CHAPTER 10

West Coast Forest Diseases

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Forest diseases along the West Coast can be devastating, especially new introductions that are escalating with increased world trade of forest, ornamental, and agricultural products, as well as increased passenger travel and cargo shipments wrapped in wood-packing material. Recently introduced nonnative diseases such as sudden oak death have seriously affected the ornamental nursery industry in California, Oregon, and Washington as well as native coastal evergreen and redwood/tanoak (*Sequoia sempervirens*/*Lithocarpus densiflorus*) forests in California. Although relatively small in acreage because of early detection and mitigation, sudden oak death is also causing a deleterious impact to the tanoak ecosystems of southwest Oregon (total quarantine area in Curry County is 162 square miles (419.5 km^2) as of the drafting of this chapter.

Other diseases of particular concern include white pine blister rust, which, despite being introduced over 100 years ago, continues to impact the five-needle-pine forests of western North America. Of special concern are the impacts of white pine blister rust on the fragile high-elevation ecosystems of California, Oregon, and Washington where whitebark pine (*Pinus albicaulis*), western white pine (*P. monticola*), and foxtail pine (*P. balfouriana*) are known to be infected and where limber pine and Great Basin bristlecone pine are threatened.

Even native diseases, such as Swiss needle cast of Douglas-fir (*Pseudotsuga menziesii*), that historically have had little impact in native forests currently resemble introduced diseases in their epidemiology and subsequent damage. There are several hypotheses about why this is so: new lineages of the causal fungus; overplanting of the only host species, Douglas-fir, in a historically spruce-hemlock zone; and warmer winters that favor the pathogen.

Climate change is affecting the health of many forests in the West, with probably the greatest impact in Alaska where forest declines in birch (*Betula* spp.) and yellow-cedar (*Chamaecyparis nootkatensis*) are radically changing the ecosystems of these tree species (see p. 98). In Hawaii, dry forests are among the most threatened ecosystems, so development of accurate methods of estimating canopy cover and critical habitat for restoration will lead to better management of these important ecosystems.

Sudden Oak Death Projects

The sudden oak death pathogen *Phytophthora ramorum*, first discovered in 2000, serves as a model of an emergency monitoring need. The disease appeared unexpectedly, affecting tanoak and coast live oak (*Quercus agrifolia*) on valuable properties in many coastal counties. The extent and severity of the puzzling mortality in coastal California had to be determined. As one of the first sources of funds, the Evaluation Monitoring (EM) Program of the national Forest Health Monitoring (FHM) Program of the Forest Service, U.S. Department of Agriculture, played an instrumental role in determining that (1) the pathogen was not confined to coastal California but had established in Curry County, Oregon (Goheen and others 2002a) and (2) that 10 percent of the land area in California coastal forests was infested within a few years of the pathogen's discovery.

The EM program has funded four sudden oak death projects in California and Oregon. These projects, along with other FHM-funded projects, serve as templates for monitoring a new, invasive pathogen, as follows: (1) early detection, (2) risk determination by host mapping, (3) survey of high-risk sites, (4) delimitation and impact assessment, (5) mortality quantification, and (6) early detection surveys in distant areas not known to be infested. It took several years for specific programmatic sudden oak death funding to become available; EM funding was especially critical in the initial discovery phases, since it was one of the few sources of competitive funds.

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Project WC-F-01-05: Monitoring Sudden Oak Death in Oregon (Ground Survey, Aerial Survey, and Aerial Photography)—In 2001, three sudden oak death surveys were conducted in Oregon. Two aerial surveys were conducted by the Oregon Department of Forestry and the Forest Service, noting dead or dying tanoak or Pacific madrone (*Arbutus menziesii*), with subsequent ground verification. A ground survey conducted by the Oregon Department of Agriculture involved noting symptoms and mortality in known hosts near gypsy moth (*Lymantria dispar*) trap locations and along roads, with subsequent field verification. All surveys concentrated on extreme southwest Oregon, an area with extensive host types and proximity to California.

Nine sites in two drainages near Brookings, OR, were detected as positive for *P. ramorum*, with dead tanoak present at all sites and symptoms also found on rhododendron (*Rhododendron macrophyllum*) and evergreen huckleberry (*Vaccinium ovatum*) (McWilliams and others 2002).

These first detections in Oregon triggered a State quarantine for the affected area and a Canadian quarantine of the entire State. A cooperative State/Federal/landowner eradication effort (cutting and burning infested stands) was initiated (Goheen and others 2002b).

Project WC-EM-04-05: Detection and Monitoring of *Phytophthora ramorum* in Oregon—Two fixed-wing and four helicopter aerial surveys for sudden oak death were conducted over 1,316,000 acres (532 600 ha) in southwest Oregon. In 2003, despite ongoing eradication attempts, 292 new dead tanoaks were confirmed from the air and ground checks.

Monitoring within eradication sites indicated that (1) host species sprouted prolifically following cutting and burning; (2) infected sprouts were found on half of infested sites 1 year after treatment; (3) symptom expression and recovery of *P. ramorum* from sprouts was greatest during rainy season but rare in summer; (4) *P. ramorum* rarely was recovered from soil and usually from soil associated with an infected stump; and (5) infected sprouts usually were associated with the stump of a tree known to be infected before cutting. *P. ramorum* was shown to have survived cutting and burning on most eradication sites.

