

CHAPTER 6

Interior West Forest Diseases

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Forest disease projects in the interior West focused mainly on characterizing the health of white pines relative to white pine blister rust (WPBR) incidence and intensity, and the dieback and mortality of quaking aspen (*Populus tremuloides*) relative to drought, warmer temperatures, and accompanying secondary organisms. The dieback and mortality of thinleaf alder and incidence of armillaria root pathogens were also explored.

Five-Needle Pine Blister Rust Projects

White pine blister rust, caused by the invasive pathogen *Cronartium ribicola*, is a serious disease of white pines and other five-needle pines. Around 1998, surveys and observations demonstrated the disease was spreading into areas once thought to be too arid, high, and remote for the rust to become established. An Evaluation Monitoring (EM) project was initiated in 2001 to expand monitoring efforts into the largely unsurveyed central and southern Rocky Mountains encompassing Regions 1, 2, 3, and 4. Surprisingly, isolated WPBR outbreaks were discovered in several locations in Colorado and the disