SNCC

Swiss Needle Cast Cooperative

ANNUAL REPORT 2007

Oregon State UNIVERSITY

ERRATUM

$\beta_{11}$and β_{21} in Table 1 of the SNC modifier report (P. 64 of the 2007 SNCC Annual Report) should be **negative**

SNCC

Swiss Needle Cast Cooperative

Edited by David Shaw

Layout by Gretchen Bracher, FCG

SNCC Income Sources and Expenditures: 2007

Income

Membership dues	107,500
Oregon State Legislature	95,000
Carry-over	24,984
Total 2007 Budget	**227,484**

Expenditures

Salaries and Wages	77,289
Travel	7,050
Operating Expenses	9,000
Contract Work	61,100
Materials and Supplies	4,300
Indirect Costs	20,939
Total Expenditures	**182,010**
Commitment for re-measurement of GIS/PCT plots in 2008	47,806
Total:	**227,484**

Contents

SNCC Members

This 2007 Annual Report is our 10th, and we continue to investigate the largest epidemic of foliage disease ever known in Oregon. It now appears that the Swiss needle cast epidemic is occurring on over one million acres along the Oregon coast. Although annual aerial surveys pick up about 300,000 acres each year with visible symptoms, the disease is ubiquitous across the coastal region and inland along the valley bottoms, low elevations, and south slopes. It is clear that disease severity is related to climate, including winter temperature and spring/summer rain and fog. However, soil nutrients may also play a role in disease and we are collaborating with Doug Maguire and his associates to investigate soil amendments and their influence on tree growth and disease severity.

The current direction of the SNCC includes a focus on developing a control strategy that involves aerial detection and survey, studies on epidemiology of the disease with applications to risk rating, management through silviculture with a growth yield foundation, collaborating with the Northwest Tree Improvement Cooperative to develop improved genetic stock, studies in forest biology especially below ground mycorrhizae impacts and assessment, and development of predictive models for individual parameters that can be integrated into market sector and economic models.

In short, we are developing an Integrated Pest Management Strategy that is based on all the available science. Forest landowners will be able to adapt the IPM model for their specific lands.

To aid this effort, we are also seeking external funding from CSREES-National Research Initiative (NRI). Darius Adams, Greg Latta, Jeff Stone, Len Coop and I have had a letter of intent accepted, and we are in the process of writing a large grant proposal to integrate weed management, disease epidemiology, and market sector models to provide an overarching model to aid in decision making for forest growers in the zone of the SNC epidemic.

This 2008 Annual Report reflects some of the strong work that has been on-going and supported primarily by the SNCC. Also included in this report is a Swiss Needle Cast fact sheet that is being published by OSU Forestry Extension, which should be available to the general public soon.

Due to the strong support provided by the state legislature and the College of Forestry Forest Sciences Laboratory the SNCC has about double the membership dues to fund research. We also maintain a website (http://www.cof.orst.edu/coops/sncc/index.htm) where information is provided for interested landowners and others. Thank you SNCC members for all your vision and support of research concerning this important foliage disease of Douglas-fir.

David Shaw, SNCC Director
November, 2007

Projects for 2007

- Continue aerial survey to monitor SNC in Oregon Coast Range.
- Continue Growth Impact Study and Precommercial Thinning Study.
- Continue development of the submodule for ORGANON to predict growth of Douglas-fir under different severities of SNC.
- Examination of the influence of SNC on Douglas-fir foliage dynamics and nutrient fluxes.
- Investigate whether dendrochronology can be used in older Douglas-fir trees to identify SNC epidemics that may have occurred in the past.
- Collaborate with the South Central Coast Cooperative of the Northwest Tree Improvement Cooperative to find SNC tolerant seed sources of Douglas-fir.
- Continue to develop a model that will improve prediction of the spatial geographic variation in SNC severity.
- Examine how SNC effects the soil mycorrhizal community of Douglas-fir.

Background and Organization

A major challenge to intensive management of Douglas-fir in Oregon and Washington is the current Swiss Needle Cast (SNC) epidemic. Efforts to understand the epidemiology, symptoms, and growth losses from SNC have highlighted gaps in our knowledge of basic Douglas-fir physiology, growth, and silviculture. The original mission of the Swiss Needle Cast Cooperative (SNCC), formed in 1997, was broadened in 2004 to include research aiming to ensure that Douglas-fir remains a productive component of the Coast Range forests.

SNCC is located in the Department of Forest Science within the College of Forestry at Oregon State University. The Membership is comprised of private, state, and federal organizations. Membership dues vary depending on forestland ownership. One annual report, project reports, and newsletters are distributed to members each year. All projects are carried out in cooperation with specific members on their land holdings.

Mission Statement

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

Objectives

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

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

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

List of Refereed Publications

2000

Hansen, E.M., Stone, J.K., Capitano, B.R., Rosso, P., Sutton W., Winton L., Kanaskie A., and M.G. McWilliams. 2000. Incidence and impact of Swiss needle cast in forest plantations of Douglas-fir in coastal Oregon. Plant Disease. 84: 773–779.

Manter, D.K., Bond, B.J., Kavanagh, K.L., Rosso, P.H., and G.M. Filip. 2000. Pseudothecia of Swiss needle cast fungus, Phaeocryptopus gaeumannii, physically block stomata of Douglas-fir, reducing CO_2 assimilation. New Phytologist 148: 481–491.

2001

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

Manter, D. K., Kelsey, R. G., and J. K. Stone. 2001. Quantification of Phaeocryptopus gaeumannii colonization in Douglas-fir needles by ergosterol analysis. For. Path. 31: 229–240.

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Maguire D.A., Kanaskie A., Voelker W., Johnson R., and G. Johnson. 2002. Growth of young Douglas-fir plantations across a gradient in Swiss needle cast severity. West. Jour. of Ap. For. 17: 86–95.

Johnson, G.R. 2002. Genetic variation in tolerance of Douglas-fir to Swiss needle cast as assessed by symptom expression. Silv. Gen. 51: 80-86.

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

Manter, D. K. 2002. Energy dissipation and photoinhibition in Douglas-fir needles with a fungal-mediated reduction in photosynthetic rates. J. Phytopathol. 150: 674–679.

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Manter, D.K., Bond, B.J., Kavanagh, K.L., Stone, J.K., and G.M. Filip. 2003. Modelling the impacts of the foliar pathogen, Phaeocryptopus gaeumannii, on Douglas-fir physiology: net canopy carbon assimilation, needle abscission and growth. Ecological Modeling. 164: 211–226.

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Rosso, P. and E.M. Hansen. 2003. Predicting Swiss Needle Cast disease distribution and severity in young Douglas-fir plantations in coastal Oregon. Phytopathology 93: 790-798.

Winton, L.M., Manter, D.K., Stone, J.K., and E.M. Hansen. 2003. Comparison of biochemical, molecular and visual methods to quantify Phaeocryptopus gaeumannii. Douglas-fir foliage. Phytopathology. 93: 121–126.

2004

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

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

Kelsey, R.G., and D.K. Manter. 2004. Effect of Swiss needle cast on Douglas-fir stem ethanol and monoterpene concentrations, oleoresin flow, and host selection by the Douglas-fir beetle. For. Ecol. Man. 190: 241-253.

Temel, F., Johnson, G.R., and J.K. Stone. 2004. The relationship between Swiss needle cast symptom severity and level of Phaeocryptopus gaeumannii colonization in coastal Douglas-fir (Pseudotsuga menziesii var. menziesii). For. Path. 34: 383-394.

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Manter, D.K., Kavanagh, K. and C.L. Rose. 2005. Growth response of Douglas-fir seedlings to nitrogen fertilization: importance of Rubisco activation state and respiration rates. Tree Physiology 25: 1015–1021.

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

Temel, F., Johnson, G.R., and W.T. Adams. 2005. Early genetic testing of coastal Douglas-fir for Swiss needle cast tolerance. Can. J. For. Res., 35: 521-529.

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Weiskittel, A.R., D.A. Maguire, R.A. Monserud, and E.C. Turnblom. 2006. Intensive management influence on Douglas-fir stem form, branch characteristics, and simulated product recovery. *New Zealand Journal of Forestry Sciences* 36:293-312.

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

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Stone, J. K., P. W. Reeser, and A. Kanaskie. 2007. Fungicidal Supression of Swiss Needle Cast and Pathogen Reinvasion in a 20-Year-Old Douglas-Fir Stand. Western Journal of Applied Forestry 22: 248-252.

Weiskittel, A.R. and D.A. Maguire. 2007. Response of Douglas-fir leaf area index and litterfall dynamics to Swiss needle cast in north coastal Oregon, USA. Annals of Forest Science 64:121-132.

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

Weiskittel, A.R., D.A. Maguire, and R.A. Monserud. 2007. Modeling crown structural responses to competing vegetation control, thinning, fertilization, and Swiss needle cast in coastal Douglas-fir of the Pacific Northwest, USA. Forest Ecology and Management 245:96-109.

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

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

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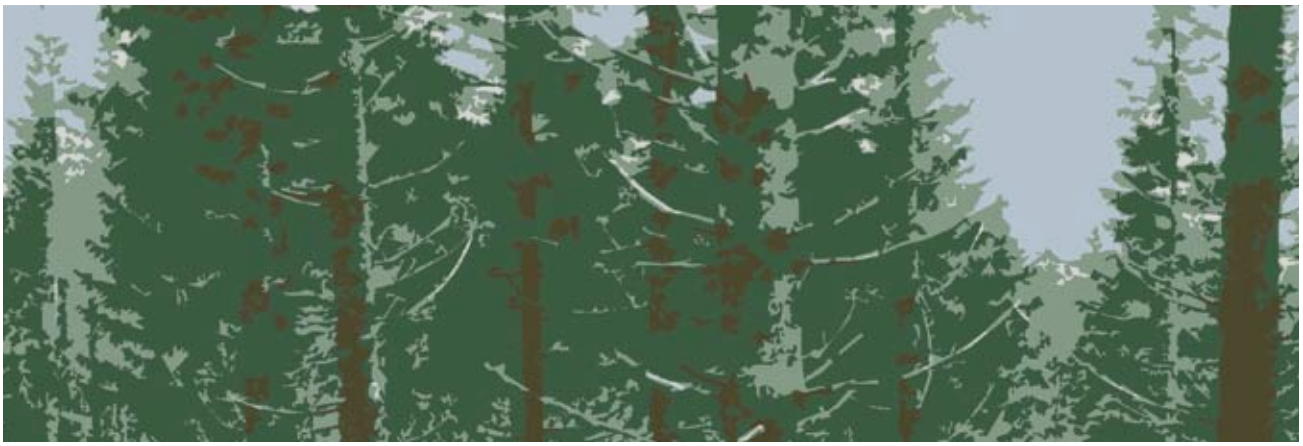


Swiss Needle Cast of Douglas-fir in Oregon

OSU Forest Extension Fact Sheet. David Shaw

What Is It?

Swiss needle cast of Douglas-fir is a foliage disease of Douglas-fir caused by the fungus, *Phaeocryptopus gaeumanii*. The disease is specific to Douglas-fir, affecting no other tree species. It was first discovered in Douglas-fir plantations in Europe in the early 20th Century, hence the name "Swiss" needle cast, but the pathogen is presumed to be native to the Pacific Northwest. In Oregon, *P. gaeumannii* is found throughout the range of Douglas-fir, where it mostly occurs as a reasonably harmless fungus within the interior of leaves. Swiss needle cast disease is typically associated with Douglas-fir grown outside of its native range such as in Europe or New Zealand, or in Christmas tree plantations in the Midwest USA. However, Swiss needle cast can also occur in western Oregon particularly on sites that have high amounts of spring/summer rain and mild winter temperatures that provide favorable conditions for growth and reproduction of the pathogen. Swiss needle cast is also one of a number of important foliage diseases in Oregon Christmas tree plantations . Currently Swiss needle cast is causing severe symptoms in the low-elevation, western-flanks of the Coast Range along the central and northern coast of Oregon. (Figure 1).

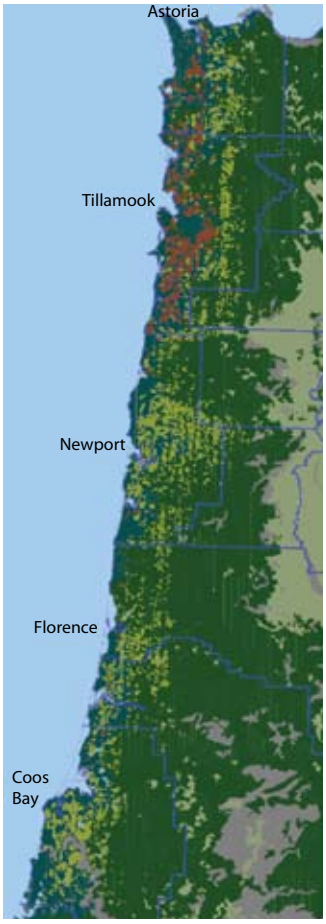


Figure 1. Area detected by observers in airplanes that have visible sign (yellow foliage, thin crowns) of Swiss needle cast disease.

What Does It Do?

Swiss needle cast causes premature needle loss (casting) resulting in thin crowns (Figure 2), and the remaining foliage may appear yellowish (chlorotic). The symptoms are most visible in late spring, just prior to budbreak (May-early June). After budbreak, the new foliage masks the yellowish foliage of previous years

Figure 2. Photo of Douglas-fir tree exhibiting symptoms of Swiss needle cast. Note the thin crown, yellowish color, and general overall peeked look. A tree like this may not die, but will have reduced growth and competitive advantage.

growth. Diagnosis can be made by examining the undersides of the oldest needles and looking for small black dots (pseudothecia, fruiting bodies of the pathogen) that plug the air pores (stomates) (Figure 3). These can be seen best with a 10X hand lens, but

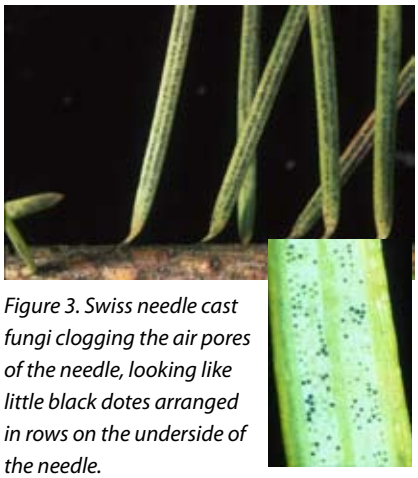


Figure 3. Swiss needle cast fungi clogging the air pores of the needle, looking like little black dotes arranged in rows on the underside of the needle.

where the disease is severe they can be seen with the naked eye. Swiss needle cast rarely kills trees, but can cause reduced tree growth (Figure 4).

Figure 4. Photo of wood disk, showing reduced growth of tree with Swiss needle cast.

Growth losses due to disease can vary depending on disease severity. Studies in the zone of the Oregon Swiss needle cast epidemic have shown average losses are between 20 and 55 percent. Growth reduction due to disease can eliminate the competitive advantage of the planted Douglas-fir, allowing other naturally seeded tree species to outgrow the Douglas-fir (Figure 5).

Figure 5. Douglas-fir being out-competed by western hemlock, near Tillamook.

Biology and Spread of the Fungus

Phaeocryptopus gaeumannii is a micro-fungus in the group of fungi which reproduce sexually by a type of spore called an ascospore. These spores are produced within the fruiting bodies, or pseudothecia, that appear as small black dots on the undersides of needles. Ascospores mature and are released in June-July, coinciding with the emergence of new foliage. Ascospores are released and are dispersed during periods of precipitation by wind-blown rain. *P. gaeumannii* lives within the needle, but it produces spores at the entrance to the air pores (stomates) on the underside of the needle. This clogs up the air pore and the leaf cannot get carbon dioxide in, or allow water and oxygen out. It appears that the fungus does no other harm to the plant, i.e. it does not kill cells within the needle and feed on them. However, the clogging of the air pores of the needle causes the tree to starve for carbon, and that reduces growth. The infection of a needle occurs only on newly emerged foliage in the spring during, or shortly after, needle flush. The spore is deposited on the needle, germinates, and grows on the needle surface until it finds a suitable air pore to grow into. Ascospore release and infection are aided by surface moisture, light rain and dew It is common on healthy Douglas-fir in Oregon to find the *P. gaeumannii* black fruiting bodies on the oldest needles as a component of normal old-age needle drop, usually 4 or 5 years, depending on elevation, aspect, and habitat. The most severe symptoms of Swiss needle cast occur on trees in which the fruiting bodies of the fungus are abundant on one and two year-old foliage, which results in early needle loss.

The ascospores are very susceptible to drying, and weather conditions have to be reasonably wet for successful infection. Mild moist spring and early summer weather is most conducive to foliage infection. Since only the newly emerged leaf is infected, the amount of inoculum (abundance of ascospores) and the weather conditions during the spring infection period strongly affect the amount of infection that will be present in a cohort of foliage for its life. Hence, after several years of favorable weather for infection to occur, the entire tree crown can be heavily infected by *P. gaeumannii*. Alternatively, dry spring weather can lead to little infection. The anomalies of annual weather patterns control much of the visual expression of the disease. Typically, Douglas-fir plantations in low

elevation, moist valley bottoms in the Cascades and Willamette Valley, which tend to have drier spring weather than the western Coast Range may have sporadic symptoms. But disease tends to be more consistently severe along the western slope of the central and northern Oregon Coast Range, where spring moisture is abundant and infection conditions are often favorable.

The Swiss needle cast epidemic in Oregon is limited in geographic extent, and does not appear to be expanding. However, the total area affected is about 1 million acres with an average of about 25% growth reductions. In the previous century the area was dominated by a mix of western hemlock, Douglas-fir, Sitka spruce, western redcedar, and red alder. The soils are rich in nitrogen and a bit on the acidic side, causing some calcium depletion. The region has gradually been converted to young, productive Douglas-fir plantations over the past 60 years. But whereas Douglas-fir previously comprised less than 20% of the forest, it has become the dominant species, and mostly young plantations. The combination of mild temperatures in winter, wet fog-laden spring/early summers that allow leaf infection, abundant young, even-aged host, and rich soils that produce succulent nitrogen rich foliage, may be the cause of the epidemic. Everything is favorable for the fungus!

How Do I Know Whether I Have a Problem?

For the forester or landowner, even though Swiss needle cast is present, you most likely do not have a problem as long as your trees retain about 3 years of foliage. We normally don't detect reduced growth until the tree is retaining less than this amount. Figure 6, is an illustration that shows how cohorts of needles are arranged on a branchlet of Douglas-fir. A simple way to confirm the number of years of foliage retention in your tree is to look at the mid-crown area on the sunny side (south usually) of the tree and count the foliage cohorts with binoculars. It is best to count several different branches, and use laterals rather than the apical leader of the branch. Take an average of several counts in this area of the tree. Again, you don't have a current problem with Swiss needle cast if your tree carries 3 or more years of foliage, even if you can find black dots on the underside of older needles.

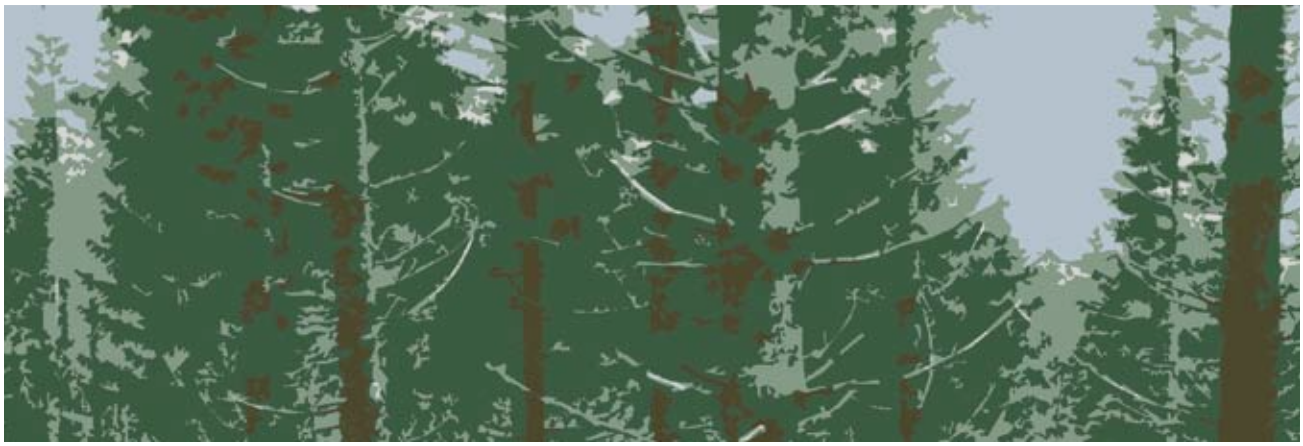
Figure 6. Age classes of Douglas-fir needles on a branch.

What are We Doing About the Epidemic Along the Oregon Coast?

In 1996, after it became apparent that there was an epidemic in the Oregon Coast Range, Oregon State University and forest landowners (state, federal, and private) came together to form the Swiss Needle Cast Cooperative. This cooperative has spearheaded research into the epidemic's cause and how to manage for it. Fungicides are effective against the disease, but impractical for use over such a vast area. Current efforts by the cooperative are focusing on melding our increasingly sophisticated understanding of the spatial distribution of disease severity, weather models, forestry practices, growth models of Douglas-fir under different severity regimes, and soils. In addition, the members of the Northwest Tree Improvement Cooperative are engaged in efforts to find tolerant Douglas-fir families through traditional tree breeding.

The expression of disease by Douglas-fir trees is clearly linked to climate, topography, and geographic location, even within the zone of the epidemic. Sites that are southerly in aspect, low elevation, and in areas of higher moisture condensation on foliage are the worst. Spatial models are being developed that may be able to predict disease severity at the scale of the plantation. In the future, these models could be linked to growth models that take into account disease severity, and allow the forester to estimate impacts to Douglas-fir growth for a specific site.

Normal silvicultural practices that encourage tree growth, such as thinning are encouraged although nitrogen fertilization is not. Mixed species management may help offset any losses from Swiss needle cast of Douglas-fir, and in some high severity zones, Douglas-fir should not be grown.



Swiss Needle Cast Aerial Surveys, 1996 to 2007

Alan Kanaskie, Mike McWilliams, Keith Sprengel, Dave Overhulser

Survey procedures

Aerial surveys for SNC have been conducted in April and May each year since 1996. The observation plane flies at 1,500 to 2,000 feet above the terrain, following north-south lines separated by 2 miles. Observers look for areas of Douglas-fir forest with obvious yellow to yellow-brown foliage, a symptom of moderate to severe Swiss needle cast damage. Patches of forest with these symptoms (patches are referred to as polygons) are sketched onto computer touch screens displaying topographic maps or ortho-photos and the position of the aircraft.

The area surveyed extends from the coastline eastward approximately 30 miles (or until symptoms are no longer visible), and from the Columbia River south to Gold Beach. We survey approximately 2 to 3 million acres each year. We occasionally have surveyed the Cascade Range, but the low damage levels have not justified repeated surveys.

Results and discussion

The Coast Range survey was flown from May 7 to May 16, 2007 and covered approximately 3 million acres of forest. We mapped 338,761 acres of Douglas-fir forest with obvious symptoms of Swiss needle cast; 220,866 acres north of the Lincoln-Lane county line, and 117,896 acres south of the Lincoln-Lane county line (Figure 1, 2). The easternmost area with obvious SNC symptoms was approximately 28 miles inland from the coast in the Highway 20 corridor, but the majority of area with symptoms occurred within 18 miles of the coast. Figures 1, 2 and 3 show the trend in damage

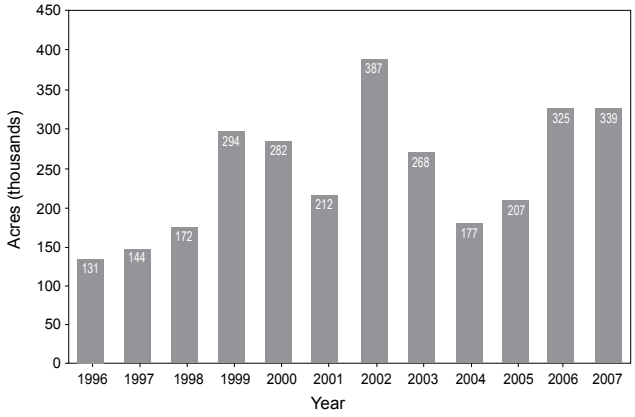


Figure 1. Trend in area of Douglas-fir forest in western Oregon with symptoms of Swiss needle cast detected during aerial surveys in April and May, 1996-2007.

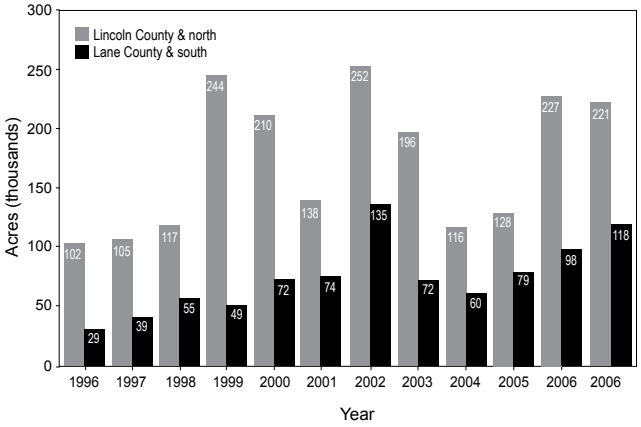


Figure 2. Area of Douglas-fir forest in western Oregon with symptoms of Swiss needle cast detected during aerial surveys in April and May, by zone, 1996-2007.

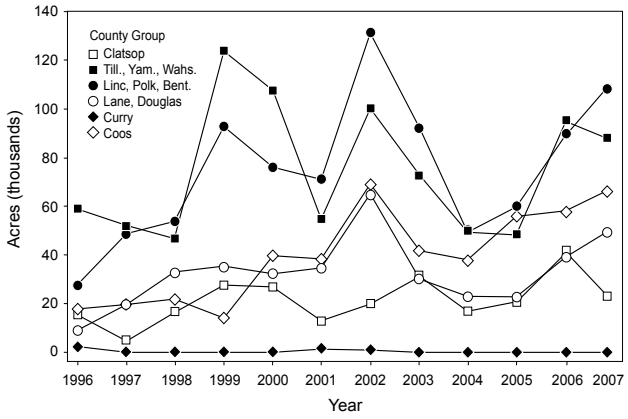


Figure 3. Area of Douglas-fir forest in western Oregon with symptoms of Swiss needle cast detected during aerial surveys in April and May, by county group, 1996-2007.

from 1996 through 2007. The survey maps for 1996 through 2007 appear in figure 4.

The 2007 survey results show a continued increase in the area of forest with symptoms of Swiss needle cast during the past 3 years. Symptoms were well-developed and survey conditions were excellent. The trend of increasing damage is troubling because it has occurred despite active management in the region to reduce damage from the disease.

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

Acknowledgments

The survey was conducted by the Oregon Department of Forestry Insect & Disease and Air Operations sections, and was funded by the Oregon State University Swiss Needle Cast Cooperative, the USDA Forest Service Forest Health Monitoring Program, and the Oregon Department of Forestry. Mike McWilliams (ODF) is the survey coordinator and primary aerial observer; Ben Smith (USFS), and Rob Flowers (ODF) were additional aerial observers. Jim Baranek (ODF) piloted the plane.

Note

The GIS data and a pdf file for the SNC surveys can be accessed via the ODF web page at http://www.odf.state.or.us/fa/FH/maps.htm

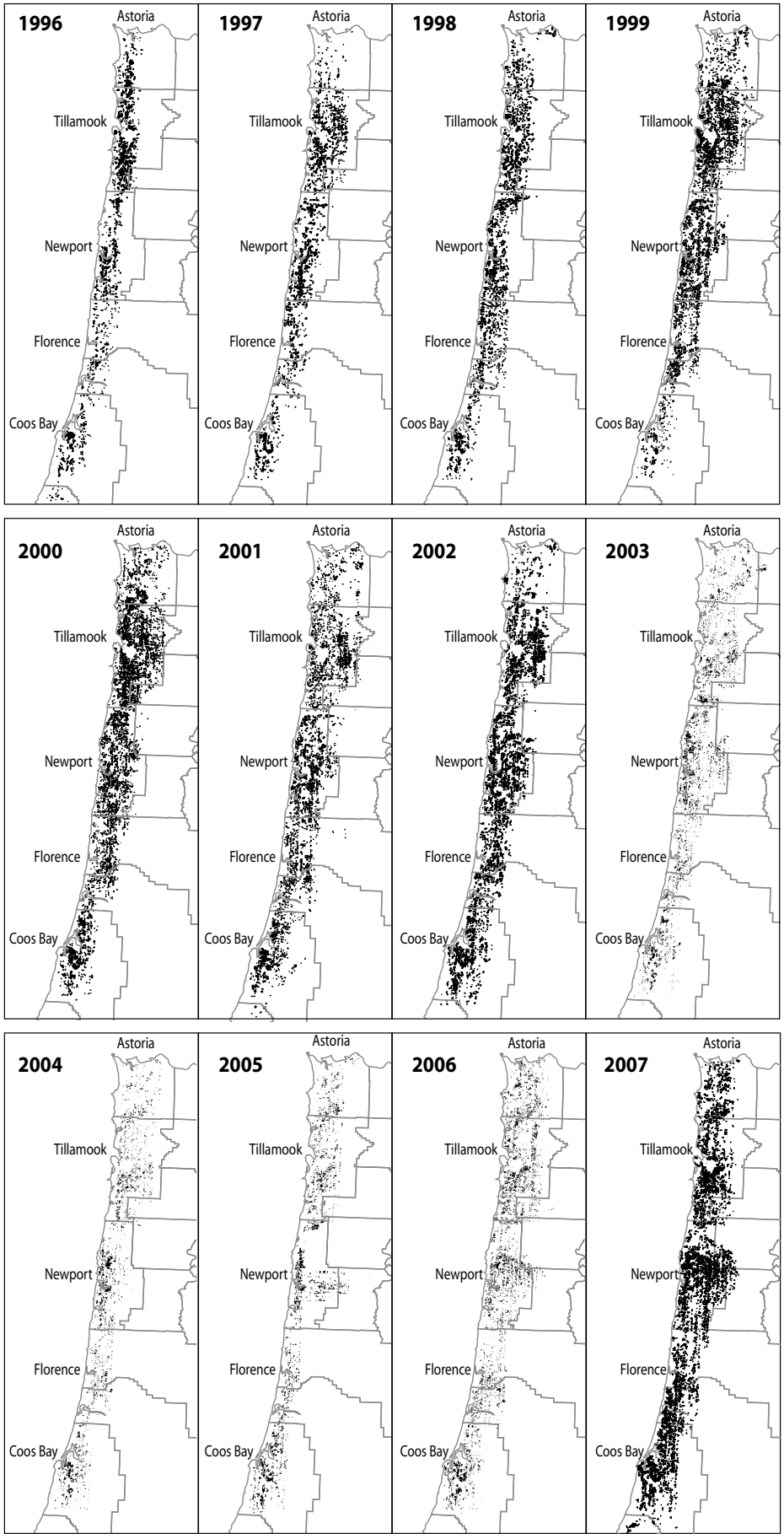
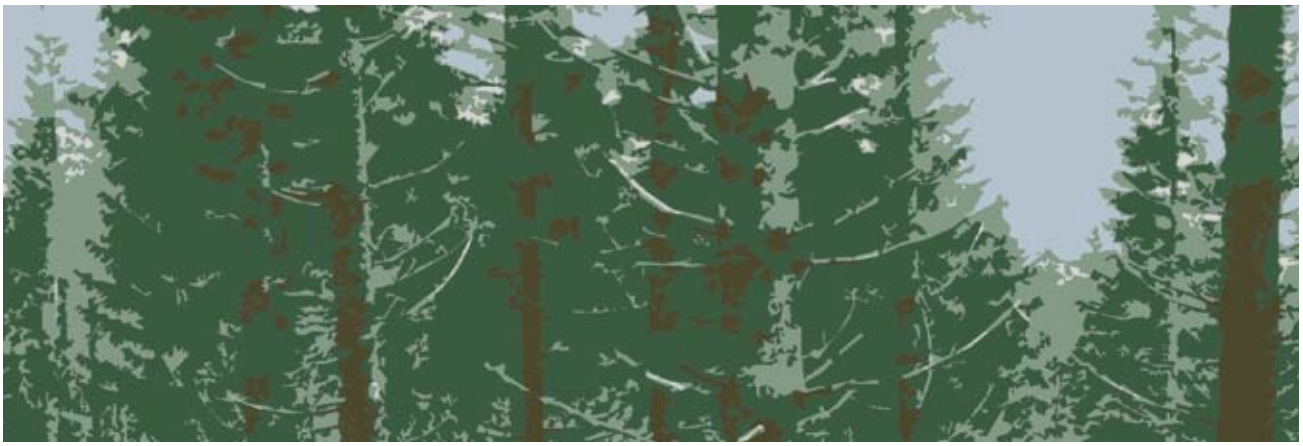


Figure 4. Areas of Douglas-fir forest in western Oregon with symptoms of Swiss needle cast detected during aerial survey in April and May, 1996-2007.



Prediction Maps of Swiss Needle Cast Needle Retention Based on Climatic Factors

Len Coop and Jeff Stone

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Summary

Swiss Needle Cast (SNC) causes defoliation, chlorosis, and growth loss in Douglas-fir tree plantations growing in OR and WA coastal areas. We document the development and testing of maps of estimated SNC needle retention that reflect recent (1996-2007) climate averages and aerial surveys. SNC sample sites from prior research were used to develop a conversion model from SNC aerial survey scores (1=moderate, 2=severe, cumulative over 12 years) to needle retention in years (range <2 to ca. 5.0). Spatial climate data averages were developed by geographically weighted regression downscaling of summer relative humidity and winter temperature PRISM climate maps for all months over the 12-year period. Several models were developed for SNC severity. Model 1 developed during Spring 2007, used converted survey results as the dependent variable and was predicted by July relative humidity (RH) and Dec-Feb degree-days (3°C lower threshold), and aspect (southwest slopes resulting in highest increase in SNC). This model was significant with respect to data used to build it (R^2 = 0.75 using aerial survey data sites; R^2 = 0.65 using 10 best SNC sample sites), and also significant with a separately collected data set (N=61, R^2 = 0.59). Additional analyses include a life table approach to estimation of needle retention in years, models for the conversion of survey scores to needle retention, and the use of GIS to overlay climate-based estimates over survey-based estimates of needle retention values for a combined map.

Introduction

Swiss Needle Cast (SNC) is a major foliar disease of Douglas-fir, caused by *Phaeocryptopus gaeumannii* (T. Rhode) Petr., in coastal areas of Oregon and Washington. Recent models were developed to predict SNC severity due to climate, terrain, and other factors (Rosso and Hansen 2003, Manter et al. 2005, Stone and Coop 2006). The latter study compared yearly survey data to climate data to model year to year changes in total SNC acreage and average severity. This study is focused on producing maps that reflect recent climate, and can be tested as forest management and planning decision aids. These maps include needle retention in years using a climate-based model, a map of 1996-2007 aerial survey cumulative results converted to needle retention, and a combination overlay map of the two. Results are also placed at an interactive mapping website, http://pnwpest.org/snc.

Objectives

Our major objective is to develop estimates of future long-term Swiss needle cast induced reductions in needle retention of Douglas-fir based on currently available data. These data consist of a) SNC aerial survey maps 1996-2006 (as GIS raster data converted from vector polygons), b) Site samples from Manter et al. (2005) which examined climate effects on swiss needle cast severity, c) PRISM Climate map data

(Daly et al. 1994, OSU Spatial Climate Analysis Service), and d) other site-based SNC severity data (Mainwaring et al. 2003, 2006, unpublished 2007). Our previous effort (Stone and Coop 2006) focused on year-to-year fluctuations in region-wide SNC severity as reported by the aerial surveys, whereas the current focus is on estimation of long term impacts using spatially detailed GIS modeling. Improvements over earlier models (Oct. 2006, Mar. 2007) are discussed along with possibilities for further improvement of this modeling approach.

Methods

Input variables

PRISM climate data (Daly et al. 1994, 2004) were downloaded from the Oregon Climate Center PRISM website for relevant months for the years 1995-2007. Major variables of interest were relative humidity (RH) during June-Aug and temperature (avg monthly max and mins) during Dec-Feb. RH was calculated using standard dewpoint and temperature conversions to RH for each month mentioned. Winter degree-days (DDs) (3°C threshold) were calculated using the simple average (max+min/2 - threshold) formula for each month and added together. July RH and winter DDs were then averaged over the 12 years of the aerial surveys. Initial PRISM map resolution was 4km. During summer 2007, the PRISM group completed 800m temperature maps but dewpoint maps are not yet available at this higher resolution. Spatial resolution of PRISM derived maps was downscaled from 4km to 200m using a knowledge-based geographically weighted regression algorithm implemented in GRASS 5.4 that utilizes elevation as the independent variable (Coop 2004). Aspect (90m resolution) was converted to a range of 0-2 where 2=SW, 0=NE and 1=NW and SE, with flat (neutral) areas also set to 1.

Modeling Assumptions

The model output region was specified to include all coast areas including those not currently planted to Douglas Fir, to serve as a possible "what-if" guide to potential SNC impacts for future years. No WA coastal SNC severity data were obtained for this modeling effort. Therefore, WA SNC maps are entirely an extrapolation from the OR-based model. In addition, because SNC, as affected by climate over the next several years, is more likely to reflect recent warming trends than 1971-2000 average climate data, PRISM data sets used in these analyses were drawn from the more relevant 1996-2007 survey interval rather the the 1971-2000 PRISM data. To help improve the relative spatial precision of the PRISM climate data, a GWR (geographically weighted regression) downscaling step was used to standardize resolution to 200 meters.

Survey Conversion Data Model

SNC aerial severity survey data from 1996-2007 (Kanaskie et al. 2006) were combined for modeling where, in a given year, moderate SNC severity was coded as 1 and severe was coded as 2. All other areas were coded as 0. These scores were summed to provide a potential range of 0-24 to signify cumulative SNC severity. These scores were converted to average needle retention in years (NRyrs) based on a high quality (N=20 trees/plot) but spatially limited data set (10 separate sample sites; 8 from the Manter et al. data set collected from 2002-2004, representing years 1998-2004, and 2 from a study from 2001-2004 at East Beaver). Conversion model I used simple linear regression between cumulative survey score and needle retention (yrs). Conversion model II was needle retention vs. natural log (ln) of cumulative survey score plus 1. Needle retention values were computed from the 10 sites using standard ecological time-specific life table analysis (Smith 1999). This consisted of converting % needle retention for each age class (1-4 year old) as age-class survival rates to compute life expectancy of needles in years for age class zero (Ex0). This conversion from survey scores to needle retention (NR_{yrs}) thus represents a preliminary model reflecting the spatial and temporal extent of the 12 year survey and can serve as a dependent variable for further modeling exercises. Additional multi-year data (2002-3 and again 2006-7) from a SNCC sponsored thinning study by Mainwaring et al. (2003, 2006, 2007) were used for model validation.

Climate Model

A climate plus aspect derived model was fitted to the converted survey data ($surv\_NR_{yrs}$) using randomly sampled sites from within the aerial survey area, plus a random sampling of sites largely east of survey areas where forest occurs (which were set to a nominal needle retention of 4.5 years). The climate model was initially fitted to converted survey data and also to survey scores (0-22) as a check. Correlation and multiple linear and robust regression analyses using the R statistical language (RDCT 2006) were used to build all models. A test of the robustness of the model was conducted by selecting subsets of the survey data according to latitude, including (in degrees N): 42.0-44.0, 44.0-45.0, and 45.0-46.0 as well as

with the full extent of the survey data. Geographic Information System (GIS), spatial covariance, and spatial modeling analysis were conducted using GRASS GIS version 5.4 (Neteler and Mitasova 2004).

An earlier spatial climate-based model developed by Manter et al (2005) was regenerated using 800m PRISM 30-yr (1971-2000) data rather than DAYMET (1km, 1980-1997) data. To use the same units of interest, the model required a conversion factor from their infection index for 2 year old needles (/y-2) to needle retention (years), computed using regression analysis on the 10 Manter et al sites. A similar map to Manter et al.'s Fig 7(b) map was thus generated using PRISM data and then converted from their infection index to needle retention. This modified version of their model visually matches their original very closely. This revised map was used to compare to maps and models from the current modeling exercise.

Validation Data

Data from a two-phase commercial thinning study (2001-2007) were obtained from Mainwaring et al. (retrospective and permanent plot studies) and used to compare with modeling results. These samples generally consisted of 10 trees per plot and were revisited after 5 years (2002-2006 and 2003-2007). The reported foliage retention values (range 1.3-4.95 years, 2002-2006 plots) were averaged to better reflect the aerial survey period. Only control plots within the permanent plot samples were used. These data may be limited by stand age (30-60 year old stands were used), and by the retrospective plots having been thinned, 4-10 years prior to the study, which may have influenced SNC severity.

Results

Survey Data Model

The linear model for conversion of cumulative severity scores (range 0-22) from the aerial survey data to needle retention in years (surv_NR_{yrs}) is presented in Table 1.

Table 1. Data used to develop a model for survey needle retention (years) from site data needle retention values (sampled Ex0) and aerial survey scores (1996-2006) [linear model], plus climate model verification data.

	sampled survey							est.
Name	Long	Lat	Ex0	score	rh.07	w_dds	aspect	SNC_V2
MACFOR	-123.3238	44.6270	4.22	0	59.39	59.83	0.22	4.82
DOLPH	-123.7911	45.1074	3	3	73.61	97.23	0.04	3.27
SALAL	-123.8979	45.1455	2.98	6	78.54	118.49	0.41	2.59
JUNO	-123.8168	45.4931	2.14	10	80.11	113.11	0.01	2.56
CEDAR	-123.8134	45.2211	3.19	3	75.57	105.15	1.38	2.82
ROTH	-123.6064	45.0894	3.56	1	66.66	81.29	1.58	3.78
LIMEST	-123.7184	45.2531	3.19	2	75.09	102.3	0.06	3.09
ACEY	-123.8022	45.7715	3.3	3	77.36	94.65	1.29	2.76
EBEAVC1	-123.8131	45.2933	2.08	16	77.68	113.6	1.83	2.44
EBEAVC3	-123.8042	45.2863	1.76	19	77.67	113.36	1.14	2.6
	models vs Sampled Ex0:							
	slope	-0.1209	-0.0915	-0.0345	-0.1844	0.8222		
	intrcpt	3.6550	9.7303	6.3920	3.0889	0.4143		
	Rsq	0.8810	0.6085	0.6863	0.0309	0.6520		

The linear and a revised log survey data conversion models were:

surv_NR_{yrs} = survey_score x -0.1209 + 3.655 (R^2=0.88) [linear model]

and

surv_NR_{yrs} = ln(survey_score + 1) x -1.141 + 5.000 (R^2=0.95) [log model] (Fig. 1a)

The revised log model was validated using the Mainwaring et al. thinning data (Fig. 1b) and the earlier linear model was then applied to the entire aerial survey scores raster data set. These data were then sampled using a set of random points (N=114) to provide a larger data set to regress versus climate data and aspect. The log model will likely be used in future climate mapping analyses.

Since needle retention in years in the Manter et al. (2005) data set was determined using life table analysis, we cross-checked the relationship between this value (Ex0 or NR_{yrs}) and the average percentage needle retention, which is a simple average of values over the 4 needle age classes. This model was highly significant for the above 10 sample sites, R^2 = 0.995, and the resulting model,

NR_{yrs} = 0.3488 + 4.1893 x avg. % needle retention (yrs 1-4)

could possibly be validated as a quick and reliable method to estimate years of needle retention from sample data for which only % needle retention was estimated.

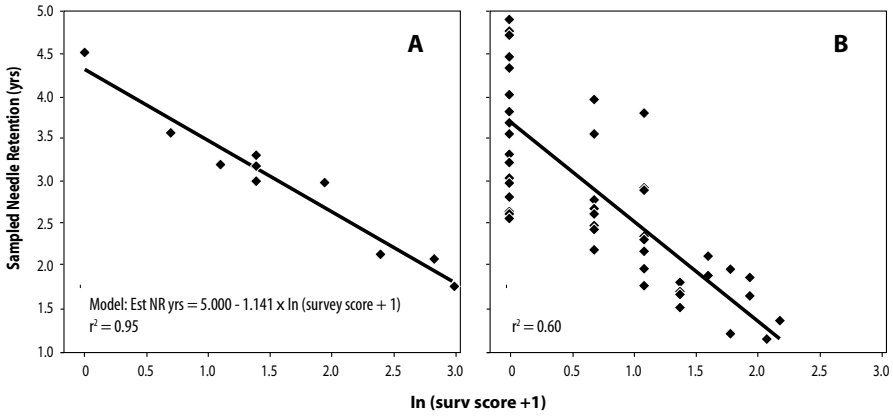

Fig. 1. Log model to convert cumulative Swiss Needle Cast aerial 1996-2007 survey scores to needle retention (yrs). 1a: Model developed using Manter et al. site data, 1b: Model validation using Mainwaring et al. (2003-2007) thinning study data.

Climate Model Using Linear Converted Survey Data

The best derived climate data model, using the linear conversion of survey scores to needle retention, from several combinations of sampled data sets and variables was: survey needle retention in years is a function of July RH, winter degree-days above 3°C, and aspect (Table 2, Figs. 2a-c):

$surv\_NR_{yrs}$ = 10.655 - 0.08918 x rh.07 - 0.008362 x w_dds - 0.15914 x aspect

This model was built with N = 165 points including the 10 Manter et al. based sites, and 41 unsampled sites east of the aerial survey area. Excluding these non-survey sites, a very similar model was obtained:

$surv\_NR_{yrs}$ = 10.39 - 0.0863 x rh.07 - 0.00815 x w_dds - 0.1286 x aspect

(R^2 = 0.752, F = 115.3 on 3 and 110 DF, p < 0.001 on all variables except aspect; p = 0.01).

Since the model is intended to be spatially robust, and therefore should not exclude sites outside the survey region, the former model is used herein.

Table 2. Climate-based model of SNC needle retention (yrs) using augmented converted survey data as dependent variable. This is the model used to generate the GIS map layer SNC_V2 (Figs. 1a-c).

Coefficients:

	Estimate	Std.Error	t value	Pr(>|t|)
(Intercept)	10.65510	0.21349	49.91	< 2e-16 ***
rh.07	-0.08918	0.00303	-29.39	< 2e-16 ***
w_dds	-0.00836	0.00060	-13.87	< 2e-16 ***
aspect	-0.15914	0.03452	-4.61	8.16e-06 ***

Signif. codes: 0 `***' 0.001 `**' 0.01`*' 0.05 `.' 0.1 ` ' 1

Residual standard error: 0.2504 on 161 degrees of freedom
Multiple R-Squared: 0.8982, Adjusted R-squared: 0.8963
F-statistic: 473.4 on 3 and 161 DF, p-value: < 2.2e-16

Very similar regression model results were obtained for all tested subsets of the survey region, thus no stratified or sub-region based models were deemed necessary and the model may be relatively geographically robust. The model was used to estimate needle retention for the entire OR and WA coast ranges and is referred to as the climate-based model (and named SNC_V2 in the GIS database).

A hybrid model (or GIS data layer) was also developed as a combination of the converted survey data and the climate-based model, using r.patch in GRASS. This model relies on converted survey data where it exists, but otherwise uses the climate-based model, and will be referred to as the combined model.

Climate Model Using Log Converted Survey Data

A second version of the climate model was derived using the log converted survey data. This model was very similar but less significant statistically (Table 3).

Table 3. Climate-based model of SNC needle retention (yrs) using augmented log-transformed converted survey data as dependent variable.

Coefficients:

	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	14.043516	0.437786	32.078	<2e-16 ***
rh.07	-0.127658	0.006190	-20.623	<2e-16 ***
w_dds	-0.012032	0.001236	-9.731	<2e-16 ***
aspect	-0.139943	0.069832	-2.004	0.0467 *

Signif. codes: 0 `***' 0.001 `**' 0.01 `*' 0.05 `.' 0.1 ` ' 1

Residual standard error: 0.512 on 161 degrees of freedom
Multiple R-Squared: 0.8109, Adjusted R-squared: 0.8073
F-statistic: 230.1 on 3 and 161 DF, p-value: < 2.2e-16

Therefore, the linear model was used for subsequent studies.

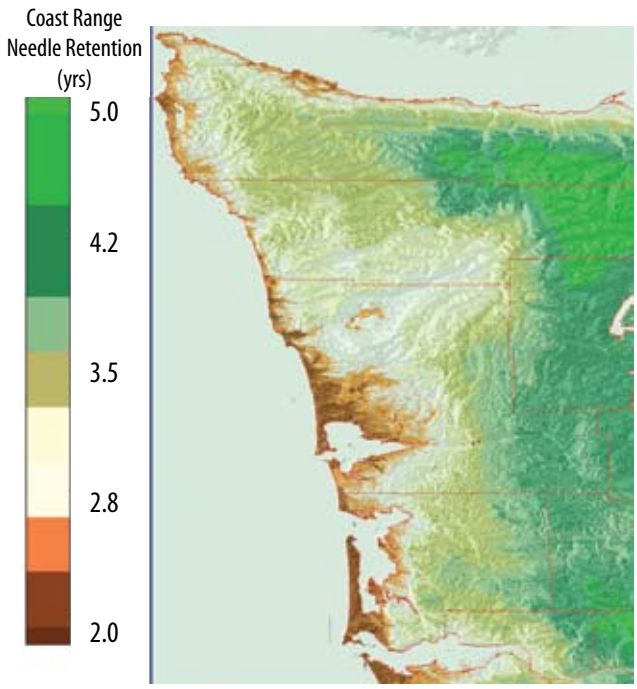

Fig. 2a. Swiss Needle Cast needle retention (yrs) climate based model described in Table 2 - WA coast region.

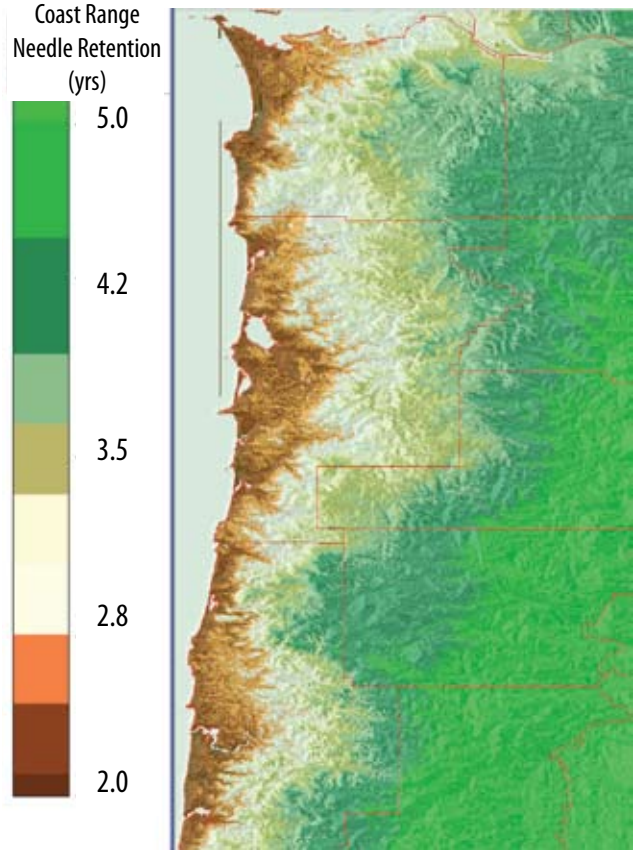

Fig. 2b. Swiss Needle Cast needle retention (yrs) climate based model described in Table 2 - N. OR coast region.

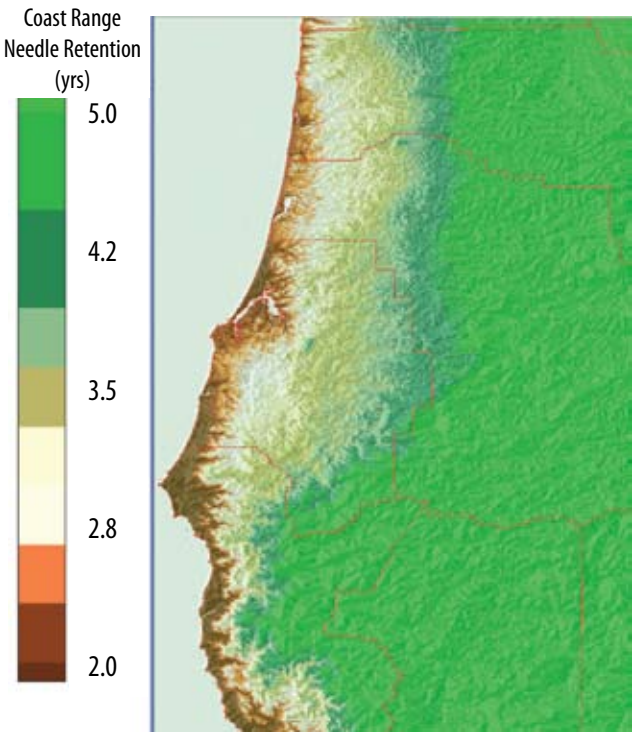

Fig. 2c. Swiss Needle Cast needle retention (yrs) climate based model described in Table 2 - S. OR coast region.

The regression equation used to convert from the Manter et al. (2005) Fig. 7 map (severity index for two year old needles, Iy-2 to needle retention in years) was:

$Manter\_NR_{yrs} = 4.266 - 0.0661 \times Iy\text{-}2;\ R^2 = 0.85$

With the appropriate color table, this map appears very similar to the original (see accompanying website).

Model Verification

Model prediction estimates using the climate-based model are shown in the last column for the 10 sites listed in Table 1. These prediction values correlated with sampled needle retention nearly as well as did winter DDs and was better than July RH alone (SNC_V2 R^2=0.65, w_dds R^2=0.68, rh.07 R^2=0.61). This is interesting as it repeats the findings of Manter et al. (2005), where, using mainly sample sites from this section of the coast range (with diseased sites mainly within Tillamook county), winter temperatures (or degree-days) provide the best single variable model to explain SNC severity.

Checking model estimates using spatial correlation analysis for the entire extent of survey data (GRASS r.covar -r, Table 4) shows correlation coefficients, while not high, are better between converted survey data and the SNC_V2 model (0.30) than for RH.07 (-0.25), w_dds (-0.17), aspect (-0.01), and the Manter_NR spatial model (0.12).

Table 4. Spatial correlation between converted aerial survey data (surv_NR_{yrs}), a climate-based needle retention model (SNC_V2), climate and aspect inputs to the model including July RH (rh.07) and Dec-Feb degree-days (w_dds), and the Manter et al. (2005) derived model. Note that here the spatial extent of correlations is limited by the aerial survey data.

	surv_ NR_yrs	SNC_V2	rh.07	w_dds	aspect	Manter
surv_NR	1.0000	0.3038	-0.2509	-0.1678	-0.0050	0.1197
SNC_V2	0.3038	1.0000	-0.7972	-0.5363	-0.1920	0.3927
rh.07	-0.2509	-0.7972	1.0000	-0.0466	0.0180	0.1509
w_dds	-0.1678	-0.5363	-0.0466	1.0000	-0.0167	-0.9014
aspect	-0.0050	-0.1920	0.0180	-0.0167	1.0000	0.0224
Manter	0.1198	0.3927	0.1509	-0.9014	0.0224	1.0000

An alternative cross-check was to use the combined survey + SNC_V2 model instead of the survey data alone (Table 5). This results in showing the high degree of similarity between the combined model, SNC_V2, and humidity. Again, the Manter model shows greatest correlation with winter degree-days, as it is based on winter (Dec-Feb) temperatures alone.

Table 5. Spatial correlation between converted survey data patched with SNC_V2 model estimates (comb_model), SNC needle retention from the climate-based model (SNC_V2), climate and aspect inputs to the model, and the Manter et al. (2005) derived model. Note that here the spatial extent includes the entire OR + WA coastal region.

	comb_ model	SNC_V2	rh.07	w_dds	aspect	Manter
comb_mod	1.0000	0.9878	-0.9033	-0.3358	-0.1089	0.2405
SNC_V2	0.9878	1.0000	-0.9068	-0.3563	-0.1141	0.2554
rh.07	-0.9033	-0.9068	1.0000	-0.0608	0.0181	0.1275
w_dds	-0.3358	-0.3563	-0.0608	1.0000	0.0245	-0.9053
aspect	-0.1089	-0.1141	0.0181	0.0245	1.0000	-0.0251
Manter	0.2405	0.2554	0.1275	-0.9053	-0.0251	1.0000

Model Validation

The data obtained from Mainwaring et al. (2003-2007), provide a well-distributed independent model validation data set, although representative only of older (>30 years) stands. Correlation between model predictions and measured needle retention was very good (N=61, $R^2 = 0.59$, $R^2 = 0.68$ with 2 outliers removed). Plots (Fig. 3) showed a moderate range of scatter with a few outliers, and good support of the fundamental relationships between measured needle retention and the SNC_V2 model inputs July humidity and winter degree days, but aspect was not significant. Using the same independent variables used to build the SNC_V2 model with these data brought very similar results formodel coefficients (adj. $R^2 = 0.72$, Table 6). Either of these models (in Tables 2 or 6) represent a significant increase in explaining variation in needle retention versus the Manter et al. 2005 model for two-year-old needles ($R^2 = 0.29$). Future versions of the model will use at least a portion of the Manter and Mainwaring data sets for model building. Currently the relative improvement in R^2 does not appear significant enough to construct a new model.

