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Swiss Needle Cast

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Swiss needle cast (SNC) is a foliage disease of Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) caused by the fungus *Phaeocryptopus gaeumannii* (T. Rhode) Petrak (Figure 1). *P. gaeumannii* is specific to Douglas-fir and completes its life cycle on live foliage. SNC causes premature needle shed, resulting in sparse tree crowns and reduced growth, but rarely causes tree mortality. Although the fungus that causes this disease is native to the historic range of Douglas-fir in western North America, the disease was first documented in Douglas-fir plantations in Switzerland in 1925, and the common name has persisted. SNC was previously considered an unimportant forest disease in the Pacific Northwest (PNW), except in Christmas tree plantations. However, since the 1990s, there has been an epidemic of SNC affecting hundreds of thousands of acres of coastal Douglas-fir forests in Oregon, Washington and British Columbia. This constitutes one of the largest foliage-disease epidemics of conifers in North America. SNC is also a localized problem in many inland areas of the west, especially in Montana, Idaho, British Columbia, Washington and Oregon.

Background and Distribution

Since the 1920s, when SNC became problematic in European plantations, the disease has spread to many other

Figure 1. Douglas-fir needles infected by the Swiss needle cast fungus, Phaeocryptopus gaeumannii.

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parts of the world where Douglas-fir is commercially grown, including central and eastern North America, Chile, Australia and New Zealand. SNC symptoms in young plantations were reported in Washington State around 1980, and serious concern about the disease had developed in western Oregon and Washington by 1990. Prior to this time, SNC problems were limited to localized forest plantations in the PNW, Christmas tree plantations, and areas outside the native range of Douglas-fir, where temperature and moisture conditions were particularly suitable for the fungus. *P. gaeumannii* was first collected in the PNW inadvertently from Douglas-fir trees heavily infected with *Rhabdocline* sp. near Roseburg, OR around 1915. The earliest documented collection of *P. gaeumannii* near the area of the current epidemic dates to 1938, at which time the fungus was not contributing to premature needle shed. Dendrochronology work in Oregon's coastal forests detected the first major growth-decline signatures of SNC around 1984.

The fungus that causes SNC, *P. gaeumannii*, is ubiquitous throughout the native range of Douglas-fir (Figure 2)