With rhododendron-leaf baits in streams at 27 locations in the vicinity of known *P. ramorum* infestations, *P. ramorum* was recovered from 9 sites in 2003. *P. ramorum* was recovered from most streams draining infested sites and almost never from streams not associated with infested sites. *P. ramorum* was also recovered from rainwater collected beneath infected tanoak.

Detection of new isolated infestations as far as 1.8 miles (2.9 km) from other infestations suggest aerial or vector transmission (Kanaskie and others 2004, 2005, 2006).

Project WC-F-01-08: Monitoring Sudden Oak Death in Coastal California: FIA Plot Remeasurement—The objective of this project was to understand the impacts of the sudden oak death pathogen by comparing 2001 plot remeasurement to 1994 plot conditions (mortality and other stand conditions found by the Forest Inventory and Analysis Program of the Forest Service) in coastal evergreen and redwood forests in eight California counties known to be infested in 2001: Napa, Marin, Monterey, Alameda, San Mateo, Santa Clara, Santa Cruz and Sonoma. Between 9 and 12 percent of the area was estimated to be infested. Over 2,200 FIA plots were visited for sudden oak death assessment in California.

Remote sensing (satellite imagery), aerial observation from fixed-wing aircraft, and aerial photography were also tested as methods for early detection or delimitation. Since the first symptoms of *P. ramorum* infection are typically leaf spots smaller than 0.02 inches (5 mm) on California bay laurel (*Umbellularia californica*), aerial methods were not effective for recognizing newly infested areas. For satellite imagery, even tree mortality was difficult to distinguish from roofs and other features of the wildland-urban interface.

Project WC-F-05-04: Determination of the Incidence and Impacts of *Phytophthora ramorum* in Coastal Forests of California—The project objective was to quantify the *P. ramorum*-killed trees in coastal evergreen and redwood/tanoak forests in California by analyzing several *P. ramorum* plot sets installed from 2000 to 2004. The plot network is made up of 1,109 plots, as follows: by UC Davis, 507 plots [598 square yards (500 m^2) each] in multiple forest types in coastal areas from Monterey County to Del Norte County; by Sonoma State University, 202 randomly located plots [269 square yards (225 m^2) each] in mixed evergreen forests across a 106-square-mile (275 km^2) area in Sonoma County; and by Phytosphere Research, approximately 400 plots [239 square yards (200 m^2) each] in several forest types across Marin, Sonoma, and Napa counties.

An attempt was made to compile plot data into a single database and make a preliminary estimation of mortality. However, an examination of plot-network bias demonstrated that, since all the data were collected in areas known to be infested, the population could not be used to generate a representative estimate of mortality for areas without the disease. Data gaps were noted and additional plots identified. The model will be reapplied to generate a mortality estimate. This project was ongoing in 2009.

Utilization of project results—Results were used to delimit the *P. ramorum*-quarantine and eradication areas in California and Oregon for constructing distribution maps that land managers, home owners, policymakers, legislators, media, and others in turn could use to develop risk maps. Findings also influenced the design of regulatory protocols and management practices.

Besides the utility of the findings themselves, there was benefit in implementing projects that needed survey protocols developed, field tested, and refined. Practitioners learned to train survey crews, handle samples, and sample most efficiently, as well as many other critical aspects of a reliable monitoring program. Monitoring on various scales was improved including remote sensing and aerial survey, vegetation survey, water detection and soil sampling. The entire suite of techniques is currently used, dependent upon the survey objectives.

Summary of key findings—

- First detection of *P. ramorum* in Oregon (Goheen and others 2002a).
- Understanding of the limited extent of Oregon's *P. ramorum* infestation, which was critical to the decision to impose a State and Canadian quarantine and launch an eradication effort (Goheen and others 2002b).
- *P. ramorum* survived in soil, tanoak sprouts, and water despite cutting and burning aimed at pathogen eradication.
- Early detection of new isolated infestations as far as 1.8 miles (2.9 km) from other infestations suggest aerial or vector transmission.
- In 2003, just 3 years after the pathogen was discovered, *P. ramorum* was present on 9 to 12 percent of coastal forests in 8 California counties.

Suggestions for further investigation—

- The project to quantify the impact of *P. ramorum* and estimate the number of trees killed is ongoing. Ross Meentemeyer, of the University of North Carolina, Charlotte, NC, is collaborating with the FIA program of the Forest Service's Pacific Northwest Research Station in quantifying the extent of damage.
- The recent discovery in Alaska of another new *Phytophthora* species, closely related to *P. ramorum,* raises the possibility that *Phytophthora* species that are present but non-pathogenic in cold climates may pose a threat to natural resources and industries in warmer climates. Early detection and exploratory survey work in Alaska, northern British Columbia, and other areas with cold climates are needed to search for additional *Phytophthoras* and potentially the origin of *P. ramorum*.
- Continued survey work is needed in areas not known to be infested but at high risk for pathogen establishment, because *P. ramorum* is a quarantine pathogen that has limited distribution, is potentially very damaging, and is difficult to treat once established,.

