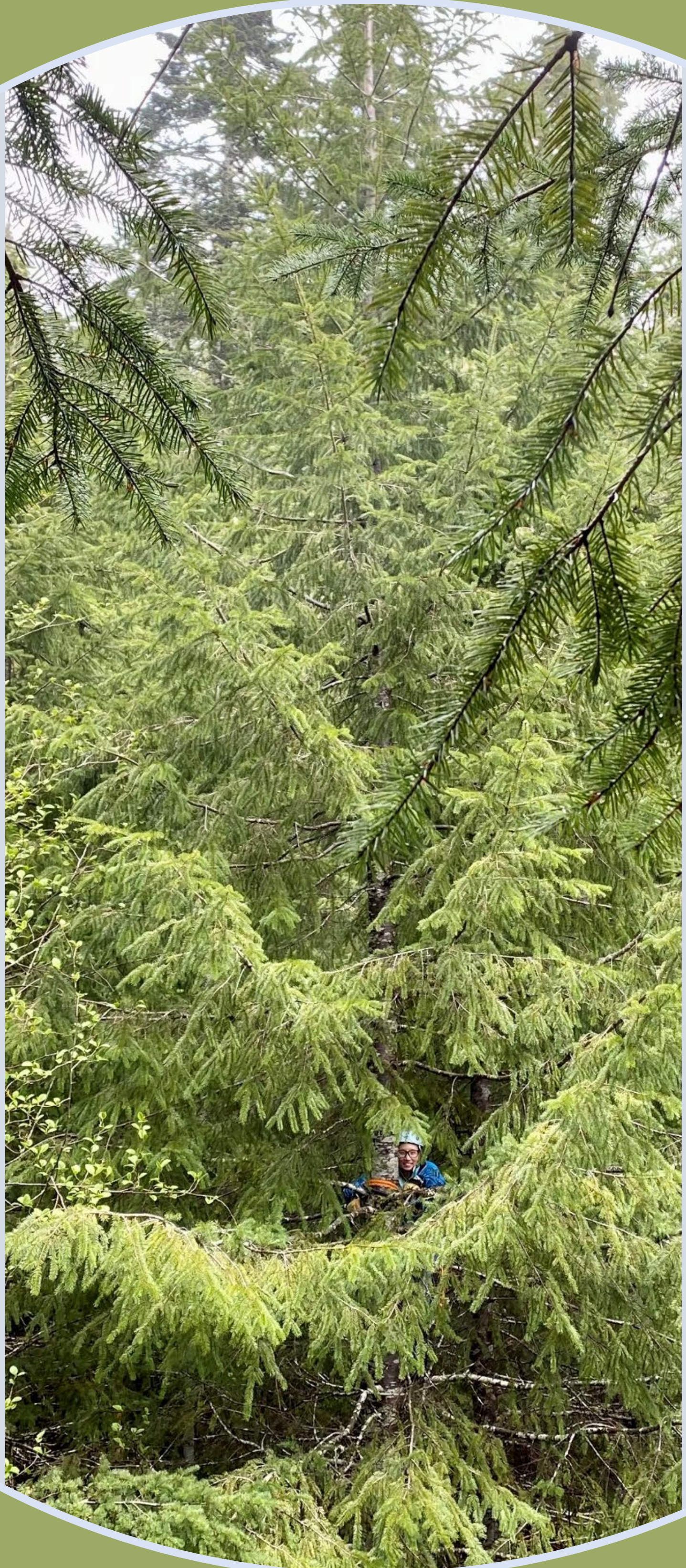
Annual Report

2024



Oregon State University

Swiss Needle Cast Cooperative

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Cascade Timber Consulting

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Swiss Needle Cast Cooperative Staff

Jared LeBoldus – Director and Associate Professor of Forest Pathology

Adam Carson – Associate Director and Faculty Research Assistant

Cover photo: Yung-Hsiang (Sky) Lan collecting foliage samples from the SNCC research and monitoring plot network

Contents

SNCC Income Sources and Expenditures: 2024

Income

Membership dues	*84,000*
Oregon State Legislature	*95,000*
Carry-over	*324,803*
Total 2024 Income	**$503,803**

Expenditures

Salaries and wages	*124,883*
Travel	*17,201*
Operating expenses	*38,327*
Materials and Supplies	*2,094*
Indirect Costs (@17.5%)	*8,719*
Total 2024 Expenditures	**$191,224**

Balance	**$312,579**

SNCC 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. The SNCC is located in the Department of Forest Engineering, Resources and Management within the College of Forestry at Oregon State University. The Membership is comprised of private, state, and federal organizations. Private membership dues are set at a fixed rate. An annual report, project reports, and newsletters are distributed to members each year. Our objective is to carry out projects in cooperation with members on their land holdings.

SNCC Mission

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

SNCC Objectives

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

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3/3/2025

To: Swiss Needle Cast Cooperative Members
From: Jared LeBoldus, Director, SNCC

Dear SNCC Membership,

The Swiss Needle Cast epidemic in the PNW continues into 2024 and the aerial detection surveys (ADS) are noting significant increases in acreage observed, and acreage assigned a severe disease severity rating. This is the second year in a row, that the Oregon survey reported a record breaking number of acres with the SNC signature. However, an aerial survey for SNC was aslso completed in Washinton this year and found decreased symptomaic agreage compared to 2022. We think the differences between the two states may be due, in part, to contrasts in forest composition and climate. These surveys are invaluable tools for identifying geographic and temporal disease trends in the landscape that help inform forest management decisions.

The Swiss Needle Cast Cooperative has successfully recruited and hired a Research Associate, Dr. Cristian González, who will begin work in March 2025. Dr. González will initiate work on several projects which include the development of a disease resistance screening assay and the use of precommercial thinning to favor western hemlock in stands severely affected by Swiss Needle Cast. We look forward to working with Crisitian and the opportunity he brings to further SNC research.

Adam Carson continues to work hard completing the final remeasurement of the plot network with fall and spring field work. One more year to go!! We also plan to analyze data collected in the first remeasurement and will try aim for a submission this coming fall. We continue to monitor the Cascade Foothills of Oregon with annual monitoring of plots in Douglas-fir plantations below 2,500 ft elevation.

The SNCC also continues to interact with a broad range of researchers, and leverages as much work on SNC as we can by collaboration with and education of the research community. The initial focus has been on associations between SNC and nutrients, climate factors, and how foliage retention and disease severity vary across the landscape. Recently, we successfully secured approximately ~$650,000 from the USDA-NIFA. This competitive grant leverages the plot network to study other foliage diseases of Douglas-fir.

Thanks to the SNCC membership for supporting the important work of the cooperative, we continue to keep the focus on Douglas-fir forest health.

Sincerely,

Jared LeBoldus

Jared M. LeBoldus, Associate Professor – Forest Pathology,
Botany and Plant Pathology & The Forest Engineering, Resources and Management Department
Director of the Swiss Needle Cast Cooperative: https://sncc.forestry.oregonstate.edu/
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Ten-Year Remeasurement of the Swiss Needle Cast Cooperative Research and Monitoring Plots, and the First Full Assessment of the New Network of Monitoring Transects in the Cascade Foothills

2024 Research Activities of the Swiss Needle Cast Cooperative

Adam Carson[1], Gabriela Ritóková[2], Dave Shaw[1], Jared LeBoldus[1,3]

[1] SNCC, Forest Engineering, Resources, and Management, Oregon State University, [2]Oregon Department of Forestry, [3]Department of Botany and Plant Pathology, Oregon State University

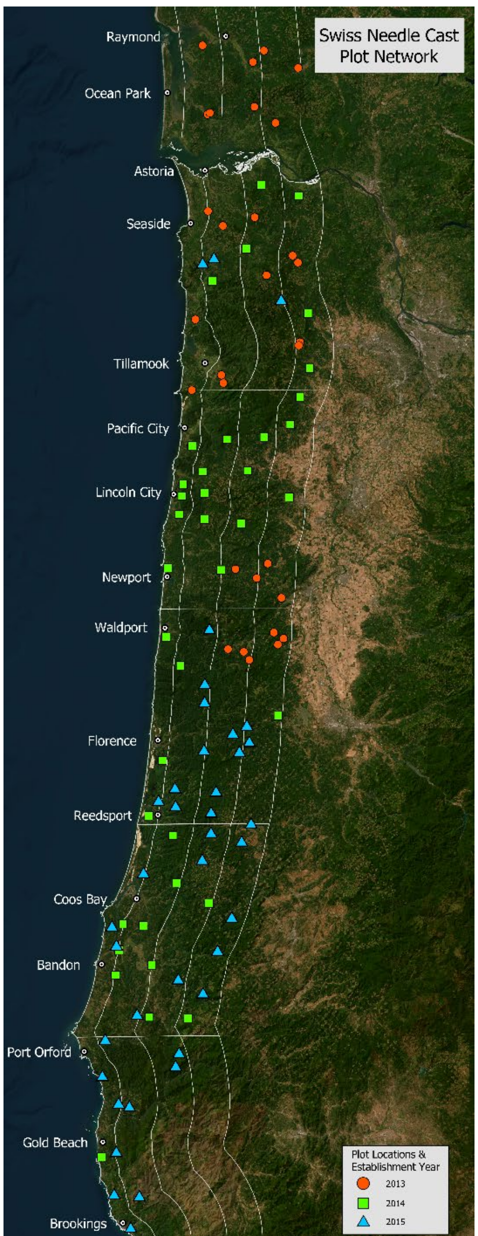

Figure 1. Distribution map of the SNCC research plot network.

Remeasuring the Research and Monitoring Plot Network

The research and monitoring plot network (RPN), established by the Swiss Needle Cast Cooperative (SNCC), consists of 106 plots installed in Douglas-fir plantations distributed across the Coast Range in Oregon and southwest Washington (Fig. 1). Installation of the network began in 2013 and took three years to complete. Four of the research plots have since been lost due to precommercial thinning, windthrow and wildfire. This network provides information on the geographic distribution and disease severity of Swiss needle cast (SNC) across the landscape, as well as growth and yield impacts to Douglas-fir. The first five-year remeasurement of the remaining 102 plots was completed in 2020. From this first re-measurement, cubic volume growth loss of 30-35% was estimated in heavily infected SNC stands with low needle retention (Mainwaring et al. 2020). This is a reduced estimate from the previous 50% growth loss calculated in 2011 (Maguire et al. 2011). Furthermore, initial assessments of foliage retention within the RPN found that disease severity increased and foliage retention decreased with latitude (Ritóková et al. 2021). Analyses from the initial and first remeasurement of the RPN can be found in the 2020 SNCC Annual Report.

The second five-year remeasurement (ten-years post establishment) of the RPN is currently underway and will conclude in 2026. The measurement of the first 29 plots (those established in 2013) were completed in the fall of 2023, and foliage samples were collected from these plots to assess needle retention and disease severity in the spring of 2024. The measurements of the second third of the network (those installed in 2014) were completed in the fall of 2024 and are scheduled for foliage sampling in the spring of 2025. The first third of the RPN plots are distributed within the four northernmost latitudinal sampling zones and are included in all four longitudinal zones (Fig. 1). Analysis of the data from the first 29 plots, and their implications for cubic volume growth, are discussed on page 10 of the 2023 SNCC annual report (Mainwaring et al. 2024) and a growth impact assessment from the second third of plots can be found on page 13 of this annual report. Here, we outline preliminary foliage retention results from the first third of plots included in the study. A 10-year analysis of disease severity within the first 29 plots is currently ongoing and will be included in the 2025 SNCC annual report.

Foliage Retention Results from the First Third of the Plot Network

Although the first third of plots in the network are in relatively close proximity, differences in foliage retention were observed. Across all plots sampled in 2024, the mean plot-level foliage retention was 2.66 years and ranged from 1.44-3.94 years. This represents a reduction in the overall mean foliage retention on the same plots compared to previous assessments in 2014 and 2019 (Fig. 2). The elevation of the plots ranged from 312-2054 ft (95-626 m), and a positive relationship was observed between foliage retention and elevation ($R^2 = 0.22$, Fig. 2). Additionally, foliage retention was lower at higher latitudes ($R^2 = 0.36$) and with decreased distance from the coast ($R^2 = 0.55$).

Compared to samples collected in 2014 and 2019, foliage retention decreased in the southwest Washington and Newport latitudinal sampling zones and increased in the Florence sampling zone (Fig. 3). Across all three sampling periods, the two southernmost sampling zones, Newport and Florence, had greater median foliage retention compared to the Tillamook and southwest Washington zones. Furthermore, median foliage retention for all three sampling years was reduced in plots located within longitudinal zones closest to the coast compared to plots located a distance of 15 miles or greater from the coast (Fig. 4). These preliminary results suggest that the correlations found by Ritóková et al. (2021) between foliage retention and elevation, latitude, and coastal proximity may remain temporally consistent across sampling periods. Subsequent analyses of the remaining plots in the network will include a wider geographic range of the SNC zone and should aid in further elucidating foliage retention and disease dynamics.