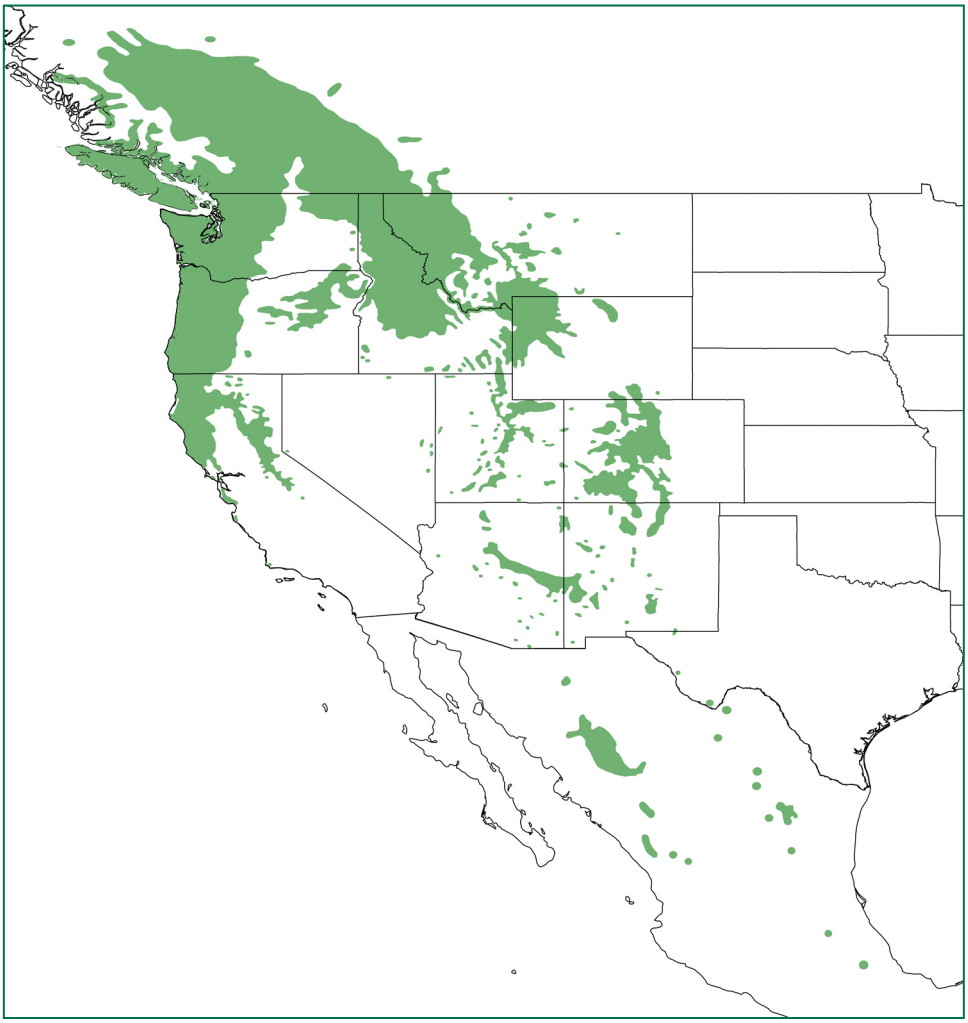


Figure 2. The distribution of Douglas-fir in North America (Little 1971).

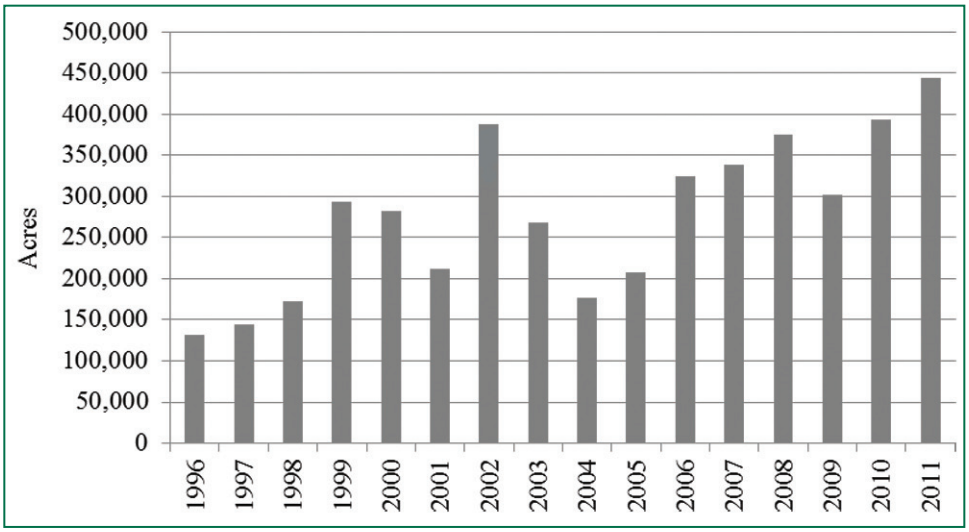


Figure 3. Acres of Douglas-fir forest with Swiss needle cast symptoms detected in western Oregon by annual aerial surveys (1996-2011). Figure from Oregon Department of Forestry.

and can be found on older needles of nearly all Douglas-fir trees. Under most conditions, the fungus does not contribute to premature needle shed or growth loss. Annual aerial surveys, covering approximately 3 million acres of the Oregon Coast Range (from Bandon to Astoria), estimate that ≥300,000 acres have been affected by SNC each year since 2006, a dramatic increase since aerial surveys for SNC began in 1996 (Figures 3 and 4). This survey is considered an underestimate of disease distribution, because only moderate