Table 6. Separate 3 variable model built using site data collected by Mainwaring et al. 2003-2007 (2 outliers omitted to decrease influence on parameter estimates).

NR_yrs =

14.5312 - 0.1433 x rh.07 - 0.01881 x w_dds - 0.06780 x aspect

Coefficients:

	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	14.53117	1.33220	10.908	2.27e-15 ***
rh.07	-0.14328	0.01720	-8.330	2.54e-11 ***
w_dds	-0.01881	0.00167	-11.263	6.64e-16 ***
aspect	-0.06780	0.10232	-0.663	0.51

Signif. codes: 0 `***' 0.001 `**' 0.01 `*' 0.05 `.' 0.1 ` ' 1

Residual standard error: 0.4678 on 55 degrees of freedom

Multiple R-Squared: 0.7351, Adjusted R-squared: 0.7207

F-statistic: 50.88 on 3 and 55 DF, p-value: 7.05e-16

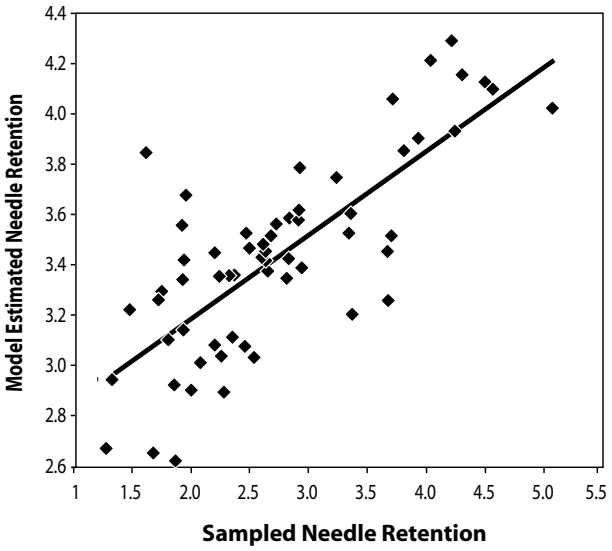

Fig. 3. Validation data scatter plot, with measured needle retention (yrs) and versus estimated by climate-based model (SNC_V2); $R^2 = 0.67$.

Discussion

According to the colors used to delineate SNC severity, the brown and light orange zones (needle retention expected to be 2.8 or less) in the climate-based model correspond to an average July RH threshold of about 77% or higher. However, this threshold tends to decrease slightly moving south (to ca. 73-74% RH) into the southern Oregon Coastal area, where winter temperatures are warmer. This humidity threshold effect, and interaction with winter temperatures, should be explored further to examine both underlying causes, and whether an interaction term should be added to the model. Interestingly, this same threshold of ca. 77% RH and estimated NR of 2.8 years or less corresponds very well with the Western Hemlock/Sitka Spruce zones of some existing maps such as "Forests of Oregon" (OFRI 2002). Fundamentally, the basic relationship represented by the model appears robust and should be usable in present form, accepting that further improvements are expected according to several new developments, including:

- Expansion of data sets. The thinning study appears to have consistent needle retention values between early and late sample dates ($r^2 = 0.84$) and could be combined with the Manter et al (2005) data and perhaps other quality samples, especially those representing younger stands.
- Incorporation of revised PRISM climate data layers. Preliminary efforts to use 800m (30 second) resolution summer and winter temperature PRISM climate data did not result in improved SNC severity models. It is expected that once 800m summer dewpoint data are made available, that the models may be improved.
- Improved representative climate data representing summer moisture. The weather reanalysis by Fox Weather, LLC was completed Oct. 15, 2007, too late to incorporate results into this report, but shows promise from preliminary examination. An updated model using this Fox weather analysis, and new PRISM data is expected by Spring 2008. Future projects may focus on satellite imagery as a way to represent effects of coastal fog and drizzle events thought to impact SNC severity.
- Aspect was not a significant model variable for the currently available validation (thinning study) data. Models based on the Manter et al. (2005) data, the aerial survey data, and studies of Rosso and Hansen (2003) do include a significant variable that represents slope, aspect or orientation. This discrepancy could be due to a lessening effect of slope and aspect for older stands represented by the thinning study plots.
- An additional test of the climate-based model would be to compare it to the Stone and Coop (2006) models for year-to year variation in SNC severity. An inoculum effect could be included in such a stepwise year to year model, which may result in better single year severity predictions.
- A test of SNC severity with this model in New Zealand might also help in calibration, validation and improvement of the model. Initial tests show promise in this area.

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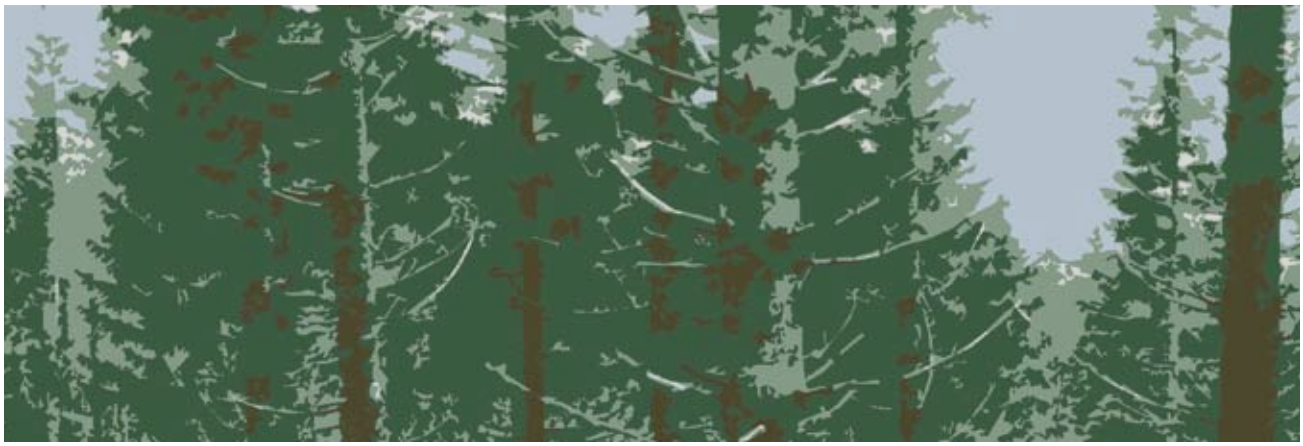

Douglas-fir Growth Response to Commercial Thinning in the Presence of Swiss Needle Cast in North Coastal Oregon

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Abstract

Forty five retrospective and thirty pairs of permanent thinning plots were established in 20-69 year old stands in 2002 to assess the growth of Swiss needle cast (SNC)-infected Douglas-fir stands previously thinned (retrospective) or scheduled for commercial thinning (permanent). Regression models were constructed to estimate the change in foliage retention, basal area growth response, and periodic annual volume growth per stand and per tree.

Foliage retentions have generally increased on both types of plots since 2002. The change in foliage retention is positively correlated with thinning intensity, and varies significantly by growth period, speculated to be a function of the annual variation in spring climate.

Volume growth for both types of plots was found to decline with increasing intensity of SNC, as measured by initial foliage retention and crown sparseness. Maximum volume growth losses were 62% and 35% on the retrospective and permanent plots, respectively. Basal area growth on the retrospective plots continues to accelerate, regardless of SNC level.

Although results from the retrospective dataset would indicate that thinning response is minimal in the first four years after thinning, a significant positive response was detected for the permanent plots on the stand level using a randomized block ANCOVA, and on the individual tree level during the second two-year period.

Introduction

Many Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) stands in western Oregon are suffering from Swiss needle cast (SNC), a foliage disease caused by the fungus *Phaeocryptopus gaeumannii* (Rohde) Petrak (Hansen et al. 2000). Although this fungus is endemic throughout the range of coastal Douglas-fir (Boyce 1940), increases in fungal presence, disease-related defoliation, and associated negative growth impacts have been apparent since at least the 1990s (Maguire et al. 2002). Annual aerial surveys across approximately 3 million acres in Oregon from 1996 to 2007 indicated that the acreage showing disease symptoms has fluctuated annually but remains high, varying from a low of 131,000 acres in 1996 to a high of 387,000 ac in 2002. The most recent survey in 2007 detected symptoms on 338,700 acres.

From 2000 to 2002, 14-34-year-old plantations with the most severe SNC were experiencing a volume growth loss of approximately 52%, with a population average loss of 21% during this period (Maguire et al. 2002). Some severely affected stands at the young end of this age range

were considered at risk of not reaching merchantable size, causing some landowners to underplant sub-merchantable stands or clear them and replant with non-susceptible species such as western hemlock (*Tsuga heterophylla* (Raf.) Sarg.).

As rotations ages have declined in intensively managed stands of coastal Douglas-fir, commercial thinning has become less common due to economic considerations (D. Briggs 2007, unpublished data). The desirability of thinning in SNC-impacted stands has become particularly questionable due to the possibility that thinning exacerbates SNC and causes further growth decline. In severely impacted stands containing trees of mechantable size, regeneration harvesting is often preferred to commercial thinning because it facilitates conversion to a non-susceptible species and brings the land back to a potentially higher level of production.

In contrast to most large private forestlands that must provide an adequate level of revenue to justify holding the asset, public forestlands are often managed for additional objectives that include enhanced structural diversity for wildlife and aesthetics. Most of the 147 000-ha Tillamook State Forest originated after a series of four major fires between 1933 and 1951 (Fick and Martin 1993). Because the forest contains closed Douglas-fir stands of a relatively narrow age range, thinning has been a key component of a structure-based management strategy for producing greater diversity in vegetation structure (Oregon Dept. of Forestry 2001). However, much of this forest has also been severely impacted by SNC, creating a reluctance to thin for fear of intensifying symptoms and reducing growth. Although the management plan calls for 40%–60% of the land base to be covered by layered, or two-storied, stands (Oregon Department of Forestry 2001), SNC may be a serious obstacle to achieving this management objective if it eliminates thinning as a silvicultural tool.

Results from early research addressing the effect of thinning on relatively young SNC-infected stands in New Zealand were either inconclusive (B. Manley 1985, unpublished data) or indicated that stands could be thinned without a worsening of symptoms (Hood and Sandberg 1979). Precommercial thinning of Douglas-fir with differing initial SNC severities did not result in either growth decline or symptom intensification (Maguire et al. 2004).

A retrospective analysis of thinned stands in western Oregon indicated that volume and basal area growth responses were lower on plots with currently more severe levels of the disease as measured by both foliage retention and crown sparseness (Mainwaring et al. 2005). Volume growth losses in the most heavily infected stands averaged ~36% and were similar to previous growth impact assessments (Maguire et al. 2002). However, all stands responded positively to thinning, and growth responses increased with increasing thinning intensity, suggesting that thinning did not exacerbate SNC growth losses (Mainwaring et al. 2005). In the retrospective approach, however, the possibility that growth responses were confounded with change in SNC severity cannot be exluded because SNC severity at time of thinning was unknown and foliage loss therefore may have increased or decreased after thinning.

The retrospective plots have now been remeasured after a 4-yr growth period for both growth and foliage retention, and results from a paired plot study of thinning have also become available. The objective of this analysis was to test the following hypotheses with retrospective plot data: (1) residual Douglas-fir trees are not experiencing a decline in foliage retention 8-14 yrs after thinning; (2) volume growth losses in the thinned retrospective plots are similar to those in unthinned growth impact plots with similar SNC severity; and (3) total basal area growth of residual trees on thinned plots continue to increase relative to basal area growth before thinning. The paired-plot study allowed testing of a similar set of hypotheses, as follows: (4) foliage retention on thinned plots did not decline or increase any more than on unthinned plots; (5) for a given initial stocking, plot volume growth did not differ between thinned and unthinned plots, regardless of initial SNC severity; and (6) volume growth of individual trees increased with increasing thinning intensity, regardless of initial SNC severity.

Methods

Four-year response data were analyzed from a two-phase study looking at the effects of thinning in 20-60 year old SNC-impacted stands: a four-year remeasurement of phase one plots from a retrospective study (Mainwaring et al. 2005) and a four-year remeasurement of phase two plots from a paired-plot study. The study sites were distributed across six different northwestern Oregon ODF districts (Tillamook, Forest Grove, Astoria, West Oregon, Santiam, Coos), five of which include land in the Coast Range. The Santiam district is located entirely within the Cascades Range, and was included due to evidence of low SNC severity in this province (Freeman 2002). Plots were distributed from 43.50° to 46.16° N latitude, from 124.06° to 122.5° W longitude, and from 30 to 800 m above sea level (Figure 1a,b).

Over the last 40 years in this region, the mean January minimum was 0°C and the mean July maximum was 25°C. Total annual precipitation averaged 150-300 cm, with approximately 70% of the total falling between October and March.

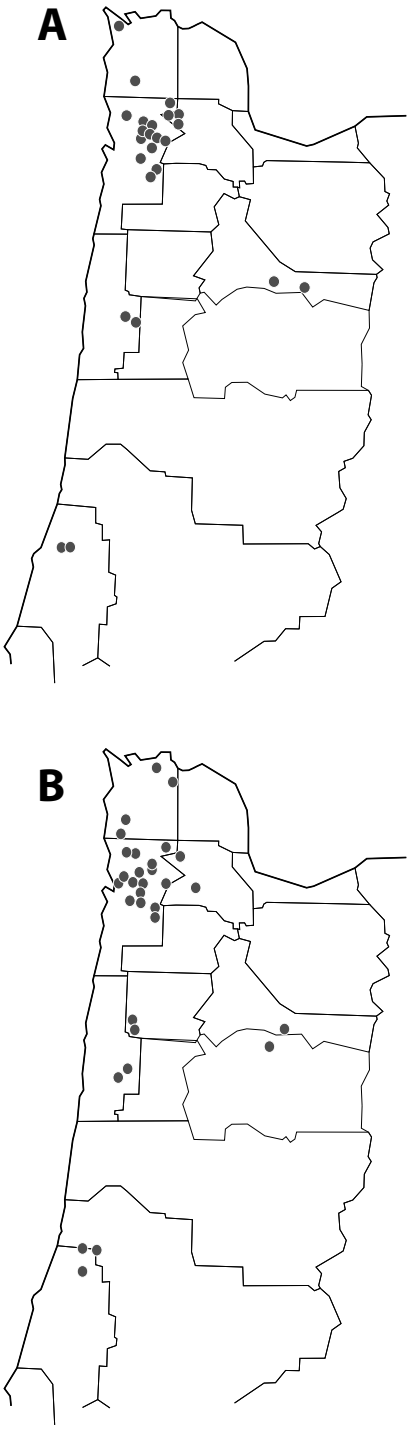

Figure 1. Locations of commercial thinning study plots: (a) retrospective plots and (b) paired plots.

Retrospective plots

Target stands were 30 to 60 years of age, contained at least 75% Douglas-fir by basal area, and had undergone commercial thinning 4 to 10 years prior to plot establishment. Plots were distributed across a range of disease severity classes and residual stand densities, and included different aspects and slopes. Forty-five fixed area plots were established during the winters of 2002 and 2003 (24 and 21 plots, respectively; Table 1). In a representative part of each stand, a square 0.2-ha (0.5-ac) plot was marked, and all trees were measured for dbh (nearest 0.1 cm). A subsample of 40 trees in each plot was measured for total height (nearest 0.01m), height to lowest live branch (nearest 0.01 m), and foliage retention (yrs). All plots were measured during the dormant season and annual basal area growth was reconstructed for varying periods before and after the last thinning for retrospective analysis (Mainwaring et al. 2005). Plots were remeasured during the winters of 2006 and 2007, although five plots had been harvested and were not available for this analysis. All trees on the 40 surviving plots were remeasured for diameter; total height, height to lowest live branch, and foliage retention were remeasured on trees previously sampled for these three attributes.

Paired permanent plots

Thirty installations or sets of paired plots were established during the winters of 2002 and 2003 (15 pairs each year; Table 2). Installations were distributed across a range of disease severity classes and initial stand densities, and included different topographical aspects and slopes. Target stands were 30 to 60 years of age, had at least 75% Douglas-fir by basal area, and were scheduled for operational or experimental thinning prior to the growing season. At each installation, a pair of square 0.2-ha (0.5-ac) measurement plots with 21-m buffer were established in a representative part of each stand prior to thinning (Figure 2). Prior to thinning, all trees >5 cm on the plot selected for thinning were marked at breast-height with paint and measured for DBH (nearest 0.1 cm). When thinning had been completed, all trees > 5 cm on both plots were tagged at breast height (on the paint mark for trees on the thinned plots) and measured for dbh (nearest 0.1 cm). A subsample of 40 trees in each plot was measured for total height (nearest 0.01m), height to lowest live branch (nearest 0.01 m), and foliage retention (yrs). Plots were re-measured during the winters of 2004 and 2005 and again in the winters of 2006 and 2007. Diameters were remeasured on

Table 1. Attributes of the retrospective plots

	Stem volume		Foliage retention (yrs)		Basal area (m^2/ha)				
Statistic	Periodic Annual, Inrement 2002-2005 (m^3/ha/yr)	Site index (m @ 50 yrs)	2002	2006	CL:SA (cm/cm^2)	Douglas-fir	Other species	Years since thinning	Age (yrs)
Min	6.56	27.69	1.63	1.73	4.51	18.85	0	4	28.3
Mean	16.72	38.92	3.14	2.50	31.55	31.55	0.32	6	42.5
Max	26.53	47.11	4.38	5.05	17.54	47.60	2.86	10	69.3

Table 2: Attributes of the permanent plots

Treatment	Statistic	Stem volume periodic annual increment(m^3/ha) 2002-03	Stem volume periodic annual increment(m^3/ha) 2004-05	Site index 50 (m @ yrs)	Foliage retention (yrs) 2002	Foliage retention (yrs) 2004	Foliage retention (yrs) 2006	CL:SA (cm/cm^2)	Basal area (m^2/ha) Douglas-fir	Basal area (m^2/ha) Other species	Age (yrs)
Thin	**Mean**	12.86	15.76	41.4	2.34	2.47	2.61	5.66	11.24	0.56	35.8
	Max	22.40	23.03	48.7	4.53	4.70	5.13	10.70	15.23	2.30	60.4
	Min	4.99	7.20	35.1	1.30	1.11	1.17	3.21	5.21	0	21.4
Control	**Mean**	19.42	21.29	41.3	2.46	2.53	2.65	5.23	18.52	1.42	35.8
	Max	31.71	33.90	47.4	4.63	4.63	5.08	8.49	28.51	6.09	60.4
	Min	8.54	11.25	36.5	1.33	1.11	1.17	3.07	9.89	0	19.8

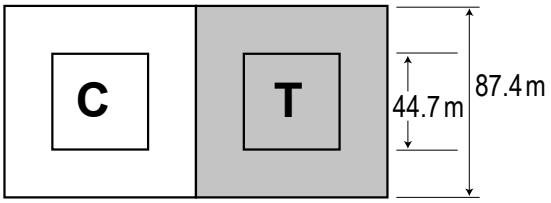

Figure 2 . Dimensions of thinned (T) and control (C) plots in commercial thinning paired-plot study.

all trees, and total height, height to lowest live branch, and foliage retention were remeasured on trees previously sampled for these attributes.

Initial stand density index (SDI, Reineke 1933) averaged 860 trees·ha-1 (348 trees·ac-1), with a range of 543-1092 (220-442). Average residual SDI was 492 (199), with a range of 245-704 (99-285). Thinning reduced stand density by 16-68%.

Analysis

Four growth periods were defined for assessing change in growth and condition of the retrospective plots (Fig. 3): the 4-yr period prior to thinning (P1), the 4-yr period after thinning (P2), the 4-yr period prior to plot establishment (P3), and the 4-yr period after plot establishment (P4). Effects of thinning and current SNC severity, as well as the interaction of these two variables, were tested by regression analysis to account for numerous other covariates contributing to variation in growth and foliage retention. Response variables in the retrospective analysis included: (1) change in foliage retention over P4 (ending retention – initial retention); 2) plot-level periodic annual volume increment over P4; and 3) ratio of plot-level basal area growth (BAG) from different 4-yr growth periods ($BAR21=BAG_{P2}/BAG_{P1}$, $BAR43=BAG_{P4}/BAG_{P3}$, and $BAR41=BAG_{P4}/BAG_{P1}$). Basal area growth ratios were based on only the trees present at plot establishment in 2002 and 2003 because the trees removed in the thinnings were not available for growth analysis (retrospective plots were thinned between 1992 and 1998). Plot-level covariates were computed for the year of initial measurement (2002 or 2003), and included Douglas-fir basal area, basal area of other species, site index, relative stand density, quadratic mean diameter, crown ratio, crown length, and breast height age. Variables were included in the final model only if they were significant at α=0.05.

To test whether thinning affected foliage retention on permanent plots, the data were analyzed as a randomized block experiment, adjusted for covariates. Each pair of plots was a block with one control and one thinned plot. Numerous covariates were combined with these categorical variables, including initial foliage retention, initial crown sparseness (live crown length (cm)/sapwood area at crown base (cm^2); (Maguire and Kanaskie, 2002), site index, and variables representing initial density and thinning intensity. Variables were included in the final model only if they were significant at α=0.05.

To isolate the "effect" of initial SNC severity on growth response to thinning, both stand and individual tree periodic annual volume growth (volumes esti-

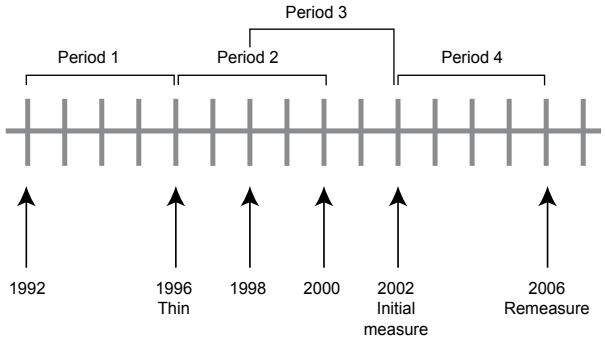

Figure 3. Retrospective study: Growth periods comprising basal area growth ratios for a stand thinned 6 years prior to plot establishment in 2002: (1) 4 years immediately prior to thinning; (2) 4 years immediately after thinning; (3) 4 years immediately prior to 2002 measurement; and (4) 4 years immediately after 2002 measurement.

mated with Bruce and Demars 1974) was regressed on foliage retention (FOLRET) and crown sparseness (CLSA), in addition to other covariates that typically influence stand growth. The latter variables included Douglas-fir basal area (BA_{DF}), basal area of other species (BA), site index (SI; Bruce 1981), crown ratio (CR), crown length (CL), total age (AGE), basal area removed in thinning (CUTBA), percentage of basal area removed in thinning (%CUTBA), years since thinning (YST), indicator variables for thinning (THIN) and growth period (GRP), and various interactions. Variables were again included in the final model only if they were significant at α=0.05.

Results

Retrospective phase

Change in foliage retention

Foliage retention on all but two retrospective plots increased over the 4-yr growth period following plot establishment (Fig. 4). Mean 4-yr change in foliage retention was 0.48 yrs (0.02-1.39 yrs) for plots established in 2002 and 0.30 yrs (-0.15-1.6 yrs) for plots established in 2003. During both periods, the increase in foliage retention was greater with increasing initial foliage retention (Fig. 4).

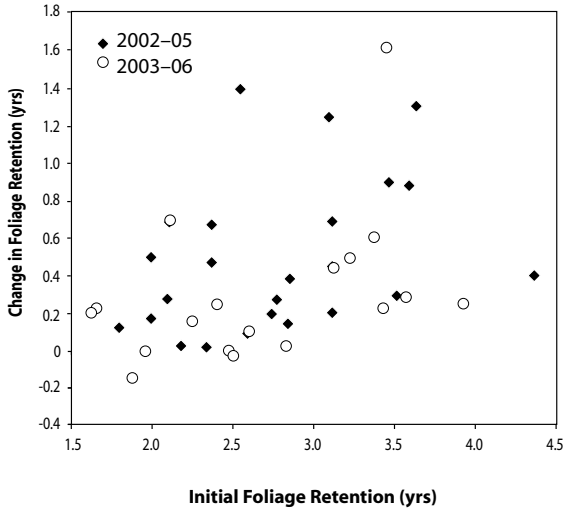

Figure 4. Retrospective study: Four-year change (most recent - initial) in foliage retention relative to initial foliage retention for plots established in 2002 and 2003.

Periodic annual volume increment

Periodic annual volume growth since 2002 or 2003 was significantly lower with increasing SNC severity after correcting for initial stand density, site index, and stand total age. Approximately 54% of the variation in the logarithm of periodic annual volume increment was explained by the following model (MSE of 0.057):

$$[1] \quad \ln(VPAI_{retro}) = a_0 + a_1\ln(BA_{retro.DF}) + a_2\ln(FOLRET_{retro}) + a_3\ln(CL{:}SA_{retro}) + a_4\ln(SI) + a_5\ln(CL)$$

where

$VPAI_{retro}$ = Predicted periodic annual volume increment on retrospective plot over P4 (m^3/ha/yr)

$BA_{retro.DF}$ = Initial Douglas-fir basal area on retrospective plot in 2002 or 2003 (m^2/ha)

$FOLRET_{retro}$ = Initial foliage retention on retrospective plot in 2002 or 2003 (years)

$CL{:}SA_{retro}$ = Initial crown sparseness on retrospective plot in 2002 or 2003 (ratio of live crown length to crown base sapwood area; cm/cm^2)

SI = Plot site index (top height at 50 yrs breast height age; Bruce 1981)

CL = Plot average live crown length (m)

Parameter estimates (Table 3) indicated that stand-level periodic annual volume increment increased with increasing Douglas-fir basal area and foliage retention, and decreased with increasing crown sparseness and crown length.

Volume growth varied dramatically across the range in foliage retention and CL:SA (Figure 5). Expected volume growth losses reached 62% when defining a "healthy" stand by the maximum observed foliage retention and minimum observed crown sparseness (average for Forest Grove and Santiam districts of 3.6 yrs and 6.9 cm/cm^2, respectively), (Figure 6).

Table 3. Parameter estimates for model describing periodic annual volume increment (equation [1]).

Parameter	Parameter Estimate	Standard Error
a_0	-1.37389	1.61847
a_1	0.82516	0.21460
a_2	0.44785	0.16613
a_3	- 0.93198	0.24460
a_4	1.98220	0.36869
a_5	- 1.56940	0.42022

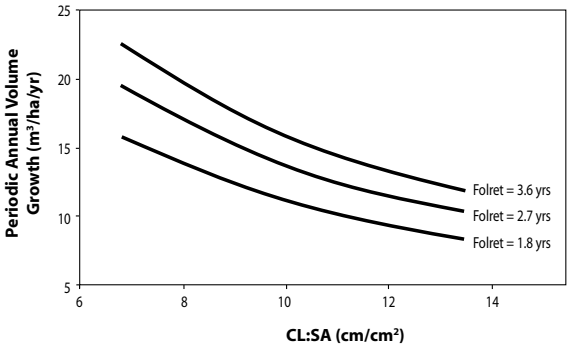

Figure 5. Retrospective study: Periodic annual volume growth as a function of foliage retention (folret) and crown length to sapwood area ratio (CL:SA). Growth was estimated by equation [1] assuming mean values of Douglas-fir basal area (32.3 m²/ha), site index (38.9 m) and crown length (16.9 m).

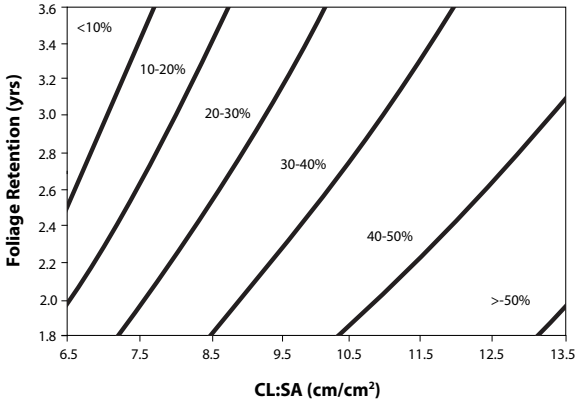

Figure 6. Retrospective study: Volume growth loss as a function of foliage retention (FOLRET) and crown length to sapwood area ratio (CL:SA). Growth loss was estimated by assuming maximum potential foliage retention of 3.6, minimum crown length to sapwood area ratio of 6.9, and mean values of Douglas-fir basal area (32.3 m2/ha), site index (38.9 m) and crown length (16.9 m).

