A Strategy for Monitoring Swiss Needle Cast and Assessing its Growth Impact in Douglas-fir Plantations of Coastal Oregon

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Abstract.—Many Douglas-fir plantations along the north coast of Oregon are exhibiting severe symptoms of Swiss needle cast disease (SNC). These symptoms include premature loss of foliage, abundant fungal pseudothecia on needles, yellowing of foliage, and apparent reduction in diameter and height growth. The development of the disease and its impacts on growth are currently being monitored at three different levels: (1) annual aerial surveys to determine extent of SNC symptoms; (2) plantation surveys to assess the extent of SNC damage and to ground-truth aerial surveys; and (3) intensively measured plots to monitor SNC development and growth impacts.

THE PROBLEM

Over 2 million hectares (5 millions acres) of commercial timberland in the Pacific Northwest are occupied by young stands (≤40 years) of Douglas-fir (Oswald *et al.* 1986). The growth, yield, and overall health of these plantations is tremendously important to the people of Oregon and Washington. A wide variety of silvicultural treatments has been applied operationally and experimentally in these stands, and yield forecasting tools for intensively managed plantations of Douglas-fir are constantly in a state of further development and improvement. Although insect and disease damage can wreak havoc on predictions of future yield, coastal Douglas-fir has been relatively free of extensive problems that complicate management (except for root diseases in some areas). Swiss needle cast (SNC), a foliage disease that affects only Douglas-fir, has emerged recently as a significant problem for Douglas-fir planted along the north coast of Oregon (Kanaskie *et al.* 1996). Many plantations of young Douglas-fir within this region began exhibiting severe symptoms of SNC approximately 6-10 years ago. These symptoms included premature loss of foliage, abundant fungal pseudothecia on needles, yellowing of foliage, smaller average size of needles, and apparent reduction in diameter and height growth. Although a range in symptom severity and assumed disease intensity was observed, the magnitude of growth loss associated with various foliar symptoms was largely unknown. Growth losses are quite apparent upon casual observation in severely damaged plantations, but may be more subtle in plantations with fewer visual symptoms. The problem may be particularly critical in young plantations (10-30 years) due to limited silvicultural options and the economic costs of starting over with a new plantation. Without the option of harvesting commercial size classes, replacement of pre-commercial, declining, SNC-impacted stands with productive stands consisting of resistant varieties or species would constitute a tremendous loss of investment; yet, without corrective action, significant yield losses will continue to accrue.

The overall effort to assess and monitor Douglas-fir stand condition with respect to SNC consists of three interactive projects: an aerial survey, a ground-based plantation survey, and a growth impact study. These projects, as well as others that will not be discussed here, are conducted under the auspices of the Swiss Needle Cast Cooperative (SNCC) at Oregon State University. This research cooperative was initiated in January 1997 at the prompting of several key industry and agency foresters. In 1996, prior to formation of the SNCC, the Oregon Department of Forestry (ODF) initiated an aerial survey to assess the extent of apparent damage from SNC. This effort has continued on an annual basis in coordination with SNCC-sponsored projects. The objectives of the aerial survey were:

1. To identify and map areas of Douglas-fir forest with obvious symptoms of SNC in the Oregon Coast Range; and
2. To monitor change over time in the amount of forest with visible symptoms of the disease.

The ODF also launched a ground-based survey of SNC severity in Douglas-fir plantations to meet four additional objectives:

1. To ground-truth areas mapped by aerial survey;
2. To describe the extent and severity of damage from SNC in randomly selected 10- to 30-year-old Douglas-fir plantations in the Coast Range of western Oregon;

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3. To identify tree attributes that were best able to discriminate among different levels of SNC intensity; and
4. To provide SNC assessment of plantations analyzed for growth impacts.

The growth impact study was funded directly by the SNC to determine the magnitude of both stand-level and regionwide growth losses. The specific objectives included:

1. To estimate the current losses of stem volume growth across the range of SNC severity;
2. To screen various tree and foliage attributes that may be identifiable as indices of severity and corresponding growth losses; and
3. To develop quantitative links among attributes that can be monitored in aerial surveys, low-intensity ground surveys, and intensively measured growth plots.

PAST WORK

Damage from SNC has frequently been observed on Douglas-fir grown outside of its natural range, first in Europe in the early part of the century, and more recently in Christmas tree plantations throughout North America and in timber stands in New Zealand (Hansen *et al.* 1996). Although some European research was motivated by concern about growth losses, relatively little work has been accomplished to date on estimation of growth impact, especially within the natural range of Douglas-fir and across a gradient in disease severity. Height growth of SNC-affected Douglas-fir in the Pacific Northwest has been estimated at 50-70 percent of normal height growth, corresponding to as much as a 30 percent volume growth loss (USDA FS 1983, as cited in Russell *et al.* 1986). In New Zealand, basal area growth of stands experiencing Douglas-fir decline is as low as 50 percent of the basal area growth of stands exhibiting no decline (Beekhuis 1978). Forest scientists in New Zealand have pointed out that, although the Swiss needle cast fungus (*Phaeocryptopus gaeumannii*) is associated with declining Douglas-fir stands, it is uncertain whether this pathogen is the cause of the decline or an aftereffect of other causes (see discussion of decline in growth, Forest Research Institute 1978).