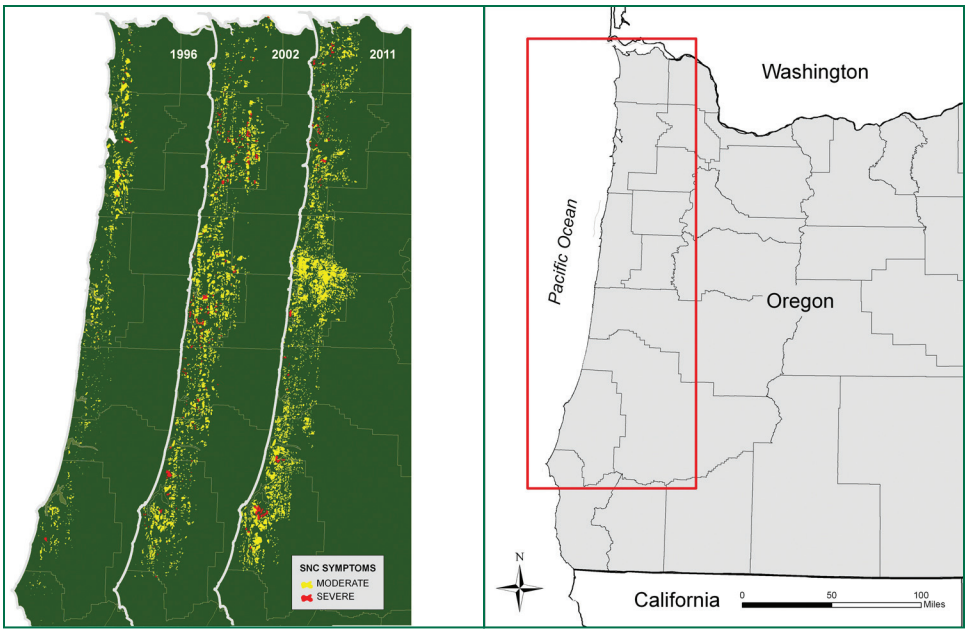


Figure 4. The distribution of Swiss needle cast symptoms detected in western Oregon by annual aerial surveys (1996, 2002 and 2011). Severe symptoms are mapped in red and moderate symptoms are mapped in yellow. The locator map shows the general survey area. Maps by the Oregon Department of Forestry

and severe disease symptoms are visible from the air, symptom detection can be hindered by weather conditions, disease expression changes over time, and diseased sites in Washington, British Columbia and the Oregon Cascade Range are not included in the annual survey. Conditions in the Cascade Range are considered far less conducive to disease development, but SNC does impact foliage retention and tree growth in some lower elevation Cascade Range forests.

The spatial pattern and total acreage affected by SNC varies by year. SNC is most damaging near the coast, with the majority of symptomatic acreage within 18 miles of the coast and few symptoms observed >30 miles inland. Moderate and severe disease symptoms are correlated with several climatic and topographic variables, including abundant spring and summer leaf wetness from precipitation and fog, mild temperatures in the winter and spring, southern aspects, and low elevation valleys and coastal areas. The climatic factors associated with severe SNC make sense biologically; the fungus requires that needles are wet in the spring when spore dispersal and infection occur, and mild winter temperatures allow the fungus to colonize needles more rapidly.

The early collections of the fungus, the lack of a SNC tree-growth-loss signature prior to the mid-1980s, and the distribution of the fungus throughout the native range of its host all indicate that the fungus is native to western North America and that the epidemic since the 1990s is unprecedented. It is believed that the epidemic is attributable to several factors, particularly the increase in Douglas-fir plantation acreage in coastal areas that were previously dominated by spruce, hemlock and alder and have conditions conducive to disease development.

Biology of *Phaeocryptopus gaeumannii*

Phaeocryptopus gaeumannii is an ascomycete fungus that produces sexual spores (ascospores) in sacs (asci). Ascospores and asci of *P. gaeumannii* are contained within black, spherical fruiting bodies called pseudothecia. Spores are discharged when pseudothecia are mature and environmental conditions are favorable in the spring and early summer.

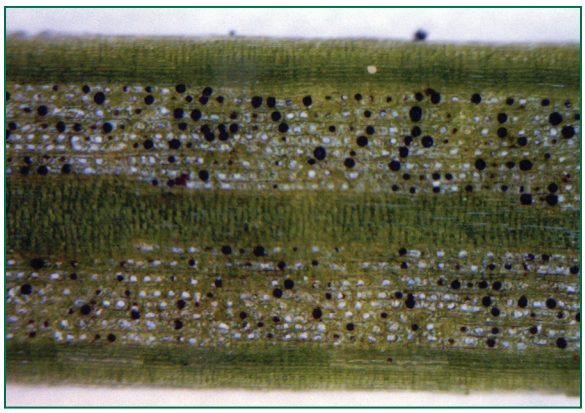


Figure 5. Spherical, black fruiting bodies (pseudothecia) of Phaeocryptopus gaeumannii *occupy stomata on the undersides of heavily infected Douglas-fir needles.*

Life cycle

P. gaeumannnii has a monocyclic lifecycle (one reproductive cycle per year). The pseudothecia of *P. gaeumannii* occupy stomata on the undersides of Douglas-fir needles (Figure 5). The majority of ascospores are released in June and July, coinciding with the emergence and elongation of new foliage.

Newly formed needles are highly susceptible to infection, and little or no infection occurs in older needles. Ascospores are wind and water-splash dispersed, and cause infection when they contact susceptible foliage, germinate, and fungal hyphae enter needles through stomata.

Following infection, fungal hyphae colonize the intercellular space within the needle, and pseudothecia develop in stomatal cavities. Infection by one spore may result in the development of many pseudothecia on a single needle, because the fungus expands within individual needles over time. Under optimum conditions for fungal infection and colonization, immature pseudothecia may be visible on needles within 6 months, but may take ≥4 years under less suitable conditions. Pseudothecia produced on 1-yr-old needles release ten times more ascospores than those produced on 2-yr-old needles. The fungal lifecycle is completed when pseudothecia mature and release spores in the spring and early summer. Relatively more fungal biomass and pseudothecia are present on older needles compared to younger needles. As a higher proportion of stomata on a needle become blocked by pseudothecia, there is increased likelihood that the needle will be shed.