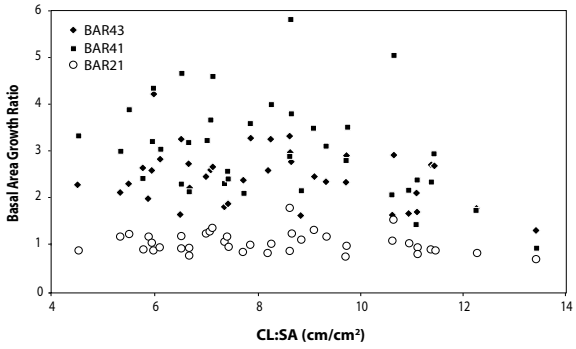

Figure 7. Retrospective study: Relationship of basal area growth ratios to crown sparseness in 2002. BAR21 is the ratio of basal area growth in Period 2 to Period 1, BAR43 is the ratio of Period 4 to Period 3, and BAR41 is the ratio of Period 4 to Period 1 (see Fig. 6 for definitions of periods).

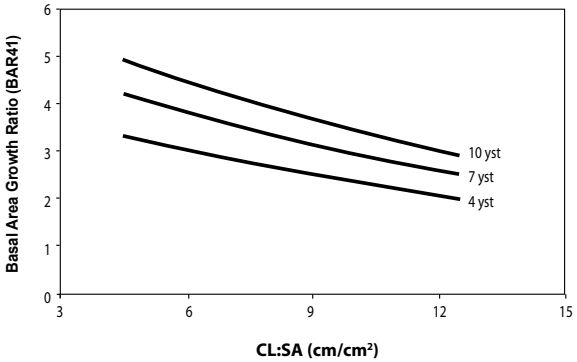

Figure 8. Retrospective study: Basal area growth ratio (Period 4: Period 1) predicted from crown sparseness in 2002 and time since thinning (yrt). Growth ratios were estimated from equation [3] assuming mean values for Douglas-fir basal area (32.3 m²/ha), crown ratio (0.54), and site index (38.9 m).

Basal area growth ratio

During the 4-yr growth period after plot establishment from (P4 in Fig. 3), basal area growth of all but one stand increased relative to the period prior to thinning (P1 in Fig. 3), with BAR41 varying from 1.5 to 5.8 in stands where growth increased (Figure 7). In contrast, basal area growth accelerated in only about half of the retrospective plots from the period immediately before thinning (P1 in Fig. 3) to the period immediately following thinning (Period 2 in Fig. 3). BAR41 was significantly influenced by initial SNC severity, stand density, plot average crown ratio, site index, and time since thinning. Approximately 48% of the variation in BAR41 was explained by the following model (MSE = 0.0699):

$$[2] \quad \ln(BAR41) = b_0 + b_1 BA_{retro.DF} + b2CL{:}SA_{retro.DF} + b_3 \ln(YST) + b_4 \ln(CR_{retro}) + b_5 SI$$

where

BAR41 = Predicted ratio of basal area growth in P4 to P1 on retrospective plots

YST = Years since thinning at time of retrospective plot establishment

CR_{retro} = Initial plot average crown ratio (expressed as a decimal)

and $BA_{retro.df}$, $CL{:}SA_{retro}$, and SI are defined above.

Parameter estimates indicated that BAR41 (response to thinning) increased with site index and years since thinning and decreased with increasing plot basal area, plot average crown sparseness, and initial plot average crown ratio (Table 1; Fig. 8).

Table 4. Parameter estimates for model describing basal area ratio of period 4 and period 1 (equation [2]).

Parameter	Parameter Estimate	Standard Error
b_0	-0.38078	0.68772
b_1	-0.01940	0.00715
b_2	-0.06529	0.02725
b_3	0.42433	0.18939
b_4	- 1.34946	0.54111
b_5	0.02649	0.01022

Paired permanent plot phase

Change in Foliage retention

The plots thinned in 2002 showed a general increase in foliage retention over the subsequent four years, particularly in the most severely impacted plots. However, the increase in foliage retention among plots thinned in 2003 was generally limited to those with low SNC severity, with high-severity plots tending to lose older foliage (figure 9). Both ANOVA (p=0.102) and regression analysis suggested that thinning did not influence the change in foliage retention. Significant block-to-block variation was evident for site index, stand density, and SNC severity, so a regression model was built to account for these covariates and test the marginal effects of initial SNC severity and thinning on change in foliage retention. As described in Methods, the 4-yr change in foliage retention on thinned plots was standardized by subtracting the control plot change in retention. The following model fitted to only thinned plots explained approximately 44% of the variation in 4-yr change in foliage retention (MSE = 0.0353):

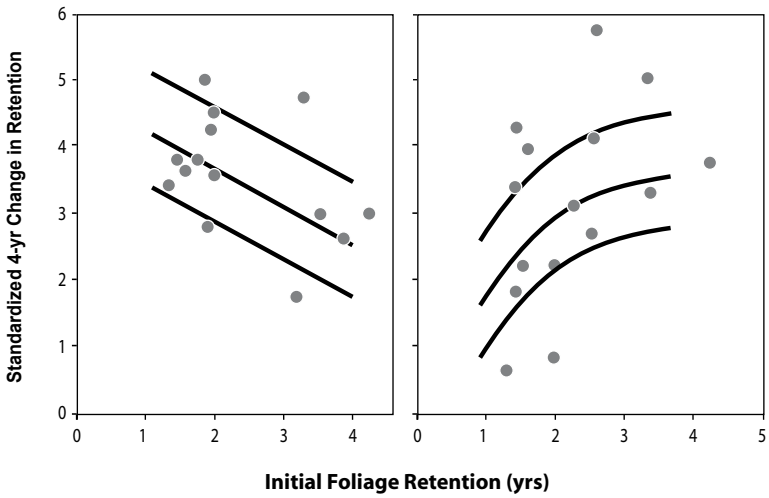

Figure 9. Paired-plot study: Observed and predicted change in foliage retention (most recent – initial - change in retention on paired control plot) as a function of initial foliage retention and thinning intensity (% of basal area removed). Four-year change in foliage retention was estimated from equation [4].

$$[3] \quad \Delta FOLRET = c_0 + c_1 \ln(tFOLRET1) + c_2(GRP) + c_3(GRPxFOLRET_{pair.1}) + c_4(PBA_{res})$$

where

- $\Delta FOLRET$ = Predicted 4-yr change in foliage retention on thinned plot, standardized to four-year change on control plot
- FOLRET1 = Initial foliage retention
- GRP = Growth period indicator (0 if 2002-2006, 1 if 2003-07)
- $FOLRET_{pair.1}$ = Initial foliage retention (yrs)
- PBA_{res} = Percent residual basal area after thinning

Parameter estimates indicated that the four-year change in foliage retention was greater with heavier thinning. Neither initial nor residual stand density accounted for any additional variation in this response variable. The effect of initial foliage retention depended on growth period; i.e., 4-yr change in foliage retention was negatively correlated with initial foliage retention on plots established in 2002, but was positively correlated on plots established in 2003 (Table 5; Fig. 9).

Table 5. Parameter estimates for model describing the net change in four-year foliage retention after thinning (equation [3]).

Parameter	Parameter Estimate	Standard Error
c_0	0.73127	0.19169
c_1	-0.11232	0.04870
c_2	-0.55186	0.16898
c_3	0.54562	0.18008
C_4	-0.62190	0.27520

Periodic annual volume increment

ANOCOVA with initial basal area of Douglas-fir as the covariate suggested that periodic annual volume increment was greater on thinned plots during the second two-year growth period (p=0.0056). Although the thinning effect was not significant during the first two-year growth period (p=0.328), it was large enough in the second two-year period to give a marginally significant treatment effect for the entire four-year period (p=0.0572). Plot attributes varied considerably (Table 2), underscoring the need to account for numerous covariates simultaneously. In the regression approach, periodic annual volume growth during the

second two-year period after thinning was significantly related to initial SNC severity and other covariates reflecting stand density and age. Approximately 81% of the variation in (transformed) periodic annual volume increment was explained by the following model (MSE = 0.021):

[4] $\ln(VPAI_{pair.2}) = d_0 + d_1\ln(BA_{df}) + d_2\ln(FOLRET_{pair.2}) + d_3\ln(AGE)$

where

$VPAI_{pair.2}$ = Period annual volume increment for the paired-plot during second 2-yr period after thinning (m^3/ha/yr)

$BA_{pair.2DF}$ = Initial Douglas-fir basal area on the paired-plot for the second 2-yr growth period after thinning (2004 or 2005; m^2/ha)

$FOLRET_{pair.2}$ = Initial foliage retention on the paired-plot for the second 2-yr growth period after thinning (2004 or 2005; yrs)

AGE = Initial total age of paired-plot for the second 2-yr growth period after thinning (2004 or 2005; yrs)

Table 6. Parameter estimates for model describing periodic annual volume increment (equation [5]).

Parameter	Parameter Estimate	Standard Error
d_0	2.7945	0.27272
d_1	0.69895	0.05708
d_2	0.33807	0.05511
d_3	-0.76778	0.07315

Parameter estimates (Table 6) indicated that periodic annual volume increment increased with increasing Douglas-fir basal area and foliage retention, and decreased with increasing initial age. No thinning variables emerged as significant when added to this model. At an initial total age of 35 years, implied cubic volume growth varied from 7 to 32 m^3/ha/yr depending on initial Douglas-fir basal area and foliage retention (Figure 10). When compared to a healthy stand ($FOLRET_{pair.2}$=3.9 yrs=mean foliage retention for Gales Creek, Hagg Lake, Westport, Tom Rock, Green Wave, and Water Wheel), growth losses in the most severely impacted stands ($FOLRET_{pair.2}$=1.1 yrs) are implied to be 35%.

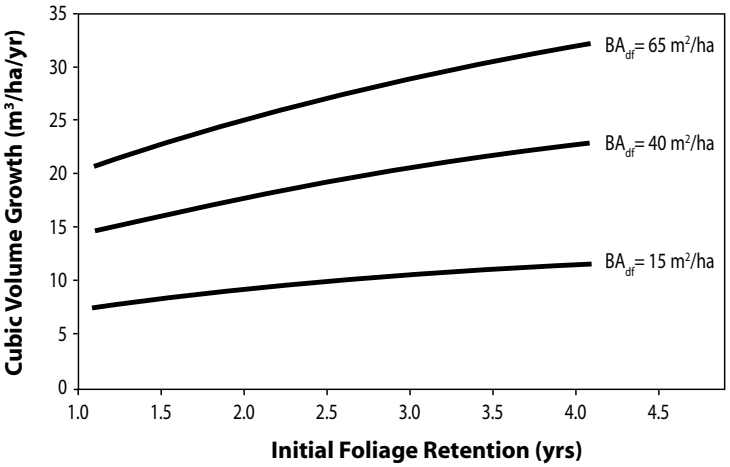

Figure 10. Paired-plot study: Cubic volume growth as a function of initial foliage retention and Douglas-fir basal area (BA_{DF}). Volume growth was estimated from equation [5] assuming a stand age of 35 years.

Individual tree growth

In order to determine how individual trees responded to treatment, an individual tree model was constructed from the subset of trees measured for height and height to lowest live branch on each plot. Approximately 81% of the variation in (transformed) periodic annual volume increment was explained by the following model (MSE = 0.22):

[6] $\ln(treeVPAI_{pair.2}) = e_0 + e_1\ln(DBH) + e_2(DBH) + e_3\ln(CR) + e_4\ln(FOLRET_{pair.2}) + e_5\ln(SI) + e_6(CUTBA)\, e_7\ln(BA_{pair.total})$

where

$treeVPAI_{pair.2}$ = Period annual volume increment of the tree during second 2-yr period after thinning (m^3/yr)

DBH = Initial diameter at breast height for the second 2-yr growth period after thinning (cm)

CR = Initial crown ratio for the second 2-yr growth period after thinning (expressed as a decimal)

$BA_{pair.total}$ = Initial total basal area on paired-plot for the second 2-yr growth period after thinning (2004 or 2005; m^2/ha)

$FOLRET_{pair.2}$ = Initial foliage retention on the paired-plot for the second 2-yr growth period after thinning (2004 or 2005; yrs)

CUTBA = Basal area removed in thinning on paired plot (m^2/ac)

and SI is defined above

Parameter estimates (Table 7) indicated that periodic annual volume increment of individual trees increased with increasing initial diameter (for all but the largest trees in the dataset), crown ratio, plot foliage retention and site index, and decreased with increasing residual basal area, and removed basal area. Although removing basal area during thinning had a negative effect on individual tree growth, this effect reversed by the increase in growth from lower stand density, as reflected in the effect of BA_{total} (Table 7). As a result, lowering stand density by thinning had a net positive effect on individual tree growth during the second period (Figure 11).

Table 7. Parameter estimates for model describing periodic annual volume increment of individual trees (equation [6]).

Parameter	Parameter Estimate	Standard Error
e_0	-17.18631	0.63565
e_1	4.67926	0.11305
e_2	-0.0379	0.00337
e_3	0.74911	0.04413
e_4	0.20821	0.03018
e_5	1.01522	0.13807
e_6	-0.00403	0.00176
e_7	- 0.53848	0.06654

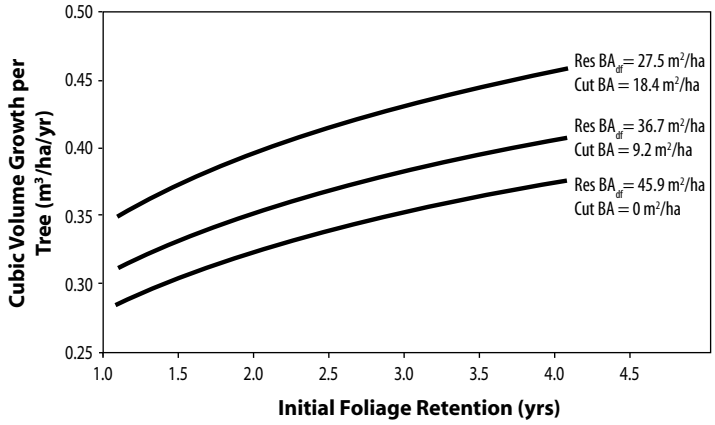

Figure 11. Paired-plot study: Individual tree volume growth as a function of plot-level initial foliage retention and thinning intensity. Cut BA is Douglas-fir basal area removed in the thinning, and Res BA is residual Douglas-fir basal area (Res BA = 45.9 - Cut BA). Tree volume growth was estimated from equation [5] assuming average dbh (38 cm), site index (41.4 m) and crown ratio (50%).

Discussion

The most difficult stands for estimating foliage retention are those with high foliage retention and/or low shoot growth because both factors create a dense crown, making distinctions between annual complements difficult. That these are precisely the retrospective stands where foliage retention improved the most may have more than one explanation. Most obviously, conditions may have improved in such a way that foliage retention has generally increased. Second, the largest changes in retrospective foliage retentions during the last four years were measured during the first year of installation in 2002, and it is likely that the accuracy of estimations has improved with four years of experience. This second scenario raises a question: if the accuracy of the 2002 estimates is in question, can current model-implied growth losses (based on 2002 foliage retention estimates) be trusted? When 2006 estimates were substituted into equation [1], growth loss estimates were essentially identical, unsurprising given the proportional similarity between 2002 and 2006 estimates.

Although the values of foliage retention and crown sparseness constituting healthy and infected stands used for the initial analysis (Mainwaring et al. 2005) were the same as those used in 2006, growth loss estimates implied by equation [1] are considerably greater over the last four years than for the period before 2002 but after thinning (62 vs. 37%). In the original retrospective analysis, calculation of volume growth required that initial heights be backdated using current height and expected dominant height growth given the measured site index. However, because height growth has been shown to diminish with SNC infection (Maguire et al. 2002), height growth estimated by this method would be overestimated for trees growing in infected stands, with subsequent underestimation of growth loss. Figure 12 shows the ratio of actual measured volume growth in 2002-05 to estimated volume growth from the time of thinning through the 2001 growing season. This graph im-

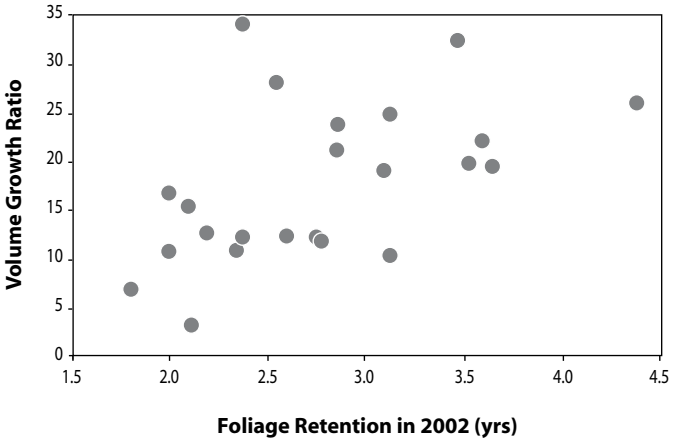

Figure 12. Retrospective study: Ratio of basal area increment for 2002-05 growth period to 1998-2001 growth period plotted on foliage retention in 2002. All thinnings occurred prior to 1998.

plies that volume growth on numerous infected plots has decreased as time since thinning has increased, though values of BAR43 indicate otherwise. Clearly, pre-2002 volume growth was overestimated on infected plots.

A second factor is that because SNC-induced diminishment of height and branch growth (Mainwaring et al. 2002) can be expected to slow crown expansion, canopy closure and maximum individual tree growth response to thinning is delayed in infected stands. Given this fact, relative volume growth rate differences between healthy and infected stands should be maximized when trees in thinned healthy stands have filled available space. This has already happened to some extent. Equation [2] implies that the average stand with a crown sparseness of 6.9 cm^2/cm^2 currently has a BAR41 that is 54% greater than a stand with a crown sparseness of 13.4 cm^2/cm^2. When healthy stands already growing ~50% faster (based on a 35% volume growth loss) than the most infected stands have an additional 48% boost in basal area response relative to those infected stands (based on equation describing trendline in figure 7), it should be expected that the growth of infected stands decreases relative to healthy stands. Over time, as intertree competion in healthy thinned stands increases (and basal area growth subsequently slows), this difference will presumably diminish as infected stands have unfilled space remaining.

The basal area growth ratio comparing periods 4 and 1 (BAR41) (Figure 7) reinforce earlier findings that stands, on average, respond positively to thinning regardless of the level of SNC (Mainwaring et al. 2005). The much greater value of BAR41 vs. BAR21 also indicates that while only a few stands show a marked positive response in the first four years after thinning, a clear positive response becomes apparent during the four year period starting 4-10 years later. Furthermore, basal area growth is continuing to accelerate in all stands, as evidenced by values of BAR43 greater than 1 (Figure 7). This is informative for what may be expected from the permanent plots.

Although thinning was originally feared to have a negative effect on foliage retention, equation [3] indicates that thinning intensity is associated with a net positive change in foliage retention during the last four years. The implied improvement between the heaviest and lightest thinnings encompassed by this dataset amounted to a difference of nearly 0.4 years of foliage. Further clarification of this effect with the use of covariates such as residual stocking level and quantity of basal area removed, or interaction of percent basal area removed and foliage retention was not successful. The change in foliage retention depended on both the initial foliage retention and the period during which it was monitored. This relationship is further influenced by the fact that initial foliage retention is a legacy of previous years' fungal germination and development conditions. The very different results for the two (mostly overlapping) growth periods indicate the degree to which annual climate and disease cycles can effect foliage retention on a given site.

Interestingly, during the annual foliage surveys many trees were observed to have a greater amount of 2003 foliage than 2004 foliage. Because only current year foliage can become infected during the period of shoot elongation (Stone et al. 2000), this suggests that conditions during 2004 were more conducive to fungal infection than were conditions in 2003. Why?

Previous work has shown that fungal infection success is positively correlated with atmospheric moisture during the period of shoot elongation, generally May-June (Manter et al. 2003). In 2002 and 2003, precipitation measured at five weather stations throughout the study area (Nehalem, Otis Junction, Seaside, Tillamook, Willamina) was at its lowest level in the last 10 years (Figure 13). Tracking this was a decrease in acreage reported as showing SNC symptoms by the ODF aerial survey in 2003 and 2004 (Kanaskie et al. 2006), suggesting a one-year delay in symptom expression. This delay is consistent with the spring moisture hypothesis, given that symptom expression takes place in older needle cohorts about to be cast, thereby requiring at

least one season of post-germination fungal development. In contrast, 2004 and 2005 precipitation at the same locations during May and June was closer to normal, and ~88 and 164% higher respectively than in 2003 (Figure 13). Consistent with this pattern, the numbers of acres showing SNC symptoms as measured by the ODF aerial survey increased in 2005 and 2006 (Kanaskie et al. 2006). It has been speculated that abundant moisture in the Coast Range, coupled with heavy spore loads during the spring makes these measured precipitation differences unimportant. However, tracking the precipitation totals is the number of days per month without measurable precipitation during this period recorded at the same five weather stations. During May and June of 2003, there were, on average, 2 fewer days per month without precipitation than in 2004, and eight fewer days without precipitation than in 2005 (Figure 14).

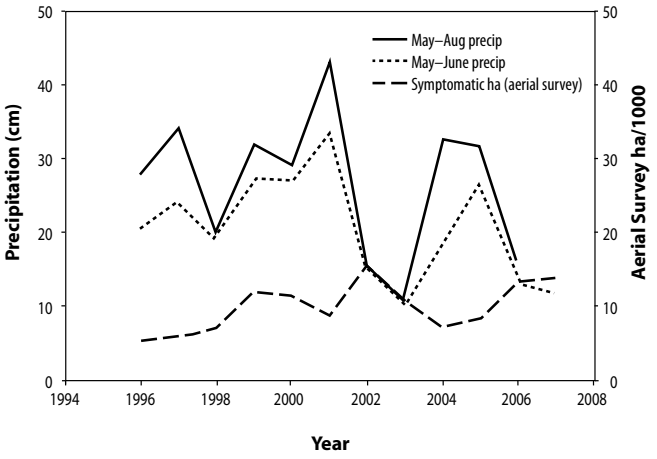

Figure 13. Average annual precipitation for five weather stations in north coastal Oregon and total area (% x 100) showing SNC discoloration detectable from annual ODF aerial surveys.

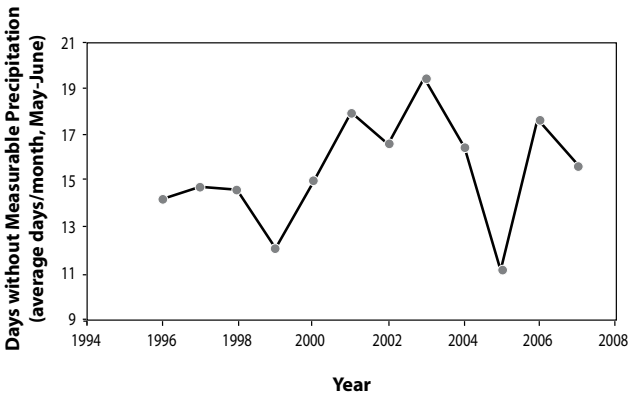

Figure 14. Average number of days without measurable precipitation at five weather stations in north coastal Oregon, May-June

Climate differences between the two periods affected volume growth in at least two ways. The 2002-03 seasons followed a three-year period of high spring moisture and maximum symptom expression (Figure 13), due to which it could be speculated that functional foliage retentions were at minimum levels. When coupled with low levels of growing season precipitation (Figure 12), the 2002-03 growth period probably represents a period of relatively low growth. Because, due to dryer springs, the 2002 and 2003 needle cohorts were more lightly infected, more of those needles remain functional longer, thereby augmenting growth during 2004-05 when those 2-3 year old needle cohorts might otherwise have been highly infected or cast. Further enhancing volume growth during 2004-05 was the relatively high precipitation during the growing season (Figure 13). The contrast in growing conditions between the two periods was thus great, and may, for the average stand, represent two extremes in growth performance. Volume growth of the group 1 permanent plots during the second two-year period amounted to an average increase of ~27% versus the first period on the control plots (range: -22-66%). In contrast, the second group of 15 plots had an average volume growth equal to that of the first period (range from –23-24%). .

When compared to a healthy stand (represented by mean foliage retention from Gales Creek, Hagg Lake, Westport, Tom Rock, Green Wave, and Water Wheel: foliage retention: 3.9 years), volume growth losses in heavily infected stands (folret=1.1 yrs) are implied to be 34.8%. This value is comparable to that calculated for the first two-years of the full permanent plot dataset. However, two-year losses during the second growth period for group 1 plots, given the same values of foliage retention, were 30.4%, suggesting better volume growth per unit of foliage retention during 2004-05. For reasons described in the preceding paragraphs, foliage in the 2002 and 2003 cohorts may be less infected. While previous work has indicated that needles tend to be cast when ~50% of stomates are plugged (Hansen et al. 2000), retained foliage can presumably have between 0 and ~50% of stomates plugged. In this

scenario, two trees can have similar foliage retentions, yet if one has retained needles with fewer plugged stomata, it would have greater photosynthetic capacity and improved volume growth per unit of foliage retention. This highlights one of the shortcomings of using foliage retention as an index of SNC infection level.

While a positive growth response to thinning was not evident at the stand level for all plots after the first two-year period (p=0.35) it was for the full dataset during the second two-year period (p=0.0056) and marginally significant for the entire four-year period (p=0.057). Although covariates were included in the stand level model (equation [4]) to account for this positive thinning effect, none proved to be significant. However, stand level covariates were significant in describing the positive response of individual trees to thinning, where the positive response to thinning increased as the percentage of basal area removed increased (Figure 11). With the demonstrated increases in basal area growth ratio as time since thinning has increased on the retrospective plots (Figure 7), it is likely that a similar significant quantitative relationship will become apparent in an equation describing stand-level volume growth.

The increases in spring moisture during 2004 and 2005 are likely to be reflected in decreased foliage retention in subsequent years. At the same time, the ability of stands to continue satisfactory growth may depend on continued retention of older, less infected needle cohorts from 2002 and 2003. While foliage has been found to lose production efficiency with aging (Teskey et al. 1984), this is partially the result of an increasingly shaded position within the crown and subsequent nutrient translocation to younger needle cohorts (Field 1983). However, in thin crowns, or where needle cohorts of intermediate age are missing, older needles may continue to be productive. Recent collections of needles from separate age classes of the same 5th whorl branches across an SNC gradient confirm that foliar N% in trees with low needle retention is relatively similar across age classes—in contrast to diminishing foliar N% with increasing needle age on healthy trees. On Juno Hill, near Tillamook, Oregon, where Swiss needle cast infection levels are particularly high, a branch on a Douglas-fir tree that has been repeatedly sprayed with Bravo fungicide has retained some needles as long as 10 years (Alan Kanaskie, pers. comm), suggesting that the 2002-03 needles, in the absence of significant within-crown shading, may continue to contribute to growth.

Of the six springs since 2002, only one has had a higher precipitation total than in any of the six springs prior to 2002 (Figure 13). The number of days without measurable precipitation has generally followed the same pattern. In addition, regeneration harvesting and species conversion within the SNC zone has reduced acreage of the most infected Douglas-fir stands, and by consequence, probably reduced overall spore loads. Finally, while infection levels will probably be greater on 2005 foliage than that of other recent needle cohorts, spring precipitation data for 2006 and 2007 are similar to 2002-03 (Figure 13), suggesting relatively poor conditions for fungal infection.

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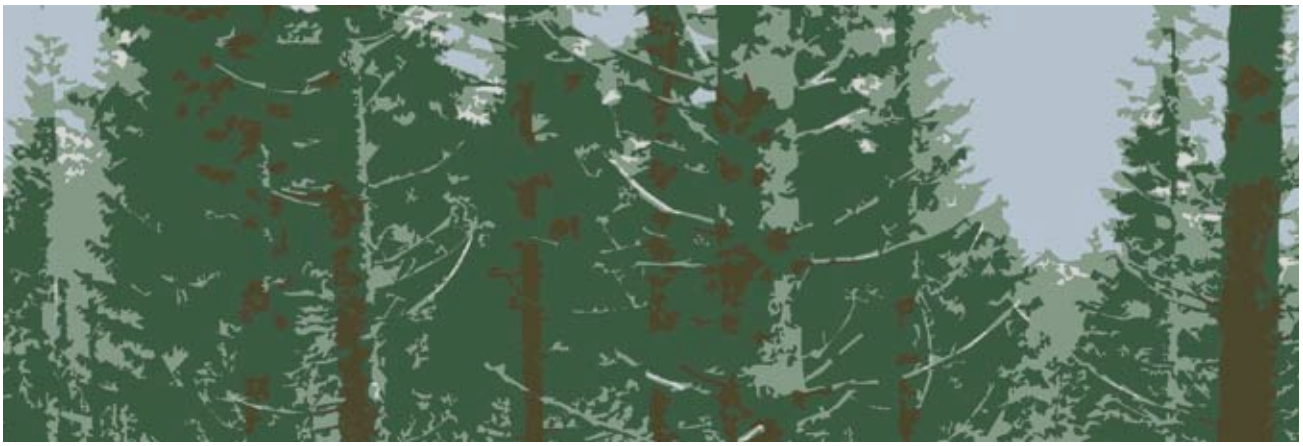

Douglas-fir Foliage Age Class Dynamics and Nutrient Flux

Doug Mainwaring, Doug Maguire, Jeff DeRoss

Introduction

Swiss needle cast (SNC) impacts tree growth in two ways: (1) premature loss of foliage; and (2) hindrance of carbon fixation by surviving foliage. Foliage age class dynamics are difficult to track in Douglas-fir trees with varying SNC severity because SNC fluctuates with annual weather patterns, because different stands have experienced differing durations of SNC, and because many other factors influence needle longevity (Reich et al. 1995). Poor understanding of foliage age class dynamics and associated nutrient fluxes in live needles, senescing needles, and needle litter continues to frustrate efforts to identify cause and effect in the correlation between foliage retention (FR) and foliar nitrogen concentration (%N).