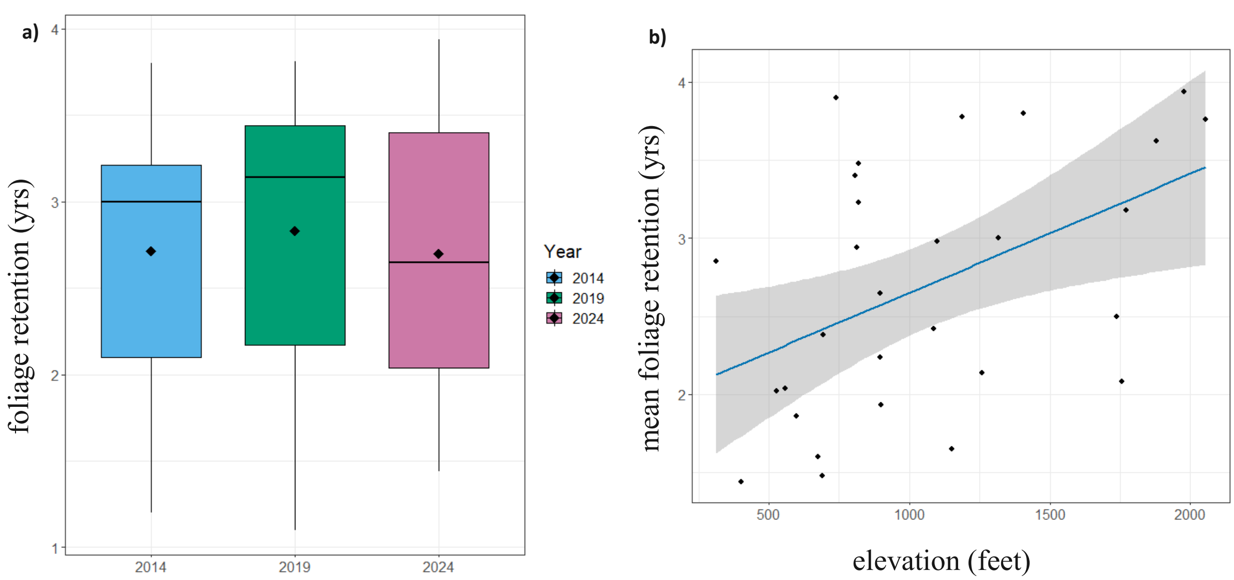

Figure 2. Box plots showing the distribution of foliage retention across the three sampling periods (a) and a scatter plot showing the relationship between mean foliage retention and elevation for plots sampled in 2024, R^2= 0.22. Note: ◆ indicates mean foliage retention

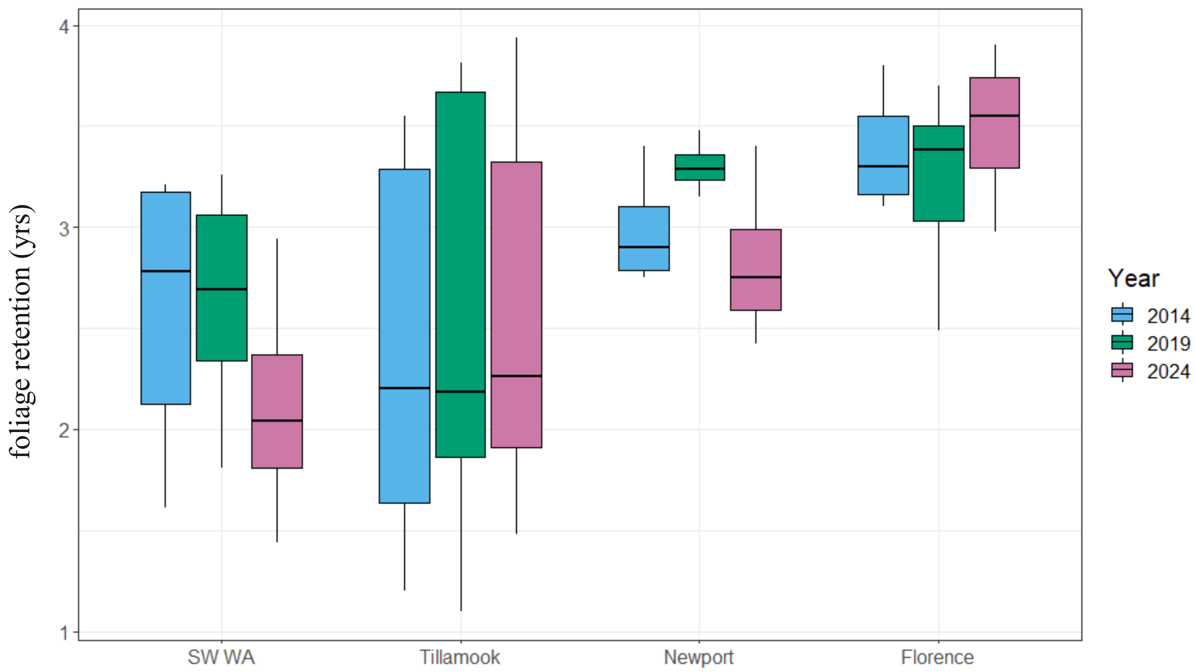

Figure 3. Box plots showing foliage retention within latitudinal zones by sampling period. Note: results are preliminary and are based on a small number of total plots in each sampling zone.

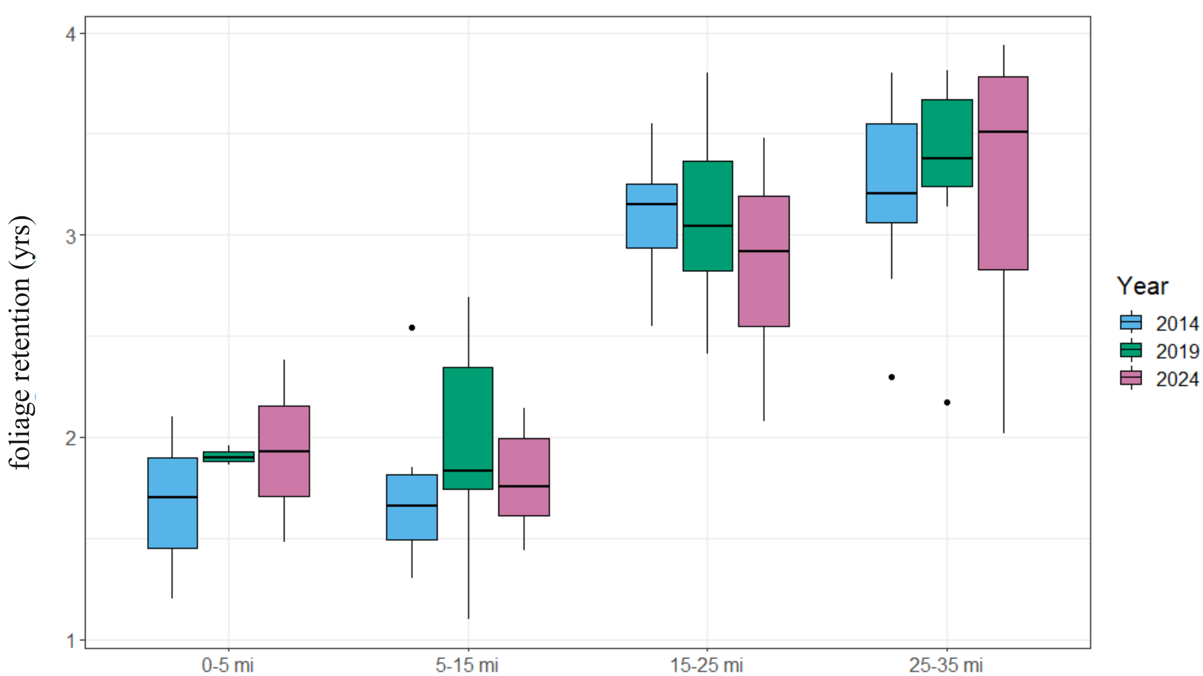

Figure 4. Box plots showing foliage retention within longitudinal sampling zones by sampling period. Note: results are preliminary and are based on a small number of total plots in each sampling zone.

Swiss Needle Cast Transects in the Oregon Cascade Foothills

Background

In addition to the RPN, the SNCC monitors SNC disease conditions within the foothills of the Cascade mountains using a network of monitoring transects. Thirty-five transects were installed in 10-to-15-year-old Douglas-fir stands in the spring and summer of 2023 (Fig. 5). Each selected stand contains a single 100-meter transect with five sample points located at 20-meter intervals. At each sample point, the nearest co-dominant or dominant Douglas-fir on each side of the transect are selected for a total of 10 trees per stand. Diameter at breast height, foliage retention, and disease severity is collected for each sampled tree. Each transect is representative of the stand in which it was established.

The transects are surveyed annually with the aim of evaluating SNC conditions using an index rating system for disease severity (Fig. 6) and foliage retention (Fig. 7). The first full assesment of the transect network occurred in spring of 2024. A partial assesment was conducted in the spring of 2023 on plots installed prior to bud burst (n = 15).

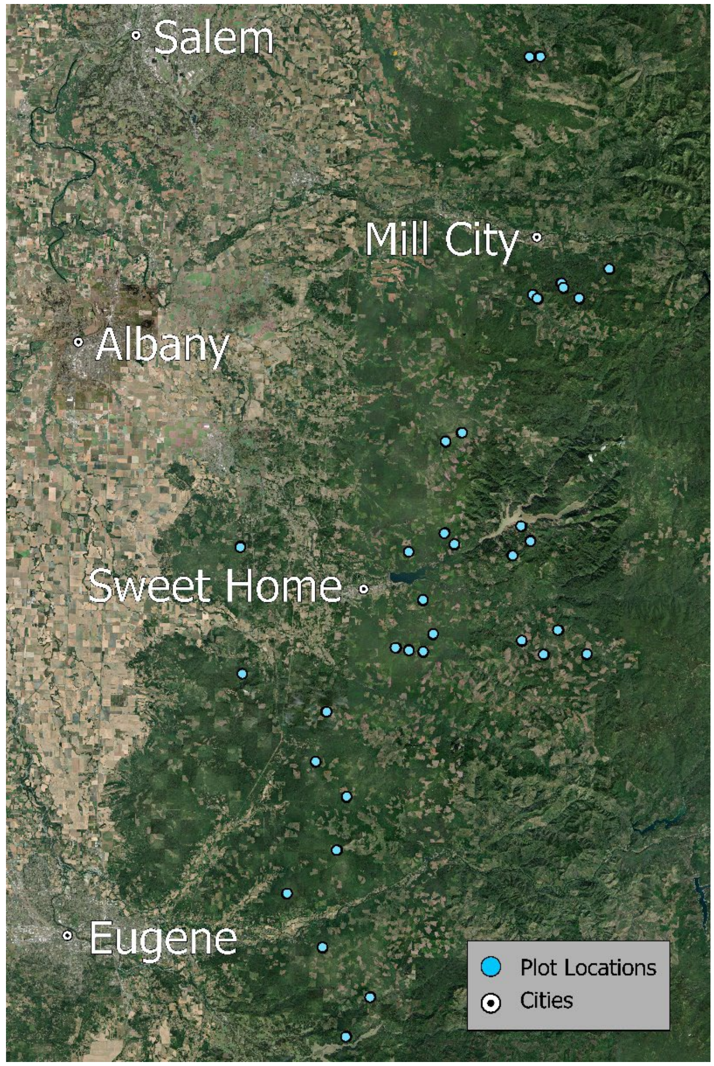

Figure 5. Distribution map of the Cascade foothills SNC monitoring transects.

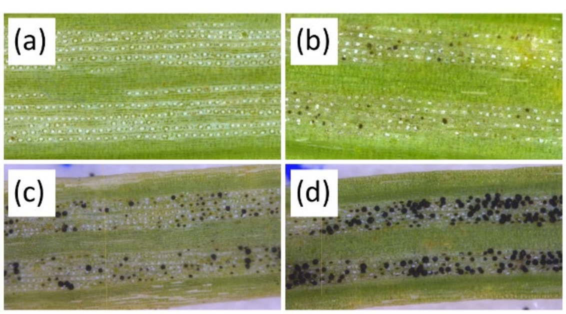

Figure 6. Disease severity index rating for cascade monitoring transects. (a) No pseudothecia present = 0; (b) light stomatal occlusion, up to 20% = 1; (c) moderate occlusion, between 20-50% = 2; (d) heavy occlusion, above 50% = 3.

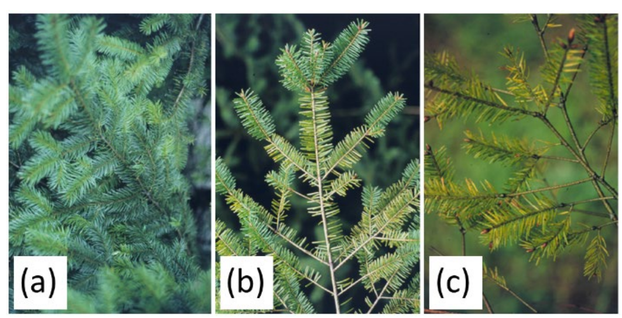

Figure 7. Examples of foliage retention ratings on 4-year lateral branches. (a) Full needle retention across all 4 cohorts = 4.0; (b) near full retention on 1st & 2nd cohorts, partial retention on 3rd & 4th cohorts = 2.4; (c) partial retention on 1st cohort only = 0.9.

Results

Overall, the results were similar to what has been observed in previous assessments, indicating that the disease is present over time despite observed improvements in foliage retention and reduced disease severity. The elevation of transects within plot network ranged from 478-3273 ft (146-998 m). The mean foliage retention of each plot varied from 2.27-3.95 years, and the mean index rating for disease severity ranged from 0.6-2.1 (light to moderate). Across all stands surveyed, the median foliage retention was 3.49 years (Fig. 8), and the median disease severity was 1.71 (Fig. 8). No relationship was observed between foliage retention and latitude (R^2 = 0.06) or foliage retention and longitude (R^2 =0.06). However, weak relationships were found between disease severity and latitude (R^2 = 0.24) and longitude (R^2 = 0.27).