Pseudothecia block gas exchange between the leaf and the external atmosphere, inhibiting the uptake of carbon dioxide for photosynthesis. When the proportion of stomata blocked by pseudothecia surpasses a threshold (~25%), the carbon cost of respiration exceeds the carbon gained through photosynthesis, triggering needle abscission. The reduction in carbon dioxide intake may also lead to the accumulation of damaging photo-oxidative chemicals within needles, causing more pronounced defoliation in parts of the crown with higher light exposure. In contrast, diseased trees in inland environments tend to have more pronounced defoliation in the lower crown, where the microclimate favors infection.

Figure 6. A comparison of cross-sections cut from healthy (bottom) and diseased (top) Douglas-fir trees of approx-imately the same age from different locations, demonstrating that growth loss can be severe and that wood density, earlywood to latewood ratio, and quality can be affected by Swiss needle cast.

Signs and Symptoms of Infection

SNC symptoms include a yellow to brown discoloration of the needles and tree crown, and decreased needle retention, resulting in sparse crowns and reduced tree-diameter and height growth (Figures 6, 7, 8). Identification of *P. gaeumannii* requires ≥10X magnification with a hand lens, as other foliar fungi appear superficially similar without sufficient magnification (Table 1). Pseudothecia of *P. gaeumannii* are

Table 1. Comparison of Phaeocryptopus gaeumannii *and other common damage agents of Douglas-fir. Photos: Rhabdocline (right) by J. Schwandt, needle midge by S. Tunnock and USDA FS Archive, and spruce gall adelgid by W. Cranshaw and USDA FS Archive (from www.forestryimages.org).*

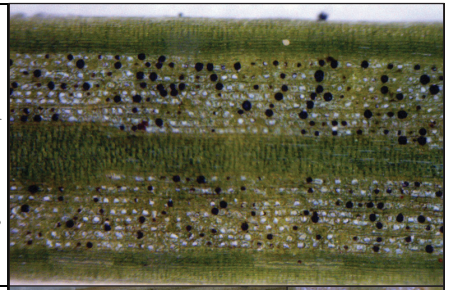
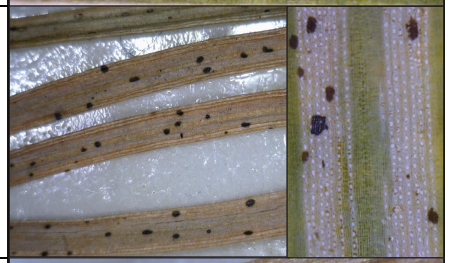
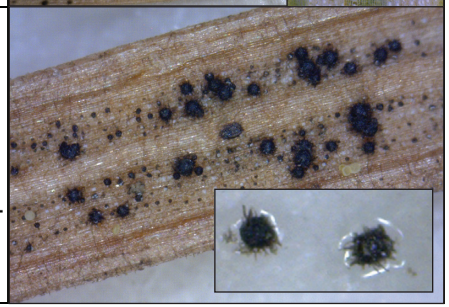
Swiss needle cast *Phaeocryptopus gaeumannii*	Pseudothecia are brown to black, are always centered on stomata, have smooth margins, and are not significantly larger than stomata; larger pseudothecia are spherical, and begin to swell outward from stomata; fruiting bodies are present on needles (≥1 yrs old) year-round, and are most abundant on older needles	
Flyspeck or Black mildew *Stomiopeltis pinastri*	Large, brown to black needle spots (overlap multiple stomata); round to oval or elongated; flat (not spherical); spots are not necessarily associate with stomata; grows superficially (on needle surface) and does not cause significant damage or needle shed	
Black mildew or Sooty mold *Rasutoria pseudotsugae*	Large, spherical black fruiting bodies (often large enough to overlap multiple stomata) with "hairy" margins; grows superficially (on needle surface); fruiting bodies appear to protrude from stomata, but are not necessarily associated with stomata; only weakly parasitic and rarely causes significant needle senescence or needle shed	

Table 1, continued.