White Pine Blister Rust Projects

Project WC-EM-99-04: Geographic Distribution of Champion Mine Strain of White Pine Blister Rust—Since the mid-1950s, the Forest Service and its cooperators have been actively engaged in a program to develop genetic resistance to white pine blister rust for western white pine (*P. monticola*), sugar pine (*P. lambertiana)*, and most recently, whitebark pine in Oregon, Washington, and California. Seed orchards have been established, and, for many of the breeding zones, resistant seed to be used for reforestation and restoration is or soon will be available. Efficient utilization of resistant seedlings by land managers will depend upon knowledge of several factors, including white pine blister rust hazard of the site and the existence or potential presence of a virulent strain of white pine blister rust that might render some resistance mechanisms ineffective. There are a few small geographic areas, notably the Champion Mine area on the Umpqua National Forest, where there is known to be a strain of white pine blister rust (vcr2) virulent to Cr2, the single major gene that controls a dramatic hypersensitive-reaction mechanism found in western white pine.

This project was undertaken to determine whether a strain of white pine blister rust virulent to Cr2 in western white pine existed beyond the Champion Mine area, and if so, how widespread it might be. In the summers of 1999 and 2000, *Ribes* leaves infected with *Cronartium ribicola* were collected in Oregon, Washington, and California. Seedlings from known major-gene-resistance parents were inoculated in a dew chamber while still in the cotyledon or early primary needle stage and scored when spots appeared on the needles. Spots were classified (phenotyped) as virulent (vcr2) or avirulent (AVCr2) based on pattern and counted. The number of spots rated "virulent" or "avirulent" was used to obtain an approximate frequency of the putative vcr2 gene in each inoculum.

In 1999, 20 of the 30 collection areas from which *Ribes* were sampled indicated an incidence of the virulent race, with the frequency of vcr2 varying from 2 to 100 percent. In 2000, 12 of 36 geographic areas tested showed a frequency of vcr2 >0 percent (varying from 1 to 100 percent). In general, vcr2 seems to be present west of the Cascades in Oregon (frequency ranges from low to high) and also near Happy Camp, CA. Only a few locations were sampled in California, and therefore, the southward distribution of vcr2 is uncertain. Vcr2 was present in most of the collections from Cottage Grove Ranger District in the general vicinity of the Champion Mine [site of the first known occurrence of a race of white pine blister rust capable of overcoming the hypersensitive reaction (HR)].

Ribes leaves with a high level of vcr2 were collected from an area in the northern Oregon Coast Range from infected plants inter-dispersed among a planting of western white pine; all of the western white pine at this site (except for a few trees) were dead or heavily infected and stunted. No details are currently available concerning the planting stock used for this planting, but resistant seed with HR was probably available for that breeding zone. If so, the high incidence of vcr2 may be from a combination of factors including high-hazard site and selection (Cr2 western white pines being prevalent in the area). Tested areas showing no incidence of vcr2 may indicate an absence of vcr2 in the area or a frequency lower than the resolving power here. In any case, there appear to be several large parts of Oregon and Washington with no measurable incidence of vcr2.

Results from this project indicate that the Champion Mine strain of white pine blister rust exists beyond the Champion Mine vicinity, and seems to correspond somewhat to the general range of the resistance gene (Cr2).

The Pacific Northwest *C. ribicola*-resistance program for *P. monticola* will continue to emphasize selection and breeding for durable resistance, incorporating an array of resistance mechanisms. Information from this project will help in guiding strategies in the future.

Project WC-EM-98-03: Whitebark Pine Survey in Southwestern Oregon—Whitebark pine is an important high-elevation forest species in southwestern Canada and the Western United States. It tolerates extreme environmental conditions and may act as a nurse tree, modifying microclimatic conditions so that other, less hardy plant species can become established. It is important for watershed protection, catching and retaining snow, and stabilizing rock and soil on harsh, open areas. It provides cover and roosting sites for wildlife and has considerable aesthetic value. Its large nutlike seeds, high in fat and protein, are important food sources for many mammals and birds.

There is widespread concern regarding population declines of whitebark pine throughout the West. Data on the distribution, stand conditions, and health of the species are not generally available. Although whitebark pine is an important species in the southern Oregon Cascade Range, its condition in this area had not been rigorously evaluated. Along the Pacific Crest National Scenic Trail on the Umpqua National Forest, 21 transects were established. The objectives of this work were to (1) determine the distribution of whitebark pine in this local area in the southern Oregon Cascade Range, (2) characterize site and stand conditions where whitebark pine occurs, (3) evaluate the current health of the species, and (4) establish a benchmark of information for comparison in the future.

Whitebark pine occurred on 76 percent of the survey transects. In general, whitebark pine was found in stands with lower overall densities and fewer late-seral species, particularly Shasta red fir (*Abies magnifica* var. *shastensis*) and mountain hemlock (*Tsuga mertensiana*). Whitebark pine stocking differed widely, from < 1 up to 24 percent of the trees on transect plots. Most whitebark pines (87 percent) were under 16 feet (5 m) tall.