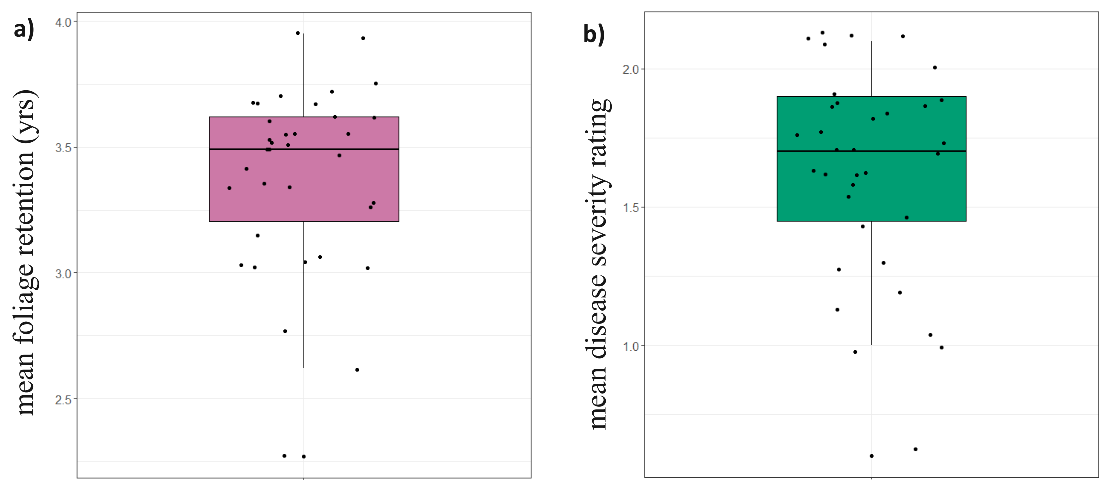

Figure 8. Box and dot plots showing foliage retention (a) and disease severity (b) observed at the plot level

When assessing the relationship between foliage retention and disease severity, a negative association was observed (R^2= 0.22, Fig. 9). Additionally, elevation was found to be negatively correlated with disease severity (R^2= 0.54, Fig. 10) and positively associated with foliage retention (R^2= 0.17).

Comparisons of the partial 2023 and 2024 results, found that foliage retention improved in those stands overall (Fig. 10). The mean 1-year change in foliage retention (0.41 years) was positive, with only 13% of tree showing decreased retention. There was little change in mean disease severity (-0.02), but the distribution of ratings was more widespread in 2024 (Fig. 10). This suggests that while foliage retention improved, disease pressure remained present in the landscape.

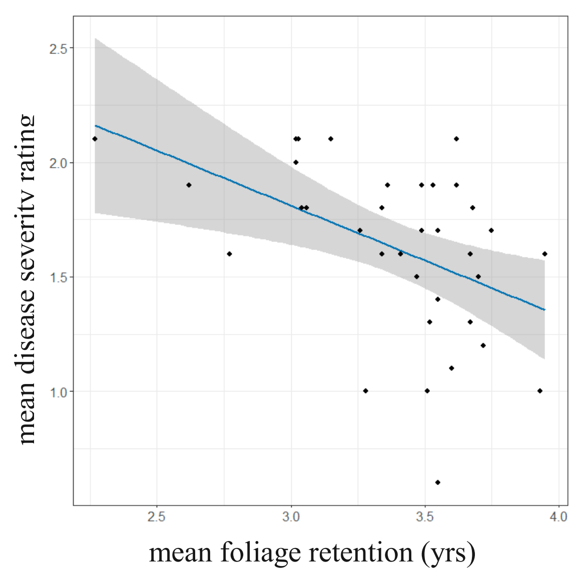

Figure 9. Scatter plot showing the relationship between mean disease severity and mean foliage retention ratings, R^2= 0.22

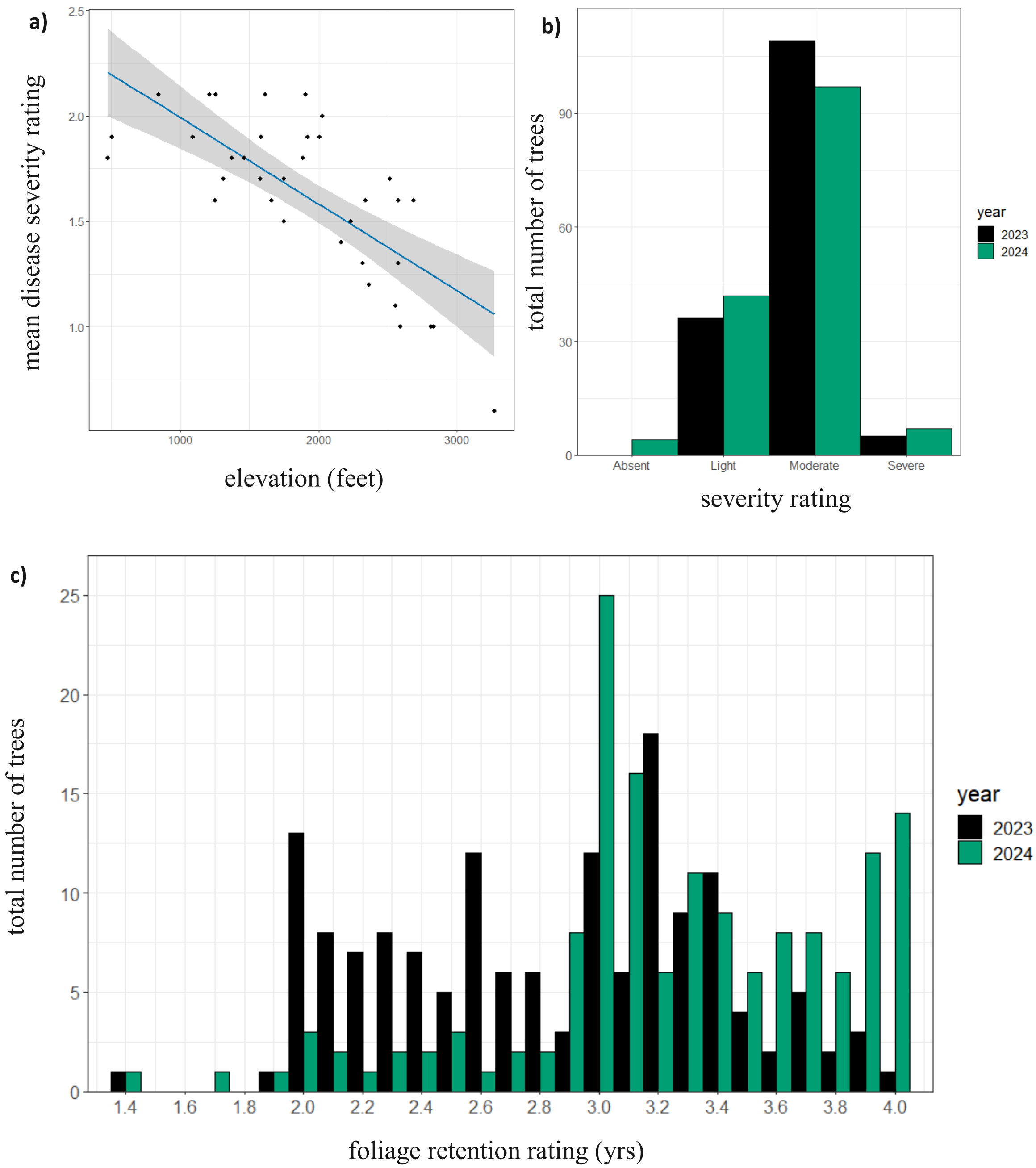

Figure 10. (a) Scatter plot showing the relationship between mean disease severity rating and elevation, R^2= 0.54; (b) bar plot of the total number of trees rated within each disease severity index by year; (c) bar plot showing the total number of trees rated within each foliage retention index by year. Note: foliage retention is rated to the nearest tenth.

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Swiss needle cast research plot network: second remeasurement of group 1 and 2 plots

Doug Mainwaring

Abstract

The second five-year remeasurement of the first- and second-thirds of the SNCC research plot network (RPN) has been completed (63 plots). For the most infected plots, the estimated negative effect of foliage retention on volume increment is approximately similar to that estimated for the 1998-2008 GIS plots. The negative effect of foliage retention on moderately infected plots is highly dependent on the specifics of the foliage retention term, and final selections of this term are probably best resolved using the entire dataset (fall 2025) and a final estimate of foliage retention (spring 2026). Changes in foliage retention during the relatively long five-year growth periods of the current plot network has the potential of affecting estimated growth losses, and should be accounted for in future analyses.

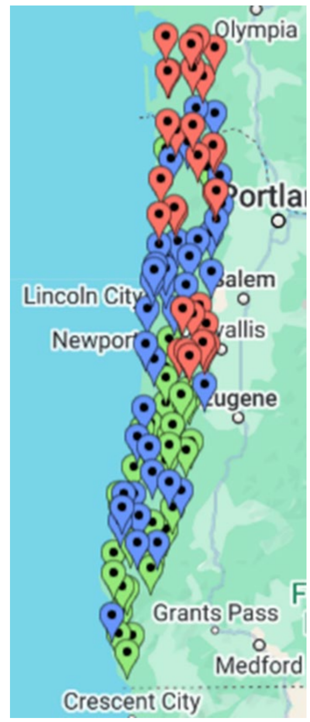

Figure 1 Location of the SNCC RPN; Red and blue symbols show location of group 1 and 2 plots analyzed in this report.

Introduction

The RPN was initiated in 2013 to address two major objectives: 1) to monitor Swiss needle cast (SNC) symptoms and tree growth in 10-25-yr-old Douglas-fir plantations throughout the Oregon Coast Range and southwest Washington; and 2) to provide an improved estimate of growth losses associated with a given initial level of SNC. Volume growth losses were estimated to average 23% for the target population in 1996, with losses reaching 50% in the most severely impacted stands. Four subsequent remeasurements through 2008 confirmed these estimates (Maguire et al. 2011). In contrast, during the five-year period of the RPN's first measurement period, estimated cubic volume growth losses were a maximum of ~35% at a foliage retention of 1.0 years.
The objectives of this report are: 1) to quantify the most recent 5-yr growth responses relative to initial SNC severity; and 2) to compare this 5-yr growth response to previous results.

Methods

Study sites

Establishment of the RPN began in the Fall of 2013, and ultimately included 106 plots installed over three years. These plots were established in 10-25 year old Douglas-fir plantations (>80% BA in Douglas-fir) that had not been treated in the last five years, and were distributed from the Oregon-California border to SW Washington, and from the coastline to 35 miles inland (Ritóková et al. 2017). These plots and their measurement protocols are identical to the original Growth Impact Plots (Maguire et al. 2011).

In the spring following establishment, and again following the second remeasurement, foliage retention (nearest 0.1 year) was estimated from laterals within the middle crown third of five dominant trees on the plot. In young stands with highly visible crowns, this could usually be done visually from the ground; for older stands, estimation required climbing. Data summaries of the plot network can be found in a previous SNC annual report (Ritóková et al. 2017).

The second remeasurement of the first group of thirty plots of the network took place in the fall of 2023, and that of the second group of 33 plots in the fall of 2024 (fig. 1).

Statistical analysis

The equation for estimating the stand level cubic volume for the entire plot network was:

$$[1] \quad CFV\_PAI = a_1 \cdot (BA_{df}^{a2}) \cdot \exp(a_3 \cdot BA_{ndf}) \cdot SI_{adj}^{a4} \cdot (1-\exp(a_5 + a_6 \cdot FR^{X}))$$

With CFV_PAI being the five-year periodic annual cubic volume increment (volumes estimated using CIPSANON), BA_{df} was stand level Douglas-fir basal area, BA_{ndf} was stand level basal area of all other species, SI_{adj} was site index adjusted for foliage retention (Mainwaring et al. 2020), and FR was initial foliage retention at the start of the period. The original value of X, the exponent on foliage retention, was 3, though exploration of other values is thought to be warranted. For the second remeasurement of the first group of 30 plots, a_3 and a_4 were insignificant predictors, resulting in the reduced equation [2], fit separately to each period:

$$[2] \quad CFV\_PAI = a_1 \cdot (BA_{df}^{a2}) \cdot (1-\exp(a_5 + a_6 \cdot FR^{X}))$$

For the second remeasurement of groups 1 and 2 (63 plots), a_5 was insignificant, leaving the reduced version of equation [2]:

$$[3] \quad CFV\_PAI = a_1 \cdot (BA_{df}^{a2}) \cdot (1-\exp(a_6 \cdot FR^{X}))$$

Results and Discussion

Using different values of X as a power on foliage retention resulted in different estimates for parameter a_6 and significantly different estimates of the negative effect of foliage retention on cubic volume increment in moderately infected stands (FR = 2-2.5 yrs) (fig. 2). It is notable that regardless of the value of X, the negative effect of SNC on volume increment within the most infected stands is similar, estimated to be ~45% for a foliage retention of ~1.3 years (fig. 2), a value comparable to the average minimum foliage retention within the plot network for each spring assessment so far (1.21 years). The estimated growth losses for a foliage retention of 1.0 years (50-60%), often cited within these reports, is comparable to what was found for the original 1998-2008 GIS plots. The mean squared error (MSE) of each X-dependent fit declined with the value of X, suggesting a improved fit with lower values of X, though the marginal improvement of MSE was small for X < 2.

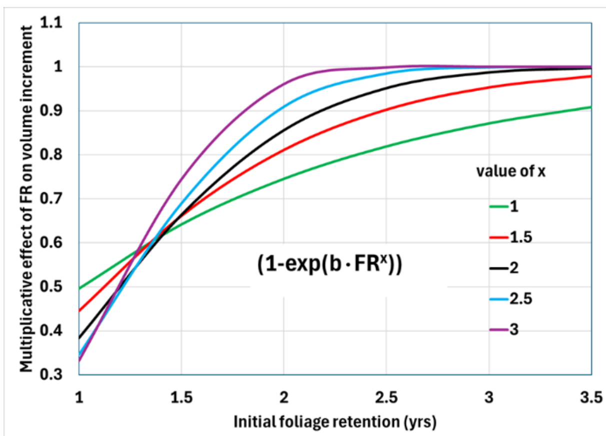

Figure 2 Estimated growth loss of the second remeasurement of groups 1 and 2, based on different exponent values on FR.

In the analysis of the second remeasurement of the first 30 plots (2024 SNCC annual report), it was emphasized that changes in foliage retention over the five-year growth periods could significantly influence the estimate of the effect of SNC on growth loss, particularly given the use of initial (year 0) foliage retention in the prediction model. To emphasize this point, in between the first and second measurement of the research plot network, foliage retention generally increased (fig. 3), which was not captured in the analysis of the first five-year period, and is probably partially responsible for the reduction in estimated growth loss relative to the original 1998-2008 growth impact plots. The estimated growth losses shown in figure 2 also don't account for any foliage retention changes, because those changes won't be known until the foliage retention assessments for this set of plots, scheduled for spring 2025, are completed.