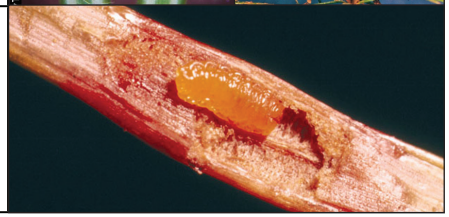
Rhabdocline needle cast *Rhabdocline psuedotsugae*	Orange to red-brown fruiting bodies on the undersides of 1-yr needles beneath tan to red-brown flaps in the epidermis and spores colorless to dark brown; similar needle shed symptoms to SNC (needles shed shortly after spore release), but differentiated by red-brown needle banding and distinctive fruiting bodies in spring & fall; often associated with off-site plantings	
Cooley spruce gall adelgid *Adelges cooleyi*	Feeding on upper needles surfaces of first-year Douglas-fir needles causes yellow spots and needle kinking; insects are present in spring and fall; adults are covered by white, cottony wax; newly hatched adelgids (crawlers) are small and black; feeding damage is not usually associated with needle shed; alternate life stages (galls) on spruce new growth	
Douglas-fir needle midge *Contarinia pseudotsugae*	Feeding by small, yellow midge larvae (legless maggots) causes yellow to red spots and swelling on new growth; insects are present in spring to summer and cause needle shed in late summer	

Figure 7. The sparse crown of a SNC-diseased Douglas-fir tree with approximately 1 year of needle retention.

brown to black and are located on the undersides of needles, occupying the needle stomata. Pseudothecia of different sizes are frequently observed on the same needle, with larger, more mature pseudothecia taking on a spherical shape and swelling outward. Pseudothecia are centered on, and are not significantly larger than, stomata.

Impacts on Tree Growth, Wood Properties, Mycorrhizae, and Bark Beetles

A relationship between needle retention and growth loss has been developed for Douglas-fir in western Oregon. The loss of photosynthetic capacity due to premature needle abscission reduces tree diameter and height growth when mean needle retention is less than 3 to 3.5 years (Figure 9), and becomes especially significant when foliage retention is less than 2 years. It takes one year or more before newly infected foliage is significantly affected, so tree-growth losses rarely fall below 50-60% of expected growth.

Figure 8. Swiss needle cast causes Douglas-fir tree crowns to look yellow–brown in spring. Symptomatic Douglas-fir is surrounded by light-green red alder and dark-green Sitka spruce and western hemlock. Photo by Rob Flowers, Oregon Department of Forestry.

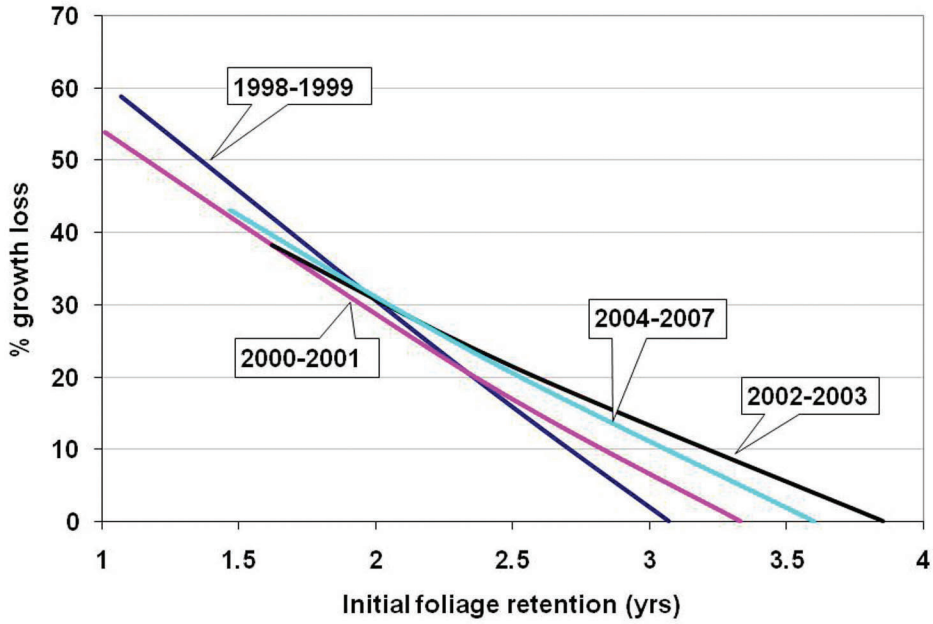


Figure 9. The relationship observed between needle retention and percent volume-growth loss in a ten-year growth impact study of 76 Douglas-fir stands in north coastal Oregon. Each line represents the needle retention-growth loss relationship during a specific measurement period. In general, growth loss peaks at about 50-60% and no growth loss is expected when trees retain more than 3-4 needle cohorts (Maguire and others, 2011).