Of all whitebark pine encountered, 44 percent were alive and healthy, 46 percent were alive but infected by *Cronartium ribicola*, and 10 percent were dead. Two-thirds of the mortality was due to white pine blister rust. Mountain pine beetle (*Dendroctonus ponderosae*) accounted for 13 percent of the mortality, whereas evidence of mountain pine beetle was found with white pine blister rust on 18 percent of the dead whitebark pines. White pine blister rust-affected trees were tallied in all but the largest size class; 70 percent of the whitebark pines taller than 5 feet (1.5 m) and smaller than 3.0 inches (7.6 cm) d.b.h. were infected. Most (92 percent) of infected whitebark pines had bole cankers or cankers within 6 inches (15 cm) of the bole.

Whitebark pine was common in centers of laminated root rot (caused by the fungus *Phellinus weirii*) where substantial canopy openings were found. In these centers, whitebark pine contributed 73 percent of the large tree stocking.

The results of this survey constitute a reference condition for whitebark pine that can be used to assess change in its status in this part of southwest Oregon. It provides a framework and survey design for evaluating the species in the context of its local environment (Ward and others 2006, Goheen and others 2002c, Aubry and others 2008, Shoal and others 2008).

Project WC-EM-02-02: Evaluating the Health of Five-Needle Pines in Washington and Southwestern Oregon—Five-needle pines are ecologically important components of Pacific Northwest forest ecosystems. They contribute significantly towards biological diversity and fill important niches including: importance as pioneer species, resistance to root disease, cold tolerance, providing essential large tree components of high-elevation stands, and existing as large, long-living dominants in mixed species stands.

Five-needle pine damage and mortality are reported but are not well quantified. Chief concerns include impacts due to: the introduced pathogen, *Cronartium ribicola*, cause of white pine blister rust and the native insect, mountain pine beetle.

The objectives of this project were to evaluate the status of western white pine and sugar pine with respect to stocking, regeneration, and species composition of stands, mortality, damaging agents and severity at the Regional level using information from established Regional inventory databases [Current Vegetation Survey (CVS) and FIA], and at the local level using newly established surveys in natural stands, and newly established surveys in plantations.

A total of 15,232 inventory plots established between 1991 and 2000 in Oregon and Washington were queried. Western white pine, sugar pine, and/or whitebark pine were tallied on 2,128 plots (14 percent). Five-needle-pine plots with western white pine predominate (58 percent), sugar pine occurred on 32 percent of the plots with five-needle pines, and whitebark pine was found on 16 percent of five-needle-pine plots. A total of 519 plots (24 percent) had five-needle pine mortality, 559 plots (26 percent) had trees with white pine blister rust infection, and 232 plots (11 percent) include pine bark beetle-caused mortality. No five-needle pines were reported on plots in the north and central Oregon Coast Range which is within the bounds of western white pine's historic range. No insect and disease data were collected for trees under 1 inch (2.5 cm) d.b.h.

A total of 2,749 plots were queried from 1993 to 1997 inventory databases from Coos, Curry, Douglas, Jackson, Josephine, and Lane counties in Oregon and R6 Forest Service lands in California. Western white pine, sugar pine, and/or whitebark pine were tallied on 860 (31 percent) plots. On those plots with five-needle pines, plots with sugar pine predominated (64 percent). Only 4 inventory plots contained whitebark pine. Five-needle pine stocking averaged 6 percent of total trees per acre. White pine blister rust was recorded on 234 plots (27 percent) and was associated with an average of 74 percent of all dead five-needle pines. An average of 32 percent of live five-needle-pine stocking was found infected. Bark beetle-caused mortality was recorded on 91 plots (10 percent). Bark beetles were associated with an average of 86 percent of all dead five-needle pines.

In southwestern Oregon, 55 sugar pine and 55 western white pine stands were surveyed. Across southwest Oregon, western white and sugar pine are both in decline in natural stands. Regeneration is occurring; however, mortality and disease occur in all size classes. Substantial and increasing losses were found particularly in trees larger than 10 inches (25.4 cm) d.b.h. Western white pine data indicate high impacts in the 3 to 10 inches (7.6 to 25.4 cm) d.b.h. range as well. Overall, 25 percent of trees are infected by *C. ribicola*. White pine blister rust causes topkill and branch dieback in trees larger than 10 inches (25.4 cm) d.b.h and mortality in trees smaller than 10 inches d.b.h. *Ribes* spp. are present but not essential for disease. High levels of mountain pine beetle-caused mortality were found. Sugar pine appears to be predisposed to mountain pine beetle infestation by Armillaria root disease (caused by *Armillaria ostoyae*) in the northern part of its southwestern Oregon range. Pine engraver (*Ips paraconfusus*) infestation was common in western white pine, especially on ultramafic soils.

In southwestern Oregon, 63 sugar pine and 43 western white pine plantations were surveyed. Plantations were selected from local databases for 10 percent or more stocking of five-needle pines and represented a range of five-needle pine stock types from wild to white pine blister rust-resistant.