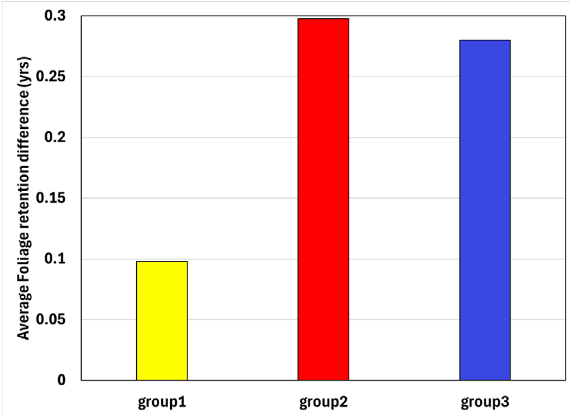

Figure 3 Change in initial foliage retentions between periods two and one for the three groups of the research plot network.

The large X-dependent difference in estimated growth loss for moderately infected stands points toward the need for rigorous testing of the foliage retention term for the full dataset, when measurements are complete in the fall of 2025, and foliage retention assessments are complete in spring 2026. It is in moderately infected stands that growth loss estimates are especially important, because it is in such conditions that decisions about whether to hold, harvest, or treat a stand are less obvious.

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2024 Swiss Needle Cast Aerial Survey

Gabriela Ritóková and Sean McKenzie

Oregon Department of Forestry

Aerial Detection Surveys (ADS) to detect and map the distribution of Swiss Needle Cast (SNC) damage have been flown annually from 1996 until 2016, after which the Swiss Needle Cast Cooperative (SNCC) members decided to conduct the survey every other year.

Survey Methods

Three fixed-wing aircraft were used for the 2024 survey: a Cessna Skylane 182 and Cessna StationAir 206 operated by Butler Aviation of Walla Walla, WA, and a Kodiak K-100 operated by the USDA Forest Service Region 6 Aviation Program. The observation plane flew at 1,500 to 2,000 feet above ground level, travelling at approximately 80 – 120 knots along north-south transect lines separated by 2 miles. Our survey grid covered Oregon's Coast Range from the coast to approximately 25 statute miles inland and from the Columbia River to as far south as Bandon (figure 1). Additional acreage was surveyed in Clatsop County to ensure full coverage of the main block of the Clatsop State Forest. Observers looked for areas of Douglas-fir forest with obvious yellow to yellow-brown foliage, a symptom of Swiss needle cast (SNC). Patches of forests with these symptoms (patches are referred to as polygons) were sketched onto computer touchscreens displaying topographic maps or orthophotos and the position of the aircraft. Each polygon was classified as either "S" (severe) or "M" (moderate) based on the degree of discoloration. Polygons classified as "S" had very sparse crowns and brownish foliage, while those classified as "M" were predominantly yellow to yellow-brown foliage with slightly denser crowns than those classified as "S". In 2024, the survey did not include any of the Cascade Range or the southwestern part of the State (south of Port Orford) despite SNC occurring at damaging levels in some of these areas.

Historically, the software used to map SNC damage only allowed aircrew staff to draw polygons where they observed damage without assigning additional attribute data. The acres with SNC damage were reported as the sum of the spatial extent of all polygons drawn. This assumes that the polygons drawn consist entirely of SNC affected Douglas-fir. In reality, this assumption is rarely valid. In 2018, aircrew staff adopted Digital Mobile Sketch Mapping (DMSM), specialized software developed by the Forest Health Assessment and Applied Science Team (FHAAST) at the USDA Forest Service, to record data for the SNC aerial survey. DMSM's interface allows aircrew staff to assign a 'percentage of area affected' category, consisting of a range of values for each polygon. We now report two related, but distinct values: "acres with damage" is the sum of the spatial extent of all polygons drawn, while "affected acres" are the acres with damage weighted by the median values of the percent affected categories for each polygon. For example, if an observer drew a 1,000 acre polygon and assigned it the 50 – 75% affected category, then that polygon would have 1,000 acres with damage and 625 affected acres. For the purposes of this report, we will emphasize the more accurate "affected acres" for the 2024 data. However, for consistency with our legacy data, we will report the "acres with damage" to allow for temporal comparisons.

Results and Discussion

The survey was flown between May 8, 2024 and June 6, 2024, covering approximate 3.25 million acres in the Oregon Coast Range (figure 1). In 2024, bud break was on time, but the survey was delayed until later than planned because of a staffing shortage, technical and administrative difficulties related to the aircraft, and contract delays. Despite this, symptoms remained visible to observers well after bud-break and into June.

The survey showed an increase in the area of forest with symptoms of SNC compared to the previous 5 years, reaching an all-time high with aerial observers mapping a mosaic of 948,656 acres with damage containing 441,573 affected acres of Douglas-fir forests with obvious symptoms of Swiss needle cast (figure 2). As has been the case for the past several years, the easternmost area with obvious SNC symptoms was approximately 25 miles inland from the coast in the Highway 20 corridor, but most of the area with symptoms occurred within 18 miles of the coast. Figures 3 and 4 show the trend in damage from 1996 through 2024. This year's increase in SNC is probably due in part to prolonged wet spring of 2023, which was very conducive to infection.

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 SNC occurs throughout the survey area, but discoloration often is not severe enough to enable aerial detection. The total area of forest affected by Swiss needle cast is far greater than indicated by the aerial survey. The aerial survey does, however, provide a reasonable depiction of the extent of moderate and severe damage and coarsely documents trends in damage over time.

Acknowledgements

The 2024 survey was conducted by the Oregon Department of Forestry Forest Health and Air Operations sections and the USDA Forest Service and was funded by the Oregon State University Swiss Needle Cast Cooperative. Sean McKenzie (ODF) was the survey coordinator and an aerial observer. Gabriela Ritokova and Christine Buhl (ODF), Sarah Navarro, Tim Bryant, Danny Depinte and Justin Hof (USFS) were the other aerial observers.

Additional Notes

We appreciate any information regarding the usefulness of the maps. If you have a chance to look at some of the mapped areas on the ground, please let us know what you observe.
Please contact Gabi Ritokova (gabriela.ritokova@odf.oregon.gov; 503-978-2404) or Sean McKenzie (sean.c.mckenzie@odf.oregon.gov; 971-453-2692) if you have questions, suggestions, or comments.

The GIS data and a .pdf file can be accessed via the ODF web page at:

http://tinyurl.com/ODF-ForestHealth

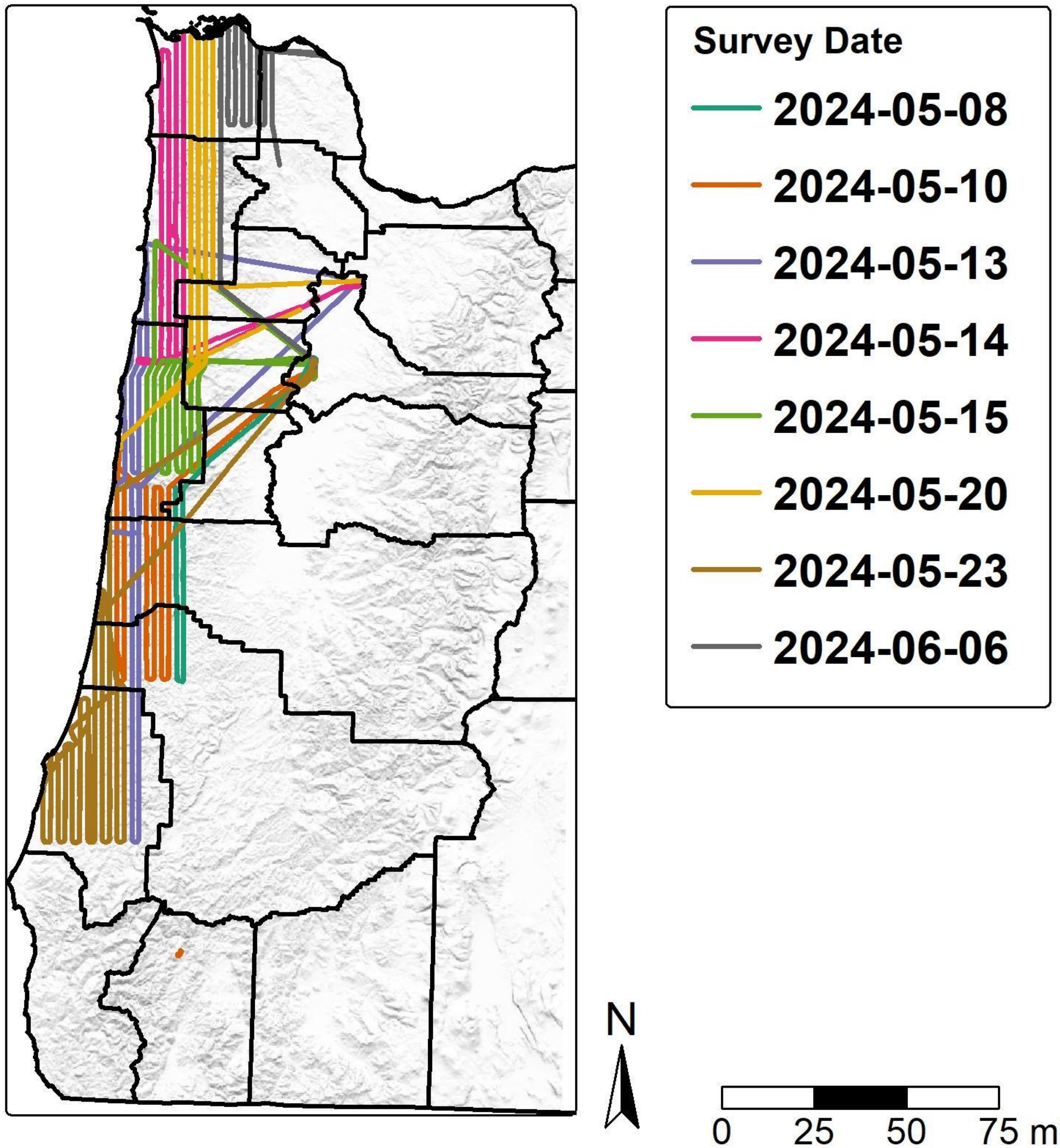

Figure 1. *Area surveyed for Swiss needle cast symptoms, 2024. Flight lines are two miles apart.*

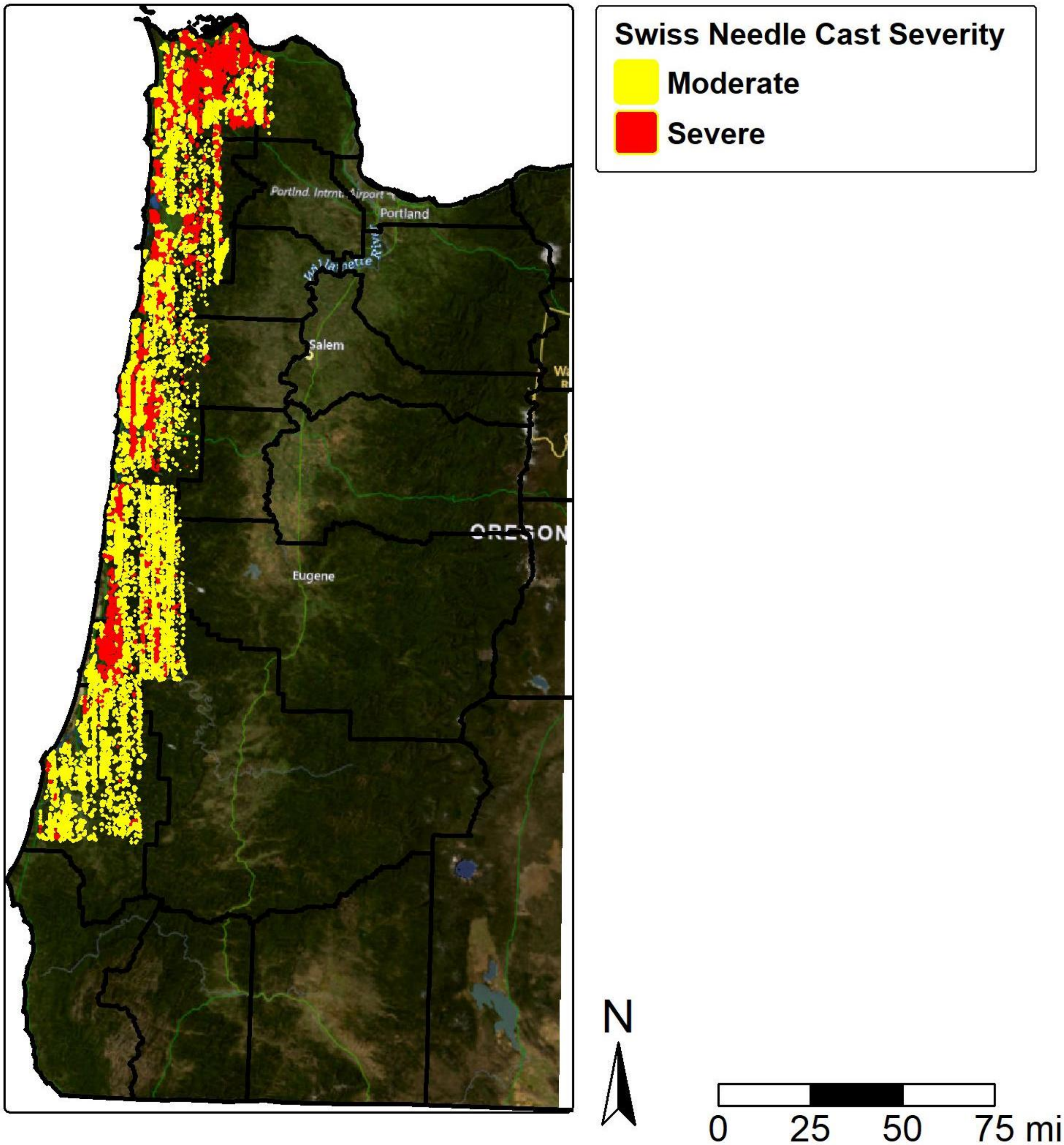

Figure 2. *Areas of Douglas-fir forest with symptoms of Swiss Needle Cast detected in the 2024 aerial survey, Coast Range, Oregon.*