Ultimately any height and basal area growth losses must be translated into volume growth losses to facilitate economic analysis and to choose among management options. Studies of volume growth losses from SNC have apparently not been conducted, or at least not published, for the Pacific Northwest; yet this information is essential to providing an economic basis by which to judge the need for, or economic benefits of, an aggressive control or rehabilitation program. Likewise, an analysis of growth responses to SNC can establish a biological basis by which to assess silvicultural options. In New Zealand, thinning did not reduce *Phaeocryptopus* infection or increase needle retention, despite the healthier appearance of thinned stands (Hood and Sandberg 1979). In northwestern Oregon, there is concern that thinning may exacerbate the negative growth effects of SNC, perhaps through a thinning shock effect (sensu Harrington and Reukema 1983)

METHODOLOGY

Aerial Survey

The Oregon Department of Forestry and the USDA Forest Service Region 6 Forest Health Protection program conducted cooperative aerial surveys of SNC damage in coastal Oregon in April and May of 1996, 1997, and 1998. Discoloration caused by SNC is most visible from late winter until shortly after bud break in spring; peak discoloration occurs in late April and early May. Flights were made at 450-600 m (1,500 to 2,000 feet) above the terrain, following north-south lines separated by 3.2 km (2 miles). The flight lines extended from the Columbia River in the north to a latitude even with Bandon in the south, and extended up to 38 km (24 miles) inland. The eastern and southern limits of the survey were dictated by the disappearance of SNC-induced discoloration.

Areas with obvious discoloration were drawn onto 1:100,000 scale topographic maps and classified as either lightly or heavily discolored and later transferred onto the ODF GIS. The resulting GIS layer portrayed the geographic extent of SNC and provided an estimate of the area with apparently severe SNC.

Plantation Surveys

Target Population

The target population for the plantation survey and the growth impact study was defined by stand condition and geographical location (Kanaskie *et al.* 1996, Oregon Department of Forestry 1998). Specifically, the sample was drawn from the population of Douglas-fir plantations between 10 and 30 years of total age and located within 29 km (18 miles) of the coast, north of Newport and south of Astoria.

A list of plantations meeting these criteria was assembled, and plantations were selected from this list with probability proportional to size (area). The target population included 4,504 plantations covering 75,929 ha (187,545 acres). The sample included 77 plantations covering 2,783 ha (6,873 acres). Each plantation was assessed for SNC intensity, and all landowners were contacted for any information available on management history of the unit.

The plantation surveys provided verification that aerially mapped polygons were Douglas-fir stands with severe SNC symptoms, facilitating refinement of GIS-generated maps depicting stands with obvious SNC damage. The field procedure involved assigning each plantation a walk-through rating for degree of discoloration and an overall rating based on color, foliage retention, and apparent growth reduction. In addition, a five-point transect was established in a representative area of the plantation. Sample points were separated by 15 m (50 ft), and the two dominant or codominant Douglas-fir trees nearest the point but on opposite sides of the transect line were selected as sample trees. Each tree was assessed for the following indicators of SNC damage: presence or absence of fruiting bodies, recent height growth reductions, degree of yellowing, and needle retention. Degree of yellowing and needle retention were estimated for the fifth whorl from the top as well as for each third of the tree live crown. In the 1998 plantation surveys, three variables used in the USDA Forest Health Monitoring program were also included: crown density, foliage transparency, and crown dieback.

Growth Impact Study

Field and Lab Work

Phase 1.—The growth impact study complemented the ODF aerial and plantation surveys by collecting additional information on fixed-area plots in 70 of the 77 plantations selected for survey. The third sample point on each plantation survey transect was flagged, marked with a PVC stake, and subsequently used as the center of a 0.02-ha (0.05-ac) plot (10.6-m or 26.3-ft radius) on which all trees were measured for dbh. The four Douglas-fir trees with the largest dbh and the two with the smallest dbh were felled, as were the two Douglas-fir closest to the midrange of the diameter distribution. Each felled tree, except for of the two smallest Douglas-fir, was measured for total height, height to crown base, and cumulative height growth (height of each bud scale scar, at or just above each annual branch whorl). Two stem disks were removed from each of the felled Douglas-fir trees, one at breast height and one at crown base. These disks were labeled and stored in a plastic bag for transport to the lab. Finally, a sample branch was collected from the fourth largest Douglas-fir tree on each plot. This sample branch was identified as the southernmost branch in the fifth whorl from the top of tree. After the diameter of the branch was measured, it was cut from the tree flush with the stem, and one of the secondary branches in the third whorl down from the primary branch tip was removed, placed in a plastic bag, stored on ice up to 4 days, and then frozen in the lab. The remaining portions of the branch were placed in a plastic bag and transported to the lab for drying and weighing.