The seasonal patterns of foliage age class dynamics also are largely unknown, creating uncertainty in interpretation of foliage retention assessed at different times of the year. Any seasonal effects contribute to sampling error in estimating SNC severity and could lead to sub-optimal silvicultural decisions. The ability to adjust foliage retention based on the season of sampling would allow much greater flexibility for on-the-ground assessment of SNC severity because it would allow assessments during seasons other than early spring (March-April, called for in the current protocol).

For needle retention to provide meaningful information about tree and forest health, the retention level representing the healthy condition must first be established. This baseline level is known to vary by site and stand age, but little is known about baseline levels for managed stands because foliage retention does respond to silvicultural treatment. For example, fertilization in several species has been shown to cause a decline in foliage retention while increasing tree and stand growth (Brix 1983;Balster and Marshall 2000a, b). It is likely that foliage retention alone is insufficient for predicting health, vigor, growth, and NPP of managed plantations because silvicultural treatments may have opposite effects on foliage retention and total needle area (e.g., Balster and Marshall 2000b). Needle retention or longevity reflect only the number of years that needles remain on the tree, whereas age class distribution accounts for differences in the amount of foliage in each age class. This is an important difference because under similar environmental conditions, Douglas-fir needles of varying age assimilate carbon at different rates per unit surface area. The age class distribution of needles is therefore key to accurately estimating tree and stand growth from basic ecophysiological principles.

Ecological research has identified numerous factors correlated with needle longevity in conifer species, including drought, nutrient availability, herbivory, air pollution, and others (see literature cited by Reich et al. 1995), but this research has focused almost exclusively on unmanaged stands. Nutrient availability, in particular, is very dynamic in managed Douglas-fir stands, being responsive to site preparation, competing vegetation control, thinning, and fertilization. Forest fertilization prescriptions have often been based on foliar chemistry (Weetman et al. 1992), but

with mixed results, particularly with regard to identifying sites likely to respond to N fertilization. Many questions remain about sampling foliage and interpreting foliar chemistry to prescribe fertilization treatment. Sampling variation accrues from many sources: season, age class, sample position in the crown, tree size/social position, site, etc. In short, better knowledge of concurrent age class dynamics and nutrient fluxes under alternative silvicultural treatments would go a long way toward refining our ability to: (1) assess "normal" conditions with respect to forest health; (2) estimate growth impacts of factors influencing foliage age class structure and nutrient content; (3) predict likely response to fertilization; and (4) separate cause from effect in observed correlations between foliar chemistry and foliage retention or age class structure.

Objectives

The goal of the proposed research was to quantify patterns in Douglas-fir needle longevity and foliar chemistry under SNC and several fertilization treatments. Specific objectives included:

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

(2) Test and quantify the effects of SNC and fertilization on needle size and nutrient concentrations among age classes, including fresh needle litter, over the course of a year;

(3) Test and quantify the effect of SNC and fertilization treatments (including control) on needle longevity through the course of a year;

(4) Quantify the seasonal dynamics of foliage retention and develop a way to standardize field estimates conducted at any time of the year;

Methods

The Beyond Nitrogen Fertilization project (BNF) involves 16 separate sites (Figure 1), each with five or seven treatments distributed among 10 individual dominant/codominant trees. Treatments included 1) control; 2) nitrogen; 3) lime; 4) calcium chloride; 5) phosphorus; 6) site-specific Kinsey blend; 7) site-specific Fenn blend.

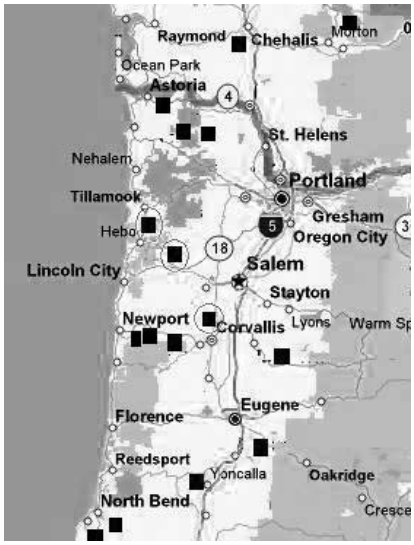

Figure 1. Map of Beyond N fertilizer sites. Circled sites were repeatedly sampled.

Nutrient concentrations by age class

On all measurement trees on all sites, a 20-needle subsample was randomly picked from each foliage age class of the branch sampled in fall 2007, then was lumped into a composite sample by site and treatment. Samples were dried and weighed. Chemical analysis is being performed by the Central Analytical Laboratory at OSU. Labwork is currently ongoing. A similar sample was taken from the 2006 sample branches for pre-treatment analysis.

Recurrent sampling for needle weights, nutrient concentrations, and litter nutrient concentrations

On three sites of the BNF project (Green Diamond/Hemlock, Hampton/Grand Ronde, and OSU's MacDonald-Dunn Research Forest) one average tree from each of four treatments (control, N, P, lime) was selected from among the 10 trees in each treatment (Table 1). Four litter traps were placed a fixed distance from the subject tree. Litter from these traps was collected in the middle of January, March, April, May, June, July, August, and September

Table 1. Characteristics of repeatedly sampled trees

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

and submitted for chemical analysis to the Central Analytical Laboratory at OSU. During these 9 site visits ~200 needles were picked from each of the four age classes on a five-year secondary lateral of a 6th whorl branch. Each 200-needle sample was dried, weighed, and submitted for chemical analysis.

Foliage retention

During the 9 site visits described under *Objective 2*, foliage retention was assessed visually on the two largest four-year-old secondary lateral branches on each of the northernmost and southernmost branches on the 7th whorl down from the top. Photos were taken of these branches to ensure accurate month-to-month monitoring.

Results and Discussion

Nutrient concentrations by age class

Chemical analysis of the four post-treatment needle cohorts is underway, but will be completed after foliar collections this fall. Site-level foliage chemistry of all four needle cohorts was analyzed on the branches sampled in 2006 (i.e., pre-treatment) The only nutrients showing negative correlation with needle age were nitrogen (yrs 2-4) and potassium, while calcium and manganese showed a positive correlation. Nitrogen concentration in first-year foliage was generally lower than that of second year foliage. These results are similar to those found in a previous study of Douglas-fir foliage age classes (Lavender and Carmichael 1966).

Needle weights

Needle weights were generally positively correlated with age with the exception of year 3 needles at OSU and HAGR (Figure 2). Needle weights were variable throughout the year, with each cohort reaching a maximum value just prior to the onset of shoot growth and then decreasing. Presumably, this maximum results from older needles acting as a reservoir of resources for the newly expanding shoots.

Nutrient concentrations

Nitrogen, calcium, and phosphorus levels of 1-yr foliage varied by treatment and site (Figs. 3-5). Urea fertilization (Figure 3b) clearly resulted in elevated levels of foliar N compared to the other treatments, particularly at GDH and OSU. The urea fertilization also minimized the depression in foliar N that takes place during shoot growth initiation in the late spring. Both of these effects were less obvious at HAGR.

The absolute levels of foliar calcium at each site were negatively correlated with the amount of SNC at each site (Fig. 4). Liming may have resulted in the elevated levels of foliar calcium at OSU, although increases in foliar calcium over time were also apparent on the other treatments at this site.

Phosphorus fertilization (Figure 5) had no apparent effect on foliar P levels. The cause of elevated levels of P at the GDH site in March were unknown.

Litter

The nitrogen concentration in litter declined appreciably during the growing season when rapid photosynthesis and expanding shoots created a

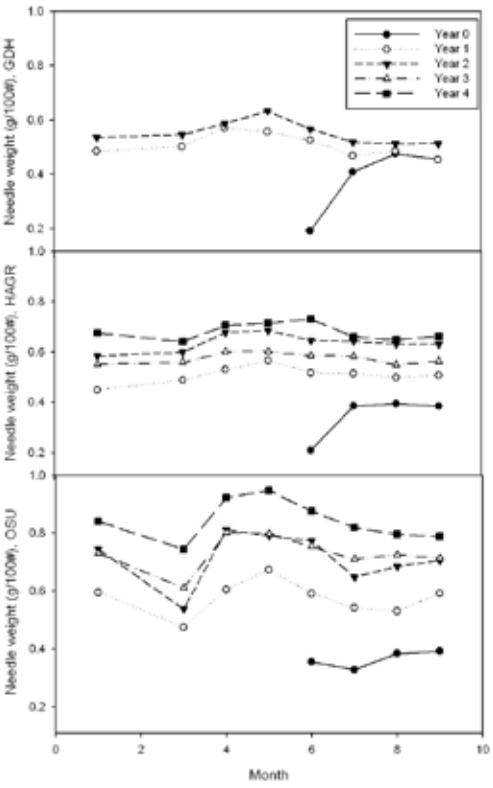

Figure 2. Needle weights by site, needle cohort, and month (1=January, 2= Feburary, etc.).

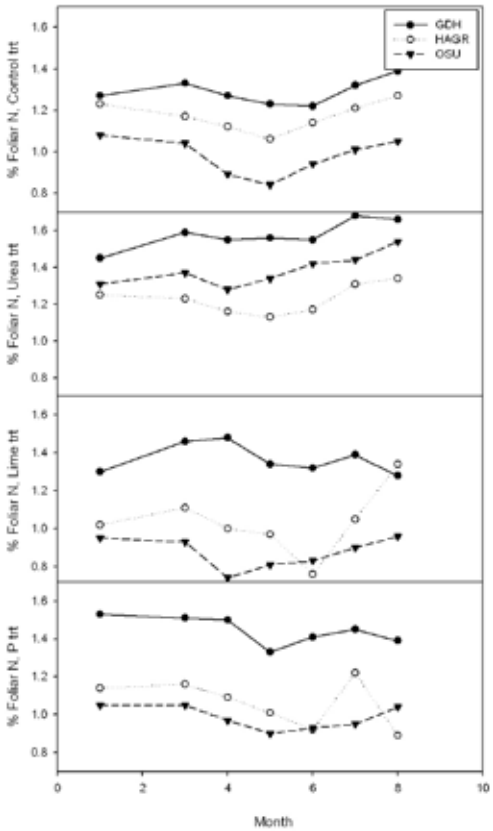

Figure 3. Foliar N concentration (%) by treatment, site and month.

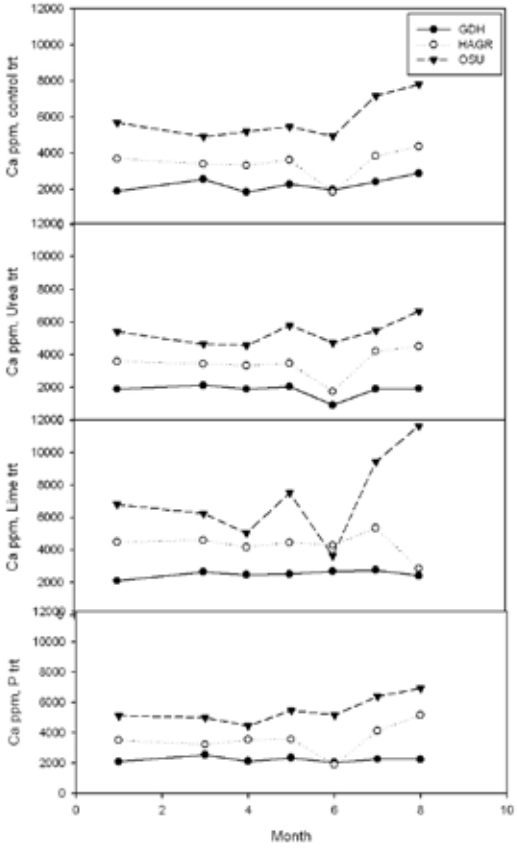

Figure 4. Foliar Ca concentration (ppm) by treatment, site and month.

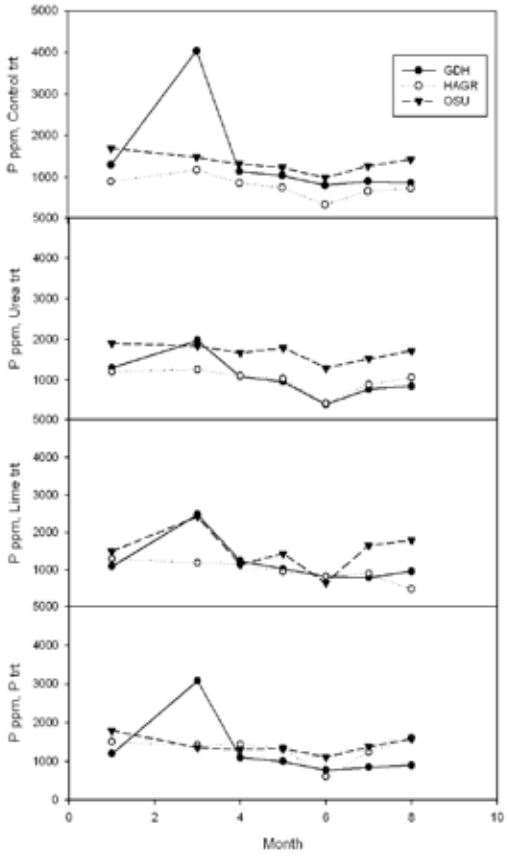

Figure 5. Foliar P concentration (ppm) by treatment, site and month.

strong nitrogen demand (Fig. 6). Although the % nitrogen in litter was highest on the urea fertilized trees, total nitrogen lost during the year was lowest in this treatment due to the lower total litterfall of foliage (Fig. 7). This results was consistent with studies that documented crown densification after nitrogen fertilization (Brix and Ebell 1969, Brix 1983). Crown densification was partly the result of retaining older needles that would otherwise have fallen off. Nitrogen concentration in litter at each site was roughly proportional to the foliar N%, ranging from highest at the coastal GDH site to lowest at the OSU site.

Other than the elevated June levels of calcium and phosphorus after liming, calcium and phosphorus concentrations in litter were relatively unchanged during the year. Relative levels were greatest on the limed plot, where an elevated pH was expected to make calcium and phosphorus more available to trees over the long term. Absolute losses (Figure 7) were proportional to total litterfall, causing calcium and phosphorus losses on the nitrogen treated plots to be the lowest.

Foliage retention

Within-tree variability in foliage retention was large, with average standard deviation in foliage retention during a given month varying from a low of 0.24 yrs at OSU to 0.37 yrs at HAGR. The standard deviation in foliage retention for specific trees within given months was greater than 0.5 yrs nearly 17% of the time.

The protocol for assessing branch-level foliage retention in SNC-infected stands has been limited to branches on the southernmost side of the tree, based both on observed differences in foliage retention and the positive correlation between winter temperature and *P. gaeumannii* development (Manter et al. 2005).

While the average April foliage retention on southern branches was lower (2.43 v. 2.65), this difference was not statistically significant (p=0.13). When limited to the two sites with Swiss needle cast, the difference was greater (1.91 v. 2.24), though significance remained marginal (p=0.074).

The change in foliage retention between May and September 2007 differed significantly among fertilization treatments (p=0.0539). Trees fertilized with phosphorus lost the least amount of foliage during this period, losing significantly less than the control and nitrogen treatments, and marginally less than the lime treatment (p=0.0607) (Figure 8).

The annual pattern of foliage loss varied between sites, though whether this was a result of Swiss needle cast or some other site factor (climate, soil, etc…) was unknown. The delay in seasonal foliage loss on repeatedly sampled 4-yr-old branches was greatest on the site with highest initial foliage retention, and least on the site with lowest initial retention (Fig. 9). In contrast to the OSU site, where the most rapid foliage loss took place at the end of summer, foliar loss at the severely impacted coastal site occurred during and shortly after initiation of shoot growth in the spring. Nevertheless, it should be noted thatFigure 9 is based on 3 trees. The three other trees at the OSU site, whose seasonal foliar loss

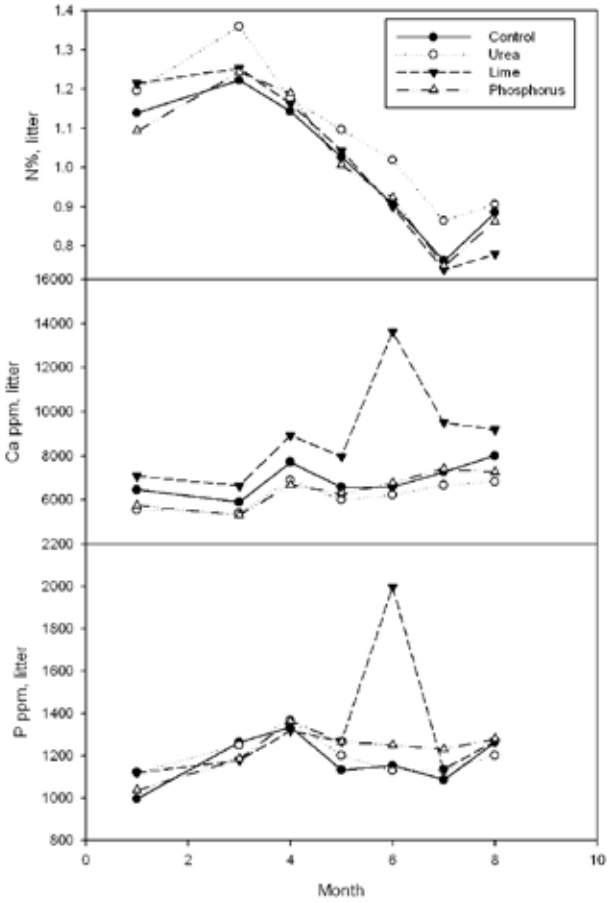

Figure 6. Litter nitrogen, calcium, and phosphorus concentrations by treatment and month.

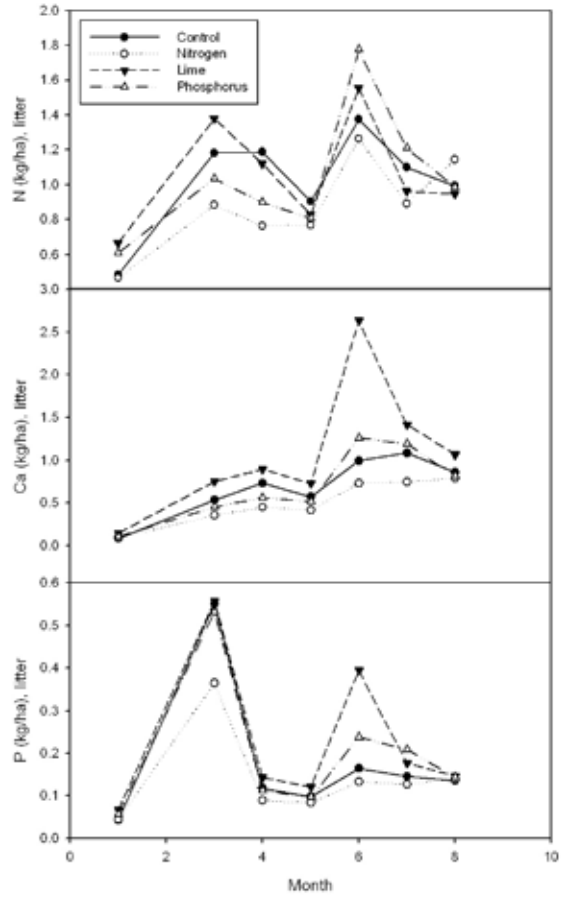

Figure 7. Total nitrogen, calcium, and phosphorus litterfall (kg/ha) by treatment and month.

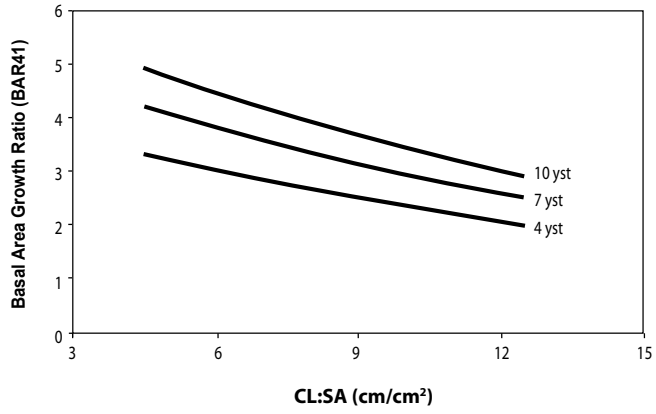

Figure 8. Change in foliage retention on 4-yr-old branch between May and September, 2007

patterns are confounded by fertilization, do not exhibit such a delayed foliar loss.

The needle cohort experiencing foliage loss depended on the site, due to different level of initial retention (Figure 10). At GDH, nearly all losses occurred from the 1- and 2-year-old cohorts, simply because most trees lacked any three year old needles. At GDH and OSU, older needles were more likely to fall, though this was not strictly true at HAGR. At a moderately infected site, annual variations in infection level were probably greater, thereby creating large differences in the retention of individual cohorts. In contrast, a greater proportion of needles from older cohorts were retained on trees fertilized with phosphorus (Figure 11).

An entire year of monitoring prior to the April/May period has not been completed yet. However, a calibration equation will be developed for adjusting foliage retention estimated at any time of year to values expected in the April/May period. The current September-January sampling gap needs to be addressed because earlier work suggested that most foliage litter falls between

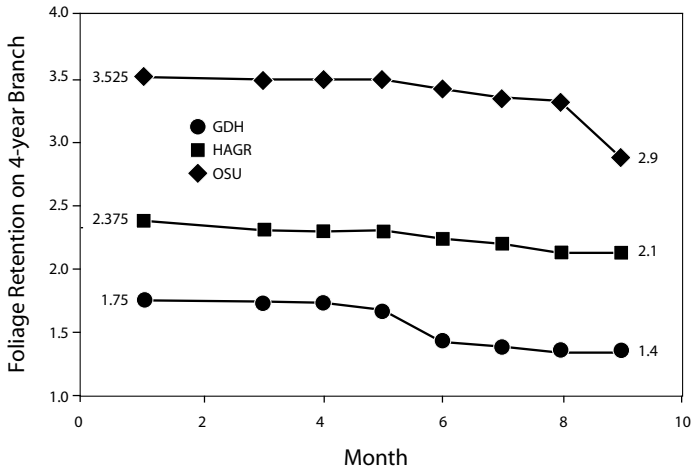

Figure 9. Seasonal trend in foliage retention on 4-yr-old branches for each site.

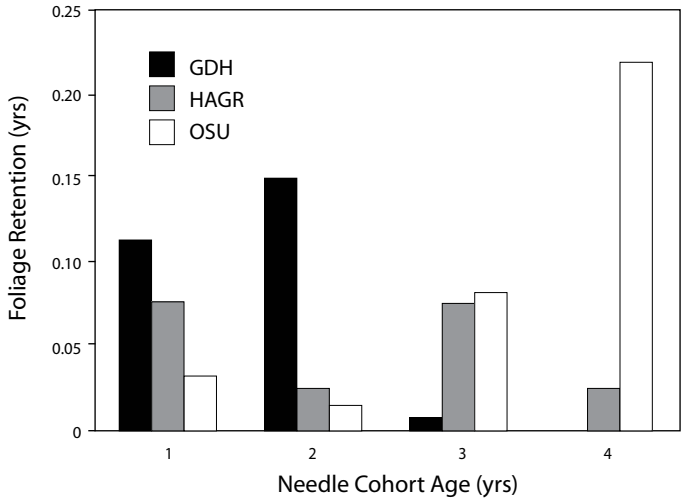

Figure 10. Proportional loss of foliage in each needle age-class on 4-yr-old branches sampled at each site (May-Sept, 2007)

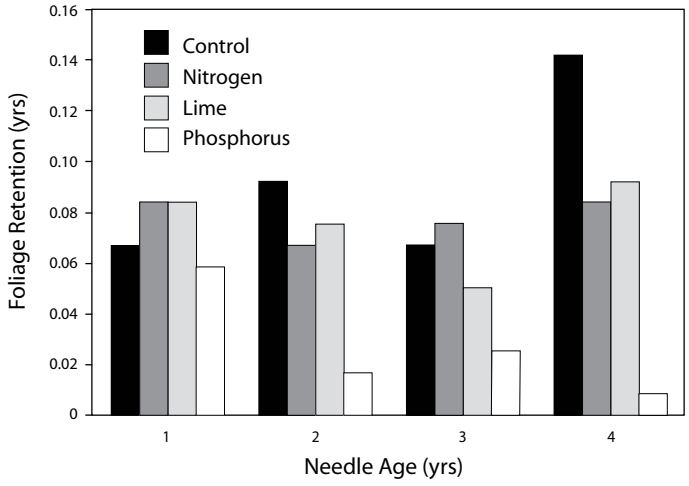

Figure 11. Proportional loss of foliage in each needle age-class on 4-yr-old branches sampled from each treatment (May-Sept, 2007)

August and November (Weiskittel 2003, Weiskittel and Maguire 2006). Foliage retention assessed after January 15 should be roughly consistent with retention assessed in April/May (Fig. 9). However, this conclusion is based on a single year (2006-2007) and a branch from a single crown position.

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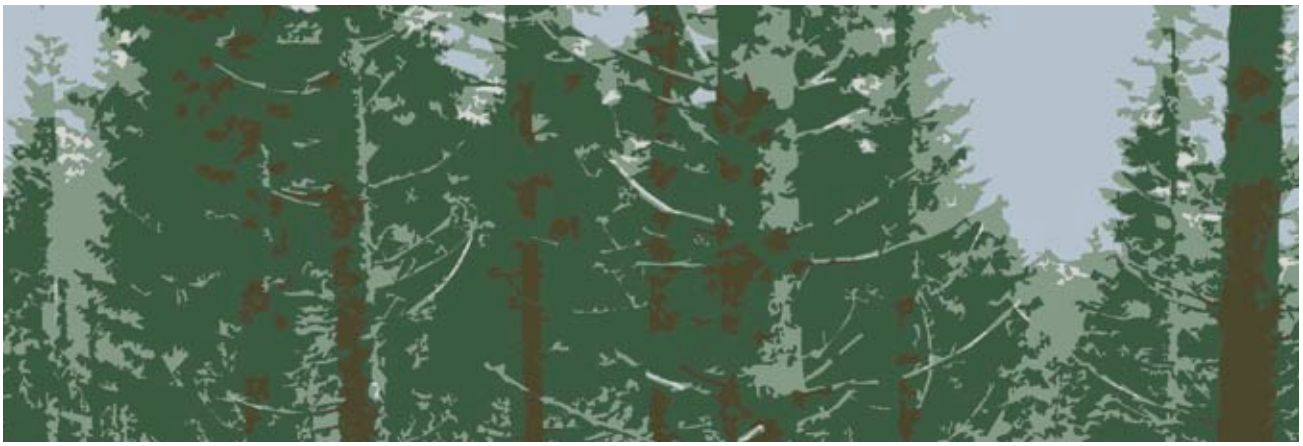

Nutrient Limitations to Growth of Western Oregon Douglas-fir Forests: A Look Beyond Nitrogen

Establishment Report

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Sites

Sixteen sites ranging from Coos Bay, Oregon to Mineral, Washington (Figure 1), were established and measured during the winter of 2006-07. The target population was specified by total age (20 ± 5 yrs), stand density (300 ± 100 trees/ac), time since thinning (7 yrs), and past fertilization (none). Dates of measurement, sampling, and treatment are provided in Table 1. Selected stands met the age and stand density criteria, with only a few exceptions (Table 2). Elevation ranged from 200 to 3100 ft, and slopes were all mild (≤35%; Table 3). Soil texture ranged from silty clay loam to loam, and parent material on most sites was shale or sandstone, with five sites on volcanic rock or ash (Table 3).

Treatments (Tables 4-6) were randomly assigned to 0.025-acre (18.6 ft radius) plots centered on an undamaged dominant or codominant tree (Figure 2). These "measurement" trees were located on a ~ 1 chain grid, located to take advantage of road access and to avoid undesirable stand features.

