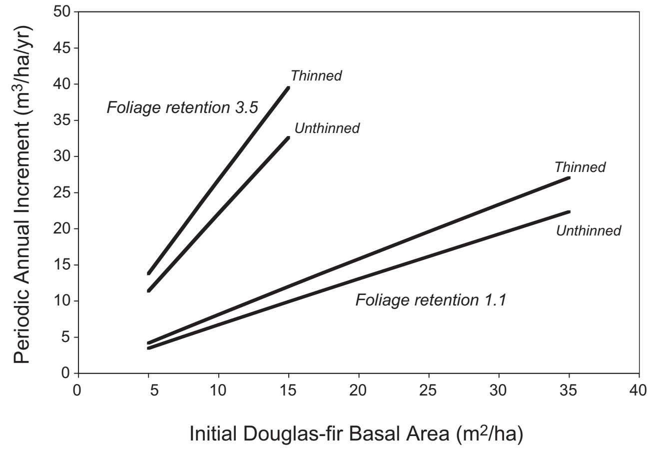

Figure 1. Periodic annual increment predicted from model [1]. Plots with the greatest initial Douglas-fir basal area experienced the lowest foliage retention (i.e., no plots had high needle retention and high initial basal area.

One final model provided some insight into possible mechanisms controlling plot growth:

$$\ln[PAI] = BLOCK + 0.8814 \bullet \ln(BA_{DF}) + 1.311 \bullet PTHIN_{TOTAL} - 1.112 \bullet PTHIN_{DF} + 1.0666 \bullet \ln(FOLRET_{00}) \quad [2]$$

where PAI, BLOCK, and $FOLRET_{00}$ are as above and

$PTHIN_{TOTAL}$ = proportion of total basal area removed in 1998

$PTHIN_{DF}$ = proportion of Douglas-fir basal area removed in 1998

All variables are statistically significant (all $p<0.002$ except $PTHIN_{DF}$ with $p=0.017$), and almost 99% of the variation in logarithm of plot growth is accounted for. As a measure of thinning intensity, the coefficient on $PTHIN_{DF}$ indicates that the most heavily thinned plot ($PTHIN_{DF}$ = 0.73) grew 43% of the unthinned plot. However, after accounting for the fact that other species are also removed with the Douglas-fir (strong positive correlation between $PTHIN_{TOTAL}$ and $PTHIN_{DF}$), the most heavily thinned plots are growing at approximately 75% the rate of unthinned plots (Fig. 2). This effect of thinning intensity is largely if not solely due to the reduced crown size and vigor of more heavily thinned stands at a given residual basal area. Conversely, when total thinning intensity ($PTHIN_{TOTAL}$) increases, or a higher proportion of other species is removed, growth is predicted to reach up to triple the growth of the unthinned plot (at $PTHIN_{TOTAL}$ = 0.84), probably due to the generally lower relative height and reduced effect of these competing species on crown ratio. When the correlation between $PTHIN_{TOTAL}$ and $PTHIN_{DF}$ is again accounted for, the growth is predicted to be enhanced only 50% by thinning. Model [2] also suggests that plots with the most severe SNC were growing 23% of the volume growth of plots with the greatest needle retention. The second highest foliage retention was 3.7, so if this was assumed closer to the average maximum, the most severely impacted plots are growing at approximately 27% the rate of the best plots.

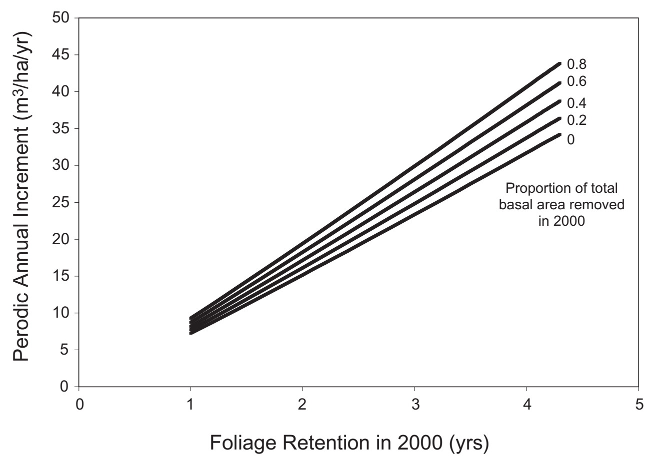

Figure 2. Periodic annual increment predicted from model [2], assuming that BA_{DF}=15 m²/ha and that the proportion of Douglas-fir basal area removed in 2000 ($PTHIN_{DF}$) was 90% of the total basal area removed ($PTHIN_{TOTAL}$).

Growth Impact Study: Growth Trends During the Second 2-yr Period Following Establishment of Permanent Plots

Doug Maguire, OSU; Alan Kanaskie, ODF; Doug Mainwaring, OSU; Randy Johnson, USDA-FS PNW Research Station; Greg Johnson, Weyerhaeuser

Abstract

Permanent plots in the Growth Impact Study have been remeasured for a second 2-yr growth period. Needle retention was measured on an annual basis from 1997 through 2002, and extreme values appear to have moderated: sites with the lowest needle retention in 1997 have a slightly increased foliage retention, and sites with the highest needle retention in 1997 have a slightly reduced retention. Foliage retention has had a significant effect on volume growth. Volume growth of SNC-impacted sites was compared to volume growth on sites with the highest foliage retention, suggesting relative growth losses of approximately 52% and average loss of 21% for 2000-01. Although SNC symptom severity has fluctuated over time, the relative growth rate between sites with the highest and lowest foliage retention is still consistent with estimates from the retrospective work (1996 growing season), as well as estimates based on the first 2-yr growth period (1998-99 growth period).

Introduction

The Growth Impact Study (GIS) was initiated in 1997 to address two major objectives: 1) to monitor Swiss needle cast (SNC) symptoms and tree growth in 10-30-yr-old Douglas-fir plantations in north coastal Oregon; and 2) to provide an improved estimate of growth losses associated with a given initial level of SNC. Retrospective work conducted in the spring of 1997 established growth losses across a range in SNC severity (Maguire et al. 1998, 2002). Volume growth losses were estimated to average 23% for the target population in 1996, with losses reaching almost 50% in the most severely impacted stands. Total losses in 1996 alone were therefore about 40 MMBF, given that the target population covers approximately 187,000 ac. Permanent plots established in the spring of 1998 and remeasured in 2000 confirmed these growth losses. Although SNC symptoms have fluctuated over the past six years, it appears that the relationship between needle retention and relative growth losses has remained stable. The most recent remeasurement was completed in the spring of 2002; therefore, objectives of this report were: 1) to quantify the most recent 2-yr growth responses relative to initial (2000) SNC severity; and 2) to compare these 2-yr growth responses to those estimated for 1998-99 and those estimated retrospectively for 1996.

Methods

In the late winter/early spring of 1998, a network of 76 permanent plots was established at locations previously sampled in Phases I and II (retrospective phase) of the Growth Impact Study. The plots were square and 0.08-ha (1/5-ac) in area (31.8 x 31.8 m). Each plot was centered on the 5th point of the ODF transect established in Spring 1997 (Phase I plots were centered on the 3rd point). On each measurement plot, all trees were tagged at breast height and a subsample of at least 40 Douglas-fir was measured for total height, height to crown base, and dbh at time of plot establishment. After two and four growing seasons, all trees were remeasured for dbh, and all trees from the original height subsample were remeasured for total height and height to lowest live branch. Trees on each plot were also scored for SNC at time of plot establishment in 1998 and just prior to bud break each year from 1999 through 2002. On 10 dominant or codominant trees per plot, the crown was divided vertically into thirds, and the average number of years that foliage was retained in each third was estimated visually to the nearest 0.1 year. Plot ratings were computed as the average of all crown thirds from all ten trees. These same trees were cored to determine sapwood width and sapwood area at breast height. Sapwood area at crown base was estimated from sapwood area at breast height using a previously-developed sapwood taper equation for Douglas-fir (Maguire and Batista 1996).

Statistical Analysis

In growth analyses of the first and second 2-yr periods, all variation in initial needle retention (1998 and 2000) was assumed totally controlled by SNC intensity. Individual tree values were averaged for the 10 sample trees on each plot to arrive at a plot average ($FOLRET_{98}$ and $FOLRET_{00}$). In 1998 only, a second SNC index of crown sparseness was computed as the ratio of live crown length to sapwood area at crown base, abbreviated as CL:SA (Maguire and Kanaskie 2002). This index was not remeasured in 2000 to avoid further damage from coring the trees. A simple growth model was then fitted to the data from all 76 GIS plots, with initial foliage retention and CL:SA as two possible predictor variables:

$$\ln[PAI] = b_0 + b_1 \bullet X_1 + b_2 \bullet X_2 + \ldots + b_k \bullet X_j + b_{k+1} \bullet FOLRET + b_{k+2} \bullet CL{:}SA \quad [1]$$

where PAI=plot-level periodic annual increment for cubic volume of Douglas-fir, X_i=plot-level predictor variables, FOLRET is $FOLRET_{98}$ or $FOLRET_{00}$, and CL:SA is the crown sparseness variable.

Results and Discussion

Swiss needle cast severity

Extremes in foliage retention have generally moved toward more moderate values since 1997; that is, stands with severe SNC in 1997 have had an improvement in foliage retention and stands with few SNC symptoms have experienced a slight decline in foliage retention (Figs. 1 and 2). Some exploratory statistical models have been run, but relatively little of the variation in foliage retention can be explained by site descriptors that include previous stand composition, current stand composition, aspect, and distance from coast. Explained variation ranges from 20 to 50%, with an average of approximately 30% among the different years. The

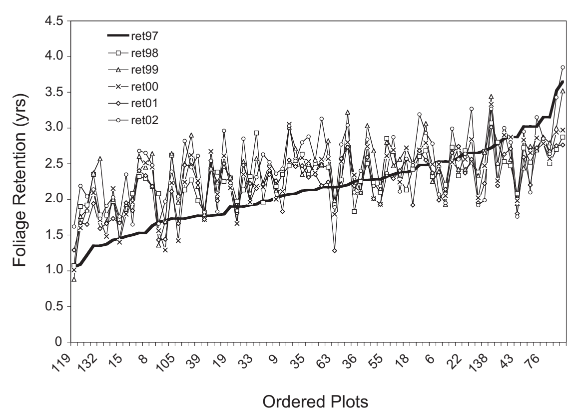

Figure 1. Foliage retention for each year from 1997 to 2002 against list of plots ordered by 1997 foliage retention.

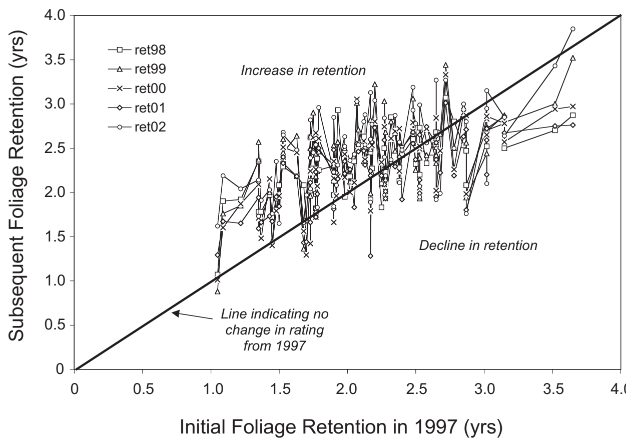

Figure 2. Foliage retention for each year from 1998 to 2002 on initial foliage retention in 1997. The 1:1 line represents no change from initial foliage retention in 1997.

variables that appear most consistently are indicators of red alder in the current or previous stand, distance from coast, aspect, and an indicator of precommercial thinning. Present of alder is associated with reduced needle retention, and precommercial thinning with increased needle retention. Foliage retention is negatively correlated with breast height age and positively correlated with distance from coast.

Cubic volume periodic annual increment

For the most recent growth period (2000-2001), approximately 92% of the variation in cubic volume PAI was explained by the following model:

$$\ln[PAI] = -2.4205 + 0.9515 \bullet \ln(BA_{DF}) - 0.4900 \bullet \ln(BA_{total}) + 0.9002 \bullet \ln(SIB) + 0.6620 \bullet \ln(FOLRET_{00}) \quad [2]$$

where PAI = plot-level periodic annual cubic volume growth of Douglas-fir for 2000-2001(m^3/ha)

BA_{DF} = initial Douglas-fir basal area ($m^2 \bullet ha^{-1}$ in 2000)

BA_{total} = initial plot basal area of all species ($m^2 \bullet ha^{-1}$ in 2000)

SIB = Bruce's (1981) site index based on intial (2000) conditions (m at 50 yrs)

$FOLRET_{00}$ = initial (2000) average foliage retention for plot (yrs)

All variables were highly significant ($p<0.0001$), and the mse was 0.0328. As expected, Douglas-fir growing stock was the major predictor, and alone it accounted for approximately 73% of the Douglas-fir volume growth; however, growth of the plots also increased as foliage retention increased (Fig. 3). Crown sparseness (CL:SA) was capable of contributing relatively little to the explanatory power of the model, perhaps in part due to the fact that it was measured in 1998 and was not repeated in 2000. Assuming the healthiest stands were represented by the greatest value of $FOLRET_{00}$ (3.3 yrs), the model implies volume growth losses depicted in Fig. 4. The most severely impacted plot had $FOLRET_{00}$ of 1.1. Setting Douglas-fir basal area to the population average of 20 m^2/ha (87 ft^2/ac) and assuming no competing woody species and average site index of 40 m (130 ft) at 50 yrs, this condition implies an average growth rate of 7.6 m^3/ha/yr (108 ft^3/ac/yr) vs. an expected value under optimal levels of $FOLRET_{00}$ amounting to 15.7 m^3/ha/yr (224 ft^3/ac/yr). The inferred cubic volume growth loss for stands experiencing the most severe SNC is therefore approximately 52%, with a population average of 21% loss (average foliage retention of 2.3 yrs).

Growth loss curves from the retrospective phase and the first 2-yr growth period are similar in magnitude to the growth losses estimated for 2000-2001 (Fig. 5). Stands with the most severe SNC were estimated to exceed 50% during this latest growth period, which is slightly higher, but probably not significantly so, than the 45-48% reported for 1996 and 1998-99.

It was expected that stands experiencing severe SNC would show either a sharper decline or more modest increase in PAI from 1998 to 2001. Although the difference in PAI between the two successive growth periods might suggest this behavior (Fig. 6), "effect" of SNC was only marginal when other stand conditions were considered. One of the best models for predicting the ratio

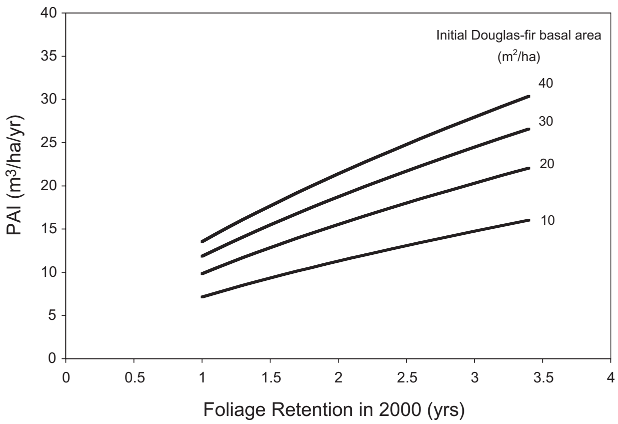

Figure 3. Relationship between cubic volume PAI and SNC severity as measured by foliage retention (FOLRET00) for various level of Douglas-fir growing stock (BA_{DF}). Estimates are for the 2000-2001 growth period and assume BA_{DF}=BA_{total} and SIB00=40m.

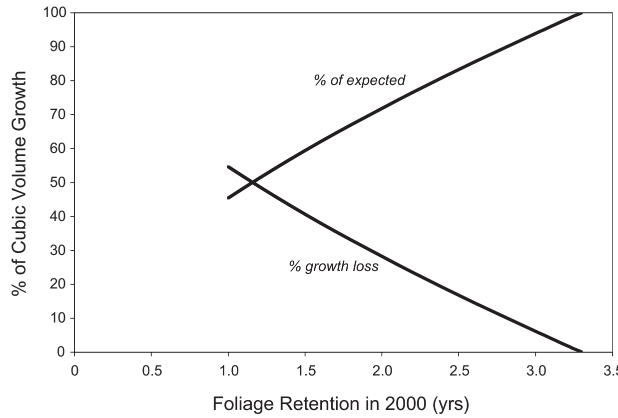

Figure 4. Volume growth losses associated with varying levels of foliage retention (FOLRET00) for the 2000-2001 growth period.

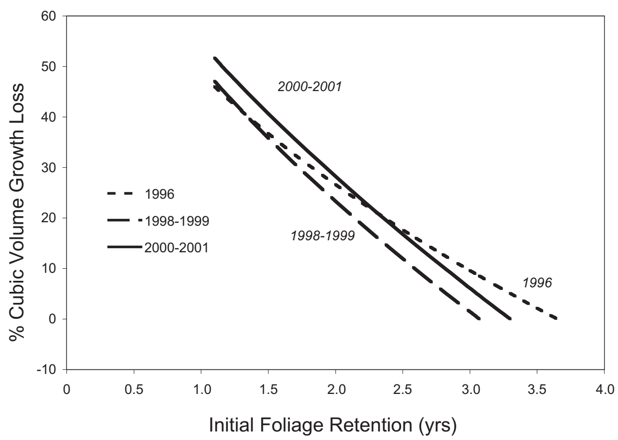

Figure 5. Cubic volume growth loss (%) as a function of foliage retention at the beginning of the growth period for 1998-99 and 2000-01 and the following spring for 1996.

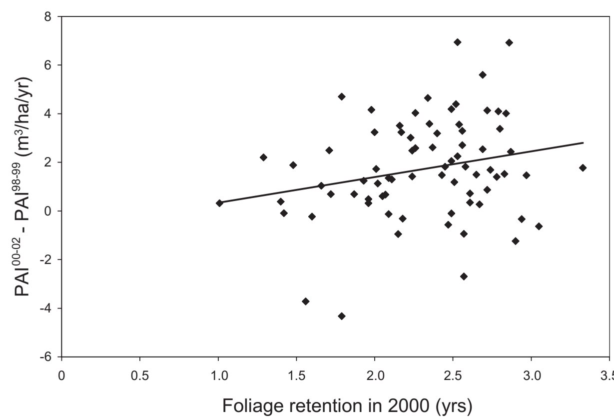

Figure 6. Change in cubic volume periodic annual increment from the 1998-99 growth period to the 2000-01 growth period, as a function of foliage retention in 2000.

of PAI in 2000-2001 to PAI in 1998-1999 was the following:

$$\ln(PAI_{2000\text{-}2001}/PAI_{1998\text{-}1999}) = 0.8903 + 0.05517 \bullet RD_{WH} + 0.1197 \bullet \ln(BA_{DF}) - 0.3864 \bullet \ln(BA_{total}) + 0.07781 \bullet \ln(FOLRET_{00}) \quad [3]$$

All variables were significant at ($p<0.007$) except for foliage retention ($p=0.13$). Approximately 69% of the variation in the ratio of the PAIs was accounted for by these stand conditions. The PAI ratio varied from 0.77 to 1.93, with an average of 1.15. Cubic volume PAI declined for only sixteen of the 75 plots between the two successive growth periods.

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The Role of Nitrogen in Swiss Needle Cast Disease: Modifying Foliar N to Improve Needle Retention

Part III. A Field Test With Fertilized Seedlings

Cathy L. Rose, OSU; Kathleen Kavanagh, University of Idaho; Dan Manter, USDA-FS PNW Research Station

Abstract

Part I of this study demonstrated a link between disease severity and foliar concentrations of nitrogen and amino acids for Douglas-fir saplings in the field. More heavily-infected seedlings have higher free amino acids per unit N, indicating that foliar N supply exceeds demand. Part II of this study employed a balanced fertilizer experiment to examine disease responses to foliar nitrogen in 1-0 Douglas-fir seedlings with and without field inoculation. This study allows us to examine the dynamics of foliar nitrogen and free amino acids in relation to both disease initiation and progression. In previous field studies, cause and effect relationships between disease development and foliar nutrients were compromised by the fact that trees were influenced by disease several years prior to sampling. During the first growing season (Part II, 2001) of this seedling study, only a modest range of foliar N was obtained among fertilizer treatments. As expected, there were no discernable treatment differences in disease severity or needle retention. By the start of the second growing season (Part III, 2002), however, wide separation in seedling nitrogen status was obtained (0.7 - 1.6% N). Important results this year are: 1) more N is being withdrawn from older foliage of infected seedlings grown at low N supply compared to high N supply, and 2) at high N supply, infected seedlings have much higher levels of amino acids (and ratio of amino acids to nitrogen) in the newly-emerging foliage compared to uninfected seedlings. These nutritional differences are optimal for testing hypotheses concerning the potential causal role of N in disease susceptibility and progression, as well as feedback effects of infection on leaf nitrogen. Differences in foliar N nutrition in needles produced during this growing season should provide a good test of the nutritional hypothesis during the coming year.

Introduction

A close relationship between tree nutrition and forest health and productivity has been clearly demonstrated in the forestry literature. In addition to differences in biomass production and allocation, tree nutrition commonly influences needle retention and susceptibility to various pathogens and diseases. Earlier studies funded by the Swiss Needle Cast Coop have demonstrated that SNC disease severity (quantified either as needle retention or fungal biomass) is directly related to foliar nitrogen (N) across a range of both unfertilized and fertilized stands in the Coast Range (Maguire et al. 2000, 2001). In addition, results of Part I of this study (Rose, Kavanagh, and Manter 2001) found that disease progression in the field may actually reduces foliar N values however, the ratio of free amino acids to %N increases. The higher ratio of free amino acids to %N in more diseased seedlings indicates that surplus N (in excess of growth demands) is accumulating.

Comparison of ecosystem-level versus stand-level responses of Swiss needle cast disease may provide clues to help clarify the role(s) of N: 1) as a predisposing factor in needle infection, 2) as an independent factor in disease progression (needle retention), and 3) in relation to feedback effects of fungal infection on needle chemistry. Cause and effect relationships between disease development and nitrogen nutrition could not be discerned because trees had been influenced by the disease for several years prior to sampling. In Part II of this research, we developed both inoculated and uninoculated Douglas-fir seedlings with wide variation in foliar N values. Continuation of this experimental approach in Part III will enable us to clearly differentiate how disease initiation and progression relate to foliar N and free amino acids

Based on the N nutrition hypothesis discussed earlier (Rose, Kavanagh, and Manter 2000, 2001), we hypothesized that if N is a causal factor in disease development, then: 1) seedlings with higher foliar N should have higher infection rates, quantified by pseudothecial density, or fungal biomass. If nitrogen is a mediator of disease progression, then: 2) seedlings with higher foliar N should have reduced needle retention. If amino acids are a specific nutritional substrate for the fungus, then: 3) disease severity may be more directly related to the ratio of FAA to % N. Furthermore, if foliar N nutrition is influenced by carbon starvation in infected needles, then over time, more heavily-infected seedlings should have: 4) reduced foliar N values, but increased values of the ratio of free amino acids to % nitrogen compared to uninfected seedlings.