Breast height stem disks were brought to the lab and measured for annual radial growth (nearest 0.5 mm) on the two radii forming the long axis of the disk and on the two radii forming the axis perpendicular to the longest. Four sapwood radii (nearest 0.5 mm) were recorded on the same two axes. Secondary branches were kept frozen until they could be analyzed for specific leaf area by measuring projected area (nearest 0.001 cm^2) and dry weight (nearest 0.0001 g) of 50- needle subsamples of 1-, 2-, and 3-yr-old needles separately. Pseudothecia of *Phaeocryptopus gaeumannii* were also counted on 10 needles from each 50-needle subsample. Pseudothecia counts represented the number of occluded stomates out of the centermost 100 in the second row of stomates to the right of the needle midrib, with the petiole pointing downward.

The remaining branch samples were clipped by age class, dried, and separated into foliage and wood+bark. The samples were then re-dried for at least 24 hours and weighed (nearest 0.01 g).

Phase 2.—Immediately after the Phase 1 field work, 57 plots were measured more intensively to augment the data on tree and plot growth. During the summer of 1997, this subset of plots was revisited and all live Douglas-fir trees were measured for height to crown base and total height (ignoring the 1997 leader growth). Height growth trends of the two smallest trees felled in Phase 1 were reconstructed from branch whorls and bud scale scars as in Phase 1. An increment core was then removed from each standing Douglas-fir tree to estimate past annual radial growth. The side of the tree from which this core was extracted was defined by an imaginary line from plot center to the center of the tree at breast height. Increment cores were transported to the laboratory in paper drinking straws and measured for annual radial growth and sapwood radius (nearest 0.5 mm).

Phase 3.—A network of permanent plots was established in April 1998 at the locations previously sampled in Phases 1 and 2. These plots will be monitored continuously for height, diameter, and crown length of all conifers, and for various symptoms and indicators of SNC severity. The square plots are 0.08 ha (0.2 ac) in size and are centered on the fifth point of the ODF transect established in spring 1997 (Phase 1 plots were centered on the third point). This strategy provides several advantages over selection of entirely new locations: (1) some previous information on the status of Swiss needle cast at each plot center was available; (2) a significant cost saving was gained by not having to locate, map, and document a new set of plot locations; and (3) the sampled locations represented a standard list sample (pps sample) from the target population of Douglas-fir plantations, allowing future inferences to be extended to the population with statistical validity.

On each measurement plot, all trees were tagged at breast height and measured for total height, height to crown base, and dbh. Trees are scheduled for remeasurement every 2 years. SNC intensity was described for the 10 largest trees on each plot, considering both needle retention and chlorosis. A subset of these trees was cored to estimate sapwood area at breast height. SNC attributes will be collected on an annual basis.

Data Analysis

Patterns in past basal area and height growth were reconstructed from the annual height increments and stem section radial growth measurements. The tree and sample branch measurements from the plantation surveys and growth impact study allowed computation of many possible indices of SNC intensity. In an initial effort to gain some biological insight into the relationships among the various indices, a principal components analysis (Johnson and Wichern 1982) was performed.

Estimates of key stand-level variables for different annual growth periods required at least two assumptions: (1) no trees died from suppression mortality or were removed by thinning since the year in which the stands reached breast height; and (2) basal area growth of each species group was proportional to relative basal area growth of the sectioned and cored Douglas-fir trees on that plot. In addition to stand density measures for the total stand and for species groups, tree position variables were computed for each annual growth period, specifically expressed as the plot basal area in trees larger than the subject tree.

Height growth and basal area growth, the two major components of volume growth, were analyzed separately since it was evident early in the study that the onset of growth reductions in these two components were asynchronous and their relative magnitudes were different. The four largest trees on each plot were assumed to represent the site tree component of the stands. Site index was estimated yearly for each site tree by solving Bruce's (1981) equations iteratively for each height-age pair. An analysis of top height growth of the plots was implemented by computing potential predictor variables and subjecting the data to an all-subsets regression analysis with the logarithm of annual height growth as the response variable. In the final model, the "effect" of SNC was assessed by fitting the growth model on an annual basis, computing the percent of expected growth for extreme and moderate values of the included SNC index, and graphing this percent of expected growth from 1978 through 1996. In this approach, growth of plantations with the least severe SNC ratings serve as the expected growth rate, after correcting for the effects of other covariates in the regression model (that is, holding all other variables such as site quality and initial size constant).