Mortality from SNC is rare, although the competitive advantage of a planted tree may be lost and the tree may be shaded out. A growth-impact study in north coastal Oregon from 1998-2008 estimated that annual volume-growth losses reached slightly over 50% in stands with the lowest levels of foliage retention compared to healthy stands with similar attributes, and that annual growth loss averaged ~20% across sampled stands.

Diseased trees experience changes in wood properties and branch morphology associated with diminished photosynthetic capacity. Wood density is greater because of the higher ratio of latewood to earlywood. Branches in the lower crown of diseased trees are less shaded by sparsely foliated upper branches and have relatively higher needle retention; therefore, branches in the lower crown tend to increase in diameter at a faster rate than branches in the upper crown. Since diseased trees assimilate less carbon, they support fewer ectomycorrhizal root tips and exhibit lower species richness of ectomycorrhizal fungi compared to healthy Douglas-fir trees. There has been no notable increase in Douglas-fir beetle (*Dendroctonus pseudotsugae*) activity related to the current SNC epidemic. This is probably because SNC-affected trees produce minimal carbon-based ethanol, a stress compound that serves as an aggregation signal for bark beetles, and have reduced phloem thickness, contributing to low beetle reproductive success.

SNC in Christmas Tree Plantations

SNC is the most common disease of Douglas-fir Christmas trees in the

PNW. Rhabdocline needle cast, caused by *Rhabdocline pseudotsugae* and *R. weirii*, can also be a serious problem on intermountain sources of Douglas-fir, but is not typically a problem on coastal forms of Douglas-fir more commonly grown in the PNW. On Christmas trees, SNC causes a yellowing and premature casting of older needles during the spring. Studies have shown that there are no differences in infection incidence among different quadrants of individual trees in Christmas tree plantations. Infection incidence is significantly higher in the lower and middle tree crown compared to the upper crown, probably due to more favorable infection environment in the lower crown (high relative humidity and free moisture on the needles). In contrast, disease is generally more severe in the upper crown in coastal forest settings.

In the mid- to late- 1970s, it was recognized that SNC decreased crown density and adversely affected quality and marketability of Douglas-fir Christmas trees. Surveys of Douglas-fir Christmas trees in western Oregon and Washington in 1981 showed that 84% of trees were infected, and 90% of the plantations had infected trees. Of the infected trees, 16% retained less than two full-year complements of needles and were reduced in commercial grade, while 11% retained only current-year needles and were unmarketable. Monetary loss within the region attributed to needle loss was estimated at $3.4 million for 1981. In addition, many infected trees with limited symptom development had reduced postharvest quality. As a follow-up to the 1981 survey, surveys conducted between 1987 and 2007 found that only 13% of the 5,030 trees sampled had any evidence of infection. Thus, the SNC disease management program developed in the early 1980s (described below) has significantly reduced the prevalence of this disease in PNW Christmas tree plantations.

Controlling SNC is an important means of reducing losses at harvest and improving postharvest quality of Douglas-fir Christmas trees. The goal is to obtain a minimum of two to three years of healthy needles on harvested trees. Increasing air movement around trees is a cultural practice that helps to reduce the development of needle cast diseases in Christmas trees. This can be achieved through a combination of approaches, including avoiding sites that are adjacent to existing stands of Douglas-fir, using wider planting spacing, and maintaining adequate weed control.

Several fungicides are registered for control of SNC. To determine if fungicide applications are warranted, growers are encouraged to begin monitoring their plantations about 4 years prior to harvest. This is typically done by examining ≥1-yr-old needles from branches located in the middle of the trees for the presence of pseudothecia in early spring prior to bud break. Particular attention should be paid to trees located near stands of Douglas-fir, which may be a source of inoculum, and parts of the plantation with conditions that favor extended periods of free moisture on needles. If *P. gaeumannii* is detected, fungicides can be used to protect new growth. If >10% of trees are infected or growers are beginning to see premature casting of older

needles, they may want to consider spraying.

The timing and method of fungicide application are important. Since the timing of bud break varies, application should be made when half of the trees in the plantation have new growth between ½ to 2 inches long. Generally, a single spray will provide effective control, and there is little benefit to spraying trees in the year leading up to harvest. While several fungicides provide effective control when applied with ground-based application equipment, chlorothalonil-based products, such as Bravo, Echo, and Daconil, have been shown to effectively reduce infection levels when applied by either ground or aerial application. With aerial applications, the highest labeled rate should be used.