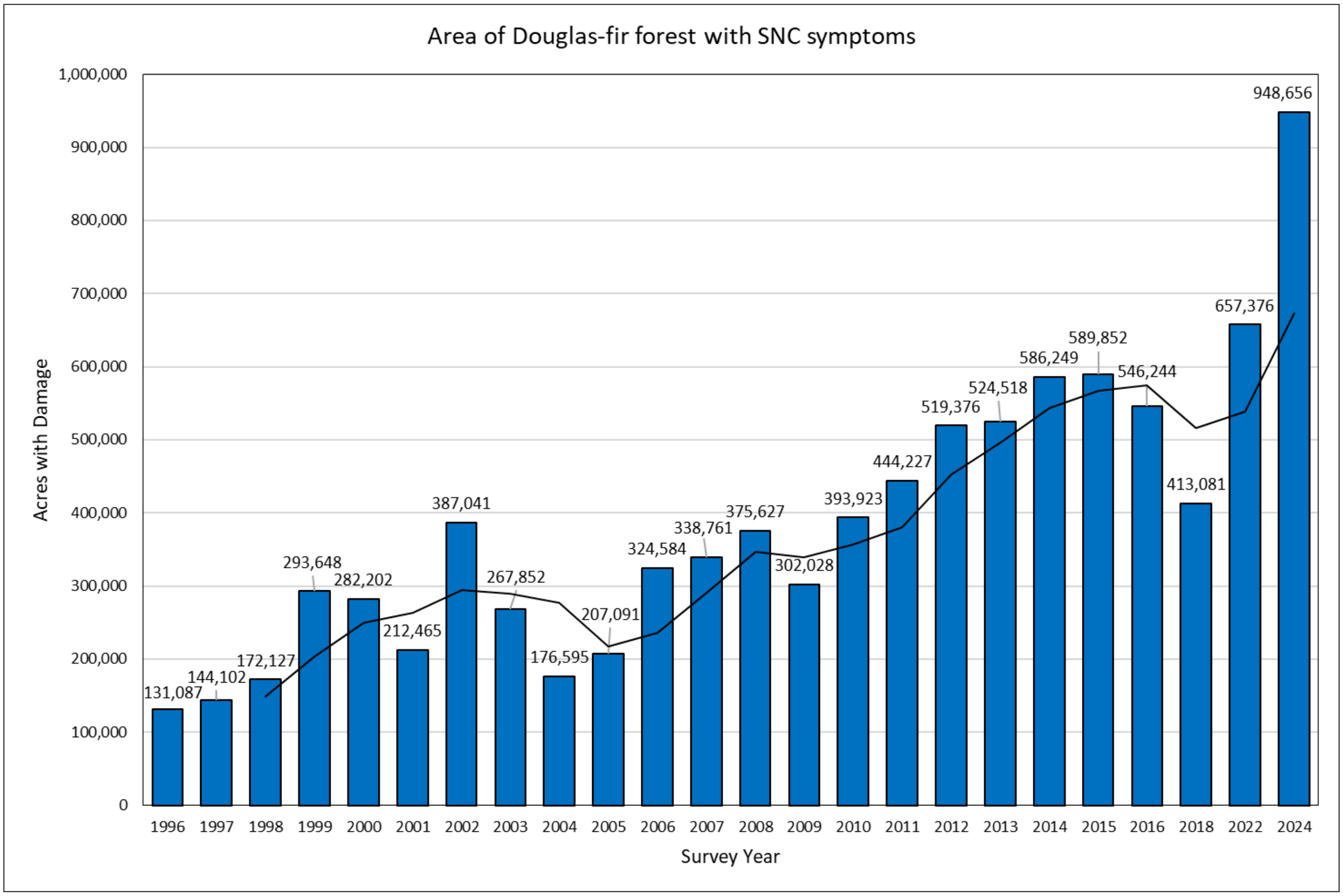

Figure 3. *Area of Douglas-fir forest in western Oregon with symptoms of Swiss needle cast detected during aerial surveys conducted between April and June, 1996-2024. Results from 2008 were estimated by extrapolating from three survey blocks. Trend line is 3-year rolling average.*

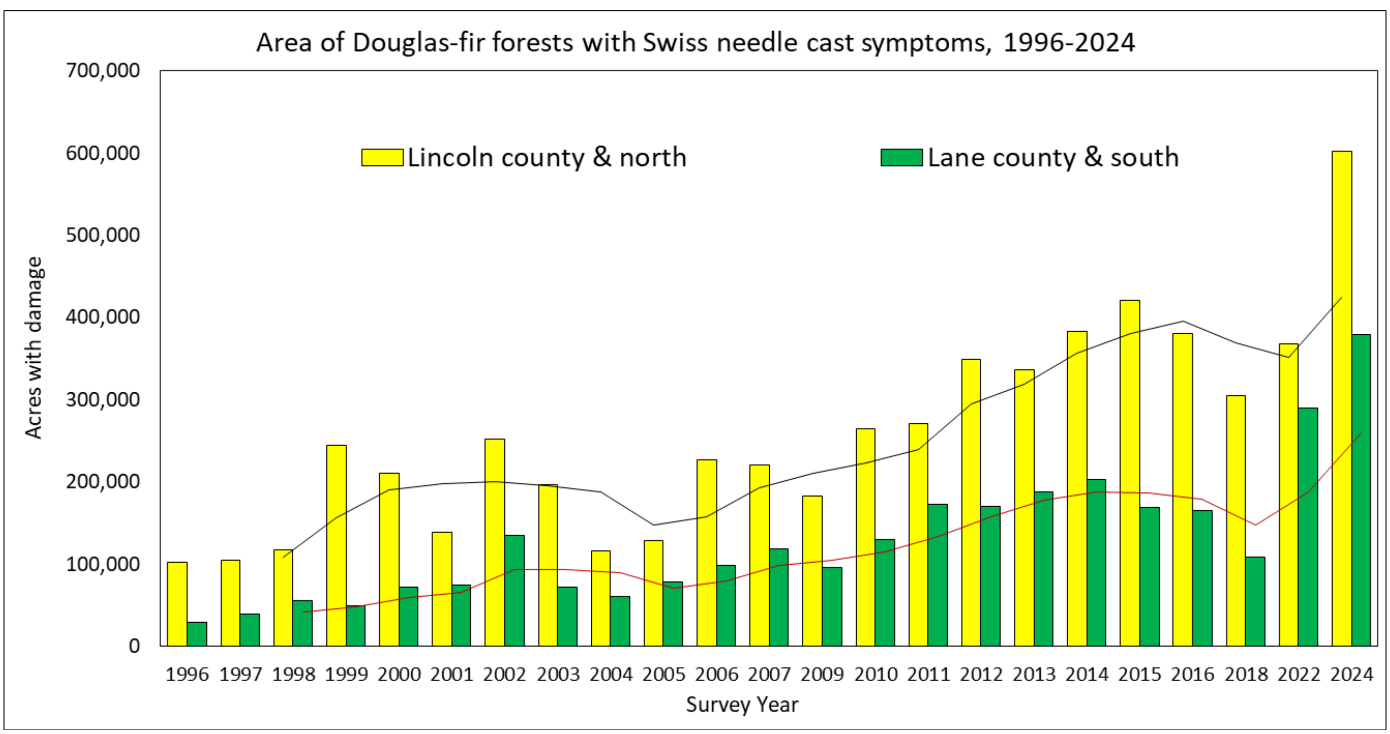

Figure 4. *Area of Douglas-fir forest in western Oregon with symptoms of Swiss needle cast detected during aerial surveys conducted in April-June, 1996-2024; north and south halves of survey area. Trend line is 3-year rolling average. Coast Range, Oregon.*

Western Washington Swiss Needle Cast Aerial and Ground Surveys, 2024

Swiss needle cast (SNC) is a native fungal foliar disease of Douglas-fir, often associated with Pacific NW coastal forests. Impacts of infection may include:

- Foliage discoloration
- Premature needle loss
- Reduced tree growth

Aerial survey

- Completed April and May 2024
- 2.1 million acres surveyed along the coast
- 49,500 acres displaying symptoms mapped, representing 2.4% of the total area surveyed
- Acres mapped are below recent measurements
- Aerial surveys detect discoloration and thinness in trees, not necessarily SNC symptoms

Ground survey

- Conducted spring 2024
- Assessed 61 ground plots representing over 3 million acres along the Pacific coast and in the NW region
- Along the coast, needle retention and SNC fungal counts were comparable to previous observations
- In the NW region, average SNC fungal counts and needle retention measurements were higher than along the coast, with higher fungal count variability
- Correlations between needle retention and SNC fungal counts in each region were significant but did not account for all the variation seen, suggesting other stressors are likely contributing to needle loss in addition to SNC

Based on these criteria, there has been no overall increase in SNC over the past decade in coastal Washington

Surveys conducted by

Washington Department of Natural Resources, USDA Forest Service, and Washington Department of Fish and Wildlife

Discolored yellow-brown Douglas-fir stands in coastal Washington

Map of 2024 Swiss needle cast aerial survey data

Western Washington Swiss Needle Cast Aerial and Ground Survey, 2024

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Abstract

Swiss needle cast (SNC), caused by the native fungus *Nothophaeocryptopus gaeumannii*, is a foliar disease of Douglas-fir (*Pseudotsuga menziesii*) associated with Pacific Northwest coastal forests. This disease can cause foliage discoloration, foliage loss, and reduced growth in Douglas-fir. In April and May 2024, an aerial survey covering 2.1 million acres was flown to map the distribution of discolored Douglas-fir trees in coastal Washington forests. 49,500 acres of symptomatic Douglas-fir were mapped, which is lower than acreage mapped in previous years. In support of the aerial survey, 44 ground plots across the range of the aerial survey were also assessed in the spring of 2024. Fungal counts (percent of stomata blocked by fungal fruiting bodies on two-year-old needles; pseudothecia density) and needle retention (amount of needles from previous years retained on a secondary lateral branch) were estimated at each plot. Average needle retention was measured at 2.3 years and fungal counts were measured at 14.1%, both within range of previous surveys. During the same period, 17 ground plots were surveyed in the NW region, an area not covered by the aerial survey. Needle retention averaged 2.5 years and fungal counts averaged 17.1%, which are higher than those measured along the coast, though fungal counts varied greatly in the NW region. The correlation between fungal counts and needle retention was significant in both locations, though only accounted for a portion of the variation observed. This indicates that SNC in addition to other drivers, such as weather, site quality, tree genetics, or other diseases and pests, are driving needle retention in Douglas-fir in these areas. Based on these criteria, there has been no overall increase in SNC over the past decade on Douglas-fir in coastal Washington.

Introduction

The native fungus that causes the foliar disease Swiss needle cast (SNC), Notho*phaeocryptopus gaeumannii*, is found everywhere its only host Douglas-fir (*Pseudostuga menziesii*) is grown. This foliar disease can cause premature needle loss and foliar discoloration that results in reduced tree growth (Shaw et al. 2021). This native pathogen became a priority in the coastal forests of Washington and Oregon in the 1990s, and more recently has been a concern in British Columbia (Shaw et al. 2021). These areas have likely seen high SNC levels due to the fungi-favorable topographic and climatic conditions (including mild winters and wet springs), historical plantings using off-site Douglas-fir seed sources, and increases in Douglas-fir numbers due to forest management practices (Shaw et al. 2021). Monitoring SNC and its symptoms along the Pacific NW coast from the air and on the ground has become common practices in Washington and Oregon.

In Washington, an aerial survey along the coast was completed in 1998, 1999, 2000, 2012, 2015, 2016, 2018, and 2022 with mapped symptomatic acres ranging between 44,000 to over 400,000 (Ramsey et al. 2018; Brooks, et al. 2022). In Oregon, where the disease is most severe, an aerial survey has been conducted most years since 1996 along the coast (https://sncc.forestry.oregonstate.edu/survey-maps). In Oregon, Washington, and recently in British Columbia, ground plots have also been used to support aerial surveys and help correlate the observed discoloration with fungal counts, needle retention, and tree growth. In Washington, ground surveys have been conducted most years since 1997.

The goal of the 2024 SNC survey was to build upon past monitoring efforts within Washington in order to detect any significant changes.

Methods

The Washington State Legislature and the USDA Forest Service provided funding to conduct aerial and ground surveys of SNC in Washington in 2024. Two regions were targeted for surveying: the 'coastal region' along the Pacific coast and the 'NW region' representing the active timberlands between the cities of Mount Vernon, Darrington, Concrete, Bellingham, and Sumas. The coastal region represents the area where SNC impacts have historically been of greatest concern since the mid-90s, while the NW region has been included in surveys since 2021 due to its proximity to British Columbia where SNC has been reported as a growing concern (Shaw et al. 2021). In 2024, both aerial and ground surveys were conducted in the coastal region and a ground survey was completed in the NW region.

The aerial survey in the coastal region was conducted during April and May 2024 and covered 2.1 million acres (Figure 3). This survey is timed to occur after crown discoloration symptoms have developed, but before new foliage has emerged (bud break). The survey area extended from the Columbia River north to the Strait of Juan de Fuca, and from the coastline eastward. The observation aircraft flew at 1,500 to 2,000 feet above ground level, following north-south or east-west lines separated by 3 miles. Observers on both sides of the aircraft looked for areas of Douglas-fir with apparent yellow-brown thinning foliage, a rather generic symptom that is considered to be indicative of moderate to severe SNC disease. Patches of forest with these symptoms were sketched onto touch-screen tablets displaying topographic maps or ortho-photos and the position of the aircraft. Each polygon was classified as either severe or moderate depending on symptoms observed.