Basal area growth data from all Douglas-fir measure trees, whether estimated from disks or cores, were combined in an all-subsets regression analyses to screen for the potentially most powerful predictor variables. The final model was fitted on a year-by-year basis, and the "effect" of SNC was depicted as the growth of trees across the range in the SNC index relative to those trees with the lowest apparent SNC intensity measured by the same SNC index.

CURRENT ASSESSMENT OF SNC

Aerial Survey

The aerial survey covered about 890,000 ha (2.2 million acres) of forest each year. The amount of area with obvious Swiss needle cast symptoms was 52,600 ha (130,000 ac) in 1996, 160,000 ha (395,000 ac) in 1997, and 70,000 ha (173,000 ac) in 1998 (Kanaskie and McWilliams 1998). Approximately 80 percent of the area with symptoms occurred north of Florence and the remaining portion occurred south of Florence. After 3 years of surveys, there is little doubt that Swiss needle cast symptoms continue to intensify. It is also clear that even though the disease occurs throughout the Coast Range, most areas with symptoms that can be detected from the air are within about 18 miles of the coast (fig. 1).

These estimates must be considered conservative because they represent only those areas with obvious symptoms. The aerial survey results do not depict the total extent and distribution of the disease, but only those areas where disease symptoms have developed enough to be visible from the air. Ground surveys indicated that Swiss needle cast occurred in all Douglas-fir stands throughout the survey area, but in many places symptoms were not developed enough to be detected by air. Factors other than the presence of the pathogen strongly affect disease development, and these factors remain poorly understood.

Plantation Surveys

Ground surveys revealed that many Douglas-fir stands within the survey area have SNC but were not mapped because they were not discolored enough to be visible from the air. Conversely, some mapped stands were found to be composed of predominantly western hemlock and were deleted from the GIS SNC layer. The average foliage retention for the target population of young plantations was 2.01 years. However, 67 percent of the area was estimated to have a foliage retention of 2 years or less, 22 percent to have foliage retention of 1.5 years or less, and 12 percent to have foliage retention of 1 year or less (fig. 2). Plots represented a range in stand density and tree size that is typical of Douglas-fir plantations in the Oregon Coast Range (table 1).

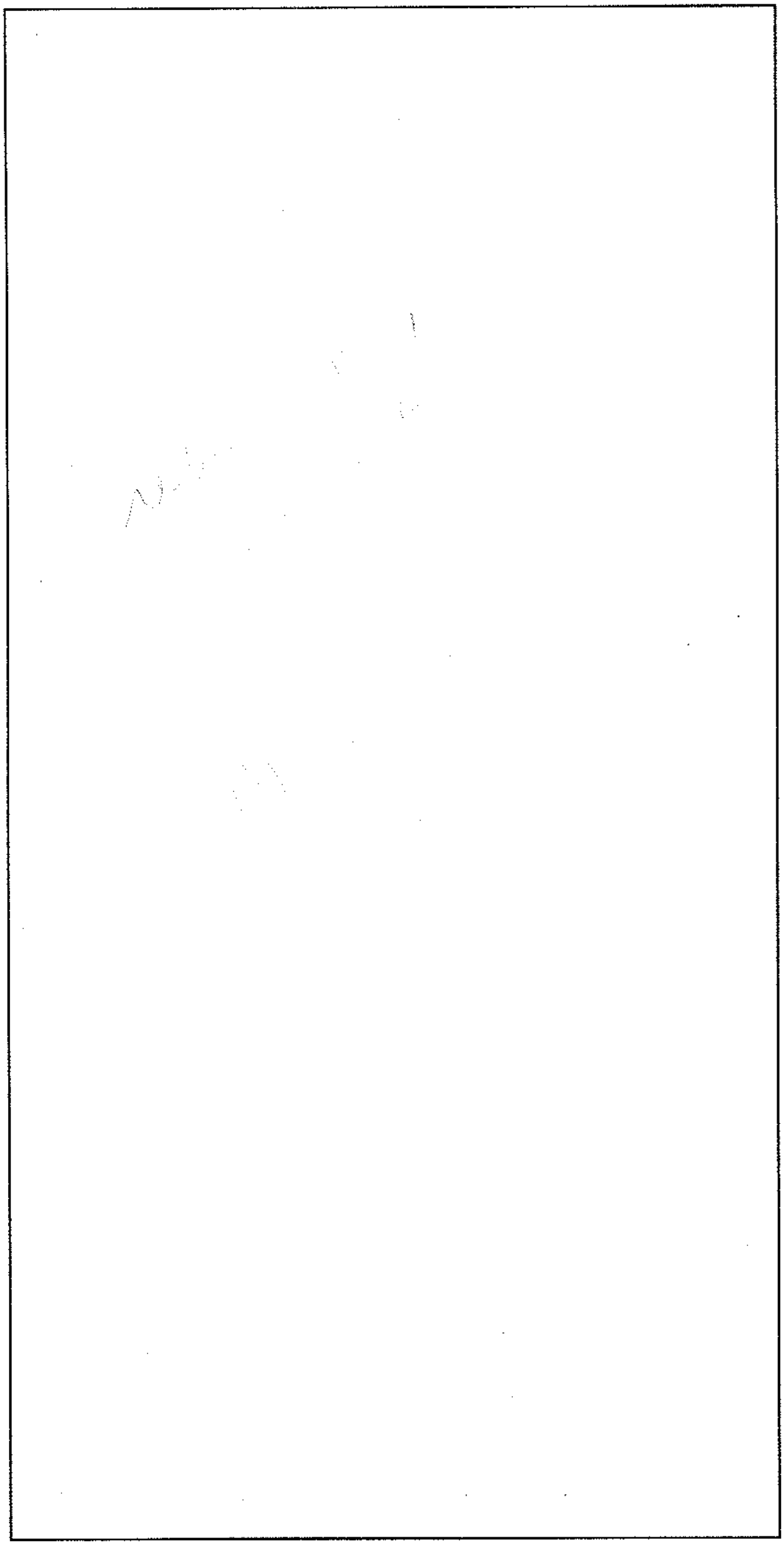

Figure 1.—*Areas of Douglas-fir forest in Oregon Coast Range with SNC symptoms detected during an aerial survey in April-May 1998.*

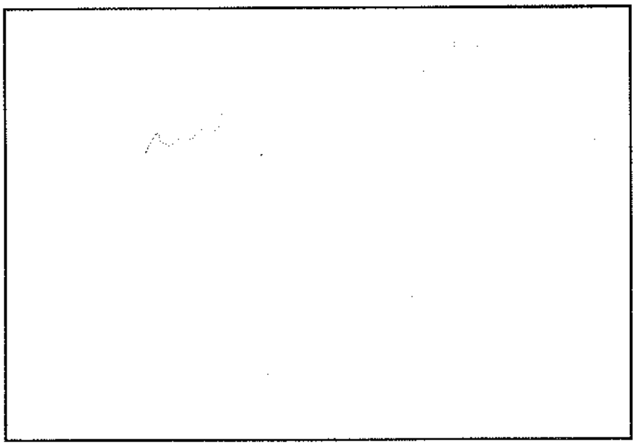

Figure 2.—*Estimated distribution of target population plantation area by SNC severity (indicated by average foliage retention in years).*

Table 1.—*Attributes of the 70 plots sampled in Phase 1 of the Growth Impact Study*

Attribute	Min	Mean	(sd)	Max
Total age	8	17	5.4	30
SI_{50}	23.40	39.25	4.62	47.20
TPH	247	1,627	2,223	17,142
TPD_{DF}	148	688	347	1,927
DQ	3.63	15.27	6.86	33.89
DQ_{DF}	5.52	17.81	6.63	3.56
BA	2.84	19.25	10.96	54.97
BA_{DF}	2.03	15.77	9.02	37.24
$BA_{CONIFERS}$	2.84	18.16	10.40	54.97
BA_{HD}	0	1.09	2.63	15.31
SDI	91	468	255	1,430
$SDI_{CONIFERS}$	91	427	235	1,430
RD	1.04	4.99	2.74	15.48
$RD_{CONIFERS}$	1.04	4.52	2.50	15.48

Growth Impact Study

Indices of SNC Infection Intensity

Principal components analysis of the SNC indices suggested that the data contained four or five functionally similar groups of variables. These groups include: (1) crown color/foliage retention; (2) fungal disruption of surviving foliage as indicated by fruiting body abundance; (3) foliage biomass age distribution / needle size; and (4) needle structure / foliage biomass amount. It is conceivable that foliage retention variables indicate effects of foliage loss in the growth analysis, while variables representing fungal density in foliage may signal direct physiological disruption of needle gas exchange. In other words, the various SNC indices should not necessarily be considered functionally equivalent or mutually exclusive.

Top Height Growth

The preliminary model for top height growth was selected to illustrate the relationship between degree of foliage retention and the trend in top height increment:

$$\ln(\Delta th) = c_0 + c_1 \bullet X_1 + c_2 \bullet \ln(retx) \qquad (1)$$

where $\ln(\bullet)$ = natural logarithm
Δth = annual top height growth (m/yr)
retx = average years of foliage retention
X_1 = Bruce's (1981) predicted top height growth
and c_0, c_1, and c_2 are regression parameters estimated from the data for each year of backdated height growth

In any given year this model accounted for 14 to 63 percent of the variation in top height growth. A significant correlation between foliage retention and top height growth emerged in 1992. The plantations implied to be most severely impacted by SNC according to impacts on foliage retention are growing at only 75 percent of the rate observed in "unaffected" plantations in 1996 (25 percent growth reduction; fig. 3). The top height growth trends prior to 1992 appear unrelated to the 1997 SNC ratings. Since 1992, however, a sustained reduction seems to have occurred in plantations rated with high SNC intensity, but this reduction was significant only in 1992 and 1996 (fig. 3). Given the average foliage retention of 2.01 years for the population, regionwide top height growth for these young plantations was approximately 90 percent of expected growth.

Basal Area Growth

The following preliminary model for tree basal area growth was based on an initial analysis of the Phase 1 data:

$$\ln(\Delta ba) = f_0 + f_1 \bullet \ln(idob) + f_2 \bullet BA + f_3 \bullet BAL + f_4 \bullet SI + f_5 \bullet retx \qquad (2)$$

where $\ln(\bullet)$ = natural logarithm
Δba = annual basal area growth of individual tree (cm^2/yr)
idob = tree DBH at start of growth period (cm)
BA = plot basal area (m^2/ha)

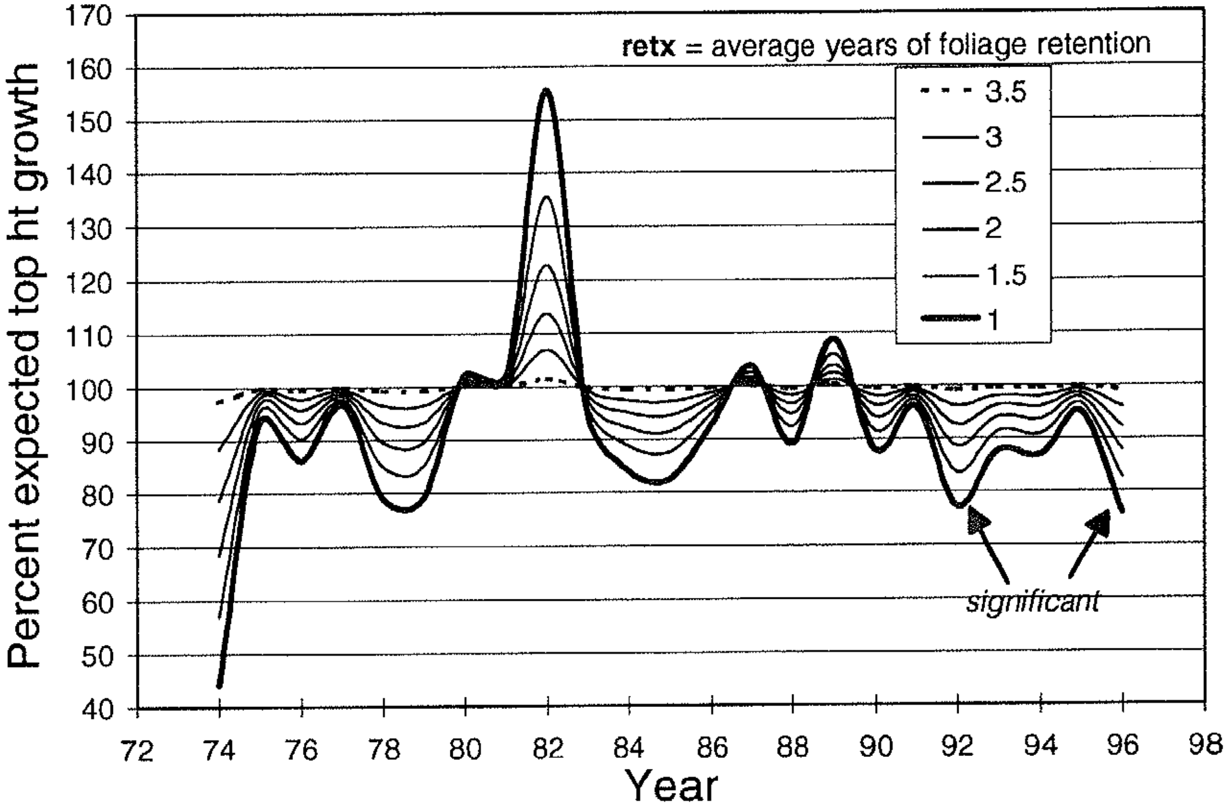

Figure 3.—*Trend in top height growth across the range in SNC severity (indicated by average foliage retention in years).*

BAL	=	basal area in trees with larger dbh than the subject tree (m^2/ha)
SI	=	Bruce's (1981) site index (m at 50 years)
retx	=	average years of foliage retention

and

f_0, f_1, f_2, f_3, f_4, and f_5 are regression parameters estimated from the data for each year

In any given year this model accounted for 53 to 97 percent of the variation in tree basal area growth. As expected, basal area growth declined with increasing BAL, increasing BA, and decreasing foliage retention (negative f_2 and f_3 and positive f_5). Plantations with a lower average age of foliage in 1997 started to slow in basal area growth around 1990 (fig. 4). In 1996, plantations with only a single age class of needles (retx=1) grew 65 percent of the growth expected for similar plantations with "normal" foliage retention (retx= 3-1/2 years). The mean foliage retention of 2.01 years implies a population basal area growth that is approximately 80 percent of the growth expected for young Douglas-fir plantations without SNC damage.

Regional Growth Losses

As mentioned above, the list sampling of the plantations meeting target population criteria yielded an average foliage retention of 2.01 years for the 75,929 ha (187,545 acres). Taking the associated values of 90 percent and 80 percent for the percentages of expected height and basal area growth, respectively, the corresponding volume growth in 1996 was approximately 72 percent of expected growth. This estimate suggests an average 28 percent growth loss in 1996 for the entire population. At the low extreme, plantations retaining only a single age class of needles were estimated to have experienced a 51 percent volume growth loss in 1996.

Most of these young plantations are not yet growing merchantable volume (for example, board feet). If expected volume growth (periodic annual increment) in slightly older stands averaged approximately 14 m^3/ha/yr (1,000 MBF/ac/yr), volume growth losses of 28 percent would translate into an annual growth loss of approximately 3.9 m^3/ha/yr (280 BF/ac). Expanding to the sampled population, growth loss in 1996 alone under this scenario would have been equivalent to approximately 297,000 m^3 (52.5 MMBF). It is important to recognize

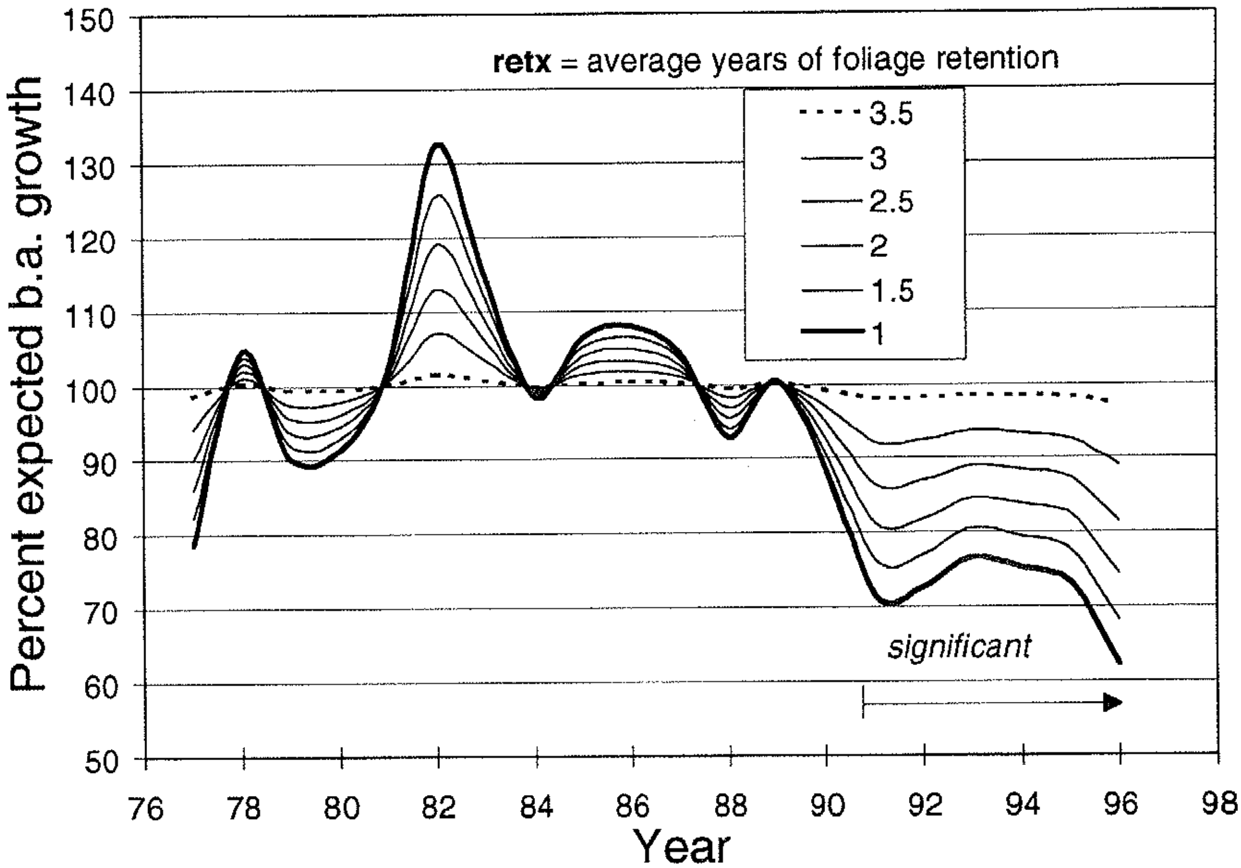

Figure 4.—*Trend in tree basal area growth across the range in SNC severity (indicated by average foliage retention in years).*

also that there is a large area of stands younger than 10 years and older than 30 years that are also affected by SNC and show growth reduction; hence, this is a conservative estimate of the regionwide growth loss from SNC damage.