Management in Forest Plantations and Stands

Management of SNC in Douglas-fir plantations and stands requires a clear understanding that SNC is the cause of foliage and growth losses. The presence of the fungus is not sufficient to warrant management action. Other pathogens and insects cause chlorosis, premature needle loss, and other damage to Douglas-fir foliage, so accurate identification of the causal agent is important. If signs of SNC are limited to older needle cohorts, it is unlikely that the disease is impacting tree growth. The presence of pseudothecia on 1- or 2-yr-old needles and overall foliage retention of <3 years indicate that SNC is contributing to tree growth loss. Off-site genetic sources of Douglas-fir are thought to exacerbate disease impacts, so knowledge about seed source is important.

Determining the level at which SNC represents an economic threat is critical to guiding management decisions. For information and various tools that provide an integrated pest management strategy for SNC along the Oregon and Washington coast, see the Swiss Needle Cast Cooperative (SNCC) website (http://sncc.forestry.oregonstate.edu/).

Assess Site Hazard

Aerial and ground surveys have been used to identify topographic and climatic features associated with severe disease. These factors, which include mild winter temperature, frequent spring and early summer fog and precipitation, low-elevation coastal areas, and constrained valleys, have been used to build disease severity models to assess current and predicted disease levels in coastal Oregon. The models and aerial survey maps can help with assessment of disease severity and risk, especially on newly acquired sites and on sites with changing disease pressure over time. Inland Douglas-fir stands are more likely to suffer long-term damage from SNC if they are located in low-elevation valley bottoms or on warm sites (southern aspects) with limited air flow and fog accumulation in summer. An example of this might be a stand adjacent to a low-gradient stream and surrounded by taller Douglas-fir trees. These landscape features encourage moist air to settle, and the trees provide a close inoculum source. If the site has chronic SNC problems, it may be best to conduct quantitative growth assessments to determine whether the stand

is experiencing significant growth loss, and to subsequently shift species away from Douglas-fir.

Assess Foliage Retention and Tree Growth

It is strongly recommended that SNC management is based on knowledge of the quantitative impacts of disease on tree growth, since symptomatic trees may still be growing reasonably well. An initial, qualitative evaluation of needle retention and the presence of pseudothecia on young needles can be performed based on the following criteria: if <3 needle age classes remain on trees and pseudothecia are detected on young needles (1-2 years old), it is likely that growth loss is occurring and quantitative assessments should be conducted. Growth loss may be particularly severe if foliage retention is <2 years.

Quantitative growth-impact assessments can be conducted using established tools, such as the Stand Growth Assessment Tool or the ORGANON growth-model adjustment for Oregon (http://sncc.forestry.oregonstate.edu/stand-growth-assessment-tool). These tools compare measured growth to expected growth given stand age and other characteristics. In regions outside of Oregon, similar assessments can be made by comparing actual tree growth to growth predicted by the best regional model.

Use tested silvicultural techniques

When monitoring, identification and quantification of disease impacts indicate that disease losses warrant management action, managers can select control methods for their situation. Some of the available tools include: increasing the proportion of alternate species on moderate and high severity sites, thinning from below and before crown closure, planting SNC-tolerant and locally-adapted Douglas-fir seedling stock, and assessing soil nutrients and pH to select an appropriate fertilization regime (including the decision not to fertilize).

1. Species Composition

Because Douglas-fir is the only tree species susceptible to SNC, mixed-species management can help to reduce volume-growth loss on sites with moderate to high SNC severity. Douglas-fir does not escape disease in mixed stands, but the increased volume growth of other species may compensate for losses associated with Douglas-fir. Species composition can be altered at the time of planting and through precommercial thinning. Managers can select the alternate species that are best suited to specific landscape features within stands, mixing these species with Douglas-fir.

Alternate species commonly planted in the Coast Range include western hemlock, Sitka spruce, western redcedar and red alder. Port-Orford-cedar, western white pine and coast redwood are now being planted at greater frequency along the Oregon coast. Strategies for alternative-species management vary depending on harvest system, landscape setting, access, and timing of intermediate treatments and harvest of various tree species. Some alternate species may require different treatment timings or have detrimental effects on Douglas-fir growth. Red alder may be planted as a substitute for Douglas-fir,

but it is not recommended to interplant these species. Alder shading is detrimental to Douglas-fir growth, and differences in the timing of treatments and harvest of alder compared to other conifers may require specialized access, potentially damaging residual trees. Most alternate conifer species are suitable to intermix with Douglas-fir. Depending on management objectives and disease pressure, it is possible to plant pure stands or mixes of alternate species, or avoid planting Douglas-fir altogether. For example:

» Low-severity sites (needle retention 2.6-3.5 yrs): maintain a large proportion Douglas-fir

» Moderate-severity sites (needle retention 1.5-2.5 yrs): reduce Douglas-fir to 50% of the planting

» High-severity sites (needle retention < 1.5 yrs): reduce Douglas-fir to ≤20% of the planting

It is important to be aware of some of the insect and disease risks of alternate species and how to mitigate these risks. For example, Sitka spruce weevils (*Pissodes strobi* [Coleoptera: Curculionidae]) frequently cause damage to leaders of Sitka spruce. Both Sitka spruce and western hemlock are prone to wounding and root damage, and new wounds and recently cut stumps provide an entrance for spores of *Heterobasidion occidentale*, cause of Heterobasidion (Annosus) root disease. Bumper trees and other practices can be used to limit damage from thinning, pruning and other operations to minimize these risks.