Data from western white pine and sugar pine plantations are currently being analyzed. Preliminary analysis indicates that, in plantations with western white pine, the average total tree stocking of plantations was 234 trees per acre with an average western white pine stocking of 43 percent. Forty percent of western white pines examined had white pine blister rust. The average total tree stocking in plantations with sugar pine was 184 trees per acre with an average sugar pine stocking of 37 percent. Forty-three percent of the sugar pine examined had white pine blister rust. Data from Washington western white pine plantation evaluations are reported in WC-EM-04-04.

The 55 western white pine, 55 sugar pine natural stands, and 106 plantations are geo-referenced and will be revisited and resurveyed at 10-year intervals to monitor changes in five-needle pine populations, impacts of insects and diseases over time, and the effectiveness of planting pines with various levels of white pine blister rust.

Project WC-EM-04-02: Status of Five-needle Pines in Washington and Northern Oregon (with Emphasis on High Elevation Stands with Whitebark Pine)—There is widespread concern regarding population declines of whitebark pine throughout the West. Data on the distribution, stand conditions, and health of the species are not generally available. To provide an understanding of how whitebark pine is faring across the Pacific Northwest, systematic transect surveys were conducted from 2002 to 2004 in whitebark pine stands on nine national forests and a national park in Washington and Oregon. The primary objectives of these surveys were to locate and map whitebark pine stands, and to assess the incidence of the damaging agents: white pine blister rust and mountain pine beetle. In addition, data were collected on total whitebark pine mortality, presence of *Ribes* spp., cone production, regeneration, and overall stand composition.

Sixty-nine sites on nine national forests and one national park were evaluated. Overall, the sample included 10,500 individual trees. Results differed across the range of sites sampled. Mean white pine blister rust incidence for all areas surveyed was 41.5 percent (range 0.0 to 100 percent). The highest average white pine blister rust incidence (61.2 percent) was found on the Mt. Hood National Forest, the northernmost national forest in Oregon's Cascade Range. The lowest levels of white pine blister rust incidence (16.8 percent) in whitebark pine were reported on the Wenatchee National Forest in north central Washington. The average mountain pine beetle incidence was 4.5 percent (range 1.1 to 34.3 percent). Overall, average mortality from all causes by transect was 33.4 percent (range 0.0 to 89.4 percent) (Ward and others 2006, Goheen and Sniezko 2007, Aubry and others 2008, Shoal and others 2008).

Project WC-EM-04-01: An Assessment of White Pine Blister Rust on High-Elevation White Pines in California—Six of nine 5-needle pine species native to the United States are found in California, and all of these are susceptible to the nonnative pathogen, *Cronartium ribicola*, the cause of white pine blister rust. Five of these species grow at high elevations and are key species in their ecosystems. They are western white pine, whitebark pine, foxtail pine (*P. balfouriana*), Great Basin bristlecone pine (*P. longaeva*), and limber pine (*P. flexilis*). This field project was initiated in 2004 to gather white pine blister rust information on California high-elevation five-needle white pines. The objectives were to determine the current incidence and levels of white pine blister rust associated with western white, whitebark, limber, foxtail, and bristlecone pines in California, and to establish a system of permanent plots for long-term monitoring of white pine blister rust incidence and severity in these pine species.

Over two field seasons, 118 long-term monitoring plots were established: 43 in western white pine, 44 in whitebark pine, 14 in limber pine, 12 in foxtail pine, and 5 in Great Basin bristlecone pine.

White pine blister rust was present in western white (25 of 43 plots), whitebark (18 of 44 plots), and the northern populations of foxtail (6 of 6 plots). It was not found in limber pine, Great Basin bristlecone pine, or the southern populations of foxtail pine. The mean white pine blister rust levels were relatively low across plots (12 to 14 percent) but varied widely from plot to plot (0 to 90 percent). Moderate incidence was observed in northwest California, north central Sierra Nevada, and the west side of the southern Sierra Nevada. In this survey, white pine blister rust was observed on whitebark pine at about 11,000 feet (3 350 m). When white pine blister rust incidence was correlated to climate data and distance was correlated to possible sources of inoculums, positive correlations were found between May relative humidity (moist spring) and mean September minimum temperature (warm fall). A negative correlation was found with distance to nearest lower-montane mixed-conifer forest. Mountain pine beetle was found associated with five-needle pine mortality in high-elevation stands in California.

Other stressors found affecting high elevation five-needle pines in California include mountain pine beetle and potential climate change; 50 to 60 percent of established plots showed signs of mountain pine beetle.

Project WC-EM-04-04: White Pine Blister Rust in Juvenile Western White Pine on State Lands in Washington—Western white pine was once an integral part of the forest ecosystems of Washington. Since its introduction, *Cronartium ribicola*, the causal organism of white pine blister rust, has been responsible for widespread mortality of western white pine throughout Washington. This has limited reestablishment of the species in forest management strategies across the State. Over the last two decades, the Forest Service and the University of Idaho have established breeding programs to genetically enhance western white pine for resistance to white pine blister rust. During this time, the Washington Department of Natural Resources has been steadily increasing the outplanting of western white pine seedlings, including those genetically enhanced for white pine blister rust resistance (F2 progeny) on State lands. However, until now, no surveys were done to assess the performance of this stock. As a result of this project, 22 permanent plots were established across Washington to assess the development of white pine blister rust in young plantations of F2 western white pine progeny and to quantitatively describe the relative success over time of genetically enhanced western white pine in resisting infection and mortality caused by white pine blister rust.