SPECULATION ON DRIVING MECHANISMS

Several hypotheses have been suggested to explain why this normally benign pathogen is causing severe damage to Douglas-fir in its native range. Certainly the presence of the pathogen alone is not sufficient because the pathogen occurs on Douglas-fir everywhere in the Coast Range. The introduction or genesis of a highly virulent strain of the pathogen is a possible explanation, but preliminary research at Oregon State University (Everett Hansen, Jeff Stone, and Lori Winton) suggests that this is unlikely.

The more likely hypothesis is that our management practices, in combination with a climate that is conducive to the disease, have shifted the ecological balance in favor of the pathogen. Much of the Sitka spruce and western hemlock zones has been planted to dense stands of Douglas-fir. Many of these plantations were established from seed collected farther inland and at higher elevations than native coastal stands. The combination of a climate favorable for the disease, increase in the amount and density of Douglas-fir in coastal areas, and slightly off-site seed sources may have set the stage for rapid and efficient spread of the fungus. As a result, the pathogen population may have increased to levels that can overwhelm naturally occurring mechanisms of disease tolerance.

When Douglas-fir and the SNC pathogen are established beyond their natural geographic range, SNC consistently becomes severe and mitigation of damage is difficult and slow. Apparently a delicate balance exists between the tree, the pathogen, and the environment. Understanding the effects of various factors on this balance is critical for predicting long-term effects on forests and for formulating practical mitigation measures.

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LITERATURE CITED

Beekhuis, J. 1978. Growth decline in Douglas-fir. In: James, R.N.; Bunn, E.H., eds. A review of Douglas-fir in New Zealand. FRI Symposium No. 15. Rotorua, New Zealand: Forest Research Institute: 119-125.

Bruce, D. 1981. Consistent height-growth and growth-rate estimates for remeasured plots. Forest Science. 27: 711-725.

Forest Research Institute. 1978. Discussion on decline in growth. In: James, R.N.; Bunn, E.H., eds. A review of Douglas-fir in New Zealand. FRI Symposium No. 15. Rotorua, New Zealand: Forest Research Institute: 23-36.

Hansen, E.; Winton, L.; Cappitano, B. 1996. Swiss needle cast problem analysis: Why here? Why now? Unpublished report on file at Oregon Department of Forestry, Salem, OR.

Harrington, C.A.; Reukema, D.L. 1983. Initial shock and long-term stand development following thinning in a Douglas-fir plantation. Forest Science. 29: 33-46.

Hood, I.A.; Sandberg, C.J. 1979. Changes within tree crowns following thinning of young Douglas fir infected by Phaeocryptopus gaeumannii. New Zealand Journal of Forest Science. 9: 177-84.

Johnson, R.A.; Wichern, D.W. 1982. Applied multivariate statistical analysis. Englewood Cliffs, NJ: Prentice-Hall. 594 p.

Kanaskie, A.; McWilliams, M. 1998. Results of the 1998 Swiss needle cast aerial survey. Unpublished report. Salem, OR: Oregon Department of Forestry.

Kanaskie, A.M.; McWilliams, M.; Overhulser, D.; Kline, L. 1996. Aerial survey to monitor Swiss needle cast in coastal Oregon. Research proposal. Salem, OR: Oregon Department of Forestry.

Oregon Department of Forestry. 1998. Swiss needle cast of Douglas-fir in coastal western Oregon. Forest Health Note, March 1998. Salem, OR: Oregon Department of Forestry, Forest Health Program.

Oswald, D.D.; Hegyi, F.; Becker, A. 1986. The current status of coast Douglas-fir timber resources in Oregon, Washington, and British Columbia. Pp. 26-31 In: Oliver, C.D.; Hanley, D.P.; Johnson, J.A., eds. Douglas-fir: stand management for the future. Institute of Forest Resources Contribution No. 55. Seattle, WA: College of Forest Resources, University of Washington.

Russell, K.; Johnsey, R.; Edmonds, R. 1986. Disease and insect management for Douglas-fir. In: Oliver, C.D.; Hanley, D.P.; Johnson, J.A., eds. Douglas-fir: stand management for the future. Institute of Forest Resources Contribution No. 55. Seattle, WA: College of Forest Resources, University of Washington: 189-207.

USDA Forest Service. 1983. Swiss needle cast and rhabdocline needle cast. Forest Disease Management Notes. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region. 53 p.