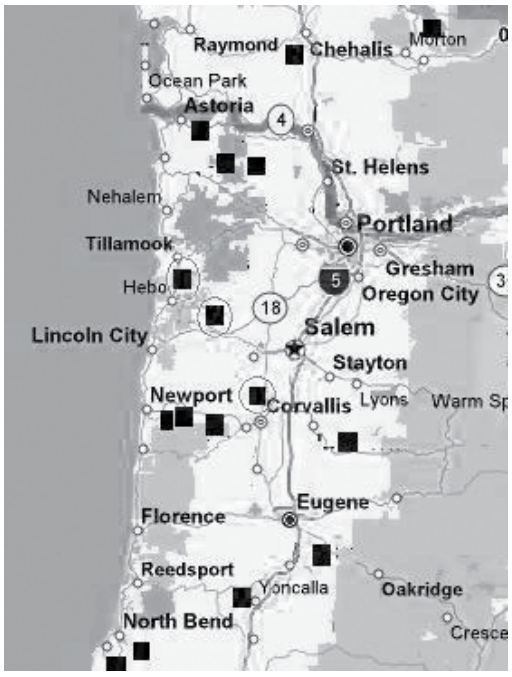


Figure 1 Approximate locations of the 16 sites

Measurements

Plot trees (All tagged trees)

Every tree on the plot was marked with a blue spot at head height and facing plot center, and was tagged with an aluminum nail and "racetrack" tree tag at breast height). Each plot tree. was then measured for Dbh (diameter at breast height) to the nearest 0.1 cm, with the bottom of the diameter tape touching the top of the tag nail.

Measure trees (plot center tree)

The tree at plot center was measured for additional attributes, including total height (Ht, 0.1 m), height to lowest live branch (Hllb, nearest 0.1 m), sapwood width at breast height (Sapwood, nearest 1mm), stem diameter at 18 ft, (Diameter (18 ft), nearest 0.1 cm) at a nail placed at ~18 ft, and foliage retention on the southern-most fifth-whorl branch from (nearest 0.1 yr.

Table 1: Sampling and treatment dates

Site	Foliar sampling	Soil sampling	Treatment dates*
Cascade Timber	10/1/06	12/8/06	2/19/07, 4/27/07
Giustina	9/14/06	11/28/06	2/13/07
Green Diamond, Eddyville	9/10/06	10/11/06	3/12/07, 4/30/07
Green Diamond, Hemlock	10/3/06	11/22/06	2/9/07, 4/16/07
Hampton, Grand Ronde	10/11/06	12/12/06	2/7/07, 4/16/07
Hampton, Knappa	9/29/06	12/27/06	2/23/07, 4/25/07
Lone Rock	9/15/06	10/18/06	3/7/07
Menasha north	9/20/06	12/5/06	2/1/07, 3/22/07
Menasha south	9/19/06	12/5/06	2/2/07, 3/23/07
ODF	10/26/06	12/6/06	2/20/07, 4/30/07
OSU	11/13/06	12/7/06	2/14/07, 4/27/07
Port Blakely	9/24/06	12/27/06	2/22/07, 4/24/07
Starker	10/18/06	12/6/06	2/27/07, 4/30/07
West Fork	9/23/06	10/27/06	11/16/06
Weyco east	10/13/06	10/27/06	3/9/07
Weyco west	10/12/06	10/26/06	3/8/07

*Second dates are date of Fenn application

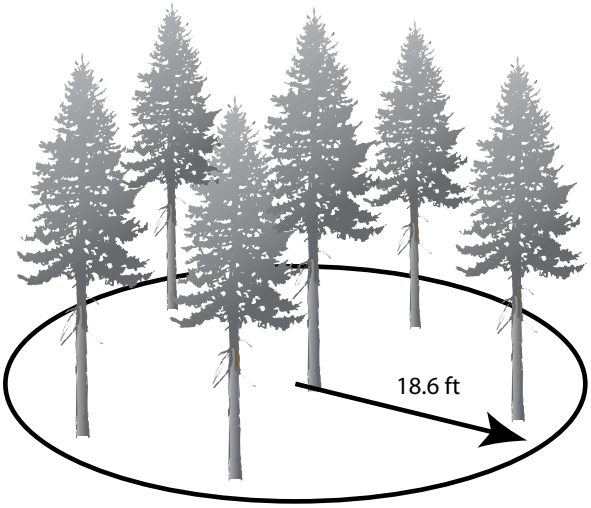


Figure 2 Graphical representation of a treatment plot

Treatment level (combined for all 10 plots receiving the same treatment)

All trees were climbed, and the most foliated four-year-old lateral from the southernmost fifth whorl branch was collected for a foliage sample. An equivalent sample of one-year-old foliage was collected from all branches within a treatment and composited for chemical analysis. Results of the chemical analysis are given in Table 7.

Two soil cores (12.5 cm) were collected from opposite sides of each tree, perpendicular to slope. At each tree, once these 2 core samples were fully mixed, a small quantity was subsampled and combined for all trees within a given treatment. Results of the chemical analysis are given in Table 8.

Winter storm damage to measurement trees and plots was limited. Because treatment at all but one site took place after the winter storms, established plots experiencing damage were replaced. Unfortunately, during a late April visit, one measure tree was discovered to have been lost at the November-treated West Fork site, and sufficient fertilizer was not available to treat a replacement plot.

Schedule of work

2007	Sept.	Foliage, soil sampling
2008	Jan.	Apply lime to Kinsey plots
2009	Sept.	Remeasure plots (growth), Foliage and soil sampling
2010	Jan.	Issue report on first growth period
2012	Sept.	Remeasure plots
2013	Jan.	Issue final report

Table 2. Tree and stand attributes for the 16 installations of the Beyond Nitrogen fertilization trials.

		Tree data					Plot data				
Plot	Owner	QMD (inches)	Ht (ft)	CR	Foliage retention (yrs)	Age (bh)	TPA, df	BA, df	QMD, non-df	TPA, non-df	QMD, non-subject tree clf
CTC	Cascade Timber	11	75.7	0.57	3.38	23	395.4	154.4	5.1	31.4	8.1
GDE	Green Diamond (Eddyville)	15.4	92.1	0.51	2.77	27.1	207.4	189.1	4.5	0.6	12.3
GDH	Green Diamond (Hemlock)	11.5	69.1	0.64	1.62	19.8	293.1	142.2	6.7	32	9
GPH	Giustina	9.2	56.3	0.64	3.64	15	372.8	108.6	3.2		7
HAGR	Hampton, Grand Ronde	10.7	54.5	0.75	2.22	15.9	276.6	121.7	2.7	37.7	9.1
HAK	Hampton, Knappa	12.6	78.3	0.6	2.36	21.8	254.9	162.3	8.3	6.3	9.9
LRT	Lone Rock	14.5	74.1	0.65	3.35	21.1	176	158.2	NA	NA	12.3
MNN	Menasha (north)	10.8	58.3	0.7	2.22	13.3	316.6	136.9	3.7	37.7	8.6
MNS	Menasha (south)	11.6	68.6	0.61	2.66	20	310.9	147.5	3.4	320	8.9
ODF	ODF	10.2	55.4	0.69	2.34	14.7	354.9	131.5	5.7	14.9	8
OSU	OSU	10.2	59.2	0.67	3.31	14.8	331.5	142	NA	3.5	8.7
PB	Port Blakely	10.4	70.6	0.47	3.41	20.4	480	158.9	3.9	40	7.5
STR	Starker	11.5	66.4	0.65	2.71	17.7	305	156	5.5	0.5	9.4
WE	Weyco (east)	7.7	42.4	0.71	2.13	13	624.8	136.7	3.3	69.6	6.2

†Quadratic Mean Diameter ‡Crown Ratio

Table 3. Soil, topographic, and parent material attributes for 16 installations of the Beyond Nitrogen fertilization trials.

Stand	Location	soil type	elevation	aspect	Parent material
CTC	T12SR1ES28	Honeygrove silty clay loam	1450′	15%	Residuum and colluvium derived from sedimentary, basic igneous, or tuffaceous rock
GDE	T11SR9WS5	Apt-MacDuff silty clay loam	650′	15%	Colluvium derived from sedimentary rock
GDH	T3SR9WS8	Astoria silt loam	400′	10%	Colluvium derived from basalt
GPH	T19SR2WS24	Bellpine silty clay loam	1000′	10%	Colluvium and residuum derived from sandstone, siltstone, and tuff breccia
HAGR	T5SR8WS6	Astoria silt loam	1200′	35%	Colluvium derived from basalt
HAK	T8NR7WS29	Hemcross silt loam	600′	10%	Colluvium derived from volcanic rock
LR	T22SR6WS34	Windygap silt loam	900′	20%	Colluvium and residuum derived from sandstone and siltstone
MNN	T3SR9WS9	Preacher-Bohannon loams	800′	15%	Colluvium derived from arkosic sandstone and siltstone
MNS	T26SR13WS10	Geisel silt loam/Templeton silt loam	200′	30%	Residuum and colluvium derived from sedimentary rock
ODF	T11SR10WS1	Preacher-Bohannon-slickrock complex	500′	30%	Colluvium and residuum derived from sandstone and siltstone
OSU	T9SR5WS4	Wellsdale-Willakenzie-Dupee complex	300′	0%	Loamy colluvium and residuum derived from sandstone and siltstone
PB	T13NR3WS25	Olympic silty clay loam	600′	5%	Residuum and colluvium from igneous rocks
STR	T11SR7WS30	Apt-MacDuff complex	1000′	10%	Clayey colluvium and residuum derived from sandstone and siltstone
WE	T5NR4WS25	Scaponia Braun silt loam	700′	20%	Colluvium derived dominately from siltstone
WF	T13NSR6ES16	Cotteral very cindery sandy loam	3100′	25%	Cinders and volcanic ash
WW	T5NR5WS34	Mayger silt loam	800′	5%	Residuum and colluvium derived dominately from shale

Table 4 Fertilization treatments in the Beyond Nitrogen fertilization trials.

Treatment #	Material	Color code (tree stripe)	Source	Per acre quantity	Per acre quantity, A.I.
1	Control	Blue			
2	Nitrogen	Yellow	Urea	440	202.4
3	Calcium	Double orange	Lime	2600	910
4	Calcium	Orange	CaCl2	260	94
5	Phosphorus	Red	Mono-sodium phosphate	2000	500
6	Kinsey	Double blue	See below	See below	
7	Fenn	Orange/blue	See below	See below	

Table 5 Kinsey fertilization treatments by installation in the Beyond Nitrogen fertilization trials.

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

Table 6 Fenn fertilization treatments by installation in the Beyond Nitrogen fertilization trials.

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

Table 7 Pre-treatment foliar chemistry by treatment and installation in the Beyond Nitrogen fertilization trials.

site	trt	P %	K %	Ca %	Mg %	Mn ppm	Cu ppm	B ppm	Zn ppm	C%	S%	N%
CTC	1	0.14	0.70	0.52	0.14	111	4	26	14	51.1	0.07	1.29
CTC	2	0.15	0.82	0.56	0.14	129	4	24	20	50.9	0.07	1.31
CTC	3	0.15	0.81	0.51	0.14	124	4	20	15	51.1	0.07	1.31
CTC	4	0.16	0.77	0.53	0.16	165	4	25	19	51.1	0.08	1.36
CTC	5	0.15	0.74	0.62	0.16	263	4	27	25	50.7	0.09	1.38
CTC	6	0.16	0.76	0.57	0.15	145	4	21	19	50.9	0.08	1.50
CTC	7	0.15	0.80	0.56	0.13	119	4	22	17	50.8	0.08	1.45
GDE	1	0.11	0.60	0.20	0.11	86	4	16	12	52.0	0.09	1.47
GDE	2	0.12	0.62	0.21	0.11	68	4	15	12	52.1	0.08	1.45
GDE	3	0.12	0.63	0.19	0.09	65	5	17	11	51.9	0.09	1.51
GDE	4	0.14	0.67	0.22	0.11	68	4	17	13	51.9	0.09	1.61
GDE	5	0.13	0.68	0.21	0.11	62	5	17	12	52.0	0.08	1.50
GDE	6	0.12	0.61	0.20	0.01	61	5	16	11	52.0	0.09	1.51
GDE	7	0.12	0.63	0.21	0.11	58	4	13	12	52.2	0.08	1.51
GDH	1	0.11	0.61	0.16	0.10	76	4	12	10	52.5	0.07	1.37
GDH	2	0.12	0.59	0.21	0.10	83	5	13	9	52.3	0.08	1.49
GDH	3	0.12	0.63	0.17	0.01	83	5	14	11	52.1	0.08	1.51
GDH	4	0.12	0.62	0.14	0.10	66	5	14	11	52.0	0.09	1.49
GDH	5	0.13	0.66	0.18	0.11	76	4	13	11	52.2	0.09	1.57
GDH	6	0.12	0.66	0.16	0.09	65	4	12	10	52.1	0.08	1.48
GDH	7	0.12	0.71	0.16	0.09	69	5	15	10	52.1	0.08	1.46
GPH	1	0.14	0.77	0.55	0.13	127	4	21	13	51.0	0.08	1.22
GPH	2	0.16	0.85	0.51	0.12	123	4	19	11	51.5	0.09	1.30
GPH	3	0.15	0.86	0.51	0.12	137	4	18	10	51.4	0.08	1.27
GPH	4	0.16	0.88	0.50	0.12	159	4	20	11	51.3	0.09	1.28
GPH	5	0.16	0.87	0.52	0.15	267	4	22	11	51.1	0.09	1.26
HAGR	1	0.13	0.78	0.32	0.14	72	5	17	13	50.37	0.06	1.45
HAGR	2	0.15	0.79	0.30	0.14	67	4	15	11	50.29	0.08	1.57
HAGR	3	0.15	0.79	0.33	0.13	76	5	14	11	50.08	0.07	1.52
HAGR	4	0.14	0.67	0.35	0.12	72	6	12	12	50.25	0.08	1.65
HAGR	5	0.16	0.81	0.33	0.13	78	6	18	13	50.27	0.09	1.81
HAGR	6	0.14	0.75	0.29	0.12	76	5	13	12	50.15	0.08	1.61
HAGR	7	0.15	0.73	0.30	0.12	77	5	14	11	50.17	0.08	1.51
HAK	1	0.14	0.72	0.34	0.12	63	7	16	13	50.2	0.07	1.33
HAK	2	0.13	0.65	0.25	0.12	65	6	16	12	50.8	0.06	1.29
HAK	3	0.14	0.67	0.27	0.13	67	7	16	13	50.3	0.06	1.24
HAK	4	0.14	0.71	0.27	0.12	91	6	18	11	50.6	0.06	1.30
HAK	5	0.14	0.67	0.24	0.12	72	7	18	16	50.3	0.07	1.33
HAK	6	0.13	0.69	0.23	0.12	63	7	16	12	50.9	0.06	1.27
HAK	7	0.14	0.62	0.30	0.12	84	6	20	12	50.1	0.08	1.49
LRT	1	0.17	0.79	0.56	0.13	156	4	28	11	51.1	0.08	1.26

Table 7 continued

site	trt	P %	K %	Ca %	Mg %	Mn ppm	Cu ppm	B ppm	Zn ppm	C%	S%	N%
LRT	2	0.18	0.80	0.52	0.13	131	4	22	13	51.0	0.07	1.22
LRT	3	0.19	0.86	0.53	0.13	113	4	21	9	51.0	0.08	1.26
LRT	4	0.18	0.85	0.45	0.12	100	4	23	10	51.2	0.07	1.26
LRT	5	0.16	0.81	0.53	0.13	118	4	20	9	50.7	0.08	1.17
MNN	1	0.11	0.57	0.23	0.01	71	5	16	9	49.9	0.07	1.45
MNN	2	0.11	0.59	0.18	0.01	61	5	16	9	49.7	0.08	1.39
MNN	3	0.12	0.62	0.23	0.09	69	5	17	9	50.2	0.06	1.54
MNN	4	0.10	0.55	0.19	0.09	66	5	14	9	50.0	0.07	1.37
MNN	5	0.01	0.56	0.21	0.09	69	6	17	9	49.9	0.07	1.45
MNN	6	0.01	0.58	0.20	0.09	75	5	17	9	49.9	0.07	1.31
MNN	7	0.11	0.52	0.21	0.10	87	5	18	10	49.8	0.06	1.41
MNS	1	0.11	0.67	0.31	0.01	60	7	13	13	49.96	0.07	1.42
MNS	2	0.11	0.73	0.29	0.10	59	6	15	14	50.02	0.08	1.44
MNS	3	0.11	0.63	0.28	0.08	59	6	13	11	49.83	0.08	1.41
MNS	4	0.11	0.60	0.27	0.09	63	5	16	11	50.21	0.07	1.44
MNS	5	0.11	0.74	0.26	0.09	70	5	15	11	50.01	0.06	1.41
MNS	6	0.12	0.69	0.35	0.10	62	5	17	12	49.55	0.08	1.52
MNS	7	0.11	0.58	0.32	0.01	88	4	15	12	49.84	0.08	1.44
ODF	1	0.13	0.72	0.30	0.14	82	5	18	11	50.60	0.08	1.52
ODF	2	0.14	0.75	0.28	0.12	71	6	15	11	50.06	0.07	1.59
ODF	3	0.13	0.81	0.28	0.15	76	5	20	12	50.72	0.08	1.50
ODF	4	0.12	0.71	0.25	0.14	63	5	13	11	50.48	0.07	1.50
ODF	5	0.15	0.78	0.34	0.15	84	8	18	12	50.32	0.08	1.53
ODF	6	0.15	0.78	0.38	0.18	78	7	20	14	50.52	0.08	1.45
ODF	7	0.13	0.74	0.32	0.15	77	4	18	11	50.52	0.08	1.55
OSU	1	0.17	0.77	0.66	0.13	140	5	27	9	50.6	0.06	1.21
OSU	2	0.19	0.75	0.55	0.14	119	4	29	9	51.2	0.07	1.33
OSU	3	0.18	0.76	0.69	0.15	104	5	26	10	50.5	0.07	1.29
OSU	4	0.18	0.79	0.66	0.14	108	4	22	9	51.2	0.06	1.28
OSU	5	0.16	0.78	0.59	0.13	97	4	23	10	50.9	0.08	1.29
OSU	6	0.17	0.80	0.70	0.14	124	5	27	11	50.6	0.07	1.34
OSU	7	0.17	0.90	0.64	0.13	84	5	21	11	50.5	0.06	1.25
OSU	9	0.19	0.89	0.63	0.14	113	5	25	11	51.2	0.08	1.38
PB	1	0.18	0.71	0.48	0.12	116	5	25	10	50.8	0.07	1.29
PB	2	0.17	0.73	0.43	0.12	120	5	20	11	50.6	0.07	1.31
PB	3	0.15	0.67	0.44	0.12	160	5	25	12	50.6	0.07	1.30
PB	4	0.15	0.62	0.46	0.13	130	5	23	12	50.8	0.07	1.33
PB	5	0.16	0.73	0.45	0.12	114	5	23	11	50.9	0.08	1.47
PB	6	0.16	0.70	0.47	0.13	89	5	21	10	50.8	0.07	1.19
PB	7	0.15	0.65	0.41	0.12	94	5	23	10	50.6	0.07	1.21
STR	1	0.18	0.82	0.49	0.13	123	6	19	14	49.9	0.06	1.26

Table 7 continued

site	trt	P %	K %	Ca %	Mg %	Mn ppm	Cu ppm	B ppm	Zn ppm	C%	S%	N%
STR	2	0.17	0.76	0.49	0.13	98	6	17	14	50.5	0.06	1.28
STR	3	0.18	0.78	0.46	0.13	77	6	20	13	50.4	0.06	1.29
STR	4	0.17	0.74	0.51	0.12	72	7	20	12	50.3	0.15	1.27
STR	5	0.17	0.80	0.63	0.13	78	9	21	12	50.4	0.07	1.40
STR	6	0.18	0.80	0.55	0.13	75	8	19	13	50.1	0.06	1.38
STR	7	0.17	0.77	0.50	0.12	78	6	21	12	49.7	0.07	1.48
STR	8	0.17	0.83	0.55	0.13	68	8	20	13	50.1	0.06	1.31
WE	1	0.19	0.86	0.48	0.12	84	5	19	12	50.2	0.07	1.54
WE	2	0.19	0.86	0.56	0.13	134	9	18	12	50.4	0.07	1.34
WE	3	0.19	0.82	0.62	0.12	94	9	21	12	50.2	0.07	1.49
WE	4	0.18	0.85	0.50	0.12	79	14	16	15	50.6	0.06	1.55
WE	5	0.20	0.82	0.64	0.12	62	8	17	12	50.1	0.06	1.58
WF	1	0.17	0.62	0.40	0.14	166	4	12	14	49.9	0.08	1.19
WF	2	0.17	0.65	0.43	0.13	183	4	12	14	50.1	0.07	1.26
WF	3	0.20	0.67	0.67	0.15	245	3	10	17	50.2	0.03	1.13
WF	4	0.17	0.60	0.50	0.13	233	4	10	15	50.1	0.08	1.25
WF	5	0.17	0.69	0.42	0.13	189	3	11	15	49.6	0.04	1.05
WF	6	0.19	0.66	0.38	0.15	169	4	10	15	IQ	IQ	IQ
WF	7	0.19	0.63	0.40	0.14	214	4	12	16	49.9	0.08	1.17
WW	1	0.21	0.89	0.34	0.11	70	8	19	13	50.3	0.08	1.21
WW	2	0.21	0.88	0.36	0.12	72	6	18	13	50.1	0.07	1.16
WW	3	0.22	0.95	0.40	0.10	67	7	18	13	49.8	0.08	1.09
WW	4	0.22	0.95	0.35	0.10	76	5	21	14	49.8	0.07	1.09
WW	5	0.22	0.92	0.37	0.11	77	7	23	16	50.1	0.05	1.13

Table 8 Pre-treatment soil chemistry by treatment and installation for the Beyond Nitrogen fertilization trials.

Site	trt	pH	P (ppm)	K (ppm)	Ca (meq/100g)	Mg (meq/100g)	Na (meq/100g)	CEC (meq/100g)	C %	S %	N %	C:N ratio
CTC	1	5.43	1.4	568	16.3	5.0	0.2	51.9	6.19	0.02	0.32	19.6
CTC	2	5.25	0.7	445	15.3	5.6	0.2	50.3	6.52	0.02	0.31	21.1
CTC	3	5.35	0.7	501	17.1	5.5	0.2	58.6	6.70	0.02	0.31	21.6
CTC	4	5.44	0.8	568	19.6	5.7	0.2	59.8	7.10	0.02	0.33	21.6
CTC	5	5.37	0.9	523	17.1	5.6	0.2	46.2	6.58	0.02	0.31	20.9
CTC	6	5.43	0.6	533	16.8	5.7	0.2	53.1	6.62	0.02	0.33	19.9
CTC	7	5.43	2	476	15.5	5.0	0.2	51.8	6.24	0.02	0.28	22.3
GDE	1	4.74	5	264	1.7	0.9	0.2	44.3	10.27	0.05	0.60	17.2
GDE	2	4.97	6	254	1.7	1.0	0.2	44.4	9.68	0.05	0.56	17.2
GDE	3	4.81	6	258	1.5	0.9	0.3	47.3	10.62	0.05	0.63	16.8
GDE	4	4.71	15	260	1.4	0.9	0.2	45.8	10.92	0.05	0.67	16.2

Table 8 continued

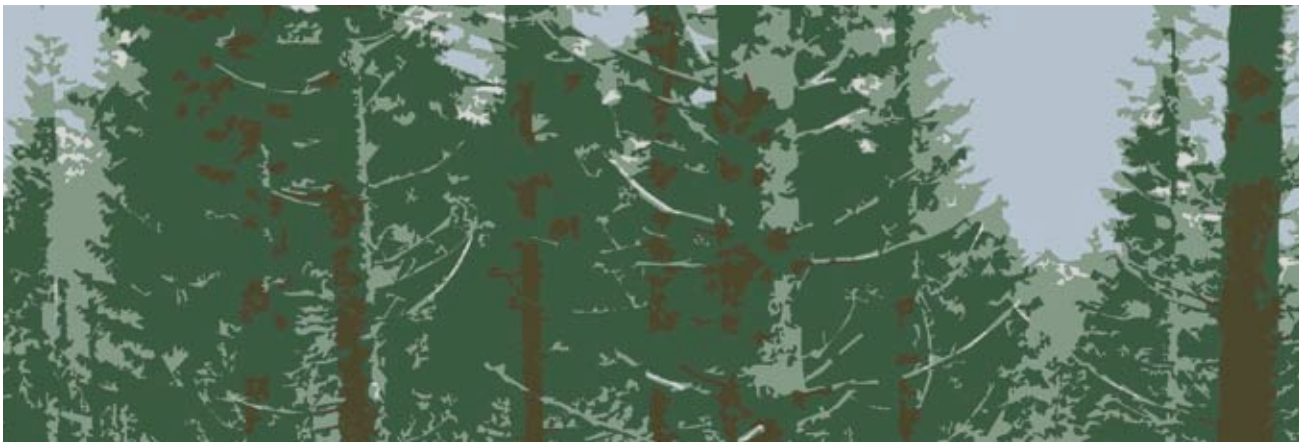
Site	trt	pH	P (ppm)	K (ppm)	Ca (meq/100g)	Mg (meq/100g)	Na (meq/100g)	CEC (meq/100g)	C %	S %	N %	C:N ratio
GDE	5	4.78	10	259	1.7	0.9	0.2	40.4	10.15	0.05	0.62	16.3
GDE	6	4.92	13	252	1.5	1.0	0.2	43.5	8.93	0.04	0.52	17.2
GDE	7	4.95	6	244	1.2	0.9	0.2	43.8	9.75	0.04	0.55	17.6
GDH	1	4.79	0.2	136	0.6	0.6	0.2	56.2	10.52	0.05	0.56	18.8
GDH	2	4.69	<0.1	144	0.6	0.6	0.2	54.8	11.47	0.06	0.61	18.8
GDH	3	4.65	0.2	133	0.6	0.6	0.3	56.0	12.24	0.05	0.61	20.1
GDH	4	4.67	0.8	116	0.5	0.5	0.2	52.7	10.69	0.05	0.56	19.1
GDH	5	4.59	<0.1	116	0.5	0.5	0.3	55.8	12.36	0.06	0.64	19.3
GDH	6	4.72	0.2	112	0.4	0.4	0.2	51.3	10.85	0.05	0.57	19
GDH	7	4.74	0.8	139	0.8	0.6	0.2	50.5	10.93	0.06	0.57	19.2
GPH	1	5.98	17	332	8.8	2.0	0.1	25.1	4.07	0.00	0.19	21.4
GPH	2	5.96	9	390	10.8	2.6	0.1	26.2	3.96	0.01	0.19	20.5
GPH	3	5.83	17	328	8.6	2.1	0.1	24.7	4.49	0.01	0.20	22.7
GPH	4	5.81	10	303	7.5	2.0	0.1	26.2	4.70	0.01	0.19	24.3
GPH	5	5.93	16	380	9.0	2.4	0.1	24.5	3.95	0.01	0.18	22
HAGR	1	4.96	0.9	208	2.4	1.6	0.3	53.0	8.60	0.04	0.45	18.9
HAGR	2	5.03	1.0	234	2.6	2.0	0.2	53.4	8.17	0.03	0.45	18
HAGR	3	5.16	0.8	326	3.2	2.4	0.4	52.8	8.05	0.03	0.41	19.8
HAGR	4	5.04	1.6	256	3.2	2.0	0.3	55.6	9.90	0.04	0.51	19.6
HAGR	5	4.90	1.5	269	3.1	1.8	0.2	61.9	11.73	0.05	0.64	18.4
HAGR	6	4.89	1.0	253	2.1	1.6	0.2	52.9	9.25	0.04	0.50	18.3
HAGR	7	5.08	2	271	3.2	2.0	0.2	51.5	8.03	0.04	0.44	18.3
HAK	1	5.1	6.1	135	1.2	0.6	0.2	48.7	10.91	0.04	0.53	20.6
HAK	2	5.0	4.9	151	1.1	0.6	0.3	52.6	11.94	0.05	0.57	20.9
HAK	3	5.1	7.1	155	1.4	0.7	0.3	48.1	10.06	0.04	0.52	19.3
HAK	4	5.2	3.9	152	1.2	0.7	0.2	49.1	10.16	0.04	0.52	19.5
HAK	5	5.0	5.8	165	1.5	0.8	0.4	52.6	12.46	0.05	0.62	20.1
HAK	6	5.1	5.1	174	1.4	0.8	0.3	51.5	11.59	0.04	0.54	21.5
HAK	7	5.2	3.2	134	1.3	0.6	0.2	58.0	12.94	0.05	0.59	21.9
LRT	1	5.82	7	345	5.7	2.0	0.1	25.6	3.13	0.01	0.16	19.6
LRT	2	5.85	16	279	5.0	1.5	0.1	21.7	3.04	0.01	0.16	18.9
LRT	3	5.74	8	353	7.1	2.9	0.1	26.3	2.84	0.01	0.15	18.7
LRT	4	5.85	5	392	6.7	2.5	0.1	27.2	3.47	0.01	0.17	20.8
LRT	5	5.80	8	367	6.4	2.3	0.2	24.7	3.11	0.01	0.16	19
MNN	1	5.31	1.5	232	1.0	0.7	0.2	56.2	15.67	0.07	0.96	16.4
MNN	2	4.55	2.6	258	0.7	0.5	0.4	48.4	10.76	0.05	0.69	15.5
MNN	3	4.46	2.0	222	0.9	0.7	0.2	50.2	11.74	0.06	0.73	16.1
MNN	4	4.56	2.0	221	0.5	0.4	0.2	48.2	10.70	0.05	0.73	14.6
MNN	5	4.31	1.8	223	0.8	0.5	0.2	52.4	13.34	0.06	0.85	15.7