The permanent plots (with each plot consisting of 100 live 4- to 5-year-old planted white pine blister rust-resistant juvenile western white pines) were established across the range of the species in Washington. Plots were evaluated annually after establishment.

White pine blister rust infection rates on plots ranged from 0 to 95 percent. Highest individual plot infection rates (95 percent) occurred in the northwest region of the State, followed by 76 percent in the Pacific Cascade region, 32 percent in the Olympic region, 6 percent in the South Puget Sound region, and 0 percent in the northeast region. White pine blister rust-infection rates on plots increased each year on those plots where the disease was present initially. White pine blister rust-infection levels among the plots showed that, even though the rates of infection on several plots were relatively high (59 to 95 percent), the rates of mortality were low. Less than 1.1 percent of tagged trees were killed by stem girdling cankers due to white pine blister rust over the measurement period.

Summary of key findings—

- The virulent Champion-Mine strain of *Cronartium ribicola*, the cause of white pine blister rust, exists beyond the Champion Mine area in west-central Oregon in areas west of the Cascade Mountains in Oregon and also near Happy Camp in California.

- Ground survey of whitebark pine in southwest Oregon showed that 44 percent were healthy, 46 percent were live but infected, and 10 percent had been recently killed by white pine blister rust.

- Of 15,232 CVS and FIA inventory plots queried in Oregon and Washington, 14 percent had western white pine, whitebark pine, or sugar pine, 26 percent of the pine plots had white pine blister rust infection, and 11 percent had bark-beetle–caused mortality.

- Of 10,500 individual whitebark pines sampled in Washington and northern Oregon, mean blister-rust incidence was 41.5 percent and mountain pine beetle incidence was 4.5 percent with mortality from all causes at 33.4 percent.

- Of a total of 118 plots established in California, white pine blister rust was found in western white pine (58 percent), whitebark pine (41 percent), and northern populations of foxtail pine (100 percent) but not in limber pine, Great Basin bristlecone pine, or southern populations of foxtail pine.

- Of 100 permanent plots established in western white pine plantations in Washington State, highest white pine blister rust infection (95 percent) occurred in the northwest region, 76 percent in the Pacific-Cascade region, 32 percent in the Olympic region, 6 percent in the South Puget Sound region, and 0 percent in the northeast region.

Utilization of project results—

- Data collected in whitebark pine assessments WC-EM-98-03 and WC-EM-04-02 were used as a part of a Region-wide whitebark pine assessment. Findings and conclusions from these studies were also used to develop a restoration strategy for whitebark pine in Washington and Oregon.

- The information gained from surveys done to assess the health of high-elevation five-needle pines in California in WC-EM-04-01 is being used to develop a restoration strategy for those species. These data are currently guiding cone collection and seed banking efforts.

- WC-EM-02-02 has quantified the status of sugar pine and western white pine in southwestern Oregon. These data have been presented in a variety of workshops and training sessions to emphasize the importance of planting of white pine white pine blister rust-resistant stock and reducing stand densities to reduce the risk of mountain pine beetle infestation.

Suggestions for further investigation—

- Continue to emphasize selection and breeding for durable resistance to white pine white pine blister rust by incorporating an array of resistance mechanisms.

- Conduct new surveys for white pine blister rust in areas of whitebark pine not previously sampled, and continue to monitor previously surveyed sites.

- Continue to monitor five-needle pine natural stands and plantations in southwest Oregon for impacts of insects and diseases.

- Continue to examine permanent plots established in California, Oregon, and Washington for incidence of white pine blister rust infection and five-needle pine mortality.

Swiss Needle Cast of Douglas-fir Projects

Projects WC-EM-98-01; WC-EM-99-01; WC-EM-99-02; WC-EM-00-01: Aerial Surveys to Monitor Swiss Needle Cast in Oregon and Washington—Swiss needle cast (SNC) is a debilitating foliage disease seriously affecting Douglas-fir along the Pacific coast in Oregon and Washington (Hansen and others 2000, Maguire and others 2002). Five projects were funded from 1998 to 2002 to conduct aerial surveys of Douglas-fir with SNC, caused by *Phaeocryptopus gaeumannii*, along the Oregon and Washington coast and in the northern Cascade Mountains of western Oregon. Surveys were flown, weather depending, at an altitude of 1,500 to 2,000 feet (460 to 610 m) in May to June when visible foliar symptoms were optimum. Foliar symptoms were rated as severe or moderate. Light defoliation cannot be seen from aircraft. Stands with < 50 percent Douglas-fir or younger than 7 to 8 years old were not mapped. Forest areas with symptoms were drawn onto a 1:100,000 scale topographic map. Maps were digitized in GIS format and distributed to cooperators by mid-June. A random sample of 50 to 100 polygons was ground-checked to verify SNC.