The relative commercial value of alternate species and the range of species accepted for processing are other key considerations. Quantifying Douglas-fir volume-growth losses from SNC provides a means to make economic decisions. Under extreme SNC conditions, disease impacts may be so great that trees are unlikely to reach merchantable size, and managers may elect to implement sanitation or salvage harvests.

2. Thinning

Precommercial thinning (PCT) and commercial thinning do not substantially affect needle retention or disease severity. Therefore, standard thinning practices are recommended on all but the most severely affected sites (on which the benefits of thinning may not be worth the cost of the operation). Thinning does not mitigate SNC, but confers the same relative growth benefits as thinning in the absence of disease.

Foliage is frequently retained longer in the lower crown than in the upper crown in SNC-affected stands, so it is recommended that stands are thinned prior to crown closure to maintain crown length and foliage in the lower crown. SNC stands should be thinned from below, favoring individual trees that have demonstrated the ability to grow well under the site conditions, including disease pressure. The *D-minus rule* is a practical management tool that applies a deficit to Douglas-fir diameters when mixed-species stands are thinned from below. Depending on the severity of SNC in a stand, a preset number of inches (1-3″) can be subtracted from the diameter of Douglas-fir trees to identify which trees should be cut or retained. For example, with a 2-inch deficit, a 6-inch diameter

western hemlock will be retained in favor of an adjacent 7-inch diameter Douglas-fir. The Douglas-fir is treated as though it is 5 inches (7″ - 2″ = 5″), which is smaller than the 6-inch diameter hemlock. This rule is easy for thinning crews to implement, and addresses the fact that Douglas-fir trees that are initially larger than other species at the time of PCT are frequently outgrown in subsequent years under high disease pressure.

3. Improved and Locally Sourced Planting Stock

Although all Douglas-fir trees are susceptible to SNC, it is generally believed that local Douglas-fir seed sources are best-adapted to SNC. In some areas, however, disease pressure is so intense that no seed source is tolerant. Research has shown that there is heritability in SNC tolerance, especially in areas with moderate disease severity. Some families demonstrate reliable diameter growth even after years of substantial SNC pressure. The Northwest Tree Improvement Cooperative (http://www.fsl.orst.edu/nwtic/) has been working to develop SNC-tolerant Douglas-fir seedlings. Information on established Douglas-fir seed zones for western Oregon and Washington is available through the Oregon Department of Forestry and the Washington Department of Natural Resources.

4. Soil Fertilization

Nitrogen (urea) fertilization may not be appropriate under certain soil conditions, particularly on sites with high site indices, low soil pH, high soil nitrogen, and low soil calcium to nitrogen ratios. SNC is often most severe near the coast, where soil nitrogen concentrations tend to be high, so nitrogen fertilization may not increase growth in these stands. A study in western Oregon showed no impact of various fertilization treatments (N, Ca, P and others) on pathogen abundance or disease severity. Preferably, soil nutrient levels should be analyzed to determine the most appropriate fertilization regime for a given stand, but more work on this topic is needed.

5. Fungicidal Control

In plantation forests, the disease-control benefits of fungicide application are short-lived and not cost-effective. Five successive years of aerial chlorothalonil application temporarily reduced disease symptoms but did not achieve complete disease control. Infection levels rapidly returned to pre-treatment levels when application ceased. Chlorothalonil (Bravo, Echo, Daconil) has been shown to effectively reduce infection levels in both plantation forests (ground and aerial application) and Christmas tree plantations, but is only economically viable in high-value Christmas tree plantations. Sulfur-based fungicides (with sticker) are slightly less effective than chlorothalonil in controlling infection, but are less toxic and may have less deleterious impacts on non-target organisms.

Assistance

Private landowners can get more information from County Extension Agents, State Forestry Departments or State Agricultural Departments. Federal resource managers should contact USFS

Forest Health Protection (www.fs.fed.us/foresthealth/). This publication and other Forest Insect and Disease Leaflets can be found at www.fs.usda.gov/goto/fhp/fidls.

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