Methods

In Part II of this study, during January 2001, 120 1-0 seedlings were re-potted and maintained outdoors under 50% shade at the OSU botany farm. Seedlings for this experiment were partitioned into 4 blocks and five treatments, with six seedlings per block. Fertilizer solutions were formulated to create a wide range of N availability based on recommendations provided in Walker and Gessel (1991). The fertilizer treatments consisted of different levels of N supply in combination with complete and balanced macronutrients (Table 1). The seedlings were fertilized weekly with liquid solutions from January through May, 2001. At the end of May (the pre-inoculation sample), samples of current-year needles were collected for determination of total N content, free amino acids, and fungal biomass by PCR. Samples included 25 current-year needles from single branches on three seedlings per 4 blocks and 5 treatments, for a total of 60 samples.

After June 1, 2001, the frequency of fertilizer application was reduced to once every two weeks in order to achieve a more rapid reduction of foliar N in low N treatments. Seed-

Table 1. In Part 2 of this study, five fertilizer formulations were used to produce a wide range of N supply to 1-0 Douglas-fir seedlings. Fertilizer formulations were based on recommendations in Walker and Gessel (1991). Nutrient are in units of millimoles (mM).

	Target Values for Nutrient Supply					
Fertilizer Treatment	N	P	K	Ca	S	N Supply
1	25	40	80	40	6	deficient N
2	50	40	80	40	6	deficient N
3	100	40	80	40	6	*optimum growth
4	200	40	80	40	6	luxury N
5	400	40	80	40	6	luxury N

lings were transported to a naturally infected Douglas-fir plantation (Salal Plot, Cloverdale, OR) during the month of June, 2001 for field inoculation of needles. After inoculation, seedlings were returned to ambient conditions at the OSU Botany Farm for continued growth and fertilizer application. Additional sample collections were scheduled at the end of the growing season (August-September) and during winter dormancy (December 2001). PCR analyses were conducted during December 2001; PCR and pseudothecia counts were repeated again in April 2002.

A second set of seedlings was treated identically to the first set (described above) during 2001 and 2002 except that the seedlings were not inoculated in 2001. During 2002, half of the second set of seedlings was inoculated and then returned to the OSU Botany farm along with the first set of seedlings.

Results and Discussion

2001 Growing Season

By the start of the 2001 growing season, there was only a 25% range in foliar %N (1.4 – 1.75%) from the lowest to the highest level of N fertilizer for inoculated seedlings (Figure 1). Consequently, we did not have adequate differences in foliar N among treatments prior to inoculation to expect a response in disease development according to the nutritional hypothesis. In addition, our lowest value of foliar N (1.4%) far exceeded our target of 0.8% N. For the remainder of 2001 season, we continued fertilizer applications and monitored changes in both biochemistry and disease development. By December, 2001, we observed considerable N depletion in foliage at lower levels of N supply and N accumulation at the higher levels of N supply. Since our foliar N levels were so high at the time of infection in June 2001 it is not surprising that there was no effect of N fertilizer level on fungal biomass or infection rate measured in December 2001. However, it is noteworthy that the infection or development of pseudothecia was grouped on individual needles throughout the elongating shoot. The needles appeared to be either heavily infected or almost uninfected, although there was no pattern associated with timing of needle emergence. Heavily infected needles are located adjacent to and within groups of uninfected needles.

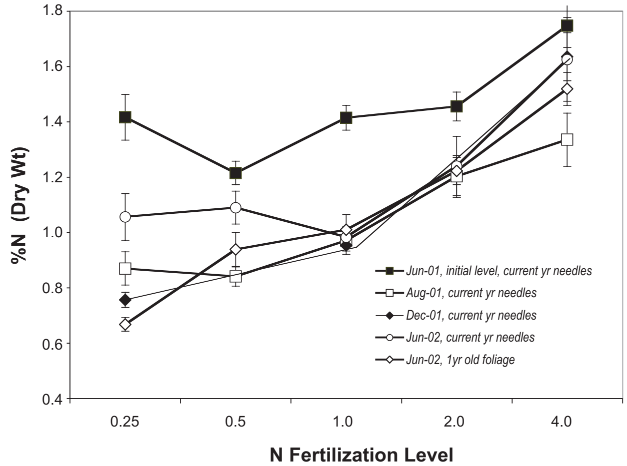

Figure1. Percent foliage nitrogen (N) of Douglas-fir seedlings treated with different levels of nitrogen supply in a balanced fertilizer. Fertilization levels are: Level 1 (2.5 mM) = optimal N supply (according to Walker and Gessel 1991), Level 2 (5.0 mM) = 2 times optimal N supply, Level 4 (10.0 mM) = 4 times optimal N supply, Level 0.25 (0.625mM) = 25% of optimal N supply, Level 0.5 (1.25mM) = 50% of optimal N supply. All other nutrients were held constant. Seedlings were placed in the field in June 2001 for inoculation, and resided at the OSU Botany Farm for the remainder of the year. Note the high foliar N values at the time on inoculation in June, 2001, and loss of foliar N over time in N treatments with 25% and 50% optimal N

2002 Growing Season

Results of PCR and infection rate analyses in April 2002 were comparable to the results obtained in December 2001, i.e. there were no differences among fertilizer treatments

At the beginning of the second growing season, we also expanded our foliar analysis to include both current-year and 1-year-old foliage. At the two lowest levels of N supply, there was a significant drawdown in foliar N from older needles (Figure 1).

In June 2002 (post budbreak period), we also compared the %N and amino acid values of previously inoculated and uninoculated seedlings across fertilizer treatments (Figure 2). At the lowest level of N supply, there was a significant drawdown of total N (20-30%) in older needles of both inoculated and uninoculated seedlings. The nitrogen and amino acid values at optimum N supply (2.5 mM fertilizer rate) were similar, regardless of needle age class and inoculation status. At highest N supply, %N concentrations of foliage were also similar regardless

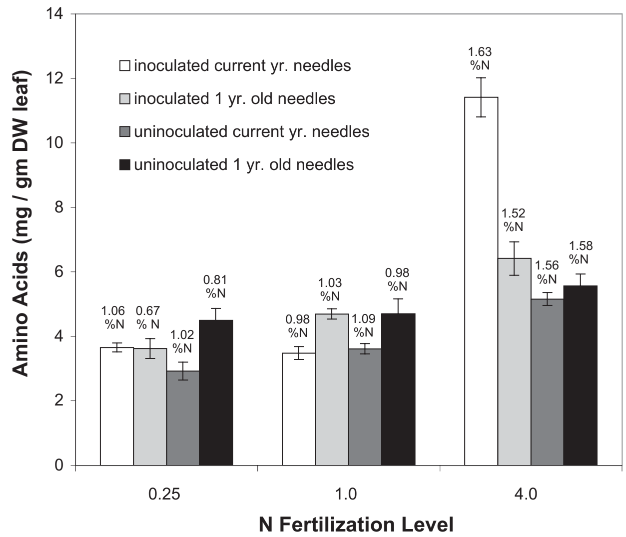

Figure 2. Foliar free amino acids of Douglas-fir seedlings treated with different levels of nitrogen (N) supply in a balanced fertilizer. Fertilization levels are: Level 1 (2.5 mM) = optimal N supply (according to Walker and Gessel 1991), Level 4 (10.0 mM) = 4 times optimal N supply, and Level 0.25 (0.625mM) = 25% of optimal N supply. All other nutrients were held constant. Some seedlings were placed in the field in June 2001 for inoculation. All other times they resided at the OSU Botany Farm. The boxes above each bar represent the corresponding %N of the foliage. Note VERY high free amino acid level in inoculated seedlings receiving high N fertilization. This may indicate that emergence of P. gaeumannii ***(blocking carbon uptake) coincides with accumulation of surplus N as amino acids in the newly emerging foliage. Note: %N not statistically different among fertilization treatments..***

of needle age class and inoculation status, however there was a notable spike in amino acid concentrations in current-year needles of seedlings that had been inoculated the previous year (Figure 2).

Discussion

Results of the first growing season indicate that nearly an entire year is required to drawdown N reserves in heavily-fertilized nursery seedlings. The lack of a notable response in both fungal biomass and infection rate in December 2001 was not surprising, as seedlings started the growing season with similar nitrogen nutrition. That is, in 2001, the seedling nitrogen status was high at the time of inoculation, and so did not provide an adequate test of the hypothesis. Therefore we cannot be certain if the lack of a disease response by April 2002 refutes the nitrogen nutrition hypothesis. We believe that it is necessary to examine disease response in December 2002, and again in April 2003, in order to determine if seedling nutritional status at the time of inoculation affects subsequent disease development.

The drawdown in foliar N from older needles at the two lowest levels of N supply (Figure 1) is a strong confirmation that N supply in these treatments is inadequate to meet seedling needs. Hence, the fertilizer application rates that we selected for this study should provide a good test of the nutritional hypothesis during the 2002 growing season.

The peak in amino acid concentrations of current-year needles of inoculated seedlings during June 2002 indicates there may be a feed-forward mechanism associated with fungal colonization (Figure 2). Such a mechanism would be expected based on known responses of conifers to stomatal-induced inhibition of photosynthesis (blockage of pseudothecia). If this is true, then high foliar N in the range of 1.5-1.6% may be an important factor in the intensification of this disease over several years.

Neither ecosystem- nor stand-level studies conducted to date have unequivocally differentiated the role of N as a predisposing disease factor, or as a mediator of disease progression. With an additional 3-7 months of sampling (in October ’02, December ’02, and April ’03), the present study has the potential to address all of these questions and provide significant insight into nutritional components of this disease.

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Genetic Studies Involving Swiss Needle Cast

Randy Johnson, USDA-FS; Fatih Temel, OSU; and Keith Jayawickrama, OSU

Abstract

Three studies were analyzed this year that examined genetic aspects of Swiss needle cast (SNC) tolerance. Families sampled across the Siuslaw National forest showed differences in foliage health traits, but very little of the variation could be explained by environmental or climatic conditions at the parent tree location. Five test sites of the Nehalem series of progeny trials were measured for DBH. The best families were continuing to have reasonable basal area increments, implying that genetic improvement can produce stock that could offset the 30% volume growth reduction predicted in moderately-impacted SNC areas. A third study suggested that Douglas-fir families do not appear to increase 1st-year needle production in response to needle loss and families may differ in the amount of foliage they produce for a given branch diameter.

Three genetics studies looking at aspects of tolerance to SNC were completed this year. These studies examined the genetic variation patterns of SNC tolerance over the landscape, the effectiveness of genetically improving tolerance, and whether families differ in their ability to respond to SNC with increased needle production. The first study was supported by SNC Cooperative funding because it was done in conjunction with the early testing study. The second study was funded by the Oregon Department of Forestry and the TRASK metacooperative and the last study was established by the USFS PNW Research Station.

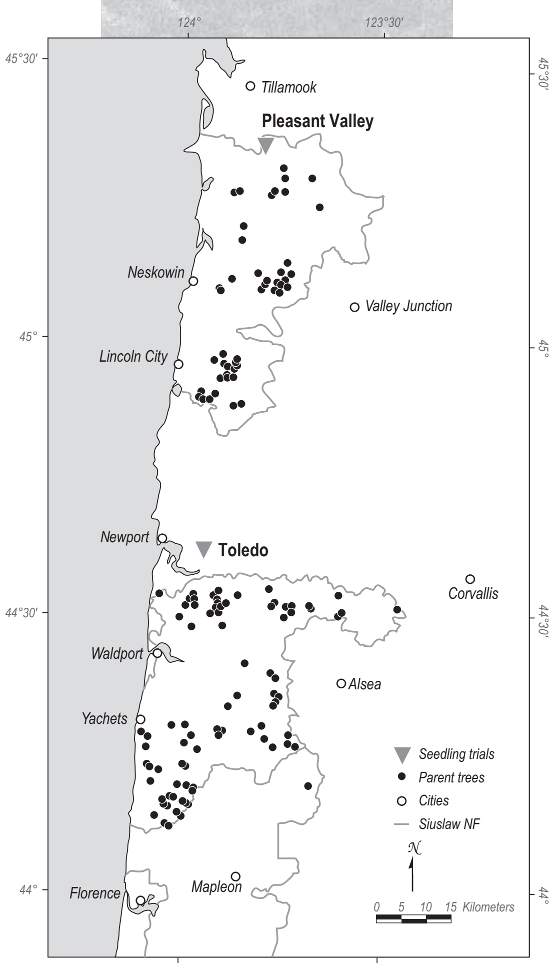

Figure 1. Parent tree locations for families studied in the geographic variation study.

Study 1 – Geographic Variation in Swiss Needle Cast Tolerance of Douglas-fir in the Siuslaw National Forest

Methods and Materials

Genetics of Swiss needle cast (SNC) tolerance and relationships between climatic and geographic variables at parent tree locations and SNC tolerance were investigated in 152 wind-pollinated Douglas-fir (*Pseudotsuga menziesii* var. *menziesii* [Mirb.] Franco) families originating from the central coast of

Table 1. Means and ranges of the 14 geographic and climatic variables considered in the analyses.

Variable	Mean (Range)
Distance to the Pacific Ocean (km)	15.20 (1.00 – 48.90)
Elevation (m)	331 (25 – 667)
Latitude (UTM)	49398.57 (48854 – 50173)
Slope (%)	20.32 (0 – 65.25)
Aspect (cosine)	-0.06 (-0.65 – 0.51)
Aspect (sine)	-0.03 (-0.45 – 0.46)
June precipitation (mm)	78.26 (52.13 – 114.14)
June average maximum temperature (°C)	20.30 (16.86 – 23.25)
June average minimum temperature (°C)	8.53 (7.19 – 9.26)
June potential evapotranspiration rate	130.60 (85.38 – 156.36)
November precipitation (mm)	367.80 (290.63 – 433.18)
November average maximum temperature (°C)	12.26 (9.82 – 13.49)
November average minimum temperature (°C)	4.30 (2.07 – 5.32)
November potential evapotranspiration rate	34.95 (0.00 – 42.48)

Oregon in the Siuslaw National Forest (Figure 1). Families were planted on two test sites (Toledo and Pleasant Valley, Figure 1) and naturally inoculated with *Phaeocryptopus gaeumannii* spores that came from the surrounding infected stands (see Temel and Johnson 2001, Temel 2002). The two-year-old progeny were visually assessed for foliage greenness (at both needle [needle color] and crown [foliage color] levels) and proportion of retained foliage (at both single internode [needle retention] and crown [foliage density] levels). Because the two color traits and the two retention traits are controlled virtually by the same sets of genes, as evidenced by genetic correlations close to 1, geographic variation was investigated only in foliage color and foliage density because they were slightly more heritable than needle color and needle retention.

Foliage traits were regressed on a total of 6 geographic and 8 climatic variables at mother-tree locations that might be related to variation in SNC severity. The environmenatal factors considered (Table 1) were those that have been shown to play important roles in variation in severity of SNC symptoms (Michaels and Chastagner 1984, Capitano 1999, Manter *et al.* 2000, Rosso and Hansen 1999).

Climatic variables were estimated for mother tree locations (UTM) using two different models. Mean minimum and maximum daily temperatures (°C) for each month and mean monthly precipitation (mm) were obtained from PRISM (Precipitation-elevation Regressions on Independent Slopes Model) (Daly *et al.* 1994). Monthly rates of evaporation, potential evapotranspiration and woody transpiration were obtained from the MAPSS (Mapped Atmosphere-Plant-Soil System) (Neilson 1995) model.

Results

Results of ANOVA indicated significant family differences for all foliage traits. There were no significant family-by-site interactions for any of the traits, indicating that the family rankings were consistent from site to site. Foliage traits were weakly heritable, with individual narrow-sense heritability estimates ranging from 0.11 to 0.20. Family mean heritabilities were moderate and ranged from 0.44 to 0.56. Heritability estimates were similar for related traits (i.e., needle color and foliage color, needle retention and foliage density).

Foliage density was not found to be significantly associated with any of the geography and climate variables. A small amount of variation in foliage color (14.5%) could be explained by a significant (best fitting) model containing a subset of the geography and climate variables (Table 2).

The limited evidence reported here suggests that a portion of variation in foliage color is associated with the geography of mother tree locations. Lack of such evidence for foliage density suggests that color is more responsive to natural selection

Table 2. Regression equation for foliage color.

Variable	Parameter Estimate	Partial R^2	P-value
Intercept	1.8889	—	<0.0001
Distance to the Pacific Ocean	0.0179	0.0296	0.0053
(Distance to the Pacific Ocean)^2	$-5.0163 * 10^{-10}$	0.0340	0.0029
Cosine of Aspect	-24.2088	0.0240	0.0118
Latitude-by-Cosine of Aspect	0.0005	0.0238	0.0123
(Elevation)^2	$-5.1643 * 10^{-7}$	0.0332	0.0032
Model (Cp = 5.72):		0.1446	0.0003

pressures of SNC. Within the Siuslaw National Forest there is not a strong tendency for climate and geography to influence the SNC tolerance of parent tree collections. This result could be because SNC has not applied significant selection pressure in the past.

Study 2 – Nehalem Breeding Program – Age-17 Assessment

Methods and Materials

In 1995, five progeny test sites were assessed for height, DBH, foliage color, crown density and needle retention. These age-11 results were reported in the 1998 annual report (Johnson and Temel 1998). In 1998, an additional DBH assessment was made on three of the five sites and examined 120 of the 400 total families (reported in the 1999 SNCC Annual Report, Johnson and Temel 1999). During the fall of 2001, all 400 families were assessed for DBH on three sites, and the remaining two sites were assessed in the summer of 2002. From these data we were able to analyze 6-year basal area increment. If one defines tolerance as continued growth in the presence of disease, then basal area over this time period represents the trait of choice to obtain SNC tolerance.

Heritabilities (h^2) were estimated for all traits that were assessed (see Johnson 2002 for statistical methods). Heritability represents the proportion of the observed variation that is controlled by a tree's genes; the remainder is controlled by environmental effects. Genetic and family-mean correlations of the age-11 traits with basal area increments were also estimated. Genetic correlations are a result of the same genes (or tightly linked genes) affecting two different traits.

The efficiency of cooperative breeding programs was examined by looking at the performance of selected families in the progeny test. Selection was based on (1) using only age-11 data to select for subsequent basal area growth (primarily) and foliage health or (2) including age 11 to 17 basal area increment to the age-11 selection criteria. This represents selection based at two different ages. Trait scores were first generated for each age-11 trait using a selection index procedure (Johnson 1997) that weighs family-site means according to the site's family mean heritability and average genetic correlation with the other sites. The age-17 data weighted the family-site means only by the site's family heritability (all sites were well correlated and almost equally correlated with one another). The family scores for each trait were standardized to mean of 0 and a standard deviation of 10. An overall index score for each family was generated by multiplying the standardized trait scores by what we felt to be appropriate values. The weightings were as follows:

Age-11 index = (2×DBH) + Ht + (0.5×Color) + (0.5×Crown Density) + (0.3*Retention)

Age-17 index = (2×BA inc) + DBH + Ht + (0.5×Color) + (0.5×Cr Den) + (0.3*Reten)

where all traits are age-11 except for basal area increment from age 11 to 17 (BA inc).

Results

Heritabilities for the age-17 traits were larger that those for the age-11 traits and growth traits typically had larger heritabilites than the foliage traits (Table 3). The age-17 DBH and basal area increment data were well correlated across sites. The family mean correlations averaged 0.49 (ranged from 0.42 to 0.57)and the genetic correlations averaged 0.86 (0.76 to 1.00).

The age-11 growth traits were better correlated with subsequent basal area growth than were the foliage traits (Table 4). Of the foliage traits, color and crown density were better correlated with subsequent basal area growth than retention. Crown density had the largest heritability of the foliage traits.

Table 3. Narrow-sense heritabilities for age-11 color, crown density, needle retention, height, DBH and subsequent basal area increment on five progeny test sites of Douglas-fir (standard errors in parentheses).

Site	Color	Crown density	Needle retention	Height	Age-11 DBH	Age-17 DBH	Basal area increment
Acey Crk.	0.04*(0.03)*	0.23*(0.04)*	0.16*(0.04)*	0.38*(0.05)*	0.40*(0.05)*	0.49*(0.05)*	0.47*(0.05)*
Coal Crk	0.10*(0.03)*	0.19*(0.04)*	0.13*(0.04)*	0.32*(0.05)*	0.32*(0.05)*	0.40*(0.05)*	0.39*(0.04)*
Cole Mt.	0.10*(0.03)*	0.16*(0.04)*	0.34*(0.05)*	0.30*(0.04)*	0.27*(0.04)*	0.47*(0.07)*	0.49*(0.08)*
Davis Crk.	0.27*(0.04)*	0.28*(0.04)*	0.28*(0.04)*	0.33*(0.04)*	0.32*(0.04)*	0.41*(0.04)*	0.41*(0.04)*
Slick Rock	0.20*(0.04)*	0.22*(0.04)*	0.20*(0.04)*	0.37*(0.05)*	0.32*(0.04)*	0.46*(0.04)*	0.46*(0.04)*

Table 4. Family mean and genetic correlations of age-11 traits with subsequent basal area growth.

Age-11 trait	Family-mean correlation	Genetic correlation
DBH	0.80	0.90
Height	0.73	0.76
Color	0.47	0.59
Crown density	0.49	0.55
Needle retention	0.20	0.25

The top 40 families selected for tolerance with the age-11 index averaged 24% more basal area growth than the population mean (Table 5). Selection using the age-17 index resulted in 27% more basal area than the population mean. More gain was obtained by using the age-17 data, but this gain would be realized 6 years later than one would get if selection was made at age 11. Gain-per-year of breeding was greater when selecting at age 11 than waiting until age-17..

Percentage gains from using the parents in a seed orchard would be greater than the family means from the progeny trials because genetic gain from a seed orchard is equal to:

Table 5. Means for total population and for top 10% (40 families) selected with age-11 and a combination of age-11 and –17 data. Percentage increase reported in parentheses.

Traits	Population mean	Top 10% Index Age-ll	Top 10% Age-l7 Index
Age 11-17 Basal area (mm^2)	14334	17783 (24.1%)	18283 (27.5%)
Age 11-17 DBH increment (mm/yr)	10.1	11.6 (14.6%)	11.8 (17.2%)
Age 17 DBH (mm)	170.3	188.7 (10.8%)	190.6 (13.9%)
Age-11 DBH (mm)	107.7	117.0 (8.6%)	117.2 (8.8%)
Age-11 height (cm)	752	795 (5.7%)	797 (6.0%)
Color	1.90	1.94 (2.1%)	1.95 (2.6%)
Crown density	3.85	3.98 (3.4%)	4.00 (3.9%)
Retention	4.73	5.10 (7.8%)	5.05 (6.8%)

Genetic gain = 2 × (family mean heritability) × (Selection differential)

Estimated genetic gain for basal area increment using the age-17 index would be 2 × 0.825 × 27.5% = 45%. Estimated genetic gain for annual diameter increment of the top 40 families was 2 × 0.815 × 17%=27.7%; which translates to a diameter growth rate of 12.9 mm\yr ; or about four rings per inch. We suggest this to be an acceptable growth rate for Douglas-fir growing under moderate SNC-presssure (average of 2 years needles).

Study 3 – Family Responses to Foliage Abuse

It has been noticed that certain trees appear to have more needles than others, but actual needle retention is the same. This study attempted to look at the family differences in a tree's ability to put on foliage and whether it changes when 2nd year foliage experience occluding of their stomates and premature casting.

Methods and Materials

A subset of 20 families from the early-testing study were grown in raised beds at the Forest Science Lab in Corvallis. In an attempt to simulate the occluding of stomates (what pseudothesia do to needles), the undersides of needles were sprayed with paint (1st year) or polyurethane (2nd and 3rd years) just prior to bud burst. Four trees per family were planted across a nursery bed. Each nursery bed contained two replications, i.e. two blocks, each with 20 4-tree family rows. In each bed, the trees on one side of the bed were sprayed and other half left as controls. The timetable of events was as follows:

Summer 1998	Seeds sown in greenhouse
Spring 1999	Foliage sprayed with white-wash greenhouse paint prior to bud burst, seedlings transplanted to raised beds
Fall 1999	Heights measured
Spring 2000	Foliage sprayed with exterior grade polyurethane prior to bud burst
Fall 2000	Heights and Diameter measured
Spring 2001	Foliage sprayed with exterior grade polyurethane prior to bud burst
Fall 2001	Heights and basal diameter measured
Winter 2001	Foliage sampled and measured in two beds (4 of 6 replications).

In the winter of 2001, foliage was sampled from two 2-yr-old branches from each tree in two of the three beds. Basal diameter of each branch was measured and oven-dry weight of the 1st and 2nd year needles were obtained for the two branches combined. From this information foliage mass per unit basal area for 1st-year needles and the 2nd-year needles was calculated.

Results

The sprayed trees were shorter, had smaller diameters and fewer 2nd-year needles per unit basal area than the unsprayed trees (Table 6). This reduction could be due to either occluded stomates, chemical damage, or poisoning from the spray treatments. Family height differences were evident at the age-3 measurement ($p=0.0623$), but had disappeared by age 4 ($p=0.3658$). No family differences were evident for diameter growth. Families did show differences for the ratio of 1st-year needles to branch basal area. For all traits there were no family-by-treatment differences, implying that families performed the same in each treatment.

These results suggest that trees are not responding to needle loss by producing more 1st-year foliage because the 1st-year foliage to basal area ratio did not increase in the sprayed trees. Second-year foliage was reduced by the spraying, as expected. Because families differ in the amount of foliage they produce per unit of branch basal area, there may be a possibility that the families that produce more foliage per branch basal area demonstrate more SNC tolerance. However, there was no significant correlation found between the ratio and age-10 growth and foliage data from these same families in field tests. Lack of correlation could be the result of none being present or the limited amount of data available for estimating ratios (12 trees from 20 families).

Table 6. Mean heights, diameters and foliage to basal area ratios for trees sprayed with polyurethane prior to bud burst and the unsprayed controls, and level of significance for the difference.

Trait	Sprayed trees	Unsprayed controls	Level of significance
Height (age 2)	47.25 cm	49.75 cm	0.0373
Height (age 3)	55.33 cm	60.90 cm	< 0.001
Height (age 4)	101.11 cm	114.35 cm	< 0.001
Diameter (age 3)	12.38 mm	12.57 mm	0.0279
Diameter (age 4)	17.84 mm	19.10 mm	< 0.001
Foliage ratio – 1st yr needles	0.331 g/mm^2	0.335 g/mm^2	0.0969
Foliage ratio – 2nd yr needles	0.072 g/mm^2	0.082 g/mm^2	0.0047

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Impact of Swiss Needle Cast on Wood Quality of Douglas-fir

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Abstract

a) The Bravo trial presented the opportunity to compare wood in the same site with high levels of SNC (the unsprayed trees) vs. with lower levels (the sprayed trees). The wood of trees that were not sprayed with Bravo was denser than the wood of trees that were sprayed, because the SNC in the unsprayed trees increased the trees' proportion of latewood. Cell wall thickness was lower in unsprayed earlywood but no different in unsprayed latewood, compared to sprayed plots. Cell lumen diameter was no different in earlywood, but was actually wider in unsprayed latewood than in sprayed latewood. b) The Nehalem progeny test allowed us to look at genetic resistance to SNC. The genetic families maintained their wood property ranking regardless of the SNC severity at a site. Additionally, the families that were tolerant of SNC had lower than average wood density and faster than average growth. c) The SNCC Growth Impact Plots allowed us to look at the sites that varied in SNC level to assess how the severity of SNC and other site characteristics and tree growth rates affected wood properties. Sapwood moisture content increased with plot needle retention, up to a threshhold value of needle retention. Heartwood moisture content was unaffected by needle retention. d) In all the studies, we are looking at how radial growth rate affects wood density. From the first two datasets, the results appear complex. Data collection is ongoing for the third dataset, and will include a number of wood properties other than density (MOE, MOR, and microfibril angle).

Introduction

Wood properties have been examined in three series of trials. The first trial was the sprayed Bravo plots established by the Oregon Department of Forestry near Beaver OR. Trial description and preliminary results were reported at last year's annual meeting (Johnson et al. 2001) and additional data are provided in this report. The second trial series was an examination of two progeny tests in the Nehalem breeding program. The third trial was within the SNCC Growth Impact Plots. These three trials provide information on how disease severity at one site affects wood (Bravo plots), how genetic families that differ in their SNC-tolerance rank in heavily vs. less-heavily infected sites (the Nehalem progeny tests), and how wood in trees in sites covering a range of SNC are affected by the disease (the Growth Impact plots).

Methods

a) ODF Bravo Trial

In the fall of 2000, growth plots were sampled in each of the six plots. Approximately 20 trees were felled and analyzed in each treatment block. Breast height disks were provided for X-ray densitometry. Each disk was examined ring by ring for the following characteristics: ring width, earlywood width, latewood width and wood density. One pith-to-back sample from three randomly selected trees in each plot (18 trees total) was examined to determine tracheid width and double cell wall thickness. Thin-sections were made by sliding microtome, stained with safranin, and mounted permanently for analysis. They included the second growth ring (1999 growing season) inward from the cambium. For both the earlywood and latewood in the 1999 ring, 15 tracheids from 3 separate regions were measured for tracheid lumen diameter and double cell wall thickness (for a total of 45 tracheids from the earlywood and 45 from the latewood) for each of the 18 trees.

The statistical model for the Bravo plots was:

$$\text{Property}_{ijkl} = m + \text{block}_i + \text{treatment}_j + \text{block*treatment}_{ij} + \text{error}_{ijk}$$

where:

Property_{ijkl} is the property of the *k*th tree of the *i*th block (rep) of the *j*th treatment

m is the overall mean,

block_i is the random effect of the *i*th block (replication),

treatment_j is the fixed effect of the *j*th treatment,

$\text{block*treatment}_{ij}$ is the random effect of the interaction among treatment and block (and is the error term to test treatment),

error_{ijk} is the within treatment plot error.

A covariate analysis was used to test for differences in wood density. Earlywood width and latewood width were used as covariables earlywood density and latewood density.

b) Nehalem Progeny Tests

The Nehalem series of progeny tests were used to examine wood properties of contrasting families and contrasting sites. One progeny test site was Coal Creek, a site with moderate to heavy SNC symptoms. The second progeny test site was Sarajarvie, a site expressing relatively few SNC symptoms (most trees carried close to 3 years of foliage). Twelve families were sampled, four from three classifications of SNC tolerance (tolerant, average and intolerant) based on growth rate in the presence of the disease and foliage health scores. Increment cores (5.5mm diameter) were taken in the winter of 2000/2001.

Cores were sawn into small beams and x-rayed to determine the density profiles. Due to breakage of the small cores while being cut to beams, only 83 trees were used in the analysis of rings 6 to 8 from the pith. This represented growth during the mid 1990s, a time period when SNC at the Coal Creek site was well documented.

The following wood properties were averaged over the three growth rings (6-8): ring width, earlywood width, latewood width, basal area, average wood density, earlywood density, latewood density and latewood proportion. The following model was used with the GLM procedure of SAS (SAS 1992):

$$\text{Property}_{ijkl} = m + \text{site}_i + \text{rep}_{j(i)} + \text{tolerance}_k + \text{site*tolerance}_{ik} + \text{tolerance*rep}_{jk(i)} + \text{error}_{ijkl}$$

where:

Property_{ijkl} is the property of the *l*th tree of the *j*th rep of the *k*th tolerance class on the *i*th site,

m is the overall mean,

site_i is the random effect of the *i*th site,

$\text{rep}_{j(i)}$ is the random effect of the *j*th rep on the *i*th site

tolerance_k is the fixed effect of the *k*th tolerance class,

$\text{site*tolerance}_{ik}$ is the random effect of the *i*th site and *k*th tolereance class,

$\text{tolerance*rep}_{jk(i)}$ is the random interaction effect off the *k*th tolerance class with the *j*th rep, and

error_{ijklm} is the random with plot effect.

For all wood properties, replication and all the interaction effects were not significant at p=0.05; therefore the model was reduced to:

$Property_{ijkl} = m + site_i + tolerance_k$

Earlywood density and latewood density were also subjected to a covariate analysis where earlywood width and latewood width were used as covariables. These analyses attempt to look for density differences that were not a function of growth rate.

c) SNCC Growth Impact Plots

In spring 2002, 15 plots were selected from the existing set of Swiss needle cast Growth Impact Plots. These 15 plots were chosen to represent a range of needle retention values (2001 data) and fell within a similar range of stand age and site index. Needle retention values ranged from 1.7 to 2.9, stand age ranged from 21 to 28 years (breast height age), and site index ranged from 38.4 to 43. The plots were all located along the western slope of the Coast range, between Highway 26 near Astoria to the north and Highway 20 near Toledo to the south. Two additional plots were identified in the western Cascade foothills, along with a third plot on the east side of the Coast range. So, in all we sampled 18 plots.

A stand of trees located ~100 m outside the boundary of the permanent plot, and sharing similar characteristics (tree size, density, understory etc.) as the permanent plot was identified. From this stand, 12 dominant to co-dominant trees were marked for felling. The selection of trees was not random; rather, they were chosen so that their removal would result in an evenly thinned (not patchy) stand. Only non-forked trees were selected. The sample trees were felled in April-June 2002.

Prior to felling, an increment core from each tree was taken at breast height, immediately split into sapwood and heartwood segments and tightly wrapped in plastic. Within 24 hours, the cores were weighed and measured. Cores were then dried at 104° C for 48 hours and re-weighed. Sapwood and heartwood moisture content were then calculated as follows:

moisture content = (fresh weight – dry weight) / (dry weight)

Moisture contents of all trees within a plot were averaged.

Two 2-inch disks were sawn from each tree, one at breast height (just above where the increment core was extracted) and one at the base of the live crown. The sapwood/heartwood boundary was determined visually. On two perpendicular axes, disk diameter and heartwood diameter were measured to the nearest 0.1 cm. The perpendicular diameters were averaged, and from them disk area and heartwood area were calculated. Sapwood area was then calculated by subtraction.

Samples to be analyzed by SilviScan were prepared from breast height disks in August 2002. From the center of each disk, a diameter section 1.5 cm wide tangentially by 1.5 cm tall longitudinally was cut. These diameter sections were placed in three successive baths of 100% ethanol for 3 days each to dry them rapidly without changing cell dimensions. The samples are now being air-dried before they will be sent to the SilviScan facility in Australia. The Silviscan analyses are cosponsored with the SNC Co-op through a joint venture of OSU and the PNW FS, granted in Aug. 2002.

A subset of all the samples will be sent to SilviScan in fall 2002 for the following analyses: earlywood and latewood width, earlywood and latewood density, fiber coarseness, and microfibril angle. After we receive and analyze the SilviScan results, we will decide whether to send more samples, and whether to have lignin analyses performed by that same lab.

A 30-cm long stem internode section was cut from each sample tree just above the breast height disk. Eight vertical beams, each 1 cm wide tangentially and 1 cm deep radially, were cut from the outer rim of this section. These beams contained the outermost growth rings, presumably those produced when the trees were most severely impacted by Swiss needle cast. Samples were stored in the ASTM standard room following cutting.

Each sample is being bent on an Instron machine with a continuous data logger attachment. Samples were placed pith side up on two points 14 cm apart. Data collection is ongoing.

Results

a) ODF Bravo Trial

Overall ring density was higher in the more severely impacted control plots than the Bravo-sprayed plots in the ODF trial; this was a result of an increased proportion of latewood. Earlywood density was greater in the sprayed trees, but there was no difference in the latewood density between the treatments. Latewood density was also not associated with latewood width. The earlywood difference between the Bravo-sprayed trees and the controls is somewhat complex because the relationship between earlywood width and earlywood density differs between the two groups. Regression analyses demonstrated a statistically different (p=0.05) relationship between groups; therefore different equations were generated for each group. There was a curvilinear relationship for the case of the controls and a linear relationship for the sprayed trees (Figure 1). The range of earlywood widths differed for the two groups as well, but for the common range, earlywood density was greater in the sprayed trees.

Earlywood cell wall thickness was larger in the sprayed trees than in the unsprayed trees (Table 1, 5.35 m for the sprayed trees vs. 3.18 m for the unsprayed). Cell wall thickness did not differ in the latewood. Latewood lumen diameter was larger in the unsprayed trees (11.05 m for the unsprayed trees and 7.28 m for the sprayed trees). Tracheid diameters did not differ between treatments in the earlywood (Table 1).

b) Nehalem Progeny Tests

The tolerance classes differed in ring width and ring density, but the relative rankings of all wood properties did not differ across the two sites as evidenced by the lack of any site-by-tolerance classes effect (p values ranged from 0.2786 to 0.9001). The family-by-site wood density interactions were statistically significant, but the family groupings themselves were stable. This implies that the more tolerant families (or least tolerant families) will maintain their wood property ranking regardless of the SNC severity at a site. The tolerant families had lower than average wood density and faster than average growth (Table 2). This is not a surprising result because tolerance was defined, in part, by greater growth rates, and the negative correlation between diameter growth and wood density is due to the relatively strong adverse genetic correlation between diameter and growth (Bastion et al. 1985, King et al. 1988, Vargus-Hernadez and Adams 1991, St. Clair 1994). The components of overall wood density (earlywood density, latewood density and latewood proportion) were all lower for the tolerant families, but the differences were not statistically significant (Table 2).

Coal Creek, the site most severely impacted by SNC, had lower wood density than the Sarajarvie site (0.412 g/cc vs. 0.394 g/cc). This was a function of a much larger proportion of latewood at Coal Creek (0.735 vs. 0.580). In contrast, latewood density was higher at the less-infected Sarajarvie site (0.608 g/cc vs. 0.558 g/cc) and the earlywood density did

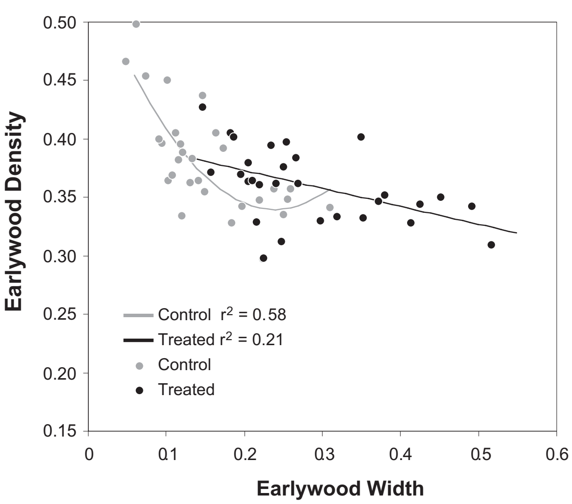

Figure 1. Relationship between earlywood density and earlywood width for Bravo-sprayed and control trees.

Table 1. Means, standard deviations, and level of statistical difference for wood properties in the last 3 rings of trees sprayed with Bravo and unsprayed control plots. Data from the trees sampled in the growth plots, except for tracheid diameter and cell wall thickness which are from a subsample.

	Control (unsprayed) Mean	Bravo-sprayed Mean	Sig. lev.
Ring Width	0.348	0.538	0.0288
Earlywood width	0.155	0.285	0.0173
Latewood width	0.193	0.253	0.0619
LW proportion	56.2	50.1	0.0001
Ring density	0.599	0.568	0.0687
EW density	0.380	0.360	0.0395*
LW density	0.772	0.778	0.5372
EW tracheid diameter	32.33	34.83	0.1949
EW cell wall thickness	3.18	5.35	0.0004
LW tracheid diameter	11.05	7.28	0.0377
LW cell wall thickness	5.70	5.62	0.8220
Sapwood moisture content**	86.1	107.4	0.0229

* earlywood width and earlywood with squared used as covariables

** combined May and September data from 2001 annual report.

Table 2. Least square means for tolerance classes means and sites for wood properties.

	Tolerance Class Means				Site Means		
	Tolerant	Average	Intolerant	P value	Coal	Sarajarvie	P value
Ring density	0.3873	0.4074	0.4154	0.0342	0.4123	0.3944	0.0597
Earlywood density	0.2663	0.2763	0.2819	0.1530	0.2732	0.2764	0.6346
Latewood density	0.5667	0.5921	0.5908	0.2328	0.5584	0.6080	0.0015
Latewood proportion	0.6381	0.6545	0.6793	0.3466	0.7350	0.5796	<0.0001
Ring width	0.7092	0.5994	0.5751	0.0024	0.6393	0.6165	0.5128
Basal area	1.658	1.2284	1.1223	0.0018	1.3833	1.3077	0.5942
Number of trees	18	31	34		28	55	

not differ between sites. When the latewood density was adjusted for growth rate, the differences between the sites disappeared (Figure 2). It appears that latewood density was affected by latewood width, and the reason for the lower wood density at Coal Creek is that it had wider latewood. No association was found between earlywood density and earlywood width.

c) SNCC Growth Impact Plots

Most of this research is ongoing. However, below is a scatter plot showing that sapwood moisture content seems to increase with the plot needle retention value (up to needle retention < 2.9), but that there is no trend in heartwood moisture content (Fig. 3).

Initial statistical exploration indicates that breast height sapwood area increases with needle retention. Results from the regression model SA = $ß_0 + ß_1$*dbh + $ß_2$*nr01 are shown in Table 3. Sapwood area at the crown base will be analyzed similarly.

Discussion

All three studies are demonstrating that SNC impacts wood quality. Latewood proportion is increased in diseased trees and this results in an increase in overall wood density. However, the effect of SNC on the density of the component parts is not clear. In the Bravo study, earlywood density increased, but no differences was found between the two progeny test sites. The increase in earlywood density in the Bravo plots appears to be a function of increased cell wall diameter. Latewood differences were shown between the two progeny test sites, but this appeared to be a function of latewood width. While the results of the two studies do not show the same results, they suggest that the disease influences wood properties. In addition, previous results have documented that SNC reduces moisture content of the sapwood (Johnson et al. 2001). We could not find any interaction between tolerance-class of planting stock and SNC with respect to wood quality. The better growing families performed the same relative to the other trees regardless of SNC severity. The larger data set on the effect of SNC severity and growth rate on wood properties will help answer many questions because eventually we hope to have solid comparisons of wood proper-

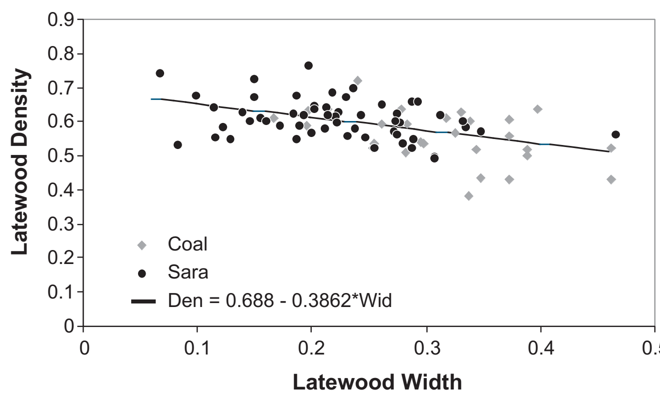

Figure 2. Relationship between latewood density and latewood width for two progeny tests.

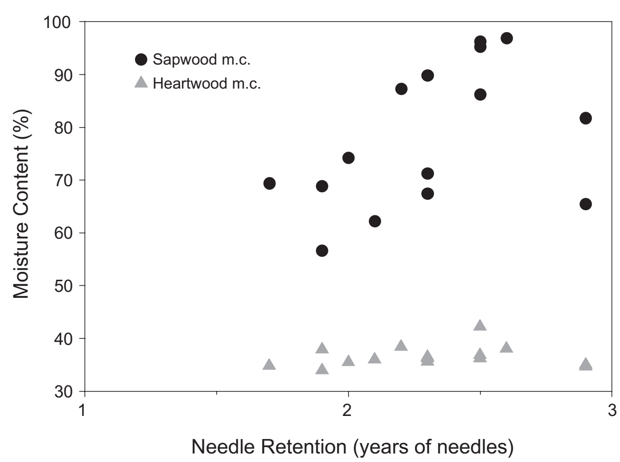

Figure 3. The effect of needle retention on moisture content in sapwood vs. heartwood in the SNCC Growth Impact Studies.

Table 3. Breast height sapwood area increases with needle retention (nr01), as shown by regression results from the SNCC Growth Impact Study Plots.

Effect	Estimate	Error	DF	t Value	Pr > |t|
Intercept	-219.74	51.8410	13	-4.24	0.0010
dbh	13.2193	0.6840	162	19.33	<.0001
nr01	41.9654	19.7912	162	2.12	0.0355

ties as a result of SNC but independent of growth ring width.

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Phaeocryptopus gaeumannii Infection, Colonization, and Pseudothecial Development: Unique Characteristics and Implications on Host-Pathogen Interactions.