From 1998 to 2002, approximately 2.2 to 2.9 million acres (0.9 to 1.2 million ha) were annually flown along the Oregon coast from the Columbia River in the north to the city of Bandon in the south. Acreage with aerially visible symptoms increased from 173,000 to 387,000 acres (70 013 to 156 619 ha) in the 4 years. Ground plots verified that most of the symptoms were due to SNC.

In 1998 and 1999, about 1.7 million acres (0.7 million ha) were flown along the southwest Washington coast from the Columbia River in the south to the city of Aberdeen in the north. A total of 44,500 acres (18 009 ha) had symptoms in 1998 with at least as many acres mapped in 1999. In 2000, almost 2 million acres (0.8 million ha) were mapped from the Columbia River to near the tip of the Olympic Peninsula in the north. A total of 410,000 acres (165 927 ha) had symptoms.

Between 1999 and 2000, an area from the city of Roseburg in the south to the Columbia River in the north was flown for SNC in the Oregon Cascade Mountains. Symptoms of SNC are less developed than in the Coast Range, and areas with symptoms tended to occur infrequently and in small patches.

Project WC-EM-01-01; WC-EM-01-03: Impacts of Swiss Needle Cast in the Northern Oregon Cascade Mountains—Two projects were funded to conduct ground surveys of Douglas-fir with SNC in the northern Cascade Mountains of western Oregon. In 2001, 590 Douglas-firs in 59 stands were examined from the city of Oakridge in the south to the Columbia River in the north. Permanent plots were established on Federal, State, and private land. Besides stand data, each plot tree was examined for current d.b.h., height, needle retention, and percentage of needle stomata with SNC fruiting bodies. In 2003, needle retention and fruiting-body data were collected again.

A third project was regionally funded in 2006 to determine 5-year changes (2001 to 2006) in (1) d.b.h. and height growth, (2) needle retention, and (3) fruiting-body density (Filip and others 2007). Correlations were examined between stand, site, and tree variables.

The 59 surveyed stands had an average 5-year d.b.h. growth of 2.4 inches (6.1 cm) (range 1.2 to 3.4 inches, 3.0 to 8.6 cm), total-height growth of 11.9 feet. (3.6 m) (range 7.7 to 15.5 feet, 2.3 to 4.7 m), and mid-crown needle-retention increase of 1.2 years (range 0.2 to 2.3). Mean percentages of stomata with fruiting bodies (pseudothecia) were 13.6 percent for 2-year-old needles and 1.7 percent for 1-year-old needles sampled in 2002, and 13.3 percent for 2-year-old needles sampled in 2006. There were poor correlations (R-square <0.3) for all variables except for stand elevation where there was a moderate correlation with either percentage of stomata with fruiting bodies sampled in 2002 (R-square = 0.43) or 2006 (R-square = 0.50). There were fewer fruiting bodies at the higher elevations. Either 5 years was not enough time to evaluate the affects of SNC on Douglas-fir in the northern Oregon Cascades or there was no significant effect of SNC on Douglas-fir growth during the latest outbreak.

There are two possible reasons there may be no appreciable effect of SNC on Douglas-fir 5-year-diameter and height growth in the northern Oregon Cascades:

1. Oregon Cascade Range site characteristics, (including plant associations, soil chemistry and parent material, air temperatures, and monthly precipitation and leaf wetness) may not be as conducive to elevated populations of the SNC-causal fungus and subsequent severe defoliation as along the Oregon coast.
2 The genetics (lineage 1) of isolates of the causal fungus in the Oregon Cascades more closely resembles isolates from Idaho, Europe, and New Zealand than isolates from the Oregon coast (Winton and others 2006). Also, lineage 2, abundant along the Oregon coast, has not been reported in the Cascades.

Project WC-F-02-04: Effect of Swiss Needle Cast on Douglas-Fir Crown Structure as it Relates to Fire Risk and Potential Fire Behavior in Young Plantations in the Oregon Coast Range—This project was funded from 2002 to 2004. The objective was to assess the degree to which young (10- to 30-year-old) Douglas-fir plantations affected by SNC experience an increased susceptibility to wildfire as a result of SNC-altered crown structure, tree morphology, stand structure, and litter dynamics. Using data from 82 destructively sampled trees and 150 litterfall traps, linear regression models were constructed to test whether the influence of SNC on Douglas-fir crown structure relates to fire risk. Vertical distribution of crown dry matter was characterized by fitting a β-distribution to each tree. Stand-level estimates of canopy bulk density and canopy fuel load were constructed as the composite of individual sample trees and litterfall. Canopy base height was defined as the lowest height above which at least 101.3 pounds per acre (112.4 kg/ha) of fuel was available (Weiskittel and Maguire 2007).

The data indicated that both Douglas-fir crown structure and morphology have been significantly altered by SNC, which increased several stand-level attributes. Due to these changes, fire risk and potential fire behavior, particularly surface fire, have been modified in the region. This is supported by the following findings:
1. Both crown bulk density and canopy fuel loads were significantly reduced by the disease due to the premature loss of foliage and reductions in the size and number of primary branches.