Ground surveys were conducted throughout both study areas (the coastal region and the NW region) during the spring of 2024, representing 2.4 million acres and 0.7 million acres respectively (Figure 4). Ground sampling locations in each of these areas were separately selected with a uniform spatial weighting function using a balanced acceptance sampling method (Robertson et al. 2013). Based on time availability and region size, 50 sampling locations were randomly selected in the coastal region and 17 selected in the NW region. Each selected point was visited once between March and April 2024. At each site, an accessible and appropriate stand (dominated by suitably sized Douglas-firs) no greater than four miles away from the random point was chosen for sampling. Points that had no appropriate or accessible sites within four miles were excluded. In total, the Coastal Region had 44 sites assessed and the NW Region had 17 sites assessed.

At each ground survey location, 10 Douglas-fir trees were selected for sample collection and measurements. Needle retention was visually estimated on each tree by totaling the amount of needles from previous years retained on a secondary lateral branch (0 indicates there were no needles retained and 3.6 indicates full retention of 4-years of foliage). Two-year-old foliage was collected from each tree and taken back to the lab for examination under a microscope. Fungal counts were determined by counting the number of fruiting bodies (pseudothecia) visible in 300 stomata on each of ten needles for each tree. Needle retention and fungal counts were compared between regions and correlations were assessed for each region.

Figure 1: The underside of a two-year old needle collected during SNC ground plot monitoring showing blocked stomata (black dots) and unobstructed stomata (white dots). Fungal counts are the percentage of stomata blocked by the black fungal fruiting bodies (pseudothecia density).

Results & Discussion

The aerial survey covered 2.1 million acres in the coastal region in April and May 2024, totaling 7 hours of flying time. SNC associated symptomatic stands (Figure 2) were detected on just under 50,000 acres, representing 2.4% of the total acres surveyed, below the acreage detected in recent surveys (Table 1; Ramsey et al. 2018). Severely symptomatic stands were generally located between Westport and Ilwaco, while moderately symptomatic stands were found scattered throughout the region (Figure 3).

Figure 2: Douglas-fir stands displaying yellow-brown discoloration and crown thinness often associated with high SNC disease near South Bend, WA in 2024.

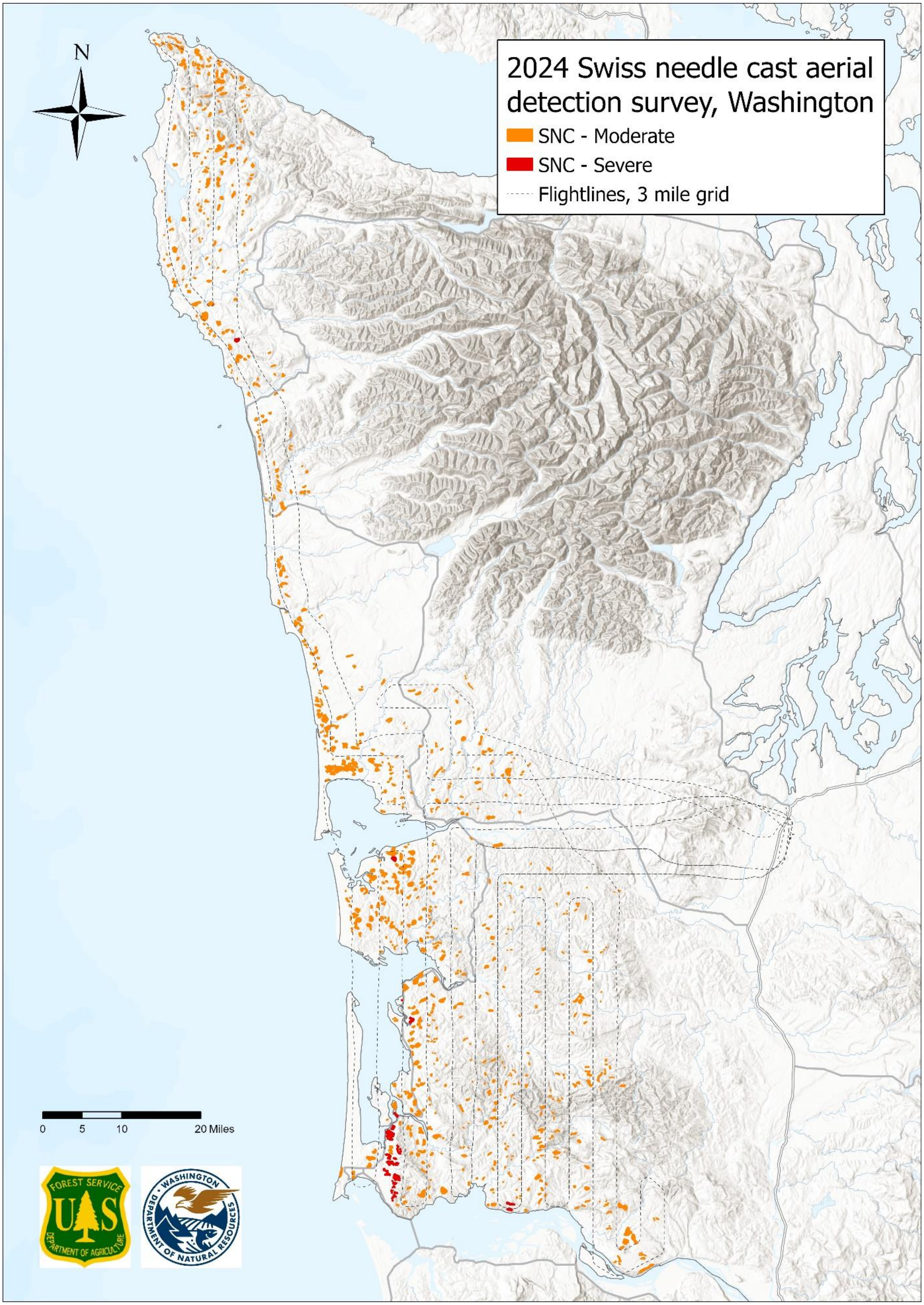

Figure 3: Washington 2024 Swiss needle cast aerial survey map showing the flight path and the mapped SNC severe and moderate stands based on discoloration and foliage thinness observed from the aircraft.

Table 1: The 2024 aerial survey results compared to previous results in the coastal region of Washington since 2012 (Ramsey et al. 2018).

	severe SNC symptoms		moderate SNC symptoms		total SNC symptoms		area flown
year	% of total acres	severe SNC acres	% of total acres	moderate SNC acres	% of total acres	total SNC acres	acres in millions
2024	< 1%	3,000	2.2%	46,500	2.4%	49,500	2.1
2022	1%	29,000	4%	87,000	6%	115,000	2.0
2018	< 1%	6,000	3%	73,000	3%	79,000	2.7
2016	< 1%	14,000	10%	234,000	10%	248,000	2.4
2015	1%	19,000	13%	332,000	14%	351,000	2.6
2012	< 1%	6,000	8%	222,000	9%	228,000	2.7

The 2024 ground surveys found that needle retention and severity varied between site, regions, and by year.

In the coastal region, average needle retention was measured at 2.3 years, with specific sites ranging from 1.6-2.7 years. Fungal counts were measured at 14%, with specific sites ranging from 4.7-34%.
Both measurements were within the range of previous measurements, with fungal counts being on the lower range and needle retention falling right in the middle (Table 2).

In the NW region, average needle retention was measured at 2.5 years, with specific sites ranging from 2.1-3.1 years. Fungal counts were measured at 17%, with specific sites ranging from 0 – 28%. The average fungal counts measured was lower than the previous years of measurements, while the average needle retention was within the range of the previous years of measurements.

Overall, needle retention and fungal counts were higher in the NW region, matching the 2021 and 2022 trends. Though fungal counts in the NW region had a much larger spread than measurements taken in the coastal region (Figure 5).

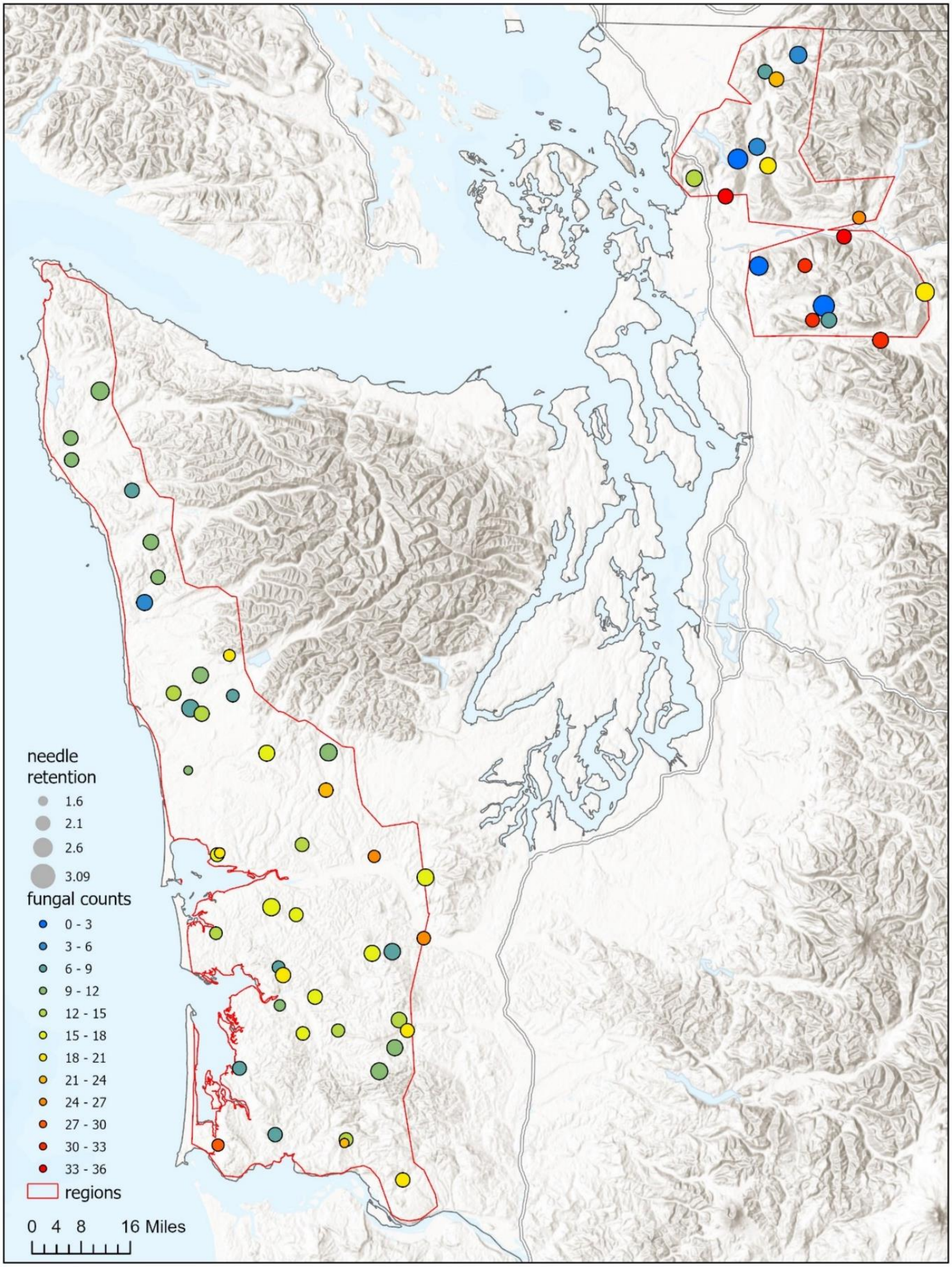

Figure 4: SNC ground survey plot results from 2024. Surveyed regions are outlined in red (NW region in the upper right and coastal region in the lower left) with points representing sampled plot locations. Point size indicates average needle retention and point color represents fungal counts.

Table 2: Number of sites, average fungal counts, and average needle retention for each region surveyed since 2012.

region	year	number of sites	average fungal counts (%)	average foliar retention
coastal	2024	44	14.1	2.3
	2022	48	8.9	2.1
	2021	48	21.1	2.5
	2018	26	16.0	2.3
	2016	63	22.1	2.4
	2015	47	22.5	2.3
	2012	75	15.5	2.2
NW	2024	17	17.1	2.5
	2022	17	25.6	2.4
	2021	15	35.9	2.9

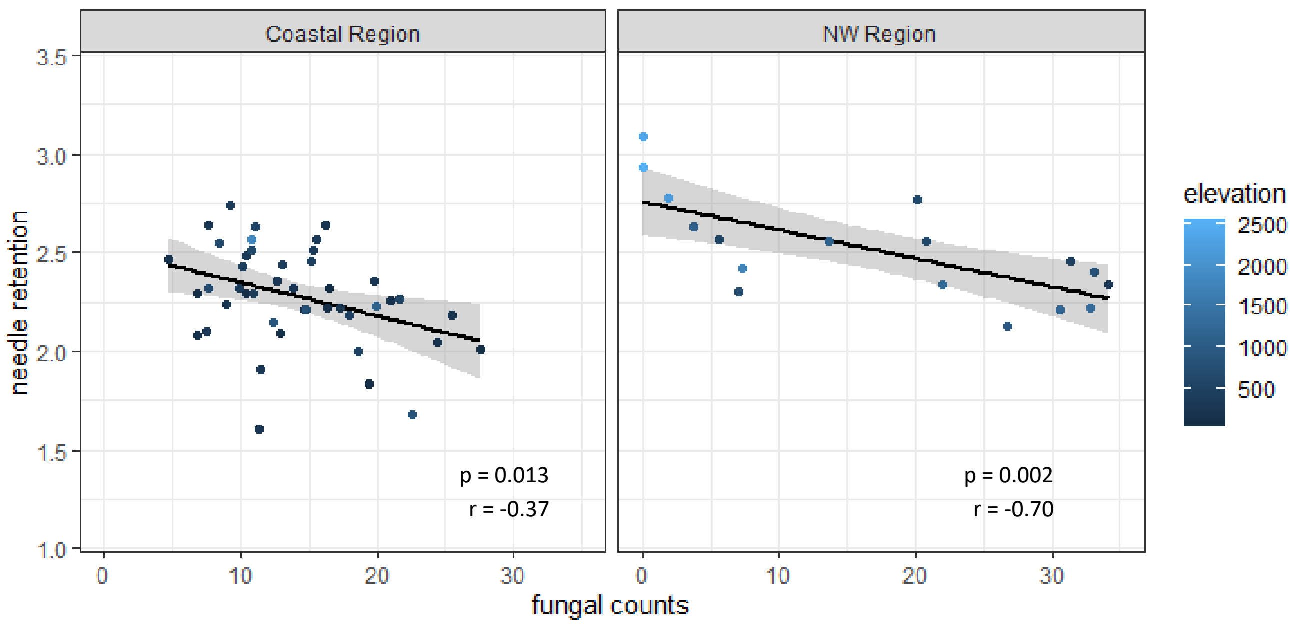

Figure 5: Correlations between average fungal counts and average needle retention for each site split by region. Elevation (feet) for each site indicated by color. Associated p-values and r values are shown on each graph.

The correlation between fungal counts and needle retention was significant in both regions, displaying the expected relationship between high fungal counts and low needle retention. This relationship explained 37% of the variation measured in the coastal region and 70% of the variation in the NW region (Figure 5). This correlation is expected because as fungal counts increase, the function of stomata which are responsible for gas and water exchange is expected to decrease, possibly causing needle loss.

As this correlation does not explain all the variation seen, this indicates that other factors besides SNC are likely contributing to needle loss in Douglas-fir in both the coastal and NW regions. Other factors that may impact needle retention include weather, site quality, tree genetics, or other diseases and pests. For example, in 2024, elevation was significantly correlated with needle retention in the NW region (p=0.019, r=0.56) but not in the coastal region (p=0.35, r=0.14) (Figure 5).

Overall numbers from both the ground survey and the aerial survey indicate that there has been no substantial increase in the severity of SNC over the past decade in coastal Washington. This is because aerial survey measurements are within the range or lower than those recorded during previous years (Table 1) and ground surveys found fungal counts and needle retention measurements within the previously measured range (Table 2). Results from the NW region are inconclusive, as ground measurements do not exist prior to 2021. Results indicate Douglas-fir in the NW region has higher levels of needle retention than the coastal region, despite having higher levels of fungal counts.

Caution should be advised when interpreting this data. The SNC aerial survey detects symptoms (discoloration and thinning) visible from above. As aerial observers can only map areas where symptoms are visible from 1,000+ feet, aerial survey data can only be used to coarsely document symptoms over time. Additionally, although correlation between fungal counts and needle retention can be seen to some degree, correlation does not confirm causation. Therefore, while the aerial survey and randomly selected ground points can be used as a guide for identifying areas impacted by SNC, site specific ground surveys should be conducted in stands of interest before SNC mitigating management decisions are made. If less than three years of foliage are being retained on Douglas-fir branches at a given site, then growth loss may occur. Given that Douglas-fir is the only host of this pathogen, forest managers with SNC impacted sites may select for or plant other tree species, such as red alder, western redcedar, western white pine, Sitka spruce, or western hemlock. For a more detailed management discussion, refer to the "Silvicultural decision guide for Swiss needle cast in coastal Oregon and Washington" (Ritóková et al. 2022) available online at: extension.oregonstate.edu/pub/em-9352

Acknowledgements

The survey was conducted by the Washington Department of Natural Resources (WDNR) Forest Resilience Division and Wildland Fire Management Division, the Washington Department of Fish and Wildlife (WDFW) Aviation Section, and the USDA Forest Service Forest Health Protection Group. Marty Kimbrel (WDFW) and Mike Burke (WDNR) piloted the aircrafts. Funding for the survey was provided by the Washington State Legislature and the USDA Forest Service, an equal opportunity employer.

Contact Us

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BC 2024 Swiss Needle Cast (SNC) Update

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British Columbia (BC) has 43 Oregon Coop style Swiss needle cast monitoring plots that were established over a three-year period between 2016 and 2018. Fourteen of the plots have weather stations. The last set (of 7 plots) had their pseudothecial counts completed in 2024. A Masters student from the University of British Columbia (UBC), Annie Dicaire, is working on summarizing the 5 year data from these plots under the direction of Dr. Richard Hamelin.

BC also conducted an aerial SNC flight of the Fraser Valley in early May (Fig. 1). Due to the mountainous terrain in the Fraser Valley, it is not possible to fly straight lines, so target Douglas-fir leading stands were selected from the provincial silviculture data base (RESULTS) in the Coastal Western Hemlock dry maritime and very wet subzones prior to the flight. The flight identified similar sites to those in a previous 2018 flight. However, the areas of highest severity differed somewhat from the 2018 flight. The contractor recommended some changes to the future flight procedures which included flying before deciduous leaf out.

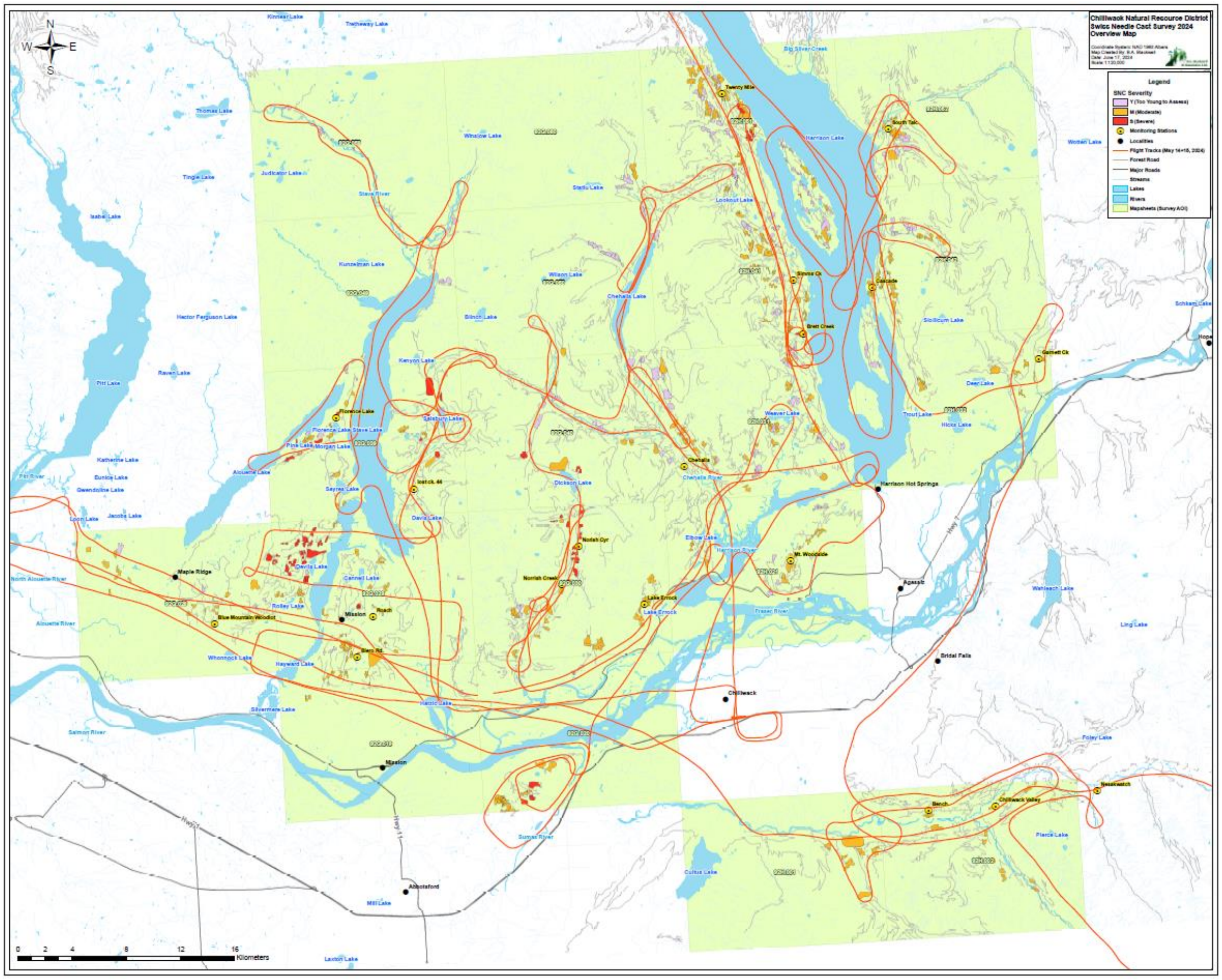

Fig. 1. SNC 2024 flight results for Fraser Valley CWHvm and CWHdm Douglas-fir leading young stands. The red line indicates the flight path. Red = high severity, Orange = moderate severity. Yellow dots are the locations of SNC long term monitoring plots.

BC has also started a SNC collaborators group made up of representatives from the University of Victoria, UBC, and provincial and federal government employees working with SNC, which has started meeting regularly to collaborate on SNC research.

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Brief Communication

Economics

Effects of Swiss Needle Cast on the Profitability and Optimal Management of Douglas-fir Plantations in Western Oregon

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Abstract

This study conducts an economic analysis to evaluate the impact of Swiss needle cast (SNC) caused by *Nothophaeocryptopus gaeumannii* on Douglas-fir (*Pseudotsuga menziesii*) plantations at the stand level in western Oregon. We examine timber and nontimber benefits across varying degrees of SNC severity considering timber benefits and carbon sequestration benefits. By comparing these values with unaffected Douglas-fir stands, our aim is to quantify the economic losses associated with SNC in terms of the land expectation values. The total land expectation value for a stand affected by SNC ranges from $556 to $2,179/ac, representing an average decrease of 50% ($1,066/ac) in economic revenues compared with a Douglas-fir stand without SNC infestation. Engaging in cost-effective annual management activities, with maximum costs of $43–$56/ac, could offset the profitability decline. On average, the total losses in profits for the current plantations affected by SNC are estimated to be around $206.5–430 million.

Study Implications: In this study, we examine the economic impacts of Swiss needle cast (SNC) on the profitability of western Douglas-fir in Oregon. Our results reveal that profits for landowners can be, on average, reduced by $1,066/ac when their stand is infested by SNC, representing a 50% loss in profitability. Landowners could potentially mitigate these losses by engaging in annual management activities aimed at preventing Douglas-fir infestation, incurring a cost ranging between $43–56/ac, which could offset the reduction in profitability.

Keywords: Swiss needle cast, Douglas-fir, land expectation value, Oregon

Swiss needle cast (SNC), a foliar disease unique to Douglas-fir (*Pseudotsuga menziesii*) and attributed to the Ascomycete fungus *Nothophaeocryptopus gaeumannii*, has emerged as a notable threat to Douglas-fir plantations in the Pacific Northwest region. Aerial observations have revealed a significant increase in the plantation area affected by SNC, with visible symptoms expanding from 141,431 ac in 1996 to 546,241 ac in 2016 (Shaw et al. 2021). The primary impact of Swiss needle cast on Douglas-fir is to diminish needle retention, thereby reducing tree diameter and height growth, as well as impeding the tree's ability to compete for growing space (Maguire et al. 2002, 2011). This disease specifically disrupts needle gas exchange and accelerates premature casting of foliage, ultimately leading to a decline in the growth of Douglas-fir plantations (Kelsey and Manter 2004; Shaw et al. 2021).

Over time, this decreased growth can significantly alter forest composition and productivity, potentially resulting in economic losses. Although mortality due to SNC has been observed in severe cases, it is rarely witnessed on a landscape scale (Maguire et al. 2011; Ritóková et al. 2021; Shaw et al. 2021). Mortality was noted in mature trees (~80-90 years old) that had been chronically infected for over two decades at one site, although drought was considered a contributing factor to this mortality (Shaw et al. 2021). In other instances, mortality may occur as a result of trees being overshadowed by competing western hemlock trees rather than directly from the disease (Maguire 2011). This disease hampers needle gas exchange and accelerates premature casting of foliage, ultimately leading to a decline in the growth of Douglas-fir plantations (Kelsey and Manter 2004; Shaw et al 2021). The environmental factors linked to the development of SNC are mild winter temperatures and leaf wetness during the spore dispersal period, typically occurring from May through August (Ritóková et al. 2016; Shaw et al. 2021).

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Several studies have highlighted the significant negative impact of SNC on the growth and yield of Douglas-fir plantations. A comprehensive analysis conducted by Maguire et al. (2002; 2011) focused on 10- to 30-year-old Douglas-fir plantations in the coastal northwestern region of Oregon. The study reported average cubic volume growth losses of 23%, reaching a maximum of 52% for plantations severely affected by SNC. These growth losses depended on foliage retention[1], with the most substantial reductions observed in plantations exhibiting the lowest levels of foliage retention (Maguire et al. 2011). For example, the average volume growth losses between 1990 and 1996 accounted for 42%, 32%, and 23% for foliage retentions of 1 year, 1.5 years, and 2 years, respectively (Maguire et al. 2002). Black et al. (2010) examined the effects of SNC on older Douglas-fir trees, specifically those exceeding 80 years of age, within the western Oregon Coast Range. Their findings revealed a significant decline in diameter growth, with reductions of up to 85% observed in the most severely affected stands.