Julia Kerrigan and Jeffrey Stone, OSU

Introduction

Studies on *Phaeocryptopus gaeumannii* growth and needle colonization have revealed unique aspects regarding the biology of the fungus (Capitano 1999, Stone and Carroll 1985). Although *P. gaeumannii*, the causal organism of Swiss needle cast of Douglas-fir (*Pseudotsuga menziesii*), has received a great deal of attention due to the development of disease epidemics over the past decade, many aspects of its infection biology remain unclear. The goal of this research is to gain a better understanding of the basic biology of *P. gaeumannii*. Specific objectives are to elucidate details of its entire life cycle, to evaluate conditions necessary for proliferation, and to investigate fundamental mechanisms of host specificity.

Materials and Methods

Douglas-fir seedlings have been inoculated by placing them under naturally infected trees in the Salal study site for approximately four weeks as described in previous reports by Stone and Reeser (2001). Needles from 2000 and 2001 inoculations have been collected at approximately six-week intervals from June 2001 to the present. Samples have been processed for examination with light microscopy (e.g. needle clearing, needle peels, and resin embedment) and scanning and transmission electron microscopy. An additional species of *Pseudotsuga* has been inoculated as described above, and naturally inoculated western hemlock (*Tsuga heterophylla*) and Sitka spruce (*Picea sitchensis*) needles were collected from trees at the Salal site. To increase the likelihood of finding fungal structures, samples also were inoculated by placing detached branches, kept turgid with water, under needles with sporulating *P. gaeumannii* pseudothecia in a moist chamber for up to seven days. Naturally and artificially inoculated non-host needles were prepared for light and scanning electron microscopy.

Ongoing Research

Details of *P. gaeumannii's* life history are being elucidated from collections made throughout the year. Nine sets of samples have been examined with light and scanning electron microscopy, and preliminary investigations have been made with transmission electron microscopy. Samples continue to be collected at regular intervals from inoculations made in 2000, 2001, and 2002. Although some results have been reported previously (e.g. Capitano 1999), all stages of the life cycle are being recorded for a comprehensive analysis.

Ascospores germinate and germ tubes grow on the needle surface, differentiating into an appressorium over a stoma. A penetration peg is formed from the appressorium and enters through the stoma, developing into a hypha that grows intercelullarly. No evidence of cell wall penetration or degradation has been seen. Intercellular hyphae grow along cell walls, appressed by an adhesive mucilaginous material deposited at irregularly spaced intervals by the advancing hyphae (Figure 1). Hyphae also proliferate in intercellular spaces, growing relatively straight for short distances until coming in contact with a cell wall, where an adhesive material is laid down and hyphal growth continues along the wall surface. These two types of growth differ from that of epiphytic hyphae, probably because of the interior host cells' convoluted shape and discontinuous surfaces. Hyphal tips sometimes appear swollen, probably providing a greater surface area for nutrient absorption; however, the nutritional relationship between the host and pathogen are not known. Internal hyphae, the adhesive material associated with them, and adjacent plant cells will be examined ultrastructurally (transmission electron microscopy) to investigate the relationship between the host and pathogen.

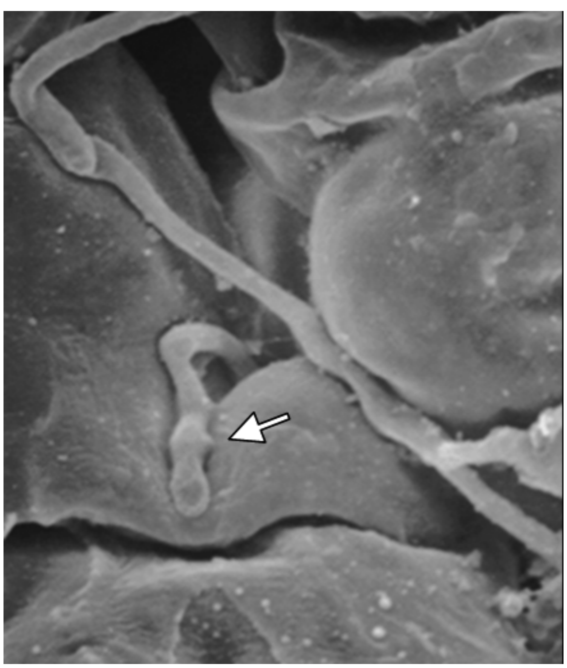

Figure 1. Internal hyphae. Note the advancing hypha is attached to the cell wall by adhesive pads.

Fruiting bodies (ascomata) develop from intercellular hyphae, and distinctive phialide-like cells are formed directly under stomata, as first reported by Stone and Carroll (1985). These have the appearance of conidiogenous cells, with a distinct apical wall thickening due to layered deposition of wall material. Such layered wall thickenings form after successive cycles of phialidic conidium formation in other fungi, although no conidial state of *P. gaeumannii* is known. These types of cells have not previously been found associated with teleomorphic structures (ascomata). The thickened walls of the phialide-like cells appear to form early because they have been seen on first-year infections when attached pseudothecial initials are relatively small. The phialide-like cells give rise to spherical pseudothecial initials that subsequently occlude the stomata, push through the cuticular wax, and extend above the needle surface.

Beyond forming pseudothecial initials, the function of these cells is not known. The wall thickenings may provide greater rigidity to the hyphae where they pass between guard cells, allowing cytoplasmic continuity to be maintained between the internal hyphae and the developing against the constricting pressure of the guard cells. The next step is to examine the phialide-like cells at different developmental ages to determine exactly which cells they form and when. Do the phialidic structures generate pseudothecial initial cells which subsequently give rise to pseudothecial cells, or are they directly involved with pseudothecial development? If they only produce pseudothecial initial cells, do these cells subsequently germinate and colonize needle surfaces (i.e. act as an asexual propagule)? Are they formed each year, or do they develop the first year and continue to produce cells for more than one year?

A large proportion of pseudothecial initial cells germinates and forms epiphytic hyphae, that heavily colonize needle surfaces throughout the fall and winter (Figure 2). Frequently these hyphae fuse with other epiphytic hyphae or pseudothecial initials. Occasionally they produce appressoria, suggesting that they can also establish internal infections but the occurrence of a successful penetration from an epiphytic hypha has not been observed. The ultrastructure of appressoria and penetration pegs that developed directly from germ tubes, associated with early (spring-summer) infections will be examined and compared with similar structures from pseudothecial initials and epiphytic hyphae (fall-winter). Epiphytic hyphae begin to degenerate the following spring while pseudothecia mature. The role of this type of growth is not known, but, based on the energy expenditure in hyphal proliferation, it appears to be a substantial part of the life cycle. Perhaps this stage helps to increase infection rates by colonizing needles and penetrating through unoccupied stomata.

Preliminary observations of non-host, coniferous substrates have revealed that ascospores germinate to produce germ tubes but do not form appressoria and do not penetrate species other than Douglas-fir. Appressoria formation may be triggered by surface topography. Needle topographies of the non-hosts examined thus far are notably different from Douglas-fir; therefore, the fungus may not recognize different stomatal conformations. To determine if appressorium formation responds to a specific thigmothrophic stimulus, observations of germ tube behavior on additional substrates, including plastic reproductions of Douglas-fir needles, are needed.

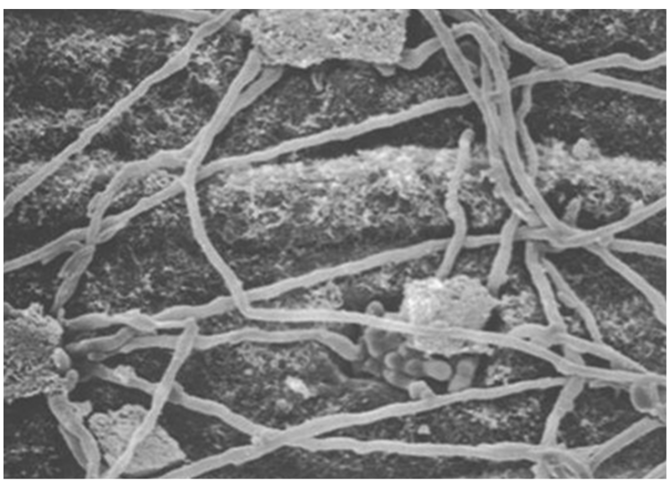

Figure 2. Needle surface with pseudothecial initials and epiphytic hyphae. The cuticular wax is being pushed aside as the pseudothecial initial cells emerge through the stomata.

We will continue to examine *P. gaeumannii* throughout the year to fill in unknown aspects of its life history. Much of the time spent over the next year will involve examining samples ultrastructurally, addressing the goals and questions mentioned above.

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Fungicidal Control of Swiss Needle Cast in a 20-year-old Forest Stand

Jeffrey Stone and Paul Reeser, OSU; Alan Kanaskie, ODF

Abstract

Annual spray appplications of chorothalonil fungicide were carried out over five consecutive years from 1996 – 2000 in a Douglas-fir forest stand. Fungicide applications reduced infection levels of *Phaeocryptopus gaeumannii* compared to the unsprayed plots in foliage sampled in 2001. Total needle retention was also increased in the fungicide spray treatment. Effects of fungicide spray on *P. gaeumannii* levels persisted in foliage produced in 2001, which was not fungicide treated but had lower infection levels in the treated plots due to reduced inoculum levels. Incidence of infection in the 2000 and 2001 foliage in the fungicide treated plots was high however, and differences between fungicide treated plots and untreated controls were slight. It appears that control of *P. gaeumannii* is beginning to breakdown after only one year of no fungicide spray.

Introduction

Although the pathogen *Phaeocryptopus gaeumannii* is widely distributed on Douglas-fir in western Oregon and Washington, extensive and severe Swiss needle cast disease (SNC) has not been the historical norm. Management options for controlling SNC in forest plantations are very limited at present, and the potential for control of SNC by fungicides has not received much attention in the United States. The disease is controlled in Christmas tree plantations by the fungicide chlorothalonil (Chastagner and Byther 1982, Skilling 1981, Hadfield and Douglas 1982). Annual applications of chlorothalonil are recommended beginning three years prior to planned harvest for marketable Christmas trees (Chastagner and Byther 1982). However, because of the longer duration of protection needed for Douglas-fir rotations, aerial fungicide sprays have not been considered an economically effective option for control of SNC in forest plantations.

Whether SNC can be controlled in forest plantations by aerial applications of fungicides is not known. Some aspects of *P. gaeumannii* biology suggest that annual spray applications throughout a rotation might not be necessary for disease control. Needles are susceptible to infection only during their first growing season. Needles only need to be protected for a few weeks during the peak period of ascospore release, late May through mid June. Needles more than one year old are not susceptible to new infection by ascospores (Stone et al. unpublished). Therefore, effective spray applications for two or three consecutive years could eliminate or significantly reduce levels of infection and inoculum production. New, unprotected foliage produced in subsequent years could become infected from residual infections or from outside sources of inoculum.

If fungicide sprays are successful in reducing infections below a critical level, SNC might be controlled for several years without additional fungicide applications. The amount of time before infection levels return to high levels would depend on the effectiveness of the fungicide spray, residual infection levels, proximity and severity of inoculum sources to the treated stands, and local environmental conditions favoring infection. Furthermore, most Douglas-fir trees can tolerate a low to moderate level of infection without developing symptoms of SNC. While it is probably impossible to completely eliminate *P. gaeumannii* from a forest stand by fungicide sprays, reducing and maintaining infection to below harmful levels may be possible.

This study was undertaken to determine whether a program of aerial fungicide spraying is effective in reducing infection levels of *P. gaeumannii* in forest stands, and how long it takes for infection levels to return to harmful levels after a multi-year treatment. This study was done in cooperation with the Oregon Department of Forestry, which treated study sites with annual aerial applications of Bravo fungicide between 1996 – 2000. Foliage produced in spring 2001 was the first year of unsprayed foliage and infection levels in this foliage should give a good indication of whether multi-year fungicide applications can provide long term control of SNC.

Materials and Methods

Study sites

Aerial sprays were applied to a sudy site established by the Oregon Department of Forestry near Beaver, OR. The stand was established in 1980 and was characterized as severely diseased in 1995. Bravo Weatherstik 720 fungicide was applied at the rate of 5.5 pt/30 gal/acre by aerial spray to three five-acre plots for five consecutive years, 1996-2000. Sprays were applied shortly after bud break, with shoots averaging 1 – 3 in. Adjacent unsprayed five-acre plots were designated controls.

Sampling

Two transects were established in two treated and two control study plots. Transects were oriented perpendicular to each other and crossed the plots from edge to edge from approximately the mid point of each side. Sampling points were located at approximately 100 ft intervals along each transect starting at approximately 50 ft in from the plot edge. Each transect had 6 sample points except in plot T3, a long narrow plot, which had 8 points in one transect and 4 in the other. Two trees were sampled at each sample point. Two secondary lateral branches were cut from the fifth to seventh whorl from the top. Needle retention on the sampled branches was assessed in the field, then branches were placed in bags and returned to the lab for infection assessments. Samples were collected in May 2001 and 2002.

Assessment

Needle retention was rated on a scale of 1-9, where 9 = 90-100% needles retained, for each internode starting with the current year (2001 foliage). Retention ratings for each internode (1997-2000) were summed to obtain a composite retention index for each branch. Needles were removed from internodes by age class, placed in envelopes and stored frozen (-20 C). Three samples of ten needles /age class/branch/tree were randomly drawn for quantitative PCR analysis (Winton et al. 2002). A sample of 50 needles/age class/branch/tree was randomly drawn for pseudothecia counts. Needles were affixed abaxial side up to index cards with double sided adhesive tape. Cards were examined under dissecting microscopes to determine the proportion of needles bearing pseudothecia (incidence of infection). The first ten needles on each card with pseudothecia present were then used to determine pseudothecia density. The needles were examined under a dissecting microscope fitted with a counting grid and the proportion of stomata occupied by pseudothecia in three segments (base, middle, tip) of each of the ten needles was determined. Infection index, the product of incidence and pseudothecia density, was used as a response variable for comparisons of treatments. Statistical analyses were performed with SAS for Windows Vers. 8 (SAS Institute, Cary, NC).

Results

For foliage sampled in May, 2001, which had been treated for five consecutive years, needle retention was significantly greater in plots that had been treated with Bravo for five years ($p < 0.05$, Table 1). The average retention index for treated plots, 27.3, represents approximately 75% of foliage in age classes 1-4 retained compared to about 40% for the control. The distribution of needles retained in the two treatments is shown in Figure 1. Nearly all current year needles were retained in both treatments. Nearly all 1999 needles were also retained in the Bravo treated plots, but only about half of this complement was retained in the unsprayed control plots. 70-80% of 1998 needles were retained in the treated plots compared to less than 10% for the control plots. A small proportion of 1997 needles remained on the treated trees but this complement was completely absent from the unsprayed trees.

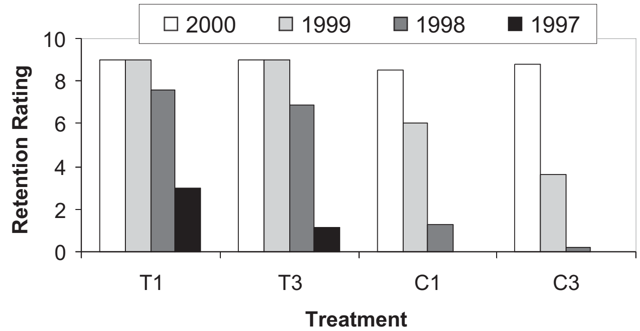

Figure 1. Comparison of needle retention ratings for plots treated with Bravo fungicide for 5 years (T1, T3) and unsprayed (C1, C3). Ratings are based on field assessment of needle retention for each internode on secondary lateral branches taken from between the 5-7th whorl from the treetop.

Quantitative PCR (QPCR) analysis of foliage sampled in May, 2001 showed significant differences in levels of *P. gaeumannii* in foliage for age classes 1998-2000 (Table 2). There were too few 1997 needles present in the control plot trees for this age class to be included in the analysis. QPCR values for both fungicide sprayed plots were significantly lower than foliage from unsprayed controls for all three age classes sampled.

Differences between fungicide sprayed and control treatments persisted through the first year that aerial fungicide sprays were not applied to the treatment plots. Foliage that emerged in June 2000 was the last age class to be treated with fungicide spray. Age class 2000 foliage from fungicide treated plots had one-half to one-third the level of infection (infection index) present in the unsprayed control at two years following emergence (Table 3). Infection levels in age class 2001 foliage were also significantly greater in the unsprayed controls than in the fungicide treated plots, although differences were not as great. Infection levels in 2001 foliage in plot C1 (unsprayed) were not statistically different from the two sprayed plots (Table 3).

Incidence of infection, the proportion of needles bearing at least one pseudothecium, measured in May, 2002 was high for fungicide sprayed as well as unsprayed plots for both age classes. Virtually 100% of needles in both treatments and both age classes were infected. Al-

Table 1. Mean needle retention indices for treated and control plots. Indices are the sum of needle retention ratings for each of four internodes, 1997-2000.

Plot	Composite Retention Index
T1	28.7
T3	25.8
C1	15.9
C3	12.4

Table 2. Comparison of quantitative PCR values (ng *P. gaeumannii* DNA/pg Douglas-fir DNA) for foliage for fungicide sprayed and unsprayed plots measured in May, 2001. Letters in the same column indicate different groups at $p < 0.05$.

	Needle Age Class		
Treatment	2000	1999	1998
C1	2.40 b	2.18 b	2.17 b
C3	2.56 b	2.38 b	2.22 b
T1	0.79 a	1.05 a	1.18 a
T3	0.28 a	0.46 a	1.14 a

Table 3. Comparison of infection index (incidence x pseudothecia density) for foliage collected in spring of 2002. Letters in the same column indicate different groups at $p < 0.05$.

Treatment	2001 Needles	2000 Needles
C1	0.12 b	0.30 b
C3	0.18 a	0.46 a
T1	0.08 b	0.14 c
T3	0.10 b	0.15 c

though infection index levels were different between sprayed and unsprayed plots, Table 4 shows that this is due to differences in pseudothecia density. Nearly all 2000 and 2001 needles were infected regardless of treatment, but the amount of infection in fungicide sprayed plots was slightly less than for unsprayed plots.

Table 4. Incidence and pseudothecia density (PSD) for age class 2000 and 2001 foliage sampled in spring 2002. Incidence is the proportion of needles bearing at least one pseudothecium. Pseudothecia density is the proportion of stomata occupied by pseudothecia, averaged for three segments of a needle.

Treatment	Incidence 2000	Incidence 2001	PSD 2000	PSD 2001
C1	1.0	1.0	0.30	0.12
C3	1.0	1.0	0.46	0.18
T1	0.96	0.99	0.14	0.08
T3	0.92	0.98	0.15	0.10

Infection levels along transects in both sprayed and unsprayed plots were examined for possible gradients from edge to center. No consistent patterns in distribution of infection levels were apparent for any of the plots in either the 2001 QPCR, or the 2002 infection index data. Analysis of QPCR for foliage collected in spring of 2002 is in progress.

Discussion

Fungicide applications for five consecutive years resulted in concurrent reduction of *P. gaeumannii* infection and significantly greater foliage retention in the sprayed compared to the unsprayed plots. Needle retention in current year needles was not different between sprayed and unsprayed plots, as expected. However, increased retention of the two- and three-year old needles resulted in approximately one additional years' complement of foliage in the sprayed vs. unsprayed plots. A separate analysis of wood characteristics from these plots showed that untreated control trees also have lower wood moisture content, decreased ring width, and increased latewood proportion compared to fungicide treated trees, characteristics that have been attributed to reduced vigor and defoliation due to disease (Johnson et al 2001). Taken together, these results reinforce the conclusion that *P. gaeumannii* is the primary agent responsible for the current decline of Douglas-fir in western Oregon and Washington. A separate analysis of growth from this study is in progress.

Foliage from fungicide treated plots had significantly lower levels of *P. gaeumannii* than unsprayed controls in 2001 foliage measured in May, 2002. Since this foliage had not been sprayed with a protectant fungicide, lower infection levels in this age complement must reflect reduced inoculum levels resulting from multiple year treatment in the fungicide-sprayed plots. However, it appears that differences in infection levels between sprayed and unsprayed plots after multi year treatment were already beginning to converge in the first complement of foliage not protected by fungicide. Infection levels in both treatment plots were significantly different from only one of the unsprayed control plots. Chlorothalonil has proved effective in controlling SNC in Christmas trees (Chastagner and Byther 1983) and forest plantations (Chastagner and Stone 2001). The WeatherStik formulation of chlorothalonil (Daconil) provided superior control to other formulations (Chastagner and Stone 2001).

Even though chlorothalonil fungicide significantly reduced *P. gaeumannii* levels in this study and others, complete elimination of the pathogen from the stands was not expected. Detectable residual levels of infection typically remain even where good disease control has been achieved (Chastagner and Byther 1983, Chastagner and Stone 2001). The amount of residual infection following a course of treatment is probably the most important factor affecting long term disease control. The amount of residual infection will be determined by the efficacy of the treatment, coverage, and timing. In this study, the amount of residual infection appears to be relatively high.

Although significant differences in infection levels were detected between treatments, our data suggest that the aerial fungicide spray treatment was only minimally effective in controlling *P. gaeumannii*. Incidence of infection in fungicide treated age class 2000 needles, measured in May, 2002 was nearly 100%, not significantly different from the unsprayed control. Even though the fungicide treatment reduced the amount of infection in these needles, there was still sufficient successful infection to effectively saturate foliage. Pseudothecia density in the sprayed plots was one-third to one-half that of the untreated control and accounted for the observed differences between treatments.

The pronounced increase in needle retention in the fungicide sprayed trees is somewhat surprising given their relatively high levels of residual infection. Manter et al. (2002) estimate that at pseudothecia densities above 25% the net annual needle carbon budget is negative due to impaired photosynthesis. Mean pseudothecia densities for fungicide treated, age class 2000 foliage in this study were below this threshold necessary to trigger absicission, but not unsprayed 2000 foliage, in agreement with the prediction of Manter et al. Given that incidence of infection in fungicide sprayed foliage was near 100%, it is not surprising that the unsprayed 2001 foliage in the fungicide treated plots also was nearly 100% infected. Furthermore, although there was a significant difference between control and fungicide treatments in the 2001 foliage, only one of the treatment plots was significantly different from contols when analyzed individually. It therefore appears that the control provided by five years of protectant fungicide application may be breaking down only one year after cessation of fungicide applications.

Aerial application of a copper fungicide was ineffective in reducing *P. gaeumannii* infections in a 19-year-old forest stand of Douglas-fir in New Zealand. However, handspraying the same material at the same concentration reduced incidence of infection to below 42% compared to 100% in unsprayed control (Hood and van der Pas 1979). The success of the handspray application was attributed to superior foliage coverage and greater amounts of material applied. Handspray applications were applied to run off by a person climbing within the tree crowns. This highlights the difficulty of achieving sufficient aerial application rates in forest tree stands compared to Christmas trees, where SNC is routinely controlled by fungicide. The relatively high amount of residual infection present in the fungicide treated plots in our study suggest that coverage may have been inadequate. Fungicide application volumes for forestry should probably be adjusted based on stand age and foliage area rather than a standard rate per acre. It is also possible that the level of disease at this site was too severe, and that aerial fungicides might be more effective in controlling SNC at sites with more moderate levels of disease.