Table 8 continued

Site	trt	pH	P (ppm)	K (ppm)	Ca (meq/100g)	Mg (meq/100g)	Na (meq/100g)	CEC (meq/100g)	C %	S %	N %	C:N ratio
MNN	6	4.35	2.3	231	0.8	0.5	0.2	48.8	12.06	0.06	0.81	14.9
MNN	7	4.50	3	204	0.7	0.5	0.2	47.3	11.28	0.06	0.70	16.1
MNS	1	5.17	2.0	294	3.1	1.6	0.2	42.8	9.23	0.04	0.50	18.6
MNS	2	5.29	1.9	249	2.9	1.5	0.2	42.8	10.23	0.04	0.52	19.7
MNS	3	5.17	1.8	261	2.1	1.4	0.2	40.2	7.17	0.03	0.39	18.4
MNS	4	5.33	2.1	313	2.7	1.4	0.3	42.7	8.91	0.03	0.45	19.7
MNS	5	5.10	1.9	268	2.3	1.5	0.3	45.4	8.88	0.04	0.49	18.2
MNS	6	5.29	1.9	270	2.7	1.7	0.2	39.7	8.28	0.03	0.43	19.1
MNS	7	5.40	2	253	2.1	1.2	0.2	38.1	8.27	0.03	0.40	20.7
ODF	1	4.73	2	238	1.1	1.0	0.2	46.0	9.92	0.05	0.53	18.7
ODF	2	4.85	5	273	1.9	1.4	0.2	44.8	9.84	0.05	0.56	17.5
ODF	3	4.95	1	246	1.4	1.3	0.2	41.8	8.90	0.04	0.47	18.9
ODF	4	4.91	2	224	1.2	1.2	0.2	38.6	8.09	0.04	0.44	18.5
ODF	5	5.08	2	299	2.3	1.8	0.2	39.0	8.69	0.04	0.42	20.5
ODF	6	5.07	3	309	2.3	1.9	0.2	42.2	10.07	0.04	0.51	19.8
ODF	7	4.92	5	278	1.7	1.4	0.2	41.9	9.26	0.04	0.47	19.8
OSU	1	6.43	22	455	14.6	2.3	0.2	25.9	3.28	0.01	0.21	15.9
OSU	2	6.50	32	545	16.2	2.8	0.1	25.0	2.93	0.01	0.20	14.6
OSU	3	6.30	19	358	10.6	1.8	0.1	24.8	3.14	0.01	0.21	15.2
OSU	4	6.09	16	436	12.4	2.7	0.2	25.1	2.84	0.01	0.19	14.9
OSU	5	6.15	23	454	13.2	2.7	0.1	25.7	3.18	0.01	0.21	15.2
OSU	6	6.18	21	443	13.0	2.7	0.1	25.3	3.53	0.01	0.22	16.1
OSU	7	6.24	18	482	13.5	2.8	0.2	26.4	3.03	0.01	0.20	14.9
PB	1	5.8	14.8	152	3.2	0.8	0.1	22.6	4.55	0.01	0.20	22.8
PB	2	5.8	22.5	185	3.8	0.9	0.2	22.1	4.99	0.01	0.22	22.7
PB	3	5.9	19.2	203	4.0	0.9	0.3	21.4	4.48	0.01	0.19	23.6
PB	4	5.9	19.5	179	3.7	0.9	0.1	18.5	4.32	0.01	0.18	24
PB	5	5.8	13.6	164	3.3	0.8	0.2	21.2	4.72	0.01	0.19	24.8
PB	6	5.9	17.9	177	3.9	0.9	0.2	22.0	4.48	0.01	0.20	22.4
PB	7	5.9	14.6	149	3.3	0.8	0.1	23.1	12.94	0.05	0.59	21.9
STR	1	5.25	15	379	6.0	3.2	0.2	34.6	4.80	0.02	0.28	17.2
STR	2	5.34	15	386	5.6	2.6	0.2	32.1	4.93	0.02	0.28	17.7
STR	3	5.39	16	374	6.5	2.9	0.2	33.3	5.11	0.02	0.28	18.1
STR	4	5.44	18	417	5.6	2.4	0.2	33.4	5.45	0.02	0.29	18.6
STR	5	5.42	19	408	6.7	3.0	0.2	34.3	5.31	0.02	0.30	17.7
STR	6	5.38	13	425	5.3	2.8	0.2	32.0	4.91	0.02	0.27	18.5
STR	7	5.31	12	375	5.6	2.6	0.2	32.0	5.23	0.02	0.28	18.5
WE	1	6.01	54	252	7.1	1.5	0.2	19.5	3.13	0.01	0.16	19
WE	2	5.99	37	240	7.6	1.7	0.1	19.2	3.22	0.01	0.17	18.6

Table 8 continued

Site	trt	pH	P (ppm)	K (ppm)	Ca (meq/100g)	Mg (meq/100g)	Na (meq/100g)	CEC (meq/100g)	C %	S %	N %	C:N ratio
WE	3	5.95	32	228	6.3	1.5	0.1	18.2	3.20	0.01	0.18	18.1
WE	4	6.19	54	248	7.5	1.6	0.1	21.5	3.53	0.01	0.19	18.5
WE	5	6.14	52	219	5.5	1.3	0.1	19.2	3.38	0.01	0.19	18.1
WF	1	5	11	73	2.21	0.55	0.08	24.6	8.11	0.02	0.24	33.8
WF	2	4.9	13	89	2.01	0.56	0.1	22.6	7.9	0.03	0.25	31.6
WF	3	5.2	12	82	1.8	0.5	0.08	26.7	7.79	0.02	0.24	32.5
WF	4	4.9	13	82	2.0	0.6	0.1	20.7	6.62	0.02	0.19	34.8
WF	5	5.0	17	109	3.1	0.8	0.2	22.4	7.04	0.02	0.21	33.5
WF	6	5.0	13	89	2.0	0.6	0.1	22.4	6.27	0.02	0.19	33
WF	7	5.0	14	102	2.9	0.8	0.1	22.1	6.62	0.01	0.18	36
WW	1	5.53	17	343	7.4	2.6	0.2	29.8	4.19	0.01	0.18	23.1
WW	2	5.62	19	323	7.6	2.5	0.2	27.5	3.91	0.01	0.17	22.4
WW	3	5.80	26	362	9.3	2.6	0.2	31.3	4.69	0.01	0.20	23.2
WW	4	5.65	36	398	8.2	2.4	0.2	30.6	4.74	0.01	0.19	24.8
WW	5	5.66	16	368	7.4	2.5	0.2	29.6	4.20	0.01	0.18	23.2



Response of Ectomycorrhizae to Swiss Needle Cast and Soil Nutritional Factors

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Summary

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

Introduction

Ectomycorrhizae and Silvicultural Manipulations

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

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

Several small studies have suggested a correlation between Swiss needle cast (SNC) disease severity and nutrient status of both soil and Douglas-fir foliage. Although preliminary fertilization trials have not found evidence of

nutritional amelioration of SNC, it is still plausible that imbalanced nutrition may contribute to the susceptibility of Douglas-fir to SNC. Research and experience in agriculture suggests that nutrients are not as available to plants if the soil microbial community is not in a stable and healthy condition. Ectomycorrhiza (EM) communities are particularly influential with respect to nutrient availability and tree nutrition, so may be influential in predisposition of Douglas-fir to SNC.

Previous Results

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

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

Here, we address questions raised by the previous pilot study and that enhance the value of the "Beyond Nitrogen" fertilization study. Our results provide essential groundwork for any future studies that would experimentally manipulate EMF in order to assess functional effects on SNC. Ectomycorrhizae are the organs by which any nutritional benefits of fertilization are conferred to forest trees.

Methods

Seven blocks of the "Beyond N" study (Mainwaring et al. 2006) were sampled (Table 1). The blocks varied by degree of SNC disease symptoms. Ectomycorrhizal roots of Douglas-fir from 3 of the fertilizer treatment units were obtained:

1) Unfertilized control (7 blocks)
2) Kinsey (6 blocks)
3) Phosphorus (1 block).

In each block, one 350 cc soil core was taken from beneath the canopy of 10 randomly chosen trees prior to, or concurrent with, application of the treatments. Five of the trees in each block were from the control, while the other 5 were assigned to receive the above listed fertilizer treatments. A total of 70 soil cores were obtained (10 trees/block x 7 blocks). Soil cores were obtained in February, 2007, just prior to or during surface application of fertilizer.

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

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

Land owner	Location	Needle Retention (yrs.)	Fertilizer plots
Cascade Timber	Waterloo	3.12	Kinsey
Giustina	Pleasant Hill	3.62	Phosphorus
Green Diamond	Hemlock	1.70	Kinsey
Hampton	Grand Ronde	2.17	Kinsey
Starker	Burnt Woods	2.94	Kinsey
Oregon Dept. Foresty	Elk City	2.31	Kinsey
Oregon State University	McDonald Forest	2.99	Kinsey

soil cores from each site. Representative samples of the predominant mycorrhiza types were saved in CTAB buffer for potential molecular analysis of the fungal DNA.

Number of EM types per soil core (species richness) and total number of EM tips per soil core (feeder root density) were used as response variables. The data were used to characterize the baseline (pre-treatment) condition and to test for gradient responses to SNC disease. ANOVA was used for baseline comparisons among the blocks. When appropriate, that was followed by Fisher's protected least significant difference test to determine whether study sites (blocks) differed from one another. Linear regression was used to examine gradient responses in EM density and EM richness to among-block variation in SNC disease. Linear regression was also used to measure the association between EM density and EM type (species) richness. When necessary to better meet the assumptions of normality and constant variance (Sabin and Stafford 1990), we transformed the dependent variables. Ectomycorrhiza density was square-root transformed while EM richness was log transformed.

Results

Mean root density varied by nearly 10x among sites (Fig. 1) while mean EM species richness varied by about 2.5x (Fig. 2). Treating mean logEM richness as a dependent variable of mean EM density produced a regression model of: $Y = 0.417 + 0.001 * X$; $R^2 = 0.65$, $p = 0.03$ (Fig. 3). Mean square-root EM density treated as dependent on mean years needle retention produced a regression model of $Y = -1.583 + 5.932 * X$; $R^2 = 0.70$, $p = 0.02$ (Fig. 4). Mean logEM richness treated as dependent on mean years needle retention produced a regression model of $Y = .002 + .232 * X$; $R^2 = 0.90$, $p = 0.001$ (Fig. 5).

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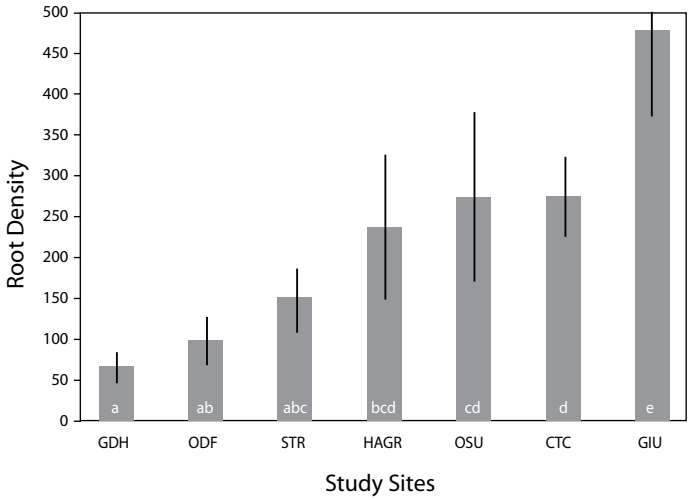

Figure 1. Variation in feeder root density (mean # of ectomycorrhizal root tips/soil core) among study sites (blocks). Bars not sharing letters are significantly different at $p \leq 0.05$, *vertical lines indicate SE,* $n = 10$.

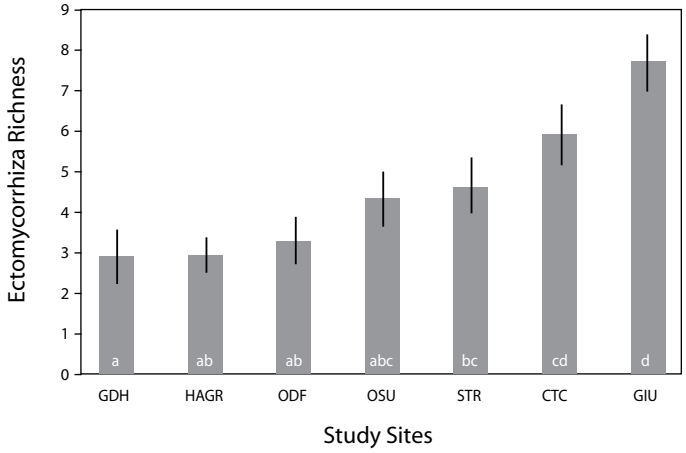

Figure 2. Variation in ectomycorrhiza richness (mean # of EM species/soil core) among study sites (blocks). Bars not sharing letters are significantly different at $p \leq 0.05$, *vertical lines indicate SE,* $n = 10$.

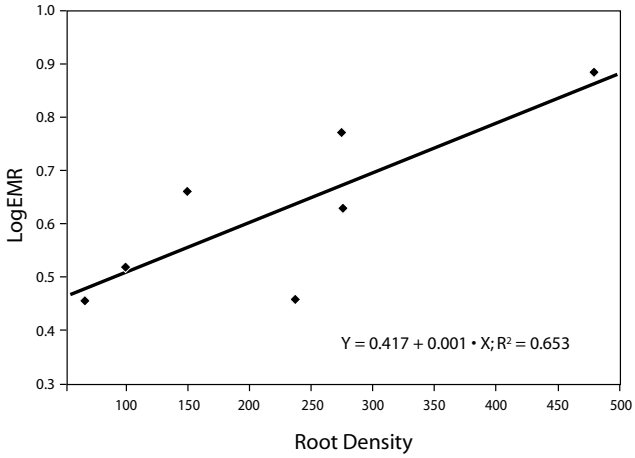

Figure 3. Regression plot of mean ectomycorrhiza species richness (log transformed) against mean root density ($p = 0.03$, $n = 10$*).*

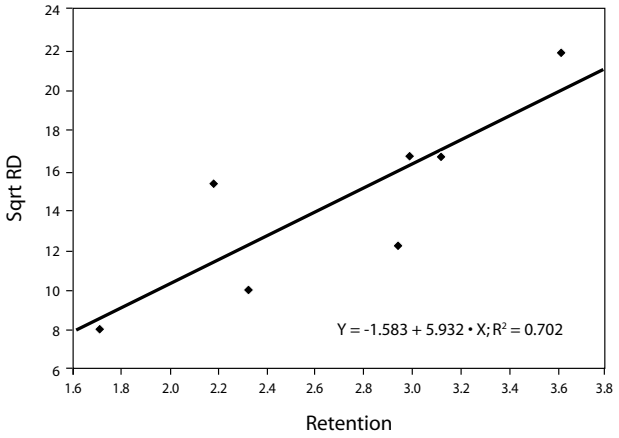

*Figure 4. Regression plot of mean ectomycorrhiza root density (square-root transformed) against mean years needle retention (*p = *0.02,* n = *10).*

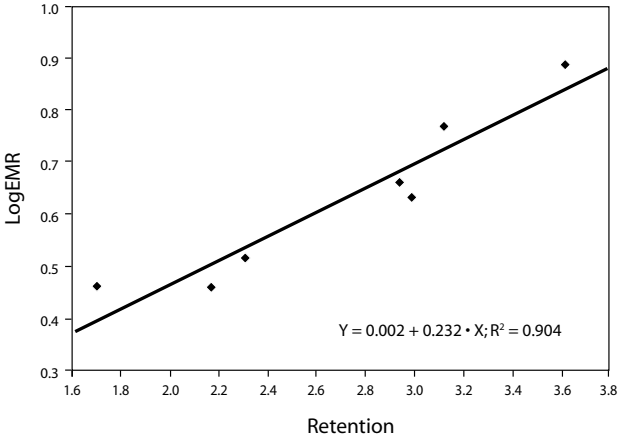

*Figure 5. Regression plot of mean ectomycorrhiza root density (log transformed) against mean years needle retention (*p = *0.001,* n = *10).*

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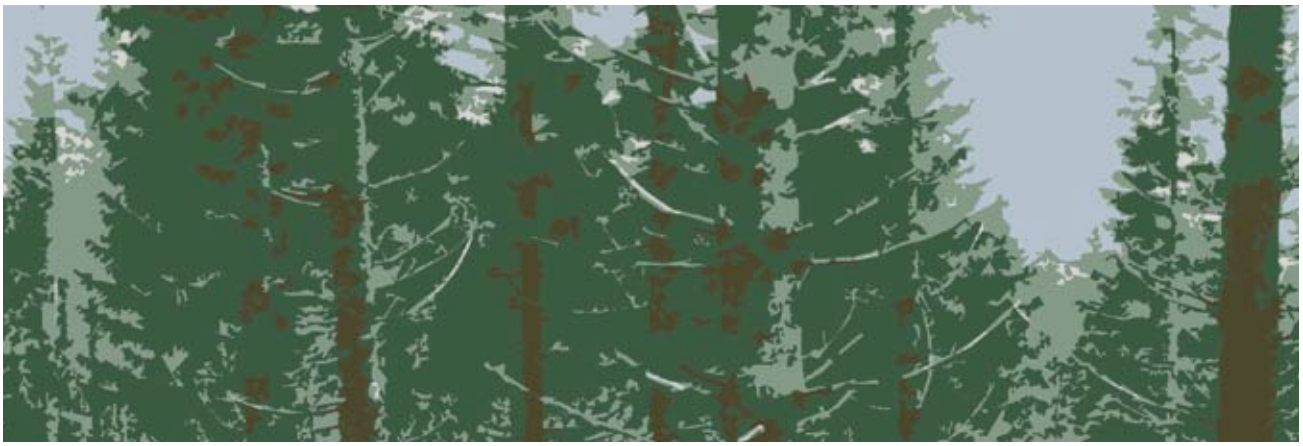

A Dendrochronological Reconstruction of Swiss Needle Cast Outbreaks in the Western Oregon Coast Range

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Dave Shaw, Dept of Forest Science, Oregon State University

Background

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

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

objectives of this pilot project, and also explore the spatial extent of historical outbreaks.

Methods

For this study we selected an old-growth Douglas-fir western hemlock stand with a minor component of Sitka spruce located in the Siuslaw National Forest at Cape Perpetua, Oregon (Figure 1). The forest was located on the upper south-facing slope of a ridge and ranged from approximately 750 – 850 ft in elevation. Slopes ranged from 10% at the top of the ridge to 30% at mid and lower elevations in the study area (Figure 1). Sitka spruce and western hemlock dominated the smaller crown and size classes while Douglas-fir occurred largely as dominants and codominants. Using a 32" and an 18" increment borer, we extracted seventeen cores from ten Douglas-fir trees and twenty cores from ten western hemlock individuals, attempting to acquire two cores per tree. All cored trees were in the dominant or codominant crown classes and sampled from within as small of an area as possible. To increase the sample size, we also included thirteen Douglas-fir tree cores taken in May 2006 during the 16th North American Dendroecology Fieldweek. These trees were significantly older than those we cored and were located just down slope of our study area.

Cores were dried, mounted, and sanded with increasingly fine sandpaper to reveal the cellular structure. Within each species, all cores were then crossdated to identify and missing or false rings in the data set and ensure that all growth increments were assigned the correct calendar year. The procedure is based on the principles that at least one climatic variable limits growth and values of these climatic variables fluctuate over time. Under these conditions, climatic variability induces synchronous growth patterns in all individuals within a given region. These synchronous growth patterns, much like bar codes, can then be matched among all individuals to verify that all growth increments have been identified. If a ring has been missed, the growth patterns in the tree will be offset relative to the growth patterns in all other trees, and the first year of the offset indicates where the error occurred. All samples were first visually crossdated using the "list year" technique in which common growth patterns were identified by noting growth increments that were conspicuously narrow or wide relative to surrounding increments (Yamaguchi 1991).

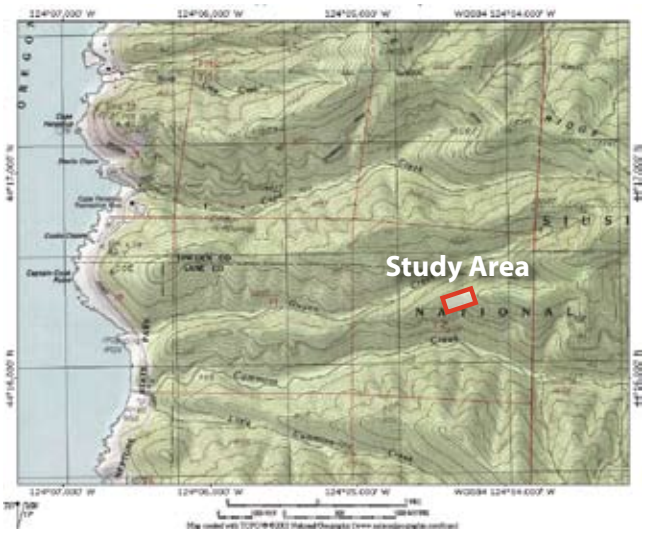

Figure 1. Map of the study area.

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

ments, the number of lags indicated the number of rings missed or falsely added, and the window at which the correlation statistic first decreased indicated the approximate location of the error.

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

Detrending with negative exponential functions or horizontal lines removed only age-related growth trends but otherwise preserved all other patterns of variability. This chronology would capture all processes that lasted from one or two years to those that lasted from one or more centuries. For Swiss Needle Cast disease (SNC), however, we were most interested in emphasizing decadal-scale processes. As in insect outbreaks, SNC outbreaks would probably be most prominent on such a timescale. To better extract decadal-scale processes, we detrended the original measurements with 50-year cubic splines, which preserve decadal-scale variability and remove longer-term processes. This type of detreding is common used in reconstructions of insect outbreaks. We then built new master chronologies for each species by averaging all series detrended with 50-year splines. To better identify the potential signature of SNC, the hemlock master chronology was subtracted from the Douglas-fir chronology. Any negative values in this subtracted chronology indicated below-average growth in Douglas-fir with respect to hemlock, and vice versa for positive values.

As an additional analysis of potential SNC events, we scanned each detrended set of measurements that had been detrended with a 50-year spline (each tree core) for severe suppression events. This approach is also very commonly used for identifying insect outbreaks and is based on the assumption that SNC will induce below-average growth on timescales less than one or two decades in length. To accomplish this analysis, we identified in each set of detreneded measurements all years in which growth fell below two standard deviations of the mean. The percentage of trees showing suppression was determined for each year of the chronology as an indicator of potential SNC outbreak. Finally, to better interpret the suppression chronology and the master chronologies, we also recorded the years in which each Douglas-fir core contained traumatic resin ducts. Although these resin "rings" can be caused by a number of disturbances, they have been shown to be closely linked with fire years in other species (Brown and Swetnam 1994). Thus a resin-ring chronology provided us with an additional perspective on fire history in the forest.

To establish the effects of climate on growth, we obtained monthly averages of precipitation, temperature, and Palmer Drought Severity Index (1895 – present) for Oregon Region 1 (Coastal Oregon) at the NOAA NCDC website http://www7.ncdc.noaa.gov/CDO/CDODivisionalSelect.jsp# . We also obtained instrumental temperature and precipitation records (1910-present) for Newport, OR through NOAA NCDC. Monthly averages were used to determine those periods of the year in which environmental variability most strongly affects growth. For example, a warm March often favors growth by allowing photosynthesis to begin early in the season. Also, given the proximity to the Pacific Ocean, we obtained several indices of ocean circulation to relate to tree growth including the Pacific Decadal Oscillation (PDO) and the Northern Oscillation Index (NOI). The NOI is the anomaly sea level pressure difference between the North Pacific High and Darwin, Australia. The index captures the strength of atmospheric circulation between the tropics and the north Pacific, particularly with respect to the El Niño Southern Oscillation on the north Pacific. High values occur during La Niña years while negative values occur during El Niño events (Schwing et al. 2002). In addition to these basin-wide variables, we also obtained monthly averages of local sea surface temperature, and upwelling. NOI (1948-present), and upwelling (1946-present) records were obtained through the Pacific Fisheries Environmental Laboratories live access server at http://www.pfeg.noaa.gov/ . We then correlated monthly environmental variables with each master chronology to determine the impacts of climate on tree radial growth.

Results and Discussion

In Douglas-fir the synchronous growth pattern among samples from each site was strong, facilitating cross-dating. Particularly prominent signature years included 1918, 1858, 1786, 1683, and 1681. The common climate signal was not as strong in western hemlock, though 1996, 1935, and 1896 were consistently narrow signature years. We found a total of three missing rings in the Douglas-fir data set and three in the western hemlock data set. The average correlation between each detrended set of measurements as the average of all other sets of detrended measurements (interseries correlation; ISC) was 0.571 for Douglas-fir and 0.381 for western hemlock. These values were highly statistically significant and comparable to those found for these species in the western Cascades. The ISC value for western hemlock was somewhat lower, which can be explained by a much stronger signal due to competition, as would be expected from such an understory tolerant species. Competitive signals were less pronounced in Douglas-fir, resulting in a relatively stronger climate signal.

The oldest western hemlock sample dated to 1881 and the oldest Douglas-fir dated to 1618. Master chronologies are shown only for those periods with a minimum of six sets of measurements (cores), a threshold not reached until 1731 and 1889 for Douglas-fir and western hemlock, respectively. A minimum of six samples in the master chronology is necessary to reduce the influence of individual samples and enhance the common stand-wide growth pattern. When detrended with negative exponential functions, the final chronologies show considerable variability on a wide range of timescales (Figure 2). Douglas-fir experiences a steady decline from approximately 1780 through 1890, then sharply increases through 1910, and declines again through the present. Western hemlock also declines from about 1910 through 1940, at which point it experiences a growth increase through 1980 and a sharp decline after 1990 (Figure 2). These long-term trends are consistent with competition. This site likely experienced a stand-thinning event around 1760 and again around 1880, both of which released trees from competition, resulting in growth increases. Steady declines in growth indicate rising levels of competition as trees recruit and the stand becomes increasingly dense, as would occur between major disturbance events.

Western hemlock and Douglas-fir vary in their long-term growth patterns (Figure 2), but decadal growth patterns are much more synchronous, as revealed when detrended with 50-year splines (Figure 3). Both chronologies closely track one another, showing synchronous declines followed by increases from approximately 1890-1910, 1910-1950, 1950-1980, and 1980-present (Figure 3). Given the periodicity of these growth oscillations, these chronologies are capturing growth patterns ranging in length from multidecadal (three to four decades) to interannual (high frequency). Such a timescale should coincide with SNC outbreaks. However, there are no substantial reductions in Douglas-fir growth relative to western hemlock, as is more clearly demonstrated in the difference between the two chronologies (Figures 3, 4). The only possible SNC outbreak is around 1910, during which time Douglas-fir growth is reduced relative to western hemlock for approximately five years (Figure 4).