2. With greater SNC, canopy base heights were significantly lower.
3. With increasing SNC, foliage litterfall rates were lower than normal, and fine woody material litterfall rates were greater due to the increased rates of crown recession.
4. Regardless of SNC level, more foliage litterfall occurred in the summer months, and litterfall rates were much higher when compared to other similar studies.
5. Live-wood moisture content was significantly reduced by SNC.

Summary of key findings—

- Aerial surveys of Douglas-fir forests along the Oregon and Washington coast from 1998 to 2002 showed an increasing acreage of forest severely affected by SNC. Aerially observed symptoms were less in the western Oregon Cascade foothills.

- Five-year monitoring of ground plots in the western Oregon Cascades showed that there were no significant effects of SNC on Douglas-fir growth during the latest outbreak, but monitoring will continue.

- Crown bulk density, canopy-fuel loads and base heights, and live-wood moisture content were significantly reduced because of SNC, whereas foliage litterfall rates during the summer increased.

Suggestions for further investigation—

- Continue aerially surveying the Oregon Coast indefinitely for SNC.

- Renew aerial and ground surveys and monitoring along the Washington coast for SNC of Douglas-fir.

- Resample permanent plots in the northern Oregon Cascade Range in 2011. Renew aerial surveys if ground plots show an increasing trend in severity.

- Continue to refine and expand models that risk-rate Douglas-fir stands for SNC as it relates to climate change.

- Determine the effects of SNC on fire risk and behavior in older stands along the Oregon and Washington Coast and in both young and older stands in the Cascade Mountains.

Utilization of project results—
Aerial and ground-survey data and maps are being fully utilized by forest landowners and managers throughout the Oregon Coast Range to determine location and changes in SNC severity. Such information is then used to augment management of Douglas-fir for multiple objectives on public and private forest lands.

A substantial modeling effort is under way to risk rate Douglas-fir stands for SNC in the northern cascades and along the Oregon and Washington coasts (Manter and others 2003, 2005; Stone and others 2008). Data from this risk-rating research is being incorporated into economic models to determine financial impacts from SNC. These are continuing research efforts that were initially made possible through FHM funding and subsequent data from both aerial and ground surveys in the Pacific Northwest.

Hawaii Insect and Pathogen Project

Project WC–EM-03-01. An Assessment of Insects and Pathogens Associated with Declining Dry-forest Ecosystems in Hawaii—Dry forests are among the most threatened ecosystems in the tropics. In Hawaii, most of the original dry forest has been converted to urban and residential areas, agriculture, and grazing. Over 90 percent of the original Hawaiian dry forests have been destroyed (Bruegmann 1996, Mehrhoff 1993). The overall health of the remaining native trees and shrubs may not recover for many years. What is needed to supplement the ecological restoration of these systems is a forest health evaluation system that can be used to prioritize restoration and monitor the response of restored ecosystems (Morales and others 2008). The FHM and FIA programs have developed guidelines for evaluating health and vigor of closed-canopy forests. These rely on visual indicators, e.g. canopy transparency, live crown to height ratio, tip and branch dieback, and symptoms of pathogens or parasites.

This EM project looked at utilizing FHM/FIA data in Hawaii's dry forest ecosystems as well as other indicators, including abundance and diversity of canopy insects; mycorrhizal colonization of fine roots; leaf mass/area, leaf nutrient concentration, and evidence of herbivory; and various measures of plant cover and diversity to assess restoration potential. Preliminary data suggest that the health of some trees vulnerable to degradation and decline, such as kauila (*Colubrina oppositifolia*) may respond positively to long-term restoration, whereas more conservative and slow-growing trees thought resistant to decline, e.g., lama (*Diospyros sandwicensis*), show little or no health response to restoration. Lama may increase its photosynthesis and water use under restored conditions, but these ecophysiological improvements have not yet translated into greater canopy density, reduced dieback, or lower incidence of parasitism or disease (Giffin 2003).

Future Work: Evaluation Monitoring projects continue to provide meaningful knowledge and understanding of pathogens and how they contribute to changes in the forest. Many of these investigations serve as the first tier on a wide variety of issues that otherwise would not be dealt with in any meaningful scientific way. This value, while a good start, can only be added to by developing more questions from lessons learned to improve disease management.

Summary of key findings—

- Using an object-based image classification technique led to a better estimation of dry-forest canopy cover in fragmented and declining dry-forest ecosystems in Hawaii.
- By improving accuracy selection of critical habitat for restoration, targets can be identified and better management of these critical areas is expected.

Utilization of project results—

- The use of this technology better reflects spatial relationships inherent to each land cover type, based on size, shape, texture, and distribution.
- The addition of tree canopy transition class to the shade-tree parameter improved estimation of canopy cover. This type of multi-spectral satellite imaging can also be used to track changes in land cover types over time.

Suggestions for further investigation—

- Determine if standard forest health assessments can be used to validate remote-sensing estimates to improve mapping of Hawaii's sensitive dry-forest ecosystems and restoration potential.
- Determine the roles that mycorrhizae play as indicators of dry-forest-ecosystem health in Hawaii.
- Determine if tree heights from a classified image can be improved by using a tree-shadow algorithm in Hawaii.

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