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Variation in Pathogenicity Among Isolates of Phaeocryptopus gaeumannii

Lori Winton, Paul Reeser, Jeffrey Stone OSU

Abstract

The ability to infect Douglas-fir needles was compared for three strains of *Phaeocryptopus gaeumannii* belonging to two different genetic lineages. In on trial, one strain produced a greater amount of infection, one a lesser amount, and one strain was intermediate. No differences were observed in a second trial. Differences in infection in the first trial did not correspond to genetic lineage. Mycelial inoculations caused infections in needles that were one-year old at the time of inoculation. Such needles are not susceptible to infection by ascospores.

Introduction

Variation in susceptibility to infection by *Phaeocryptopus gaeumannii* has been reported for different subspecies and provenances of Douglas-fir (McDermott and Robinson 1989, Stephan 1998, Stimm and Dong 2001). These assessments have been based on plantations where different host provenances are growing together and exposed to local sources of *P. gaeumannii* inoculum, presumably a mixture of *P. gaeumannii* genotypes. Whether variation exists among strains of *P. gaeumannii* with respect to virulence or ability to infect Douglas-fir has not been established. The discovery by Winton (2001) that *P. gaeumannii* in the Pacific Northwest actually comprises two reproductively isolated lineages, or cryptic species, suggested that differences in pathogen virulence may be an important factor in the current decline of coastal Douglas-fir due to Swiss needle cast.

Winton (2001) also provided evidence of variation in pathogenicity among some strains of *P. gaeumannii* on Douglas-fir seedlings. One isolate, designated “North Fork” showed a significant difference in infection incidence (proportion of infected needles) between two different seed sources (Tillamook and Klamath Falls). Needle loss was increased for all seedlings inoculated with strains of *P. gaeumannii* compared to controls. Seedlings of both seed sources inoculated with one strain from Juno Hill had approximately 12% less needle retention than seedlings inoculated with other strains, and 34% less than uninoculated controls. These results suggest differences in both the ability to infect Douglas-fir as well as ability to cause premature needle loss among strains of *P. gaeumannii*. At the time this research was done, the identities of the genotypes (Lineage 1 or Lineage 2, following Winton 2001) of the strains used was unknown.

This study was conducted to try to verify the results of Winton (2001) with strains of *P. gaeumannii* of known genotype. Three strains of *P. gaeumannii* used in this study were the same as used by Winton in her 2001 study.

Materials and Methods

Plant material

Plug-1 Douglas-fir seedlings were provided by Starker Forests and were grown by Pelton Nursery (Maple Ridge, BC) from the "Burnt Woods" seed source. Seedlings were transplanted in a soil/peat/perlite potting mix in one gallon pots. Seedlings were fertilized with Osmocote Pro 18-8-8 with micronutrients. Prior to inoculation, seedlings were preconditioned (series 1 only) for two weeks in a growth chamber at 18 C, 85% RH, 12 hr photoperiod with both fluorescent and incandescent illumination. Seedlings were maintained under the same conditions for 14 da following inoculation, then incubated under a 50% shade cloth at the OSU Botany field lab until they were sampled in May, 2002.

Fungal isolates

Isolates JH3, LS1 and NF5 were isolated from single ascospores and maintained as stock cultures on Potato dextrose agar (PDA). These isolates were also used in a similar study conducted by Winton (2001). Inoculum was prepared from cultures of each isolate grown in stationary culture in 1L Erlenmeyer flasks containing 250 mL Potato Dextrose Broth (PDB). Cultures of a fourth isolate, MW3, were found to be contaminated and were not used. JH3 is characterized as belonging to *P. gaeumannii* Lineage 1 and LS1 and NF5 to Lineage 2, following Winton (2001).

Inoculation procedures

Inoculations were done in two groups, Series 1 and 2 separated by 14 days. Inoculation procedures differed slightly between the two groups. For Series 1, inoculum cultures were harvested at approximately 60 da. The mycelium was filtered through nylon mesh (Miracloth), fresh weight determined, and added to a measured volume of 0.05% water agar to give a concentration of 0.02 g mycelium/mL. The mycelium was then fragmented with a tissue homogenizer (Brinkmann Instruments). A sample of each inoculum was serially diluted and plated on potato dextrose agar to assess the viable fragments per mL. Inoculum was applied to the seedlings in the growth chamber of the by means of an airbrush spray apparatus, at 25 mL (0.5 g) per tree in the growth chamber. For Series 2, cultures used for inoculum were aged approximately 74 days. Inoculum was prepared as above, except mycelium was added to sterile water, not dilute agar. Seedlings for Series 2 were not preconditioned in the growth chamber and new foliage was two weeks older than for series 1. An uninoculated control group was included with both Series to verify that infection only occurred from the applied inoculum.

Analysis

Two branches were sampled from each seeding in April, 2002. Needles were removed from the one-year-old internodes and pooled. Three samples of ten needles /age class/seedling were randomly drawn for quantitative PCR (QPCR) analysis (Winton et al. 2002). A sample of 50 needles/age class/seedling was randomly drawn for pseudothecia counts. Needles were affixed abaxial side up to index cards with double sided adhesive tape. Cards were examined under dissecting microscopes to determine the proportion of needles bearing pseudothecia (incidence of infection). The first ten needles on each card with pseudothecia present were then used to determine pseudothecia density. The needles were examined under a dissecting microscope fitted with a counting grid and the proportion of stomata occupied by pseudothecia in three segments (base, middle, tip) of each of the ten needles was determined. Statistical analyses were performed with SAS for Windows Vers. 8 (SAS Institute, Cary, NC). Incidence, infection index, and QPCR were compared by ANOVA with the Duncan multiple range test option. The control group was omitted from statistical comparisons.

Results

The only differences in infection that were detected occurred in Series 1. Isolate NF5 had a significantly higher infection index than the other two strains, and higher QPCR values than strain LS1 (Table 1). Due to lower overall infection levels, differences in infection index and QPCR for Series 2 were not statistically significant, but were also highest for strain NF5.

inoculations, as well as the inoculum cultures, were 2 weeks older in Series 2. Seedlings used in this inoculation were not preconditioned in the growth room as they were for Series 1, and the inoculum was applied without addition of a small amount of agar that was used in Series 1 to aid adhesion of the hyphal fragments to needle surfaces. Results of the two series were therfore analyzed separately.

Table 1. Results of inoculations of Douglas-fir seedlings with three different strains of *Phaeocryptopus gaeumannii*. Letters in columns denote means different at $p < 0.05$.

Series 1	Genotype	log cfu/mL	Incidence	Efficiency (inc/cfu)	Infection Index	QPCR
JH3	Lineage 1	5.11	0.656 A	0.13	0.075 B	2.36 AB
NF5	Lineage 2	5.50	0.828 A	0.15	0.125 A	2.78 A
LS1	Lineage 2	4.60	0.738 A	0.16	0.073 B	1.58 B
Series 2						
JH3	Lineage 1	5.41	0.350 A	0.06	0.027 A	0.91 A
NF5	Lineage 2	5.36	0.496 A	0.09	0.047 A	0.92 A
LS1	Lineage 2	5.32	0.443 A	0.08	0.032 A	0.87 A

Discussion

Because of limitations in growth room space this experiment was divided into two sets of inoculations spaced 14 days apart. The inoculation procedure was successful, with high proportions of needles becoming infected by *P. gaeumannii* in both inoculation series. Overall infection levels for all three strains was much higher in Series 1, pseudothecia density and QPCR values were approximately twice that of Series 2. Several differences in the experimental conditions between Series 1 and Series 2 could account for higher infectin levels. Shoots in Series 2

Levels of infection one year following inoculation of seedlings with macerated mycelium did not reveal strong differences between different strains of *P. gaeumannii*. All three strains colonized needles and sporulated within one year of inoculation, regardless of strain or lineage designation. In fact there appeared to be greater differences in infection levels between two strains belonging to the same lineage than between Lineage 1 and Lineage 2 (Table 1). These results therefore do not point clearly to either of the two *P. gaeumannii* lineages identified by Winton (2001) occurring in the epidemic area as being more virulent. While strain LS1 had lower infection index and QPCR values in Series 1, the measured concentration of the Series 1 inoculum for this strain (hyphal fragments per mL) was somewhat lower than for the other two strains. While care was taken to prepare all the inoculum in the same way, concentration differences were unavoidable. It is not clear if this could account for the infection differences in Series 1, but infection levels for the three strains follow the same pattern as inoculum concentrations.

These inoculations were made with macerated mycelium from pure cultures derived from single ascospores. This was done to ensure that the inoculum applied would be genetically uniform. Using macerated mycelial inoculum also allowed testing for differences between strains sooner than could be done with ascospore inoculation. In order to inoculate seedlings with ascospores of known genetic source, seedlings would have to be first inoculated with mycelial fragments from single-spore cultures as was done in this experiment. Then, one year later when pseudothecia formed on the artificially inoculated foliage, uninfected seedlings could be exposed to ascospore inoculum from the infected seedlings. The time and amount of seedlings needed to produce suffcient amounts of ascospore inoculum for experimental use make this procedure impractical.

There are differences between ascospore and mycelial inocula, however, and it is possible that mycelial inoculation masked differences between the strains in ability to infect Douglas-fir needles. For example, it is generally accepted that ascosopres are only able to infect newly emergent needles during their first growing season (Boyce 1940, Hood unpublished, Hansen et al 2000, Stone et al. unpublished). In field exposures of seedlings grown in container nurseries with very limited exposure to *P. gaeumannii* inoculum and which are therefore essentially free of infection, only newly emerged foliage becomes infected. Older needles remain free of *P. gaeumannii*. However, in our inoculations with macerated mycelium both newly emergent and needles that were one-year-old at the time of inoculation became infected. No infections were found on two-year old needles of uninoculated control seedlings sampled in April 2002. Incidence of infection of two-year–old needles from inoculated seedlings ranged from 12 to 100%, averaging 47%.

Infection of one-year-old needles by mycelial inoculum suggests a fundamental difference between ascospores and mycelial inoculum. Capitano (1999) observed superficial hyphae of *P. gaeumannii* on needles forming appressoria above stomata and penetrating the needles. This appears to be a proliferating phase of growth of *P. gaeumannii*, and may involve a slightly different infection mechanism than for ascospores. Mycelial fragments used for inoculation of seedlings may behave in a similar way and are able to infect needles that are otherwise not susceptible to infection by ascospores.

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Susceptibility of Douglas-fir Seed Sources to Infection by *Phaeocryptopus gaeumannii*

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Abstract

Nine Douglas-fir seed sources from western Oregon were tested for susceptibility to infection by *Phaeocryptopus gaeumannii*. All seed sources became infected, but one seed source had significantly higher levels of infection than other sources. No relationship between infection levels and elevation of origin, or between western and eastern Oregon seed sources was found.

Introduction

Variation in Swiss needle cast symptom expression due to infection by *Phaeocryptopus gaeumannii* among Douglas-fir provenances has been well documented. Similar patterns of susceptibility to disease have been reported for Douglas-fir provenance studies in western North America (Hood 1982, McDermott and Robinson 1989), Europe (Stephan 1998, Stimm and Dong 2001) and New Zealand (Hood and Wilcox 1971). In general, Douglas-fir from the intermountain interior (white variety or ssp. *glauca*), has more severe SNC symptoms than the western (green variety or ssp. *menziesii*) provenances when exposed to similar levels of disease pressure. Differences in susceptibility to infection in different Douglas-fir varieties have also been reported, again with the western or green variety having fewer pseudothecia-bearing needles than interior or northern California provenances (Stephan 1998, Mcdermott and Robinson 1989, Hood 1982). A general pattern has been noted where susceptibility to infection by *P. gaeumannii* and symptom severity tend to be greater in Douglas-fir genotypes originating from areas of lower rainfall and humidity (Hood 1982, Mcdermott and Robinson 1998). Hood (1982) reported a significant regional correlation between mean spring rainfall and incidence of infection. This pattern led McDermott and Robinson (1989) to suggest that higher disease pressure in geographic locations of high rainfall and humidity has led to greater selection pressure for disease resistance to SNC in local natural populations.

A similar pattern of genetic variation in susceptibility to SNC in relation to local climate patterns may exist in natural populations in western Oregon, Washington and northern California. Hood and Wilcox (1971) reported that Douglas-fir provenances from higher elevation and interior habitats in California and Oregon were more susceptible to SNC than those from coastal, low elevation habitats. Selection of appropriate seed stocks for tree improvement and for reforestation of sites with significant risk of SNC is one of the most important approaches for long term control of SNC in the Pacific Northwest. We undertook this study as a preliminary attempt to determine the range of variation in susceptibility to infection in Douglas-fir seed sources from western Oregon. We chose seed sources to reflect a gradient of altitude and latitude in order to determine whether any general relationship between geographical source and disease susceptibility may exist.

Materials and Methods

Plant material

Douglas-fir seedlings used in this study are shown in Table 1. All seedlings were grown as bare root stock except the Burnt Woods seed source which were container stock from the Pelton Nursery, Maple Ridge BC. Other seed sources were provided by the Oregon Department of Forestry Phipps Nursery, Elkton Oregon, and the USDA Forest Service J. Herbert Stone Nursery, Central Point Oregon.

All seedlings were potted in January, 2001, in 4-gal pots containing a soil-peat-perlite potting mix. Seedlings were fertilized with Osmocote Pro (18-8-8, Scott Sierra Horticultural Products).

Inoculation

Seedlings were randomly assigned to groups (blocks) in groups of five. Four blocks of 50 seedlings were exposed for 30 days at the Salal Departure study site, from May 22 until June 22, 2001. All seedlings had broken bud and shoots were 20-30 cm long when the inoculum exposure commenced. Following exposure, seedlings were returned to the OSU Botany Field lab for incubation. Seedlings were incubated in the same blocks as for inoculum exposure and kept under 50% shade cloth until November, 2001, then moved to full sun.

Evaluation

Foliage was sampled in April, 2002. Needles were removed from the 2001 internodes placed in envelopes and stored frozen (-20° C). Three samples of ten needles /tree were randomly drawn for quantitative PCR analysis (Winton et al. 2002). Incidence and pseudothecia density was determined from samples of 50 needles for each tree affixed to index cards with the abaxial side up. Cards were examined under dissecting microscopes to determine the proportion of needles bearing pseudothecia (incidence of infection). The first ten needles on each card with pseudothecia present were then used to determine pseudothecia density. The needles were examined under a dissecting microscope fitted with a counting grid and the proportion of stomata occupied by pseudothecia in three segments (base, middle, tip) of each of the ten needles was determined. Infection index, the product of incidence and pseudothecia density, was used as a response variable for comparisons of treatments. Statistical analyses were performed with SAS for Windows Vers. 8 (SAS Institute, Cary, NC).

Results

Infection levels were significantly higher in only one seed source, the Burnt Woods seed source. This result was found for both the quantitative PCR and the infection index data (Table 2). No relationship was seen between elevation of origin and in-

Table 1. Douglas fir seedlings used in this study and their origins.

Nursery Source	Type	Seed Source	Seed Zone	Elevation (ft)
Phipps	Bare root	NNC-06-71-DFR-99	5	500
Phipps	Bare root	NNC-07-71-DFR-99	5	1000
Phipps	Bare root	OAD-20-71-DFR	5 (052)	1500
Phipps	Bare root	OAD-36-71-DFR	5 (052)	1800
Phipps	Bare root	NNC-04-71-DFR-99	4	1000
Phipps	Bare root	NNC-16-81-DFR-99	9	1000
Phipps	Bare root	OSD-60-71-DFR	12 (462)	2500
Starker/Pelton	Container	BurntWoods	Burnt Woods	500
JH Stone	Bare root	340-9 PSME-14-14025-502-4444-95-SB	Umatilla NF	4,500-5,500
JH Stone	Bare root	858-9 PSME-07-07026-400-82-SIA	Ochoco NF	5000

fection levels (Figure 1). Infection index values were highly correlated with QPCR (Figure 2).

Table 2. Comparison of quantitaive PCR and infection index for nine Oregon Douglas-fir seed sources. Letters in columns indicate significantly different means at $P < 0.05$.

Seed Source	QPCR	nfx	Elevation
Burntwoods	2.26 a	0.18 a	500
NNC0471	1.01 b	0.12 b	1000
OAD2071	0.84 b	0.11 b	1500
NNC0771	0.81 b	0.11 b	1000
OSD6071	0.71 b	0.10 b	2500
NNC0671	0.66 b	0.08 b	500
OAD3671	0.64 b	0.09 b	1800
PSME14	0.48 b	0.09 b	5000
PSME07	0.36 b	0.06 b	5000

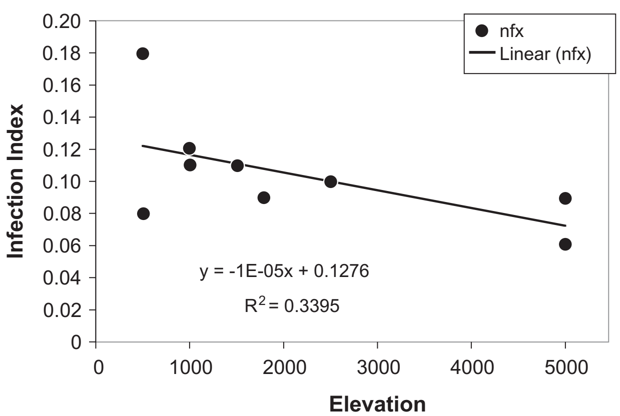

Figure 1. Relationship between infection index (incidence x pseudothecia density) for nine Oregon Douglas-fir seed sources.

Discussion

Based on previously published studies, higher infection levels were expected for the interior, high elevation Douglas-fir provenances from the Umatilla and Ochoco National Forests. Instead, these provenances had lower levels of infection than low elevation, coastal provenances. The seed source with significantly higher infection, the Burnt Woods seed source, was also the only seed source tested that was produced as container stock. Although the results suggest that seedling growing conditions may have influenced the infection levels, no apparent cause suggests itself. All seedlings were at the same phenological stage of shoot emergence when they were exposed to inoculum, and all inoculation and incubation groups were randomized to control spatial variation. Agreement between QPCR and infection index was very good. Having the two independent methods of assessment makes it unlikely that measurement errors are responsible for these puzzling results.

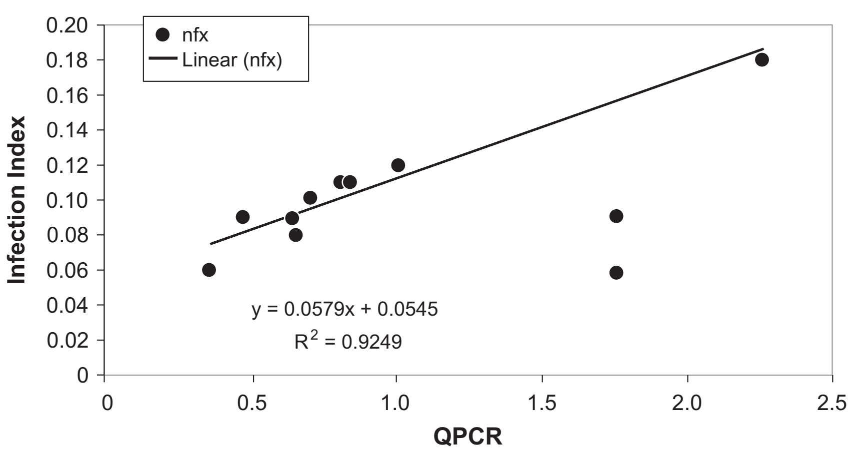

Figure 2. Relationship between quantitative PCR and Infection inex assessments of infection in nine Oregon Douglas-fir genotypes.

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Fungicidal Management of Swiss Needle Cast

Progress Report 2002

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Abstract

During 2001, applications of high rates of Thiolux and Golden Dew sulfur were applied to trees that had initially been sprayed with these fungicides in 2000. Treatments were applied either as a spray-to-wet or broadcast application. After two years of treatment, statistical analysis of the data indicated that application method had no affect on the effectiveness of the Thiolux, Golden Dew, or Daconil treatments used in this study in controlling Swiss needle cast (SNC). The 2002 results confirmed the 2001 findings that high rates of sulfur, particularly the Thiolux formulation, have the potential to provide control of SNC comparable to Daconil. However, the 2002 results from this trial also indicate that sulfur application may not be as effective as Daconil in limiting the increase of SNC on older age classes of needles. This study suggests that additional research is needed to determine the effectiveness of sulfur applications in limiting the buildup of SNC on older age classes of needles. During 2001, additional applications of Daconil were also applied to two plots that were established in 1999. During the three years of these studies, trees that have been sprayed with Daconil have had significantly lower levels of disease, better needle color and generally less needle loss than trees that were not sprayed. Growth measurement data will be collected from some of the trees in these plots this coming winter. A trial was also established during 2002 to examine the effectiveness of several types of fundicides in protecting needles from SNC. Materials included in this trial are Thiolux, several copper fungicides, a biologically-based material, and Daconil WeatherStik.

Progress Report - 2001/2002 Studies

Thiolux/Golden Dew sulfur tests (DF 600) - Data from a series of industry, Oregon State University, and Washington State University trials in Oregon and Washington indicate that it might be possible to reduce the development of Swiss needle cast (SNC) with foliar applications of Thiolux sulfur during shoot elongation. Laboratory spore germination tests have shown that Thiolux and Golden Dew sulfur were equally effective in reducing germination and inhibiting growth of SNC ascospore germ tubes. Field trials conducted during 2000/2001 showed that there was a clear trend of decreasing disease with increasing rates of Thiolux sulfur when treatments were applied shortly after budbreak and/or about two weeks later. Studies also indicated that results with Golden Dew sulfur were much more variable than with Thiolux.

During 2001, additional applications of the highest rates of Thiolux, Golden Dew, and Daconil Weather Stik were applied to trees that had received two applications of these materials in 2000. As in 2000, two methods (spray to wet the foliage or broadcast applications) were used to apply these materials to the trees. The spray to wet treatments were mixed in the equivalent of 100 gallons and the broadcast applications were applied in 30 gallons of water per acre. Each treatment was applied to a single tree in each of eight blocks on May 31 and June 14, 2001. Disease and needle color were assessed as indicated below on samples collected on April 10, 2002.