In the context of the full Douglas-fir master chronology, the growth decrease around 1910 is relatively minor (Figure 5). Much more profound growth decreases occurred earlier, specifically between 1870 and 1890 and also around 1740. A high proportion of cores also show severe suppression events during these time periods (Figure 6). In the early 1740s and also between 1870 and 1890 suppression event last multiple years and occur in over a third of the samples. Isolated years of suppression are likely due to climate extremes, but these longer-lasting events are consistent with the duration of SNC. However, these events must be carefully interpreted. A period of suppression from the late 1950s through 1970 is mimicked by western hemlock and appears to be a disturbance or climate signal not specific to Douglas-fir, and thus not a candidate for SNC (Figures 3, 5). Also, the traumatic resin-duct chronology reveals a history of fire in the forest, which could cause suppression events. According to the chronology, periodic fire appears to occur periodically through about 1880, after which time there is a quiescent period until 1920 and another quiescent

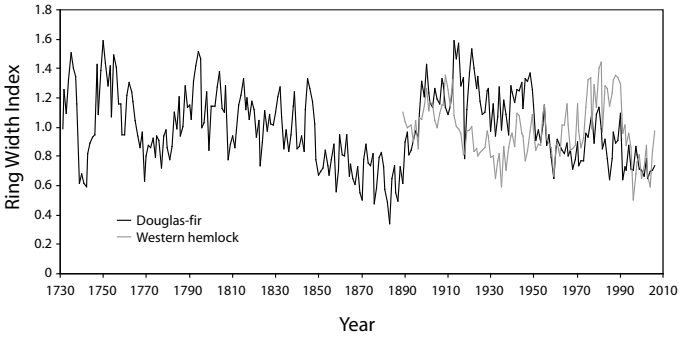

Figure 2. Master chronology for western hemlock and Douglas-fir; detrending with negative exponential functions. Minimum sample depth of six sets of measurements per species.

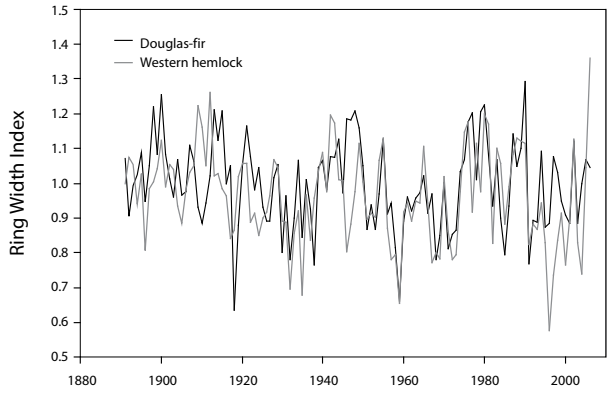

Figure 3. Master chronology for western hemlock and Douglas-fir; detrending with 50-year cubic splines.

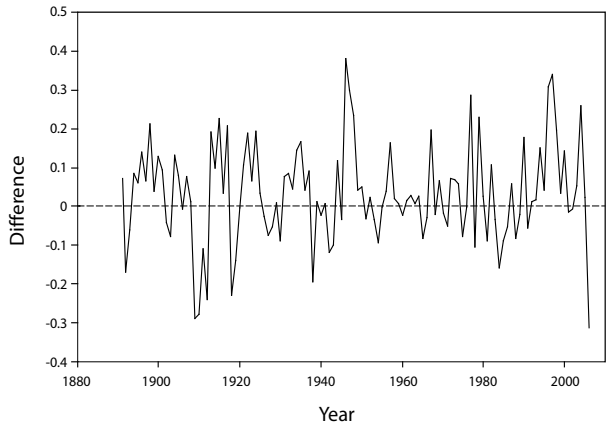

Figure 4. The difference between the western hemlock and the Douglas-fir master chronologies developed using 50-year splines. Positive values indicate above-average growth for Douglas-fir relative to western hemlock while negative values indicate below-average growth relative to western hemlock.

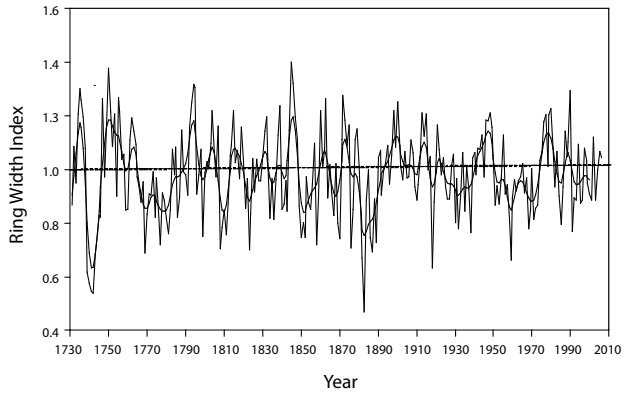

Figure 5. Master chronology for Douglas-fir; detrending with 50-year cubic splines. A low-pass filter is shown for emphasis of low-frequency (decadal) variability. Minimum sample depth is six sets of measurements (cores).

period from 1950 through the present (Figure 7). Reduced fire through the 20th century is consistent with fire suppression, and resin ducts from 1920 through 1950 may be associated with harvesting-related fires. Reduced fire after approximately 1880 is consistent with extensive hemlock recruitment in the stand after that date. This fire sensitive species never recruited in the forest until after prior to 1880, despite the potential for much greater longevity. Thus suppressions in Douglas-fir could be the result of fire in the stand, particularly suppressions prior to 1880.

The first major suppression to occur (early 1740s) is not accompanied or preceded by traumatic resin ducts. Instead, traumatic resin ducts occur in the latter half of the decade, well after the suppression event was initiated (Figures 6,7). Likewise, traumatic resin rings are not associated with the 1880-1890 suppression (Figures 6,7). Resin rings commonly occur through approximately 1875, then reduce in abundance until 1920. The absence of traumatic resin rings in the early 1740s and 1880-1890 suggests that these suppressions were not the result of fire damage. Thus the 1740 and 1880-1890 suppression may well be due to a pathogen such as SNC. Indeed rings in the 1740s and from 1880-1890 tend to have thin latewood, which suggests that the growing season was cut short. However, SNC is not the only pest that could have such an effect. Infestation by western spruce budworm could also produce a similar response. Preliminary tree-ring research involving Douglas-fir in the west Cascades has identified periodic spruce budworm outbreaks with similar qualities. In fact, one major outbreak throughout the Cascades corresponds with the sudden suppression around 1742 in Cape Perpetua Douglas-fir. Quite possibly, the suppressions of the early 1740s reflect a large-scale western spruce budworm outbreak throughout western Oregon.

As for climate, the Douglas-fir chronology correlates significantly but weakly with records of precipitation, temperature, and drought (the Palmer Drought Severity Index; PDSI). Correlations are strongest for regionally averaged climate data obtained through NOAA CLIMVIS in comparison to records from Newport, OR. As expected, Douglas-fir is most strongly associated with summer precipitation and temperature, particularly the prior summer. High temperatures, low precipitation, and drought limit growth during this time of year, resulting in positive correlations with precipitation and PDSI (negative values indicate drought) as well as negative correlations with temperature. Droughts in the late summer apparently shorten the growing season, reducing growth for Douglas-fir. Douglas-fir is well known as a moisture sensitive species and would be most prone to drought effects during the dry Oregon summers. With respect to marine variables, none are significant. Although correlations are significant for precipitation, temperature and drought, they are weak and climate explains relatively little variance in the master chronology. Thus climate is probably not a major factor in explaining extreme suppressions in Douglas-fir growth.

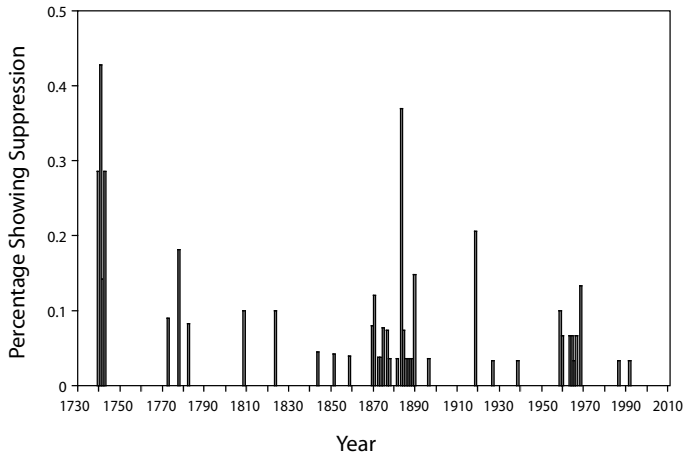

Figure 6. Percentage of samples showing suppression. Suppression is defined as growth more than 2 std dev below the mean. All samples were detrended using 50-year cubic splines before scanning for suppression. Minimum sample size is six sets of measurements (cores).

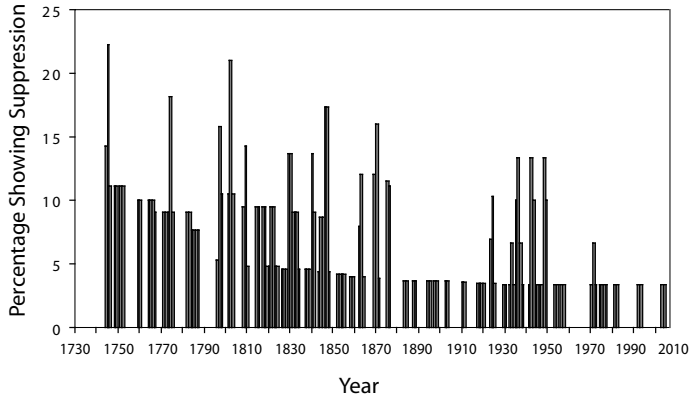

Figure 7. Percentage of Douglas-fir samples with traumatic resin ducts. Minimum sample size is six.

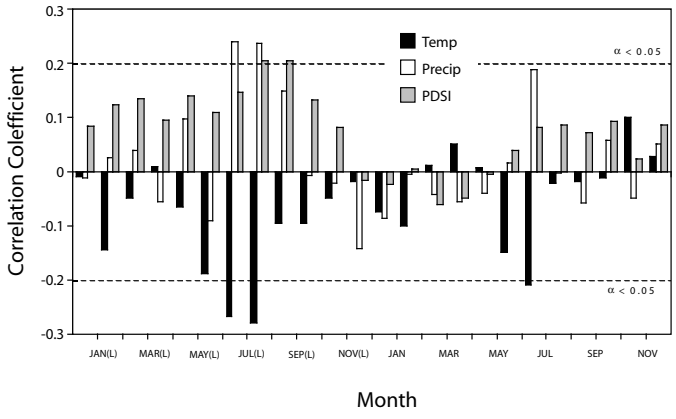

Figure 8. Correlations between the Douglas-fir master chronology (data detrended with 50-year splines) and monthly climate variables from NOAA CLIMVIS (1895-present). Temp = temperature; precip – precipitation; PDSI = Palmer Drought Severity Index

Conclusions

Swiss Needle Cast disease does not appear to have substantially influenced the growth of Douglas-fir in this forest. This is particularly true of the last 100 years in which Douglas-fir growth closely tracks that of western hemlock. During this period, other disturbances have exerted much stronger and synchronous more influence. Prior to approximately 1890, the Douglas-fir chronology experienced multiple suppression events. Many could be the result of fire, as indicated by the presence of traumatic resin ducts. But a suppression around 1740 and another between 1880 and 1890 may be the cause of a pathogen. The growth reduction is pronounced and probably not associated with climate and does not coincide with traumatic resin ducts. Furthermore, there is evidence of narrow latewood. However, these suppressions could be the result of spruce budworm. To better distinguish SNC in this forest, future work should focus on collecting tree-ring samples from a stand with a known SNC history. If unique anatomical signals can be identified in the rings, perhaps then a more conclusive test for SNC can be developed. For now, however, it is clear that SNC has not had major impacts on this stand relative to other disturbances. Even if the suppressions in 1740 and 1880-1890 were due to SNC, these growth depressions were brief and caused no long-term damage to the stand.

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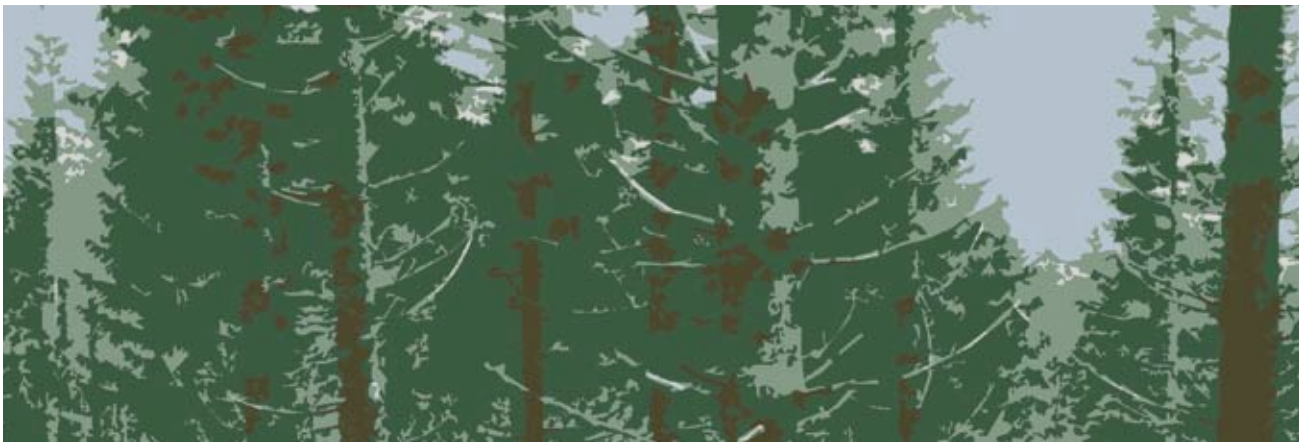

Evaluation of Swiss Needle Cast Effects on Young Douglas-fir Plantations: Measurement Techniques, Severity Indices, Growth, and Genetic Effects.

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South Central Coast Tree Improvement Cooperative

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The Purpose of this Study is to:

1. Test whether information obtained via disease severity measurements (foliage retention) improves the ability to predict and explain differences in tree growth in the presence of SNC. The null hypothesis is that disease severity rating does not help explain or predict growth (past or future).

2. Test whether there are differences in observed tree growth between different genetic families, and between selected crosses compared to woodsrun controls, and whether these differences are impacted by Swiss needle cast. There are several specific comparisons available to do this. They are:

    a. Comparing over time identical families on 3 installations within the SNC zone (SCC SNC tests) with 3 installations outside of this zone (SCC mainline tests).

    b. Evaluating the predicted genetic gains for the families planted on the SCC test sites compared with gains based on 1st generation analyses. Compare the observed gains in the 3 SCC SNC sites (in the SNC zone) with the observed gains in the SCC mainline sites (outside the SNC zone). The null hypothesis would be that the relationship between predicted and observed gains would be identical for both mainline and SNC tests.

    c. Potentially establishing fungicide treatments on portions of the 3 installations within the SNC zone to use as controls.

3. Verify if conclusions from previous work in first-generation progeny tests (Nehalem and Hebo) hold up in an independent test set up specifically to study genetic tolerance to SNC.

The South Central Coast Tree Improvement Cooperative (SCC) established three Douglas-fir progeny trials along the southern Oregon coast in the zone of Swiss Needle

Cast. These trials were established as part of a 2nd-generation breeding and testing program, and sought to find Douglas-fir seed sources tolerant to the higher levels of SNC observed in this area in the recent past. These trials are now at a point where SNC will start to affect tree growth. Recent samples show that SNC is present and active on the young trees. All trees were established as styro-20 container seedlings in February 2002, with 20 seedlings planted per cross as single-tree plots. Plantations are fenced to prevent browse.

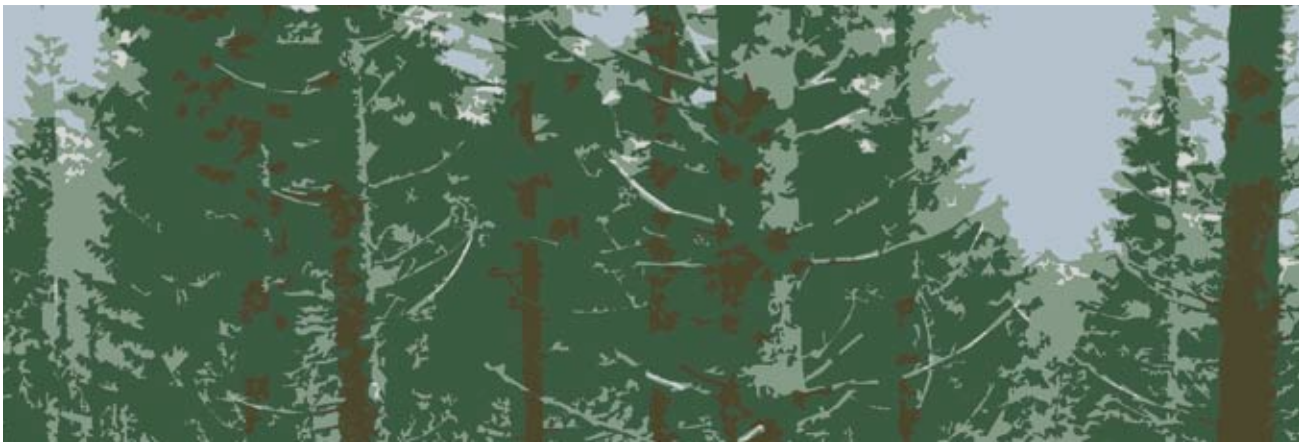
Some organizations, encouraged by results in the Nehalem and Hebo first-generation programs on the North Oregon Coast, are making significant tree improvement decisions and investments based on the premise that the most vigorous families (especially those continuing to put on DBH growth in the presence of the disease) are the best choice for reforestation of Douglas-fir in areas affected by SNC. Some of them are planting more Douglas-fir than was the case in the late 1990s, also on the premise that a moderate level of tolerance could be achieved by the use of selected families. These SCC trials afford a chance to validate these decisions, and (if the same holds true here) try and learn more why fast-growing families are more successful in the presence of SNC than slow-growing families or unimproved seedlots.

In spring of 2007, 3 SNC sites near the Coast: near Florence, Hauser and Bandon respectively were sampled for needle retention. These contain 50 full-sib crosses plus 4 controls (2 of which are woodsrun lots, from the north end and south end of the SCC testing zone). The 10 crosses estimated to have the best growth potential, from each of five first-generation breeding zones, were included in this trial. Sites affected by SNC were specifically sought out. In addition, the same 50 crosses were sampled in 3 "mainline" test sites outside (east of) the zone of SNC epidemic for needle retention. In spring of 2007, we found that counting needle retention beyond 2 years was problematic due to age of trees and height of competing vegetation (Figure 1). So our needle retention estimates are for the current 2 years of foliage. The mainline sites contain 283 families (including the 50 in the SNC sites) and 4 controls.

Figure 1. Ron Rhatigan and Alan Kanaskie investigating needle retention near Florence. The associated vegetation and age of the trees makes counting more that 2 years growth on lateral branches at hip height or higher, problematic. Since the reductions below 2 years of foliage retention are known to cause significant tree growth reductions, it was decided to focus on percent of the foliage present on the most recent 2 years.

This fall, the South Central Coast tree improvement cooperative is measuring all six sites for tree growth (height and dbh) and stem form. NWTIC expects to have those data and the needle retention data analysed by early 2008, and results on the SNC aspects will be reported to SNCC.

We plan to return in spring of 2008 and instead of sampling all 50 families + the controls, we will choose a subset of families (say the 10 best families) and only compare their pseudothecia counts with the woodsrun controls. Taking this approach, the pseudothecia counts would be done in spring 2008. We will clip branches and count pseudothecia, as well as estimate needle retention in the lab. The null hypothesis is that pseudothecia counts will not differ between the fast-growing families and the woodsrun controls.



Swiss Needle Cast ORGANON Module Update

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Introduction

In 2006, data were compiled from all the long-term SNCC studies to develop a Swiss needle cast module for ORGANON (Garber et al. 2006). Modifiers were developed for diameter and height growth. However, the modifiers reported by Garber et al. (2006), dropped below 1.0 for stands with foliar retentions greater 2.5. Previous work has suggested that noticeable growth reductions do not occur until foliage retentions drop below 2.5 (Weiskittel and Maguire 2004). The goal of this study was to refit and update the modifier equations and to simulate the impacts of these tree-level modifiers at the stand-level.

Methods

Data for this study were compiled from four ongoing studies established on predominately Douglas-fir sites to investigate growth losses and thinning effects on stand development under varying influence of Swiss needle cast including the Growth Impact Study (GIS), Precommercial Thinning study (PCT), and Commercial Thinning Study (CT), and Retrospective Commercial Thinning Study (RCT) (Garber et al. 2006). In general, plots were established across a range in stand age, topographic position, and SNC severity. Latitudes ranged from 43.5°N to 46.16°N, longitudes from 124.06°W to 122.31°W, and elevation from 30 to 800 m a.s.l. Over the last 40 years, the mean January minimum for this region was 0 °C and the mean July maximum was 25 °C. Total annual precipitation averaged 150–300 cm, with approximately 70% of the total falling from October to March.

All trees > 1.37 in total height (HT) were included in the plot tree list passed to the model. Trees without HT and height to crown base (HCB) were filled in using the default equations in the SMC variant and with the calibration factors for both variables turned on (Hann 2006). Observed periodic change in tree diameter at breast height (ΔDBH_{obs}) and HT (ΔHT_{obs}) were determined for a four-year growth period starting with the first measurement for each tree with a DBH ≥5.0 cm and a measured HT. ORGANON projections of diameter and height growth were considered to be healthy stands. Since ORGANON has a five-year time step, ORGANON projects were linearly interpolated to a four-year diameter (ΔDBH_{pred}) and height (ΔHT_{pred}) growth by multiplying the projections by 0.8. The observed DBH growth modifier (DMOD) and HT growth modifier (HMOD) were calculated as $\Delta DBH_{obs}/\Delta DBH_{pred}$ and $\Delta HT_{obs}/\Delta HT_{pred}$, respectively. Stand characteristics included the plot basal area per hectare (BA). Plot basal area per acre (BAL) in trees larger than the subject tree was calculated for each tree and each time period (Hann et al. 2003).

Initial fits were to a two parameter Weibull model (Garber et al. 2006). However, DMOD fits showed a bias with BAL that was attributed to natural trees that seeded in after planting and were growing in openings and the asymptote

was deemed to be approached too slowly (stands with FOLRET ≥ 2.5 has modifiers below 1.0. Therefore, an exponent was placed on FOLRET for the DMOD and HMOD equations and a function of BAL was added to the asymptote in the DMOD equation producing a three parameter Weibull function:

$$[1] \quad DMOD = \beta_{10}[\exp(\beta_{13}BAL^{1.4})][1.0 - \exp(\beta_{11}FOLRET^{\beta_{12}})] + \varepsilon_1$$

$$[2] \quad HMOD = \beta_{20}[1.0 - \exp(\beta_{21}FOLRET^{\beta_{22}})] + \varepsilon_2$$

where β_{ij}'s were parameter estimates determined from the data, ε_i were random errors assumed to be distributed as $N(0, \sigma_i^2)$, and all other variables were define above. Although this produced unrealistic behavior at FOLRET values less than 0.8, values below one are extremely rare in the field.

To assess the model-implied effects of SNC over multiple ORGANON growth cycles, a healthy 12-year-old Douglas-fir stand from the central Oregon Coast Range planted at 1038 trees·ha^{-1} (420 tree·ac^{-1}) with 2-year-old seedlings (site index = 40 m (130 ft) Bruce (1981)) was projected for 30 years at the following foliage retentions: 2.5 (healthy), 2.0, 1.5, and 1.0 years. Basal area and volume growth as a percent of healthy growth (FOLRET=4.0) were calculated.

Results

The asymptote in [1] and [2] were significantly greater than 1.0 (α-level=0.05) indicating healthy trees were growing faster than ORGANON predicts during this period (Table 1). Equations [1] and [2] also suggest that trees in a stand with FOLRET=2.5 would still grow at 98% of healthy growth (Table 2). The rate of decline was faster for diameter growth than height growth (Fig. 1). Growth losses, on average, do not exceed 10% until plot average foliage retentions are below 2.0 and 1.8 years for diameter and height growth, respectively. In severely infected stands, those stands with foliage retentions near 1.0, diameter growth and height growth were reduced to nearly 33 and 60% of healthy growth, respectively (Table 2). No patterns were identifiable with stand or tree level variables with the exception of a slight negative bias at large SI's.

When the modifiers were applied to ORGANON projections, the percent of healthy growth dropped dramatically with a decrease in foliage retention but increased with stand age. Percent of healthy volume growth produced analogous results over FOLRET but did not display consistent results over stand age (Table 3). At retentions of 2.5 yrs, volume growth was 98% of healthy stand volume growth. With increasing growing cycles (age 14 to 44), at a foliage retention of 1.0, the percent of healthy stand basal area growth increased from 28 to 31% while the percent of healthy stand volume growth decreased from 41 to 37% (Table 3).

Discussion

The growth losses implied by the modifiers presented here were generally consistent with those patterns observed on previous stand-level analyses of growth impact (Maguire et al. 1998; Kanaskie et al. 2002a; Maguire et al. 2002a,b; Mainwaring et al. 2005a). Significant growth impact were not observed until foliage retentions were reduced below 2.5 years, similar to that observed in previous studies

Table 1. Parameter estimates and asymptotic standard errors for diameter growth modifier ([1]) and height growth modifier ([2]).

Parameter	Parameter estimate	Standard error
Diameter growth modifier		
β_{10}	1.281594	0.036186
β_{11}	0.397308	0.069915
β_{12}	2.505400	0.150713
β_{13}	0.000230	0.000010
Height growth modifier		
β_{20}	1.192516	0.017072
β_{21}	0.911196	0.067477
β_{22}	1.598890	0.164354

Table 2. Summary of percent of healthy diameter and height growth based on equations [1] and [2], respectively at various foliage retention levels.

NR	ΔDBH	ΔHT
1.0	33%	60%
1.5	67%	82%
2.0	90%	94%
2.5	98%	98%

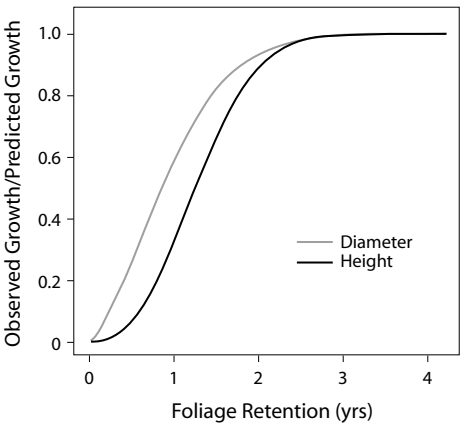

Figure 1. Observed growth/predicted growth on foliage retention for diameter growth (black line) and height growth (grey line).

Table 3. Summary of percent of healthy stand basal area and volume growth from ORGANON simulations after applying modifier equations [1] and [2] over the six 5-year growth cycles by foliage retention.

	Stand age since planting during growth period (years)					
FOLRET	14-19	19-24	24-29	29-35	35-39	39-44
Stand basal area growth						
1.0	28%	28%	29%	30%	31%	31%
1.5	63%	64%	66%	68%	70%	71%
2.0	88%	89%	90%	91%	91%	92%
2.5	98%	98%	98%	98%	98%	99%
Stand volume growth						
1.0	41%	38%	37%	37%	37%	37%
1.5	71%	69%	68%	69%	70%	70%
2.0	90%	90%	90%	90%	90%	91%

(Maguire et al. 2002a,b; Mainwaring et al. 2005a,b). Moreover, diameter growth was demonstrated to be more sensitive to SNC than height growth. Maguire et al. (2002a) estimated basal area, height, and volume growth of 10-30 yr old heavily infected plantations (foliage retention = 1.3 yrs) to be 52, 75, and 51% of healthy stand growth, respectively. Using [2], a FOLRET of 1.3 produces an HMOD of 0.75, identical to the value reported by Maguire et al. (2002a). Likewise the basal area and volume growth losses were similar to those produced by [1] and [2]. Plot basal area increment in severely infected (FOLRET=1.0) older stands (30-60 years old) was estimated to be 35 to 40% and volume increment was 58 to 63% of healthy stand growth (calculated from Mainwaring et al. 2005a; Mainwaring et al. 2005b). While these basal area growth losses were comparable to that implied by the diameter growth modifier (5 to 10% greater than those reported in Table 3), the volume growth percentages were higher (~20%) than those reported in this study.

ORGANON simulations suggested that percent of healthy basal area growth gradually increased over stand age but percent of healthy volume growth may increase or decrease. These results are not unexpected. The application of a constant modifier in ORGANON (or similar individual tree growth model) either to reduce (e.g., SNC modifier) or boost (e.g., genetic gain modifiers) growth would diminish over multiple growth cycles. The SNC modifier results in a stand with smaller basal area and basal area in larger trees than in a healthy stand at the start of the next growth cycle. Since these are key variables in the diameter growth equation (Hann et al. 2006) potential diameter growth during the next cycle would be greater than in a healthy stand. The longest period of observation on the available plots was six years. Since ORGANON uses a five-year time step, data were not available to test whether this multiple growth cycles effect occurs in or is simply an artifact of the model architecture. However, no bias was detected across stand age suggesting, that diameter and height growth impact is constant for up to 60 years. It is also reasonable to assume that since SNC does reduce diameter and height growth, competition does not increase as quickly on these stands as it would in uninfected, healthy stands.

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