Diseases caused by pests or pathogens can lead to significant changes in forest structure and fluctuations in the supply of goods and services provided by the forest ecosystem, resulting in substantial economic losses (Zhai and Ning 2022). For example, Kovacs et al. (2011) found that the cost of treating, removing, and replacing oak trees affected by oak wilt in Minnesota was $7.5 million. Similarly, Pye et al. (2011) estimated annual economic losses of $43 million for forest landowners and $30 million for wood-product consumers due to southern pine beetle outbreaks in the southern United States. Douglas-fir forests play a crucial role in the timber industry of the state of Oregon, constituting approximately 65% of the growing stock and contributing to over 70% of the total harvest volume (Oswalt et al. 2019). Therefore, understanding the economic losses caused by SNC on Douglas-fir plantations is essential, given their substantial role in Oregon's economy, as the forest sector contributes approximately $18 billion in output, supports over 71,000 jobs, and generates over $8 billion in state gross domestic product (Oregon Forest Resources Institute 2019). To the best of our knowledge, this type of economic analysis has not been explored.

In this article, we determine the land expectation values of Douglas-fir plantations at the stand level in western Oregon considering timber and nontimber benefits, with different levels of SNC severity. We then compare these values with the land expectation values of Douglas-fir plantations unaffected by SNC to ascertain the economic losses. Additionally, we extrapolate these economic estimates to predict region-wide impacts.

Economic Model Specification

We used the theoretical model proposed by van Kooten et al. (1995) for our analysis. In this model, it is assumed that a Douglas-fir stand, starting from bare land, is planted and managed for timber production and carbon sequestration. The landowner is continuously paid per metric ton of carbon sequestered by the trees as the stand is growing. Once the stand reaches the rotation age, the stand is harvested, the landowner receives timber benefits, and the stand is immediately replanted. Furthermore, the landowner faces carbon taxes levied at the time of harvesting due to forest product decay. This cycle is repeated perpetually. From a landowner's perspective, the net present value of the timber benefits assuming forestry use in perpetuity, also known as land expectation value (LEV), can be modeled as follows:

$$LEV(t)_{timber} = \frac{PV(t)\ e^{-rt} - C}{1 - e^{-rt}} - \frac{C_a}{e^r - 1} \tag{1}$$

where $P$is the timber price net of harvesting cost, $V(t)$ is the timber volume over time t, C_a is the annual management costs, C is the plantation costs, and r is the discount rate. Likewise, the land expectation value of carbon sequestration benefits can be represented as

$$LEV(t)_{carbon} = \frac{\int_0^t P_c\alpha \frac{dV(s)}{ds} e^{-rs} ds - P_c\alpha(t)\, V(t)\,(1-\beta)\, e^{-rt}}{1 - e^{-rt}} \tag{2}$$

where P_c is the price of carbon, $\alpha$is the factor that converts the timber volume in metric tons of carbon, $V(s)$ represents the timber volume at time s—thus $\frac{dV(s)}{ds}$ represents the marginal change of timber volume—and β is the proportion of carbon that is permanently sequestered by long-lived forest products. The first term in the numerator on the right-hand side of (2) represents cumulative present value of carbon benefits over the age of stand: the landowner annually receives a subsidy $P_c\alpha$ for each unit of timber volumed added to the growing stock. The second term in the numerator on the right-hand-side of (2) represents the present value of taxes due to carbon emissions: the landowner will pay a tax of $P_c\alpha$ per unit of timber volume harvested. The total land expectation value of the Douglas-fir stand can be modeled as

$$LEV(t)_{total} = LEV(t)_{timber} + LEV(t)_{carbon} \tag{3}$$

The optimal harvest age of the stand is the time t^* that maximizes the LEV in (3).

Model Application to Douglas-fir

We used CIPSANON 4.0 to simulate the timber growth of Douglas-fir at the stand level. CIPSANON is a proprietary forest growth model developed by Oregon State University, specifically constructed for modeling intensively managed Douglas-fir forest plantations. It incorporates various factors, including the impact of genetic tree improvements and the severity of SNC (Joo et al. 2020). In our analysis, we investigate four simulated plantations in Western Oregon. Each plantation has a site index of 115 feet[2] (base age = 50 years) and begins with a planting density of 435 trees per acre and undergoes simulation with varying levels of SNC effects: no infection, and infection represented by two levels of foliage retention (FR; FR = 2 years and FR = 1 year). This leads to a total of 12 timber growth simulations conducted using CIPSANON. The starting data for the simulation such as diameter, height, and crown base data is taken from measured operational plantations and then projected from those measurements to create the simulated data. We calculate the LEV of the Douglas-fir stand for each of these simulations by using the estimates of the economic parameters in Table 1). We have not included commercial thinnings in our analysis because, given the management of Douglas-fir and current market conditions (i.e., higher prices of Douglas-fir logs for lumber and a tight timber supply), commercial thinnings are not typically conducted to maximize the rotation value in Douglas-fir plantations (ResourceWise 2023; Talbert and Marshall 2005). Furthermore, thinnings are not an effective silvicultural technique to reduce SNC in Douglas-fir plantations (Shaw et al. 2021).

Results and Discussion

Our analysis shows that SNC significantly reduces timber volume of Douglas-fir plantations over time[3] (figure 1). This reduction in growth leads to substantial reductions in the profitability of plantations (Table 2). The LEV_{total} for a stand affected by SNC varies from \$556 to \$2,179/ac. This represents an average decrease of 50% (\$1,066/ac) in economic revenues compared with a Douglas-fir stand without SNC infestation. Consistent with expectations, higher reductions in LEV_{total} are observed with foliage retention of 1, resulting in an average reduction of 71% (\$1,516 per acre). Meanwhile, the reduction in total economic revenues with a foliage retention of 2 accounts for 29% (\$615/ac).

The influence of SNC has a more pronounced impact on timber revenues than on carbon sequestration benefits in Douglas-fir plantations. For instance, for plantations with foliage retentions of 1 and 2, the reduction in the LEV_{timber} is on average 73% (\$1,398/ac) and 30% (\$567/ac), respectively. In comparison, the reduction in the LEV_{carbon} is 55% (\$118/ac) and 22% (\$47/ac).

The presence of SNC leads to the extension of optimal harvest ages (Table 2). This extension is a result of the LEV maximization process under the influence of SNC: the reduction in forest growth decreases stumpage value, which consequently delays the harvest of the stand (Chang 1984).

Our average estimated economic loss, amounting to \$1,066, offers illustrative insight into the overall profitability reduction in Douglas-fir plantations across Oregon. Given that approximately 413,000 ac of Douglas-fir are presently affected by SNC, as reported by Shaw et al. (2021), and assuming an average reduction range of \$500–\$1,000/ac, the total loss in profits is estimated to be around \$206.5–\$413 million.

Table 1. Economic parameters and values.

Net timber price P	\$438 per MBF [a] (Oregon Department of Forestry 2023; Rossi and Kuusela 2023)
Planting costs C	\$400 per acre (Rossi and Kuusela 2023)
Management costs C_a	\$3 per acre per year (Rossi and Kuusela 2023)
Carbon price P_c	\$50/metric ton of carbon (California Air Resources Board 2024)
Real discount rate r	0.04 (Rossi and Kuusela 2023)
Proportion of carbon that is permanently sequestered β	0.8 (Susaeta et al. 2020)
Conversion factor of timber volume in metric ton of carbon α	0.000571 metric ton of carbon per MBF (Turner et al. 1995)

[a]The value of P was calculated assuming a delivered log price of \$738 per thousand board feet (MBF) (Oregon Department of Forestry 2023) and a harvesting cost of \$300 per MBF (Rossi and Kuusela 2023).

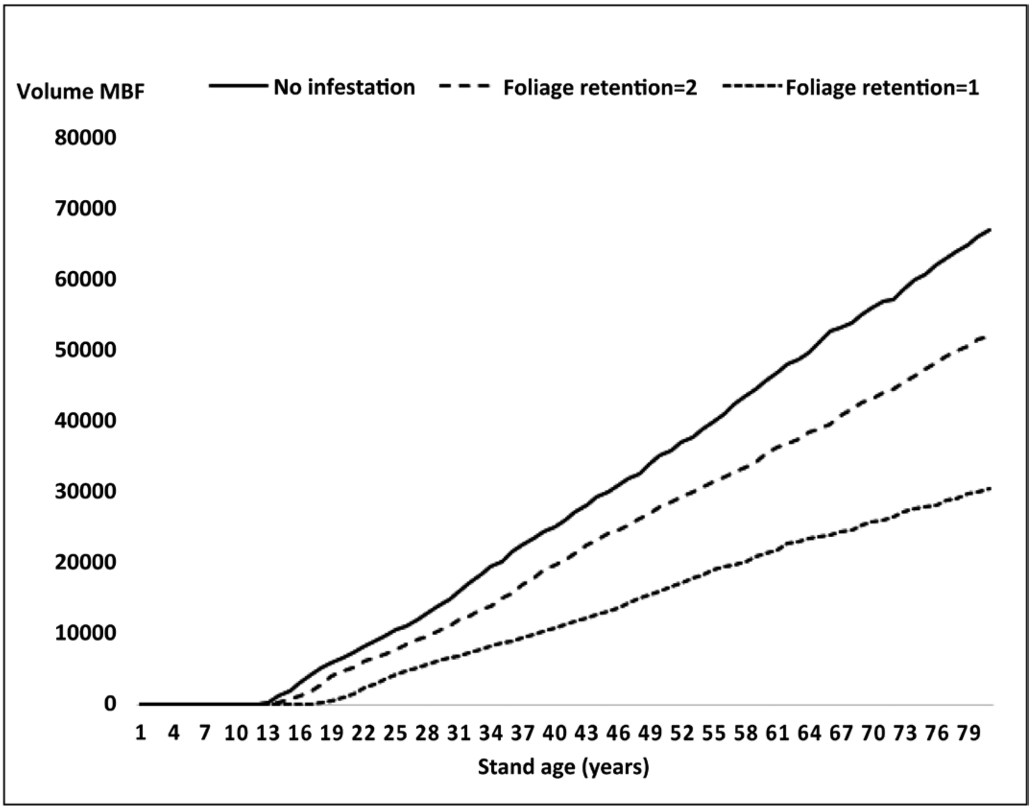

Figure 1 Average timber volume over time under the effect of SNC

Table 2. Land expectation value of timber production (***LEV_{timber}***), carbon sequestration (***LEV_{carbon}***) and total (***LEV_{total}***) along with optimal harvest ages (t^*) for Douglas-fir plantation units under different levels of foliage retention (FR).

	LEV_{timber}	LEV_{carbon}	LEV_{total}	Harvest age t^*
Unit 1	$/ac			Years
No infestation	1891.7	211.3	2103.0	41
FR = 2	1310.6	168.0	1478.6	47
FR = 1	460.5	95.1	555.6	52
Unit 2				
No infestation	1868.5	215.5	2084.0	42
FR = 2	1299.5	157.8	1457.3	44
FR = 1	483.2	97.9	581.1	52
Unit 3				
No infestation	1933.2	219.3	2152.5	40
FR = 2	1380.7	164.4	1545.1	43
FR = 1	564.5	84.4	648.9	42
Unit 4				
No infestation	1975.1	204.3	29.4	37
FR = 2	1407.5	170.1	1577.6	43
FR = 1	566.7	100.7	667.4	48

Policymakers can leverage the observed losses in the profitability of Douglas-fir plantations as a crucial metric for evaluating the potential investment in proactive forest management. This may include initiatives such as the establishment of mixed forest species stands and the use of seed sources tolerant to disease (Ritóková et al. 2022). Although not totally conclusive, these efforts aim to minimize the impact of SNC of forest health and economic sustainability. In essence, the losses in profitability can be interpreted as the opportunity costs of not proactively managing the plantations. For instance, with a reduction of $1,066/ac, forest landowners could benefit economically by engaging in annual management activities costing below $43/ac to prevent SNC[4]. For example, the average LEV for all units without SNC infestation is around $2,130/ac. If a landowner incurs an annual preventive cost of $30/ac, the total preventive cost would be $750/ac, which is still less than the $1,066/ac loss incurred when no preventive actions are taken. Comparatively, managing the plantation exclusively for timber production, with an average economic loss of $1,398/ac, would require annual management costs to be below $56/ac for proactive management to be economically preferable to taking no measures in the presence of SNC. Examples of activities that can be effective in preventing SNC infections include the annual application of fungicides, although this can be a costly operation (Shaw et al. 2021).

Additional research is crucial for a comprehensive understanding of the economic impacts of SNC on the forest sector. Investigating factors such as its influence on biodiversity, the spatial dependence of plantations in relation to SNC, and the resulting reduction in timber supply due to decreased forest productivity are vital areas for further exploration. Moreover, integrating silvicultural techniques, such as the use of local seed sources and improved seed stock with known tolerance to SNC (Shaw et al. 2021), into the economic analysis can be an essential factor to consider. Furthermore, our model assumes that forest landowners are indifferent to the risk of the arrival of SNC. Examining the implications of risk aversion to the arrival of SNC on Douglas-fir management is another avenue for further research.

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Conflict of Interest

None declared.

Data availability

The data underlying this article will be shared on reasonable request to the corresponding author.

End Notes

[1]Foliage retention is the main predictive tool for estimating timber growth losses due to foliage disease, defined as the average number of years that foliage cohorts are retained (Mainwaring et al. 2023). Foliage retention typically ranges between 1 to 2.5 years (Maguire et al. 2011).

[2]The rationale for using only a high site index is that the presence of SNC has not been observed on low productivity sites because it is a Coastal Range disease, and those sites do not exhibit such low productivity. A site index of 115 is considered the low end for the Coastal Range. The poorest sites are often at high elevations further from the ocean or have temperatures that are not as conducive to SNC development (Doug Mainwaring, Oregon State University, email, personal communication).

[3]The reduction in timber volume is a direct result of different FR levels due to SNC. Mortality is generally unaffected by SNC. Within CIPSANON, mortality is determined by factors such as diameter, basal area, crown ratio, and site index, which are independent of FR.

[4]This estimate is calculated by annualizing the reduction in profitability, that is, multiplying the economic losses ($1,066) by the discount rate (0.04). In this analysis, we annualize the economic losses for simplicity. However, the

frequency of these costs is arbitrary and could vary from a one-time lump sum up front to being distributed over the rotation period.

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