SNC impact studies (DF 399A & B) - During early spring 1999, stands of Douglas-fir timber along the central Washington coast exhibited extensive needle discoloration and premature needle loss. In an effort to obtain information on the role SNC has on the condition of the trees in these stands, paired fungicide control plots were installed at two sites in 1999. Applications of Daconil WeatherStik 720 (5.5 pts/100 gallons) were applied to half of the trees at each site using a high-pressure sprayer. At the Rayonier site (DF 399A), all of the trees within one of five 60' X 100' paired plots were sprayed. At the Grays Harbor County site (DF 399B), there are three replications of ten treated and check trees. During spring 2001, additional Daconil treatments were applied to the trees that had been treated in 1999 and 2000. Samples of 1999, 2000, and 2001 growth were collected from each tree at the Grays Harbor plot on April 11, 2002. Samples of only the 2000 and 2001 growth were collected from each tree at the Rayonier plot on April 10, 2002. Disease, needle color and needle loss were rated for each age class of needles on each shoot using the following assessment methods and scales.

Disease Incidence - Number of needles out of ten that have one or more SNC pseudothecia on them.

Disease Severity – Disease severity is rated on a 0 to 6 scale where 0 = none, 1 = <1%, 2 = 1 – 10%, 3 = 11-25%, 4 = 26-50%, 5 = 51-75%, and 6 = >75% of stomates on the needles are plugged with pseudothecia. These ratings are made with the aid of a card that illustrates sections of needles with 180 stomates that have 1, 10, 25, 50, and 75% of the stomates plugged with pseudothecia.

Disease Index - A disease index is calculated by multiplying the disease incidence times disease severity. Thus our disease index ranges from 0 to 60.

Needle Loss – Needle loss is rated on a scale of 0 to 10, where 0 = none, 1 = 1-10%, 2 = 11-20%, 3 = 21-30%,…., and 10 = 91-100% loss.

Needle Color – Needle color is rated on a 1 to 6 scale, where 1 = healthy-appearing dark green needles, 2 = healthy-appearing green needles, 3 = needles with a slight yellow mottling on a green background that may also have brown spots or tips on the needles, 4 = dull green needles with moderate chlorosis that may also have brown spots or tips on the needles, 5 = extensive yellowing/browning, and 6 = uniformly yellow needles that may have some brown spots or tips.

Results from 2001/2002 trials

Thiolux/Golden Dew sulfur test (DF 600) – Statistical analysis indicated that application method had no affect on the effectiveness of the Thiolux, Golden Dew, or Daconil treatments used in this study (Data not shown). As reported last year, the level of disease on the 2000 needles one year after treatment was significantly reduced by all the fungicide treatments (Table 1). In 2001, the disease index was similar for trees that had been sprayed with Thiolux and Daconil. Golden Dew also reduced the level of SNC, but was not as effective as the Thiolux or Daconil. A similar pattern of reduction in disease on the 2001 needles with sulfur treatments was seen one year after spraying in 2002 (Table 2). Disease data collected on the 2000 age class of needles after two years of treatments indicate that the sulfur treatments were not as effective as Daconil in limiting the buildup of disease on these needles (Table 1). None of the fungicide treatments had any effect on needle color or needle loss ratings (Tables 1 & 2).

The results of this trial confirm that high rates of sulfur, particularly

Table 1. Effect of two years of Thiolux, Golden Dew, and Daconil WeatherStik applications on the levels of Swiss needle cast on the 2000 age class of needles (DF 600).

	Disease index[2]		Needle color[2]		Needle loss[2]	
Treatment[1]	2001	2002	2001	2002	2001	2002
Check	20.9 a	38.8 a	2.4 a	2.3 a	0.0 a	0.4 a
Golden Dew	12.2 b	33.8 ab	1.8 a	2.7 a	0.1 a	0.4 a
Thiolux 80W	4.4 c	27.9 b	2.0 a	2.2 a	0.0 a	1.0 a
Daconil WeatherStik 720	0.0 c	2.1 c	1.9 a	1.6 a	0.0 a	0.0 a

[1] 90 lbs of Thiolux 80W, 78.3 lbs of Golden Dew Sulfur, or 5.5 pts of Daconil WeatherStik were mixed with 100 gallons of water and applied to wet the foliage or mixed with 30 gallons of water and applied as a broadcast application at 30 gal/acre on May 30 and June 13, 2000 and May 31 and June 14, 2001. Each treatment was applied to a single tree in each of eight blocks. The length of the new growth averaged 2.9 inches on May 30, 2000 and 3.0 inches on May 31, 2001. Tactic sticker was added to the Thiolux and Golden Dew treatments at the rate of 8 oz/100 gallons of water.

[2] Disease index and needle color/loss data are for April 2, 2001 and April 10, 2002. Since there were no statistical differences between the spray-to-wet and broadcast application methods, the data in this table is a combination of both of these application methods. Numbers in columns followed by the same letter are not significantly different, P=0.05, DMRT.

Table 2. Effect of Thiolux, Golden Dew, and Daconil WeatherStik applications on the levels of Swiss needle cast on the 2001 age class of needles (DF 600).

Treatment[1]	Disease index[2]	Needle color[2]	Needle loss[2]
Check	20.0 a	1.6 a	0.1 a
Golden Dew	12.3 b	2.4 a	0.1 a
Thiolux 80W	8.8 bc	1.9 a	0.1 a
Daconil WeatherStik 720	5.7 c	1.8 a	0.1 a

[1] 90 lbs of Thiolux 80W, 78.3 lbs of Golden Dew Sulfur, or 5.5 pts of Daconil WeatherStik were mixed with 100 gallons of water and applied to wet the foliage or mixed with 30 gallons of water and applied as a broadcast application at 30 gal/acre on May 31 and June 14, 2001. Each treatment was applied to a single tree in each of eight blocks. The length of the new growth averaged 3.0 inches on May 31, 2001. Tactic sticker was added to the Thiolux and Golden Dew treatments at the rate of 8 oz/100 gallons of water.

[2] Disease index and needle color/loss data are for April 10, 2002. Since there were no statistical differences between the spray-to-wet and broadcast application methods, the data in this table is a combination of both of these application methods. Numbers in columns followed by the same letter are not significantly different, P=0.05, DMRT.

the Thiolux formulation, have the potential to provide control of SNC comparable to Daconil. However, this trial also indicates that sulfur application may not be as effective as Daconil in limiting the increase of SNC on older age classes of needles. This study suggests that additional multi-year studies are needed to determine the effectiveness of sulfur applications in controlling SNC.

Impact studies (DF 399A & B) - At the Grays Harbor test site, virtually no disease has developed on the 1999, 2000, and 2001 age classes of needles that had been sprayed with Daconil (Table 3, 4, & 5). On the non-sprayed trees there has been approximately a two-fold increase in the disease index on the 1999 and 2000 needles between the time evaluations were initially done in 2000 and 2001, respectively, and when they were done one year later (Tables 3 & 4). On the 1999 needles, there has been about a threefold increase in the disease index for this age class of needles between 2000 and 2002 (Table 3).

Applications of Daconil have generally improved needle color and reduced needle loss ratings on the 1999 age class of needles (Table 4). Daconil has not improved the color ratings or reduced needle loss ratings for the 2000 or 2001 age class of needles (Table 4 & 5).

Similar results were obtained at the Rayonier test site (Tables 6 & 7). Trees sprayed with Daconil have significantly lower levels of disease, better needle color and generally less needle loss than trees that were not sprayed.

2002/2003 Trials

Fungicide screening trial (DF 102) - A trial has been established to examine the effectiveness of several types of fundicides in protecting needles from SNC (Table 8). Materials included in this trial are Daconil WeatherStik, Thiolux, several copper fungicides (Kocide DF, Kop-R-spray, and Phyton 27) and a biologically-based material (QRD 131). A single application of each material was applied to one tree in each of 10 blocks on May 31, 2002. All treatments were applied with a Solo backpack sprayer equipped with an 8003 nozzle @ 15 psi. Trees were sprayed to wet and the length of new growth ranged from 1.5 to 3.5 inches at the time of application. A non-sprayed tree in each block served as checks. The affects of these treatments on disease development will be assessed during spring 2003.

SNC impact studies (DF 399A & B) - On May 30, 2002, an additional application of Daconil WeatherStik was applied to all of the trees in the

Table 3. Effect of high pressure ground-based applications of Daconil WeatherStik 720 in 1999, 2000 and 2001 on the development of Swiss needle cast on 1999 needles at the Grays Harbor test site (DF 399B)[1].

		Disease index			Needle color			Needle loss		
Treatment	Prod./100 gal	2000	2001	2002	2000	2001	2002	2000	2001	2002
Check	-	16.2 a[2]	42.8 a	52.2 a	3.0 a	1.8 a	3.5 a	2.0 a	1.4 a	3.9 a
Daconil WeatherStik 720	5.5 pt	0.0 b	0.1 b	1.8 b	1.8 b	1.3 a	1.5 b	1.5 b	0.7 b	0.9 b

[1] Trees were sprayed to drip on June 11, 1999, May 25, 2000 and May 30, 2001. Disease and needle color/loss data were taken on April 6, 2000, April 4, 2001 and April 11, 2002.

[2] Numbers in columns followed by the same letter are not significantly different, P=0.05, t-test.

Table 4. Effect of high pressure ground-based applications of Daconil WeatherStik 720 in 2000 and 2001 on the development of Swiss needle cast on 2000 needles at the Grays Harbor test site (DF 399B)[1].

		Disease index		Needle color		Needle loss	
Treatment	Prod./100 gal	2001	2002	2001	2002	2001	2002
Check	-	18.8 a[2]	40.7 a	1.6 a	2.4 a	0.2 a	1.3 a
Daconil WeatherStik 720	5.5 pt	0.1 b	1.9 b	1.1 a	1.3 a	0.2 a	1.0 a

[1] Trees were sprayed to drip on May 25, 2000 and May 30, 2001. Disease and needle color/loss data were taken on April 4, 2001 and April 11, 2002.

[2] Numbers in columns followed by the same letter are not significantly different, P=0.05, t-test.

Table 5. Effect of high pressure ground-based applications of Daconil WeatherStik 720 in 2001 on the development of Swiss needle cast on 2001 needles at Grays Harbor test site (DF 399B)[1].

		Disease		Needle	
Treatment	Prod./100 gal	Incidence	Index	Color	Loss
Check	-	8.7 a[2]	13.4 a	2.1 a	0.2 a
Daconil WeatherStik 720	5.5 pt	0.1 b	0.1 b	1.6 a	0.1 a

[1] Trees were sprayed to drip on May 30, 2001. Disease incidence, index, and needle color/loss data are for April 11, 2002.

[2] Numbers in columns followed by the same letter are not significantly different, P=0.05, t-test.

Table 6. Effect of high pressure ground-based applications of Daconil WeatherStik 720 in 2000 and 2001 on the development of Swiss needle cast on 2000 needles at the Rayonier test site (DF 399A)[1].

		Disease index		Needle color		Needle loss	
Treatment	Prod./100 gal	2001	2002	2001	2002	2001	2002
Check	-	12.2 a[2]	41.7 a	2.5 a	3.2 a	0.2 a	1.1a
Daconil WeatherStik 720	5.5 pt	0.0 b	0.5 b	1.8 b	1.8 b	0.1 a	0.2 b

[1] Trees were sprayed to drip on May 25, 2001 and May 30, 2001. Disease and needle color/loss data were taken on April 4, 2001 and April 10, 2002.

[2] Numbers in columns followed by the same letter are not significantly different, P=0.05, t-test.

Rayonier test plot that have been sprayed during the past three years. During the coming winter, growth measurements will be obtained from the trees in this and the Grays Harbor plot. Disease and foliage assessments will also be made during spring 2003.

Aerial Thiolux application trial (DF 202) - In cooperation with Jeff Stone and Alan Kanaskie, a series of aerial application test plots were established during this past spring to examine the effects of Thiolux sulfur on the development of SNC and growth of the trees under operational application conditions.

Acknowledgements

Personnel who worked on this project include Joe Hudak, Kathy Riley, Jan Sittnick and Paul Kaufmann. In addition to the Swiss Needle Cast Cooperative, the Washington State Commission on Pesticide Registration also supported portions of this research. The assistance of Rayonier and the Grays Harbor County Forestry Department is greatly appreciated.

Table 7. Effect of high pressure ground-based applications of Daconil WeatherStik 720 in 2001 on the development of Swiss needle cast on 2001 needles at the Rayonier test site (DF 399A)[1].

		Disease		Needle	
Treatment	Prod./100 gal	Incidence	Index	Color	Loss
Check	-	9.1 a[2]	16.3 a	2.3 a	0.2 a
Daconil WeatherStik 720	5.5 pt	0.0 b	0.0 b	1.7 b	0.1 a

[1] Trees were sprayed to drip on and May 30. 2001. Disease incidence, index, and needle color/loss data are for April 10, 2002.

[2] Numbers in columns followed by the same letter are not significantly different, P=0.05, t-test.

Table 8. Products included in fungicide trials.

Trade name and formulation	Active ingredient
Daconil WeatherStik 720	chlorothalonil
Golden Dew Sulfur 92%	sulfur
Kocide DF	copper hydroxide, copper metallic equivalent 40%
Kop-R-Spray	copper ammonium carbonate, copper metallic equivalent 8%
Phyton 27	copper sulphate pentahydrate, copper metallic equivalent 5.5%
QRD 131 AS	*Bacillus* spp.
Tactic sticker	synthetic latex and organosilicone
Thiolux 80W	sulfur

Tree Physiology Studies. Phase II.

Stem and Root Limitations to Water Movement in Phaeocryptopus gaeumannii-infected Trees.

Dan Manter, USDA-FS PNW Research Station

Introduction

Maximum rates of gas exchange (CO_2 and H_2O) are reduced by the presence of *Phaeocryptopus gaeumannii* fruiting bodies in needle stomata (Manter et al. 2000). Theoretically, since this flux of water is reduced (i.e., water leaving needles), then more water should be available in *P. gaeumannii*-infected trees allowing them to keep stomata open longer during the day. However, in our previous field studies we observed that water potentials were lower in diseased trees - despite the reduced water loss - compromising the ability of diseased trees to keep stomata open longer during the day. Since water potential is not only affected by water loss but also root uptake and supply through xylem tissues, then one of these supply factors is also influencing the water potential in trees. The goals of this study are to assess root and xylem limitations to water transport in *P. gaeumannii*-infected trees.

Rationale

Since stomatal regulation and carbon assimilation, is dependent upon plant-water-relations, this work increases our understanding of the full impact of SNC on tree physiology, carbon assimilation, and growth. This work is also critical for understanding how diseased trees may or may not respond to control measures. For example, if disease results in reduced quantity and/or quality of hydraulic tissues, then the response and recovery to the removal of the SNC pathogen may be limited or delayed until sufficient hydraulic tissues are restored.

Methods

Whole-tree sapflux was measured using the methods of Granier (1987) in diseased and healthy (i.e. Bravo sprayed) trees (n = 6) at three Douglas-fir plantations in the Siuslaw National Forest near Beaver, Oregon. Sites 1 & 2 were measured in July 2000 and site 3 was measured in July 2001. Sapflux measurements were used to measure daily patterns of water movement in trees and to calculate estimates of whole-tree leaf specific conductance (K_L). At sites 1 & 2, root limitations to whole-tree sapflux were also determined by measuring the response of sapflux to severing of the main stem and placing in a water reservoir (i.e., complete removal of root limitations) as outlined in Roberts (1977).

In addition to sapflux measurements, direct measurements of root conductivity and xylem cell diameters were also conducted on excised roots (n = 3) from healthy and diseased trees at each site.

Results

Pseudothecia counts of *Phaeocryptopus gaeumannii* and needle retention by needle age class for the three sites are shown in Tables 1 & 2, respectively. For diseased trees, the presence of *P. gaeumannii* was from highest to lowest: site 1, site 2, and site 3, respectively; and for all sites virtually no *P. gaeumannii* was present in sprayed trees. At all sites, the presence of disease resulted in a decline in whole-tree sapflux (Fig. 1), and the difference in total daily sapflux between healthy and sprayed trees mirrored the differences in *P. gaeumannii*, i.e. site 1 > site 2 > site 3.

Based on the sapflux data, a whole-tree leaf specific conductance (K_L) was calculated, which represents the ability of all the woody tissues of the tree (i.e. roots, stem and branches) to supply water to the transpiring needles. For all sites, a significant difference between healthy and diseased trees was observed (Fig. 2). K_L is influenced by

Table 1. Pseudothecia density (%) for the three Douglas-fir plantations by needle age class. NS = nospray and S = spray. Arithmetic means and individual standard errors in parentheses (n = 6).

		Pseudothecia Density		
Site	Trt	current-yr	1-yr-old	2-yr-old
1	NS	0.0 (0.0)	55.6 (6.8)	-
2	NS	0.0 (0.0)	46.8 (5.1)	60.2 (5.9)
3	NS	0.0 (0.0)	4.7 (1.8)	14.4 (0.7)
1	S	0.0 (0.0)	0.3 (0.2)	0.7 (0.2)
2	S	0.0 (0.0)	0.4 (0.2)	0.8 (0.4)
3	S	0.0 (0.0)	1.8 (0.7)	3.7 (1.1)

Table 2. Needle retention (%) for the three Douglas-fir plantations by needle age class. NS = nospray and S = spray. Arithmetic means and individual standard errors in parentheses (n = 6).

		Needle Retention		
Site	Trt	current-yr	1-yr-old	2-yr-old
1	NS	100.0 (0.0)	38.9 (15.6)	0.0 (0.0)
2	NS	100.0 (0.0)	76.3 (26.2)	21.7 (9.2)
3	NS	100.0 (0.0)	100.0 (0.0)	94.2 (11.3)
1	S	100.0 (0.0)	100.0 (0.0)	61.5 (9.3)
2	S	100.0 (0.0)	100.0 (0.0)	83.4 (24.2)
3	S	100.0 (0.0)	100.0 (0.0)	91.3 (12.3)

Table 3. Paired t-test results comparing total daily sapflux (g m^{-2}) in Bravo sprayed (S) and unsprayed (NS) trees (n = 6) for the three Douglas-fir plantations.

Site	MeanNS	MeanS	MeanDifference	t-statistic	df	p-value
1	821	1076	-255	-11.63	6	0.000
2	808	1007	-199	-4.99	6	0.002
3	764	865	-102	-4.77	6	0.003

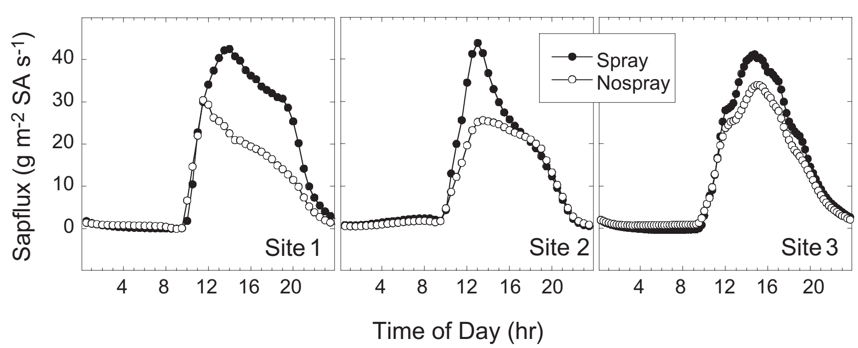

Figure 1. Diurnal pattern of sapflux in healthy (spray) and diseased (nonspray) trees (n=6) at three Douglas-fir plantations.

the ratio of leaf area to conducting sapwood area, as well as the permeability of the xylem cells. Similar to branch-level measurements (Manter 2001), changes in whole-tree K_L could not be attributed to LA:SA ratios (Fig. 3) but were consistent with changes in stem permeability associated with increased latewood production and smaller tracheid diameters.

Like whole-tree K_L, root hydraulic conductance (K_S) was significantly different between healthy and diseased trees at all sites (Fig. 4), and was significantly related to xylem lumen diameters (Fig. 5). Despite the measured differences in root conductance, complete removal of the root system did not have a significant impact of whole-tree sapflux (Fig. 6, Table 2).

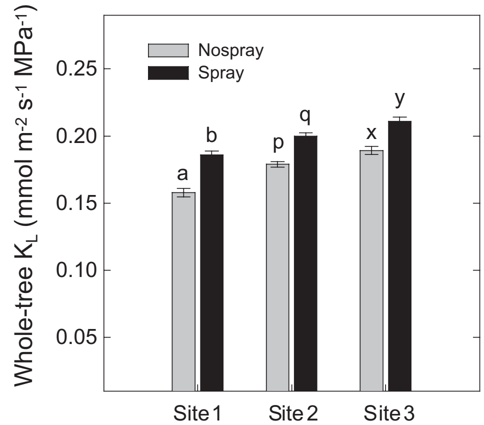

Figure 2. Whole-tree leaf specific conductance (K_L) for healthy (spray) and diseased (nonspray) trees (n=6) at three Douglas-fir plantations.

Discussion

In several experiments we have now measured hydraulic sufficiency or the ability to transport water in the xylem tissues at the tree-, branch-, and root-levels and all show a significant decline in transport capacity with the presence of SNC. Reduced growth rates and the associated production of smaller diameter xylem cells are correlated with these changes in permeability for all tissues.

Interestingly, complete removal of root limitations in this study did not result in any observable changes in sapflux. It is likely that the major limitation to sapflux and needle transpiration is not typically at the root level in coastal Oregon plantations. For example, at maximum rates of water movement the limitation occurs elsewhere in the plant-soil continuum, such as in the branches or needles. Furthermore, any disease-related root limitations may only be observable under hotter, drier conditions, which were not present during the present study. For example, under severe hot and dry conditions, day-time transpirational water loss often exceeds xylem water movement and supply leading to a decline in stem water content that may be refilled by night-time stem water flux, and during the time period of this study no night-time stem water flux was observable for either control or cut trees.

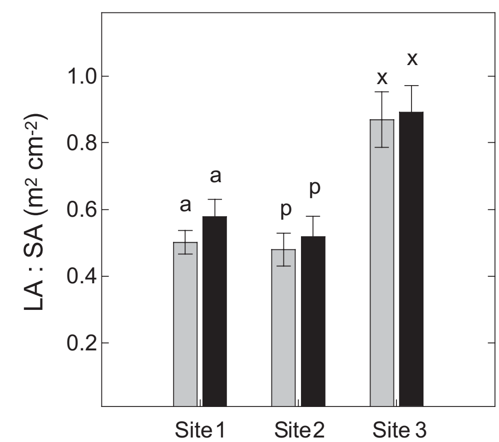

Figure 3. Leaf area to sapwood area ratios (LA:SA) for healthy (spray) and diseased (nonspray) trees (n=6) at three Douglas-fir plantations.

Bravo treatments significantly limited the presence and colonization of *P. gaeumannii* in treated needles to levels (< 5 % pseudothecia density) well below those typically associated with needle abscission. Despite the successful control of *P. gaeumannii* colonization, ca. 10 to 40 % of the sprayed 2-yr-old needles were abscissed maintaining a constant LA:SA ratio. Therefore, until new growth of xylem tissues occurs in treated trees, some degree of needle loss due to constraints of the hydraulic system should be expected.

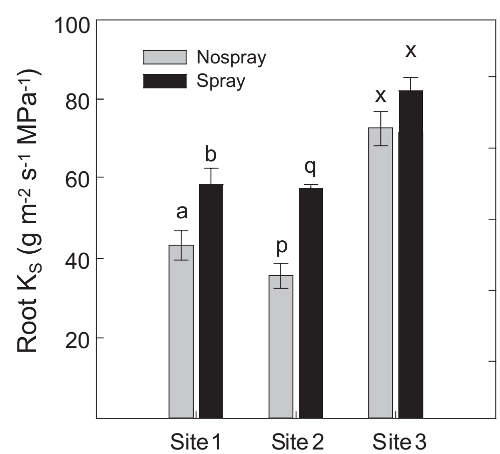

Figure 4. Root hydraulic conductance (K_S) for healthy (spray) and diseased (nonspray) trees (n=6) at three Douglas-fir plantations.

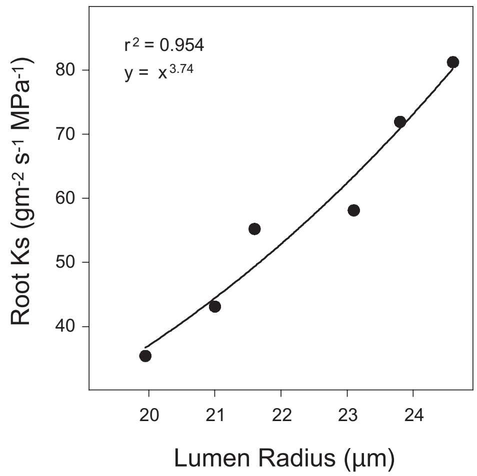

Figure 5. Relationship between root hydraulic conductance (K_S) and xylem lumen radius for healthy (spray) and diseased (nonspray) trees (n=6) at three Douglas-fir plantations.

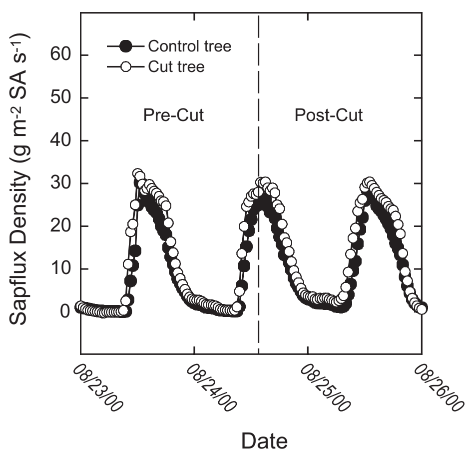

Figure 6. Sapflux before (pre-cut) and after (post-cut) severing the main stem to completely remove any root limitations to sapflux for one control and one cut tree at site 1.

Table 4. Paired t-test results comparing total daily sapflux (g m^{-2}) in one control and one cut tree for two Douglas-fir plantations.

Site	Time-period	Mean Control	Mean Cut	Mean Difference	t-statistic	df	p-value
1	pre-cut	404	410	6.9	0.695	2	0.559
1	post-cut	340	342	-2.0	-0.595	2	0.612
2	pre-cut	460	465	5.4	-0.515	2	0.658
2	post-cut	377	389	-12.4	-1.695	2	0.232

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Effects of Fertilization and Vegetation Control on Swiss Needle Cast Infection and Growth of Coastal Douglas-fir Saplings

Scott Ketchum, Diane Haase, Robin Rose, and Gabriel Crane, OSU

Abstract

This study was initiated in May 1999 over 7-year-old Douglas-fir saplings to determine if silvicultural treatments (fertilization and vegetation control) could enhance the growth of Douglas-fir saplings and/or alleviate Swiss needle cast (SNC). The study was installed across three sites located on a naturally occurring SNC gradient. Current results indicate that the removal of competing vegetation for two years has significantly increased stem volume from 5-14% depending on the site. The greatest gains have been at the more infected coastal sites. Fertilization has resulted in only slight gains as of year two. The fertilizer treatments applied in year three may add to these earlier minimal gains. There is no strong evidence that either weed control or fertilization has affected the level of SNC infection. However, needle retention index at the most severely infected site, nearest the coast, has decreased slightly with the weed control treatments. Foliar N concentrations have increased with both weed control and the fertilizer treatments in year two. Phosphorus concentrations have decreased in both fertilizer treatments in year two. No other consistent foliar nutrient concentration differences by treatment have been identified.

Introduction

The potential to increase vigor and growth of Douglas-fir saplings in areas affected with Swiss needle cast (SNC) through silvicultural manipulation is not well understood. Two silvicultural treatments that have been used in other situations to increase sapling vigor are vegetation control and fertilization. Young stands severely infected with SNC typically cast off many of their second and third year needles, which in turn allows for greater sunlight to penetrate the stands. This added light spurs on greater competing vegetation which can further suppress tree growth. The role of site fertility in SNC presence and pathological impact is currently hotly debated. One of the hypotheses for the sudden importance of this disease is the High-Nutrient capital often found in soils and foliage of infected plantations. Central to this debate is the role nitrogen plays in creating conditions favorable to the fungus and thus eventually damaging to the conifers. This study was initiated to better understand the potential to enhance growth of SNC impacted conifers by releasing the saplings from competition and to additionally determine if added nutrition negatively or positively impacted either conifer growth or incidence of the SNC disease.

Materials and Methods

Field sites

Three study sites were selected along an east/west transect of the Oregon Coast Range. The sites are along a natural SNC infection gradient with increasing disease from east to west. The site nearest the coast is on Plum Creek Timber ownership and is located between Toledo and Siletz (Coast). The second site is midway between the coast and the Willamette Valley near Eddyville (Mid-Coast) and is on Starker Forest ownership. The third site is located on the east side of the coast range (East-Coast) and is also owned by Starker Forests. At the time the study was established, each site had existing 7-year-old Douglas-fir plantations with the expression of SNC disease symptoms (needle loss and yellowing) increasing from east to west as would be expected.

Design

At each site a randomized complete block study was established with five replications of 6 treatments. The treatments consisted of a 2 x 3 factorial combination of two weed control treatments and 3 fertilizer treatments. The treatments were applied to 70 x 70' square plots. Plots within a block were arranged as contiguously as possible. Within each plot the center most 15 trees were identified and marked with aluminum tags.

The two weed control treatments tested were either no weed control or complete weed control for three consecutive years. Weeds were removed by first slashing existing vegetation with chainsaws in fall of 1998 and then maintained by repeated applications of herbicide (Accord) each spring and fall through spring 2002.

The fertilizer treatments were:

1) No Fertilization
2) Low-N fertilization, 9-17-17 (N-P-K)
3) High-N fertilization, 18-17-17 (N-P-K)

Fertilizer was applied at a rate of 400 grams per tree of a controlled release Simplot fertilizer in fall of 1999, spring 2000, and fall 2000. In spring and fall of 2001 the fertilizer rate was increased to 550 grams per tree and the fertilizer used changed to a soluble blend matching the formulations used previously. Over the three years of the study, the approximate total amount of fertilizer applied is 3120 lbs/acre for a total N application of 280 and 561 lbs N/acre for the Low-N and High-N treatments, respectively.

Measurements

Diameter-at-breast-height (DBH) and seedling height has been measured every fall since the study was initiated. Needle retention was estimated prior to treatment and again each spring following the treatment initiation. The needle assessments were carried out on the same branch for the first two assessments. By the third assessment the original branch used was beginning to be shaded out and needle retention on this branch no longer represented the impact of SNC alone but a combination of SNC and self-shading. Consequently, a new branch on the third whorl down from the top was chosen as the third year assessment branch. The percentage of needles retained per year of growth was estimated for the most recent three year's needle complements regardless of branch or timing of the assessment. Foliage samples from five randomly selected seedlings per plot were collected in December 2000 and January 2001 and analyzed for nutrient concentrations using standard laboratory procedures.

Analyses

Annual DBH and height growth increments were calculated from yearly DBH and height measures. Stem volume was also calculated using Bruce and Demars formula for second growth Douglas-fir saplings and stem volume growth increment determined for the first two seasons. The growth increments were then subjected to ANOVA using a factorial model to determine if there were significant effects due to the main factors, fertilization or vegetation control, or if these two factors interacted significantly for any of the measured or calculated growth parameters. Means separations estimates were made for main effects and significances assigned to these estimates using Fishers least significant difference tests. ANOVA was used to assess differences by main factors for mean 2001 DBH, height and stem volume using initial DBH as a covariate to control for differences in initial sapling size. Data were analyzed first as a complete data set encompassing all three sites with site considered a fixed effect and second as a series of analyses from the individual sites independently.

A similar statistical approach was used to assess for differences in plot means of foliar nutrient concentrations and needle retention index. Needle retention index was the sum of the percentage of needles remaining on the measured stem for each of the last three years compliments of needles.

Results

Significant interactions between site and either fertilization or weed control treatments were found in only a few cases and were inconsistent from year to year. Additionally, fertilization and weed control treatments did not interact significantly. All responses to both fertilization and weed control were additive. The weed control treatments consistently resulted in increased growth at all sites while growth responses to fertilization were minimal and less consistent.

Weed control

When assessed across all three sites, the weed control treatment resulted in a significant increase over the non-controlled treatment for first and second year DBH growth. DBH growth averaged 0.38 and 0.31mm greater in years one and two, respectively, for trees in weed-control plots as compared to those with no weed control resulting in a total 0.81 cm DBH larger after two years. When analyzed on an individual site basis, significant differences between weeded and unweeded plots were found in both years of the study at all sites.

Height growth in year one was not significantly affected by weed control when assessed across all sites combined (Figure 1). However, a site by weed control interaction occurred for height growth in year two. This interaction resulted from a decrease in height growth in weeded plots at the East-Coast site, while at the other two sites no differences were found between the weed control treatments. Anecdotally, a greater level of tip frost damage was also observed in the weed control plots at the East-Coast site, which may explain in part the decrease in height growth associated with this treatment.

When assessed across all sites, volume growth increased as a result of weed control in both years of the study (Figure 1). Final stem volume averaged 37.1 dm^3 in the weed control plots versus 33.6 dm^3 in the no weed control plots; a gain of 10.4% in stem volume over two years. Significant increases in volume growth were identified at all sites in year one and only the Coast and Mid-Coast sites in year two.

Needle retention did not vary by weed control treatment in year one. Significant differences by weed control treatment were identified only at the Coast site with weed control resulting in slightly less needle retention in year two (Figure 1). Regardless of treatment, needle retention tended to be greatest at the East-Coast site, intermediate at the Mid-Coast site, and least at the Coast site.

Weed control resulted in increased foliar N concentrations in year one and two (Tables 1-4). Needle weight also increased in the first year of the study for the weeded versus unweeded treatments. By year two differences in needle weight were no longer evident. Iron concentration was also greater in year one in trees from the weeded treatment than those from the unweeded but did not vary significantly in year two.

Fertilization

Fertilization did not influence first year DBH growth at any site (Figure 2). DBH growth and total DBH in year two was greater for trees in both the fertilizer treatments compared to the unfertilized treatment when assessed across all three site combined. However, when evaluated independently by site, a significant response was not identified at any of the sites.

Height and height growth increment did not vary by fertilizer treatment when assessed collectively across all three sites (Figure 2). Only at the East-Coast site was a difference by fertilizer treatment found. At this site, the Low-N fertilizer resulted in a decrease in second year height growth but total height as of year two was unaffected.

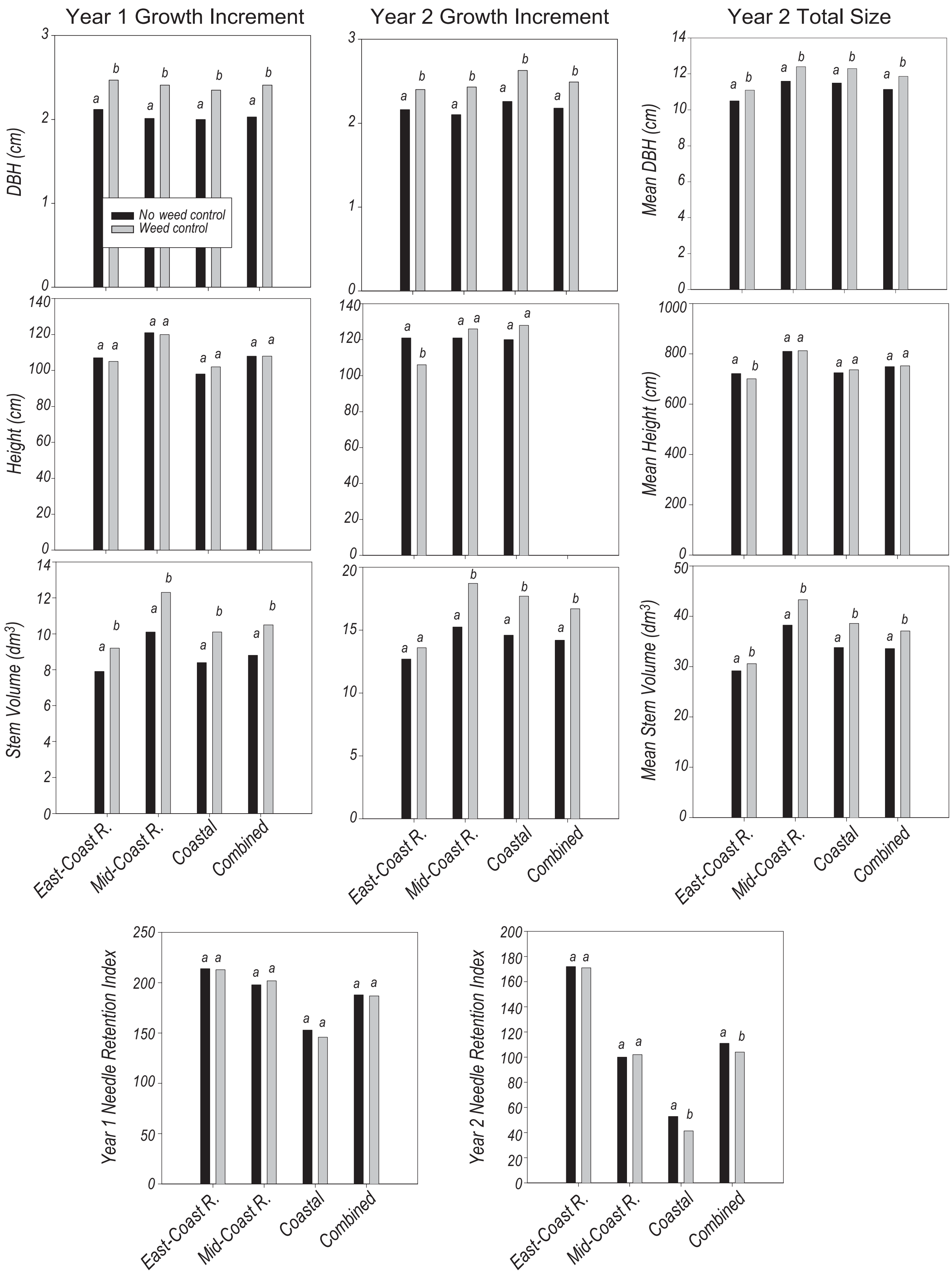

Figure 1. DBH, height, and stem volume growth increment in years one and two plus mean second year values for all three parameters by weed control treatment. Year one and two needle retention index is also shown by weed control treatment.

Table 1. Mean foliar nutrient concentrations for the weed control and fertilizer treatments at the East-Coast site.

Year 1	N%	P%	K%	Ca%	Mg%	S%	Feppm	Mnppm	Cuppm	Bppm	NwG/ 200needles
no weed control	1.54a[1]	22.9a	.63a	.53a	.12a	.098a	83a	359a	7.6a	20.6a	.55a
weed control	1.67b	22.0a	.61a	.53a	.12a	.098a	89a	446b	8.0a	23.4b	.59a
no fert	1.60a	.23a	.64a	.51a	.12a	.095a	86a	358a	8.4a	20.7a	.57a
Low-N fert	1.61a	.23a	.61a	.54a	.12a	.097ab	87a	387a	7.3a	23.5a	.57a
High-N fert	1.61a	.22a	.61a	.53a	.12a	.104b	86a	462a	7.7a	21.8a	.57a
Year 2											
no weed control	1.5a	0.15a	.46a	.49a	.11a	.12a	35.5a	166a	2.85a	23.9a	.81a
weed control	1.57a	.16a	.50a	.58a	.13a	.13a	50.4b	185a	3.55b	30.2a	.90a
no fert	1.44a	.17a	.49a	.48a	.11a	.13a	45.9a	177a	2.97a	23.5a	.84a
Low-N fert	1.57b	.15ab	.46a	.52a	.12a	.13a	39.8a	166a	3.19a	28.8a	.84a
High-N fert	1.59b	.14b	.49a	.60a	.12a	.12a	46.1a	184a	3.45a	28.8a	.90a

[1]Values within a column for a given year and for either the two weed control or three fertilizer treatments followed by the same letter (a, b, or c) are not significantly different ($p \leq 0.05$).

Table 2. Mean foliar nutrient concentrations for the weed control and fertilizer treatments at the Mid-Coast site.

Year 1	N%	P%	K%	Ca%	Mg%	S%	Feppm	Mnppm	Cuppm	Bppm	NwG/ 200needles
no weed control	1.53a	.15a	.43a	.39a	.11a	.93a	56.9a	242a	5.8a	19.3a	.59a
weed control	1.57a	.14a	.45a	.37a	.11a	.98a	62.0a	259a	6.3a	19.6a	.63a
no fert	1.54a	.14a	.42a	.39a	.11a	.097a	55.9a	294a	5.8a	17.2a	.59a
Low-N fert	1.54a	.15a	.43ab	.38a	.11a	.095a	61.1a	234b	6.1a	19.5ab	.62a
High-N fert	1.55a	.14a	.47b	.35a	.11a	.094a	61.4a	224b	6.4a	21.6b	.63a
Year 2											
no weed control	1.44a	.12a	.52a	.34a	.11a	.10a	47.8a	117a	3.0a	17.4a	.78a
weed control	1.48a	.11a	.53a	.33a	.10a	.10a	47.3a	110a	3.1a	16.7a	.81a
no fert	1.43a	.11a	.55a	.33a	.11a	.11a	44a	117a	3.1a	17.7a	.84a
Low-N fert	1.46a	.11a	.53a	.32a	.10a	.090b	41a	108a	2.9a	17.1a	.79a
High-N fert	1.50a	.11a	.51a	.36a	.11a	.095b	58a	116a	3.1a	16.3a	.76a

[1]Values within a column for a given year and for either the two weed control or three fertilizer treatments followed by the same letter (a, b, or c) are not significantly different ($p \leq 0.05$).

Table 3. Mean foliar nutrient concentrations for the weed control and fertilizer treatments at the Coast site.

Year 1	N%	P%	K%	Ca%	Mg%	S%	Feppm	Mnppm	Cuppm	Bppm	NwG/ 200needles
no weed control	1.61a	.16a	.54a	.34a	.11a	.10a	84.1a	614a	6.2a	22.7a	.57a
weed control	1.68a	.16a	.56a	.32a	.11a	.10a	87.5a	564a	7.0a	26.3b	.60a
no fert	1.65a	.16a	.54a	.33a	.11a	.10a	77.8a	612a	6.9a	19.8a	.58a
Low-N fert	1.65a	.16a	.55a	.32a	.11a	.10a	86.2ab	610a	6.5a	21.2ab	.59a
High-N fert	1.64a	.17a	.56a	.34a	.11a	.10a	93.4b	546a	6.4a	32.6b	.59a
Year 2											
no weed control	1.56a	.125a	.55a	.28a	.10a	.12a	183a	157a	2.52a	21.7a	.84a
weed control	1.57a	.115b	52a	.27a	.10a	.13a	41a	129a	2.52a	21.4a	.86a
no fert	1.52a	.12a	.56a	.26a	.10a	.13a	41a	134a	2.64a	20.1a	.81a
Low-N fert	1.56ab	.12a	.51a	.29a	.10a	.12a	41a	133a	2.29b	25.2b	.81a
High-N fert	1.61b	.12a	.53a	.27a	.10a	.12a	254a	160a	2.62a	19.5a	.91a

[1]Values within a column for a given year and for either the two weed control or three fertilizer treatments followed by the same letter (a, b, or c) are not significantly different ($p \leq 0.05$).

Table 4. Mean foliar nutrient concentrations for the weed control and fertilizer treatments for all sites combined.

Year 1	N%	P%	K%	Ca%	Mg%	S%	Feppm	Mnppm	Cuppm	Bppm	NwG/ 200needles
no weed control	1.56a	.18a	.54a	.42a	.11a	.10a	75a	405a	6.5a	int	.57a
weed control	1.64b	.17a	.54a	.40a	.11a	.10a	80b	423a	7.1a	int	.61b
no fert	1.59a	.18a	.53a	.41a	.11a	.10a	74a	421a	7.0a	int	.58a
Low-N fert	1.6a	.18a	.54a	.41a	.11a	.10a	78ab	407a	6.8a	int	.60a
High-N fert	1.60a	.18a	.54a	.41a	.11a	.10a	80b	414a	6.7a	int	.60a
Year 2											
no weed control	1.49b	.13a	.51a	.36a	.10a	.11a	89a	146a	2.79a	21a	.80a
weed control	1.54a	.13a	.51a	.40a	.11a	.12a	46a	141a	3.02a	23a	.85a
no fert	1.46a	.14a	.53a	.36a	.11a	.12a	43a	142a	2.90a	20a	.82a
Low-N fert	1.53b	.12b	.50a	.38a	.10a	.11a	40a	136a	2.78a	23a	.80a
High-N fert	1.57b	.12b	.50a	.40a	.11a	.11a	119a	153a	3.05a	22a	.87a

[1]Values within a column for a given year and for either the two weed control or three fertilizer treatments followed by the same letter (a, b, or c) are not significantly different ($p \leq 0.05$).

Stem volume was not affected by fertilizer treatment when assessed across all three sites (Figure 2). On an individual site basis, there was a significant volume response to fertilization at the Coast site where annual volume growth and total volume averaged greater for trees in the Low-N fertilizer treatment compared to those in the unfertilized treatment. Tress in the High-N treatment did not differ from either.

There were no consistent patterns in needle retention by fertilizer treatment (Figure 2). The Low-N fertilizer treatment resulted in greater needle retention in year one than the High-N treatment but this trend was no longer significant in year two. Needle retention did not vary significantly by fertilizer treatment at either of the two other sites or when all sites were combined in the larger model.

There were no differences in first-year foliar nutrient concentrations among the fertilizer treatments at any of the sites (Tables 1-4). In year two, foliar N concentrations were higher and P concentrations were lower for trees in both the Low-N and High-N treatments as compared to those in the unfertilized treatment. When assessed at the individual site level these patterns were still present but significant only at the East-Coast site.

Discussion

Weed control treatments resulted in growth gains at all three sites. This is not a surprising result and has been repeatedly demonstrated over the last three decades. Releasing young conifers from weed competition consistently results in increases in diameter growth and occasionally height growth (Loucks et al. 1995). However, this is the first study we are aware of that assesses effects of weed control on SNC-affected trees.

In this study, height growth was largely unaffected by the weed control treatments. Annual height growth averaged approximately 1.2 meters regardless of site or treatment. This is in the neighborhood of the maximum height growth that can be expected for Douglas-fir even on the best sites. To be able to induce greater gains than these through weed control is biologically unlikely. The impact that weed control has on the SNC fungus is unclear. At the Coast site, weed control resulted in a slight decrease in needle retention suggesting the fungus may also benefit from weed control. However, growth data suggests that regardless of a reduction in needle retention on this site trees are performing better in the weeded plots. Differences in needle retention index were not found at the other two sites

The lack of a growth response or foliar nutrient response to the first year fertilizer treatments suggests that increased nutrient availability did not occur in year one. This may be due to the release nature of the fertilizer used. The controlled-release fertilizer used increases its release rates as temperatures increase. The

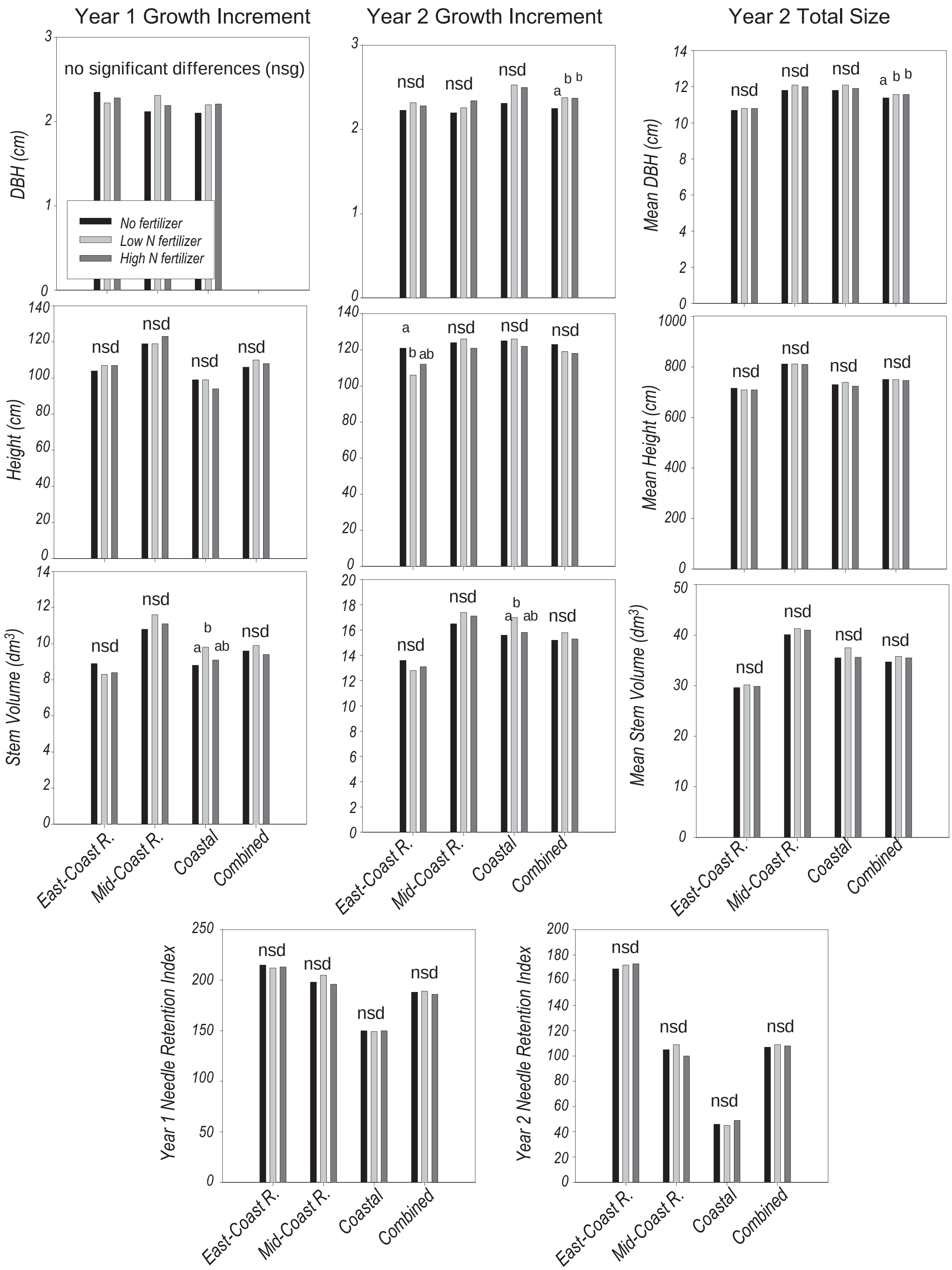

Figure 2. DBH, height, and stem volume growth increment in years one and two plus mean second year values for all three parameters by fertilizer treatment. Year one and two needle retention index is also shown by fertilizer treatment.

lack of a response to the fertilizers in year one may have occurred because the greatest release period, late spring and summer, also corresponds to the driest period on the sites. Nutrients released during this period may not have been leached into the rooting zone and N may have volatized into the atmosphere before it could be absorbed by the soil. Additionally, the amount of fertilizer applied, relative to the size of the tree, may have been inadequate to be expressed in the foliage after just one season.

Switching to a soluble fertilizer and increasing the rate applied in year two appeared to create the proper conditions for a fertilizer response to occur. The response was measured both in terms of increased DBH growth and increases in foliar N concentration. However, at the time of the last measurement, the response was minimal. Since then the sites have received two additional fertilizations. We have not been able to identify differences in the incidence of the Swiss needle cast fungus relative to the fertilizer treatments. Needle retention has remained largely unaffected by the fertilizer treatments. Third year growth data and needle assessments may help to further elucidate the impact of the fertilizer treatments on the disease fungus itself.

The three sites chosen for this study were picked based on their location across a SNC gradient and the needle assessments performed have verified that the sites represent widely divergent SNC symptom levels. One of the more interesting results is that even in the most infected site (Coast site) Douglas-fir growth appears to be quite good. For example, the saplings are averaging over 2 cm of DBH growth a year and are achieving yearly height growths of over 1 m. It is hard to make the argument that these trees are severely impacted by SNC infection. This may be due, in part, to the young sapling stage these trees are in. They are currently still on the exponential part of the growth curve and trees in this stage typically double or triple their photosynthetic area each year. Losing half of the previous year's foliage may have only a small impact on these trees. The sites are quickly approaching crown closure at this time. Once this occurs, the photosynthetic area of the saplings will be more stable and won't increase exponentially each year. It may be at this stage that the impact of the SNC disease will be more fully expressed. Additionally, the impact that weed control treatments have on Douglas-fir growth is often measurable for several years after the treatments and thus the growth responses and treatment effect on the SNC fungus may not be realized yet for several more years. These points stress the importance for the SNC Co-op to continue to monitor these sites.

Response of Douglas-fir to Fungicidal Suppression of *Phaeocryptopus gaeumannii*: Volume Growth, Branch Elongation, and Foliage Dynamics

Doug Mainwaring, OSU; Alan Kanaskie, ODF; Doug Maguire, OSU

Abstract

A paired-plot trial was established in the spring of 1997 to test the effects of suppressing the SNC-causing fungus, *Phaeocryptopus gaeumannii*, by foliar application of fungicide. Chlorothalonil (Bravo 720) was applied twice annually for five years to one plot from each pair. Average foliage retention was increased from 1.94 to 2.82 yrs by the fungicide treatments. Growth over the 5-yr treatment period was 35% greater on the treated plots, and 60% greater for the most recent 3-yr growth period. Branches in the fifth and sixth whorls from the tip of the tree grew longer during the most recent 3-yr growth period on the treated plots. The fungicide applications had relatively little effect on the number of secondary branches formed on the main axis of the primary branches, but they enhanced average foliage retention on the branch level. This latter effect was progressively stronger moving upward from the tenth to the fifth whorl from the tip of the tree.

Introduction

Assessing the effect of *P. gaeumannii* on Douglas-fir growth can be challenging due to its ubiquity and the tendency for Swiss needle cast intensity to be confounded with site and local climate. Average number of years of foliage retention provides an effective index of disease severity and is strongly correlated with stand growth (Maguire et al. 2002). Likewise, the ratio of crown length to sapwood area at crown base (CL:SA) can be interpreted as an index of foliage density and needle loss (Maguire and Kanaskie 2002). However, both foliage retention and CL:SA may be correlated with other site and stand structural conditions as well, frustrating any attempts to identify definitively the direct growth losses from *P. gaeumannii*. The most appealing strategy for isolating the effects of the fungus would be a controlled experiment in which one treatment is elimination or dramatic suppression of *P. gaeumannii*. One fungicide, chlorothalonil, has proven very effective for controlling the fungus in Christmas tree plantations, and very limited experimentation has demonstrated its efficacy on young trees in timber plantations as well. The objective of this study was to test the effect of intense chemical suppression of *P. gaeumannii* on subsequent growth and foliage dynamics of Douglas-fir.

Methods

Field work

The study sites were located near the town of Beaver, Oregon, on the west flank of the Coast Range (T3S R9W sec.20). The study was designed as a complete randomized block experiment with three separate blocks or sites, all in 16-yr-old Douglas-fir plantations. Each 4-ha study site was divided into two 2-ha experimental units, one of which served as the control and the other of which was treated with fungicide. On the treated units, Chlorothalonil (Bravo 720) was applied by helicopter two times each year at a rate of 5.5 pints per acre, with treatment areas double-flown to ensure thorough coverage. The first application occurred when new shoots on approximately 40 percent of the trees were 1 to 5 cm in length, and the second when at least 90 percent of the trees had new shoots of this length. Applications usually occurred in May, and were separated by 2 to 3 weeks. The treated units were sprayed each year for five years (1996-2000). Ten trees in each experimental unit were monitored every year to track changes in needle retention and foliage color. All needle retention ratings were done in April or May, prior to bud break.

Measurement plots were established in each of the experimental units during the dormant season of 2000-2001. Each plot was 0.04 ha in area (11.28 m radius). All trees on the plots were tagged at breast height, and live Douglas-fir trees were measured for dbh, height, and height to lowest live branch. The largest 5 trees on each plot were felled, and a stem disk was removed at breast height and at crown base. Radial growth and sapwood width were measured on four radii corresponding to the longest axis and the axis perpendicular to the longest on the disk. All standing live Douglas-fir trees were cored to the pith, and radial growth for the last 10 years and sapwood width were likewise recorded. Annual height growth for the last 11 years was also measured on the felled trees, and each was rated for foliage retention as an index of Swiss needle cast severity. Needle retention was estimated at the tree level by dividing the crown into thirds and estimating the average number of years foliage was retained. In addition, one branch was sampled from the south side of whorls five through ten from the tip of the tree. On each of these branches, the percentage of each annual age class retained on the primary and secondary laterals was estimated and summed for the total number of years retained. Annual longitudinal branch increments were recorded for each of these sample branches, and the number of whorl and interwhorl secondary branches on the primary branch axis were recorded.

Data analysis

As would be expected, plot initial conditions varied with respect to Douglas-fir basal area, top height, foliage retention, CL:SA, and basal area in other species (Table 1), underscoring the need to consider covariates in the analysis. Various stand attributes were computed from the plot data, and five-year growth responses were tested for treatment effects by analysis of covariance performed as a regression model. Traditional covariates influencing stand growth were included, such as initial Douglas-fir basal area, total basal area, and site index. In addition, indicator variables were introduced for treatment and block effects. Because the treatment effect was expected to be exerted by its effect on foliage retention, both foliage retention and CL:SA were initially treated as response variables in randomized block ANOVAs (with no covariates), but were then introduced as predictor variables in the model that accounted for fungicidal treatment effects.

Longitudinal branch growth over the 5-yr post-treatment period was also analyzed for treatment effects by ANOVA, with separate analyses run for each of the six sample whorls (whorls five through ten). Age class needle retentions and secondary branch counts similarly were tested for treatment effects to provide more detailed information on crown response. Secondary branch tallies were expressed as number of interwhorl or whorl branches per annual shoot.

Results

Plot-level needle retention and CL:SA

Analysis of variance indicated that needle retention was significantly enhanced by fungicide treatment (R^2=0.832, p<0.0001), though site was not an influence. The difference in average foliage retention on treatment and control plots within a block averaged 0.88 years, ranging from 0.62 to 1.09 years; in other words, treated plots within a block retained, on average, an additional 0.88 years of needles. Treatment thus increased the average foliage retention from 1.94 years in control plots to 2.82 years in treatment plots.

Crown sparseness (CL:SA) was also reduced by treatment (p=0.0081), but a significant block block effect was evident as well (p= 0.0005). Approximately 88% of the variation in crown sparseness was accounted for by the combined effects of block and treatment.

Stem volume growth

Cubic volume growth was also influenced significantly by both treatment and block effects. The following model represented the analysis of covariance, with initial Douglas-fir basal area as the covariate:

$$\ln(dV) = b_0 + b_1TRT + b_2BLOCK_1 + b_3BLOCK_3 + b_4\ln(BA_{DF}) \quad [1]$$

where dV = 5-yr cubic volume growth

TRT = 1 if treated by fungicide, 0 otherwise)

$BLOCK_1$ = 1 if site 1, 0 otherwise

$BLOCK_3$ = 1 if site 3, 0 otherwise

BA_{DF} = initial Douglas-fir basal area (m^2/ha)

Approximately 87% of the variation in the logarithm of five-year volume growth was explained by the model, with an MSE of 0.0179. Parameter estimates (Table 1) indicated that plot volume growth was significantly greater after fungicide treatment, and that growth increased with greater initial Douglas-fir growing stock (BA_{DF}). Very little of the basal area in these plots was contributed by species other than Douglas-fir. As a result, total basal area was not influential on Douglas-fir volume growth. The site indicator variables indicated that volume growth was also influenced by site factors; that is, there was a significant block effect. Growth of stands treated with chlorothalonil averaged 35 % higher than the control stands over the 5-yr response period (breast height ages 12-19). Growth of treated stands averaged 60% greater than control stands when the response was limited to the final three years of the study (1997-2000). This difference may be attributed to the time required for treated trees to build leaf area.

Table 1. Parameter estimates for model [1].

Variable	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob > |T|
b_0	5.726590	0.69075618	8.290	0.0001
b_1	0.296937	0.07749095	3.832	0.0064
b_2	-0.329111	0.13985333	-2.353	0.0508
b_3	-0.259560	0.14302564	-1.815	0.1124
b_4	0.773069	0.26189547	2.952	0.0214

As described above, foliage retention was significantly increased by fungicide treatment. As would therefore be expected, foliage retention served as an effective surrogate for fungicide treatment in the above model. Although CL:SA was also affected by treatment, this attribute also accounted for site differences (all p<0.01). As a result, the treatment and block effects in model [1] drop out when foliage retention and CL:SA are introduced into the model:

$$\ln(dV) = c_0 + c_1FOLRET + c_2CL:SA + c_3BA_{DF} \quad [2]$$

where dV = 5-yr cubic volume growth

FOLRET = average foliage retention for the plot (yrs)

CL:SA = crown length to sapwood area ratio (cm/cm^2)

BA_{DF} = plot level Douglas-fir basal area (m^2/ha)

The predictive power of the model increased slightly as well, with approximately 90% of the variation in cubic volume growth accounted for and MSE declining to 0.0137. Parameter estimates confirmed that the enhanced foliage retention and greater crown density (lower CL:SA) after fungicide treatment increased stem volume growth (Table 2, Fig. 1).

If the healthiest stand is represented by the highest value of foliage retention (3.07 yrs) and the lowest value of CL:SA (3.46 cm/cm^2), growth losses associated with other levels of these two variables can reach as high as 50% (Fig. 2).

Table 2. Parameter estimates for model [2].

Variable	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob > |T|
INTERCEP	7.11981	0.52421	13.58	0.0001
FOLRET	0.16756	0.08824	1.90	0.0941
DFBA	0.06152	0.01656	3.71	0.0059
CL:SA	-0.1168	0.04140	-2.82	0.0224

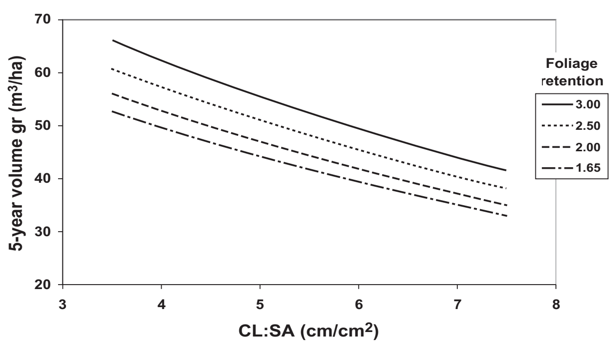

Figure 1. Five-year volume growth response implied by model [2], assuming a Douglas-fir basal area of 10.74 m^2/ha (average of all six plots).

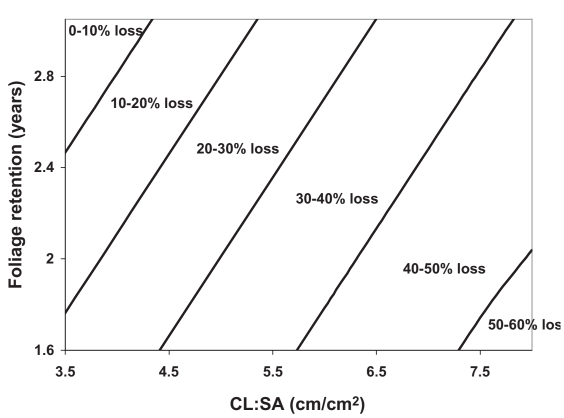

Figure 2. . Five-year volume growth loss implied by model [2].

Longitudinal branch growth

Branches from whorls five and six grew significantly greater in response to fungicide treatments, with branch five exhibiting enhanced growth for the full 5-yr growth period since treatment as well as for the most recent 3-yr period (Table 3). Branch six exhibited enhanced growth for only the most recent 3-year growth period. Other branches from whorls seven through ten showed no significant treatment response, with the exception of greater growth for branch eight over the 5-yr growth period (but not for the most recent 3-yr growth period). Branch growth in whorls six through eight were also significantly influences by site, but branches from whorls nine and ten showed neither treatment nor site effects.

The significance of site in explaining 5-yr branch growth of some of the lower branches is likely the result of stand density differences. These lower branches interact with branches of other trees within the canopy, particularly at relatively high stand density. Their growth is therefore likely to be limited more by within-canopy shading and physical abrasion than from foliar loss caused by *P. gaeumannii*. Hence, any past differences in stand density or in timing of precommercial thinning among sites can produce significant site effects. In addition, with each successive year of the experiment, the lower branches are less likely to receive significant fungicidal application.

Branch count

Branch counts were generally unaffected by treatment (Table 4). However, branch eight did exhibit a significant treatment effect. Interwhorl counts on branch eight showed a significant treatment effect for the last three and five years, while the whorl count on branch eight was significant only over the last three years.

Table 3. Results from analysis of variance on longitudinal branch growth for most recent 3-yr growth period and full 5-yr growth period since treatment.

Branch growth whorl	3 year response: Trt effect	3 year response: Site effect	5 year response: Trt effect	5 year response: Site effect
5	S	NS	S	NS
6	S	S	NS	S
7	NS	S	NS	S
8	NS	S	S	S
9	NS	NS	NS	NS
10	NS	NS	NS	NS

*S—significant; NS—not significant

Table 4. Reults from analysis of variance on secondary branch counts for most recent 3-yr growth period and full 5-yr growth period since treatment.

Branch counts	3 year response				5 year response			
	Whorl		Interwhorl		Whorl		Interwhorl	
whorl	Trt	Site	Trt	Site	Trt	Site	Trt	Site
5	NS	NS	NS	NS	NS	S	NS	S
6	NS	S	NS	S	NS	S	NS	S
7	NS	S	NS	S	NS	S	NS	S
8	S	S	S	S	NS	S	S	S
9	NS	S	NS	NS	NS	S	NS	S
10	NS	NS	NS	NS	NS	NS	NS	S

*S—significant; NS—not significant

Assuming the treatment effect on branch eight is not a Type II error, it may be a result of interactions among self-shading, nutrition, and inter-tree competition.

In contrast to the limited treatment effects, all branch counts (except the whorl count on branch 10) exhibited a significant site effect over five years. This response may help explain the high correlation between crown sparseness (CL:SA) and site. Whereas foliage retention was highly correlated with treatment, foliage retention is a characteristic of individual branches. Total crown leaf area, and thus crown sparseness, depends both on the foliage retention of individual branches as well as the total number of branches. The visually fuller and healthier crowns of trees treated with fungicide apparently result from increased foliage retention on individual branches rather than an increase in branch numbers.

While the most obvious reason for decreased individual tree growth with severe SNC is accelerated foliage loss, this effect is compounded by delayed crown expansion, primarily the result of diminished longitudinal branch growth. On the stand level, the effects of diminished crown density and the diminished rate at which the crown fills available growing space further compounds the problem by enabling competitors in the understory to persist, or in some cases to re-initiate. This competitive pressure, focused belowground, is likely to be especially apparent on sites where belowground resources are limited such as the shallow soil of ridgetops or on drier, more exposed south slopes.

Branch needle retention

The treatment response of whole tree needle retention (average value estimated from the upper, middle and lower crown third needle retention) and whole branch needle retention (average foliage retention on secondary laterals connected to sample branches from whorls five through ten) were tested by analysis of variance. Fungicide treatment had a significant effect on both whole tree foliage retention ($p<0.0001$) and branch foliage retention ($p=0.0011$). If the foliage retention estimate from each sample branch is tested individually, the strength of the treatment effect increases with height in the crown (Table 5). This trend would suggest that branch needle retention may be a better measure of needle retention if it is taken high in the crown, and/or that the fungicide penetrates only a limited distance into the crown. This response is consistent with the significant longitudinal branch growth in only the highest whorls.

Table 5: Results from analysis of variance on branch-level foliage retention. Treatment effect increases with height in crown.

Whorl	R^2	P value
5	0.917	<0.0001
6	0.818	<0.0001
7	0.490	0.0112
8	0.461	0.0152
9	0.431	0.0203
10	0.417	0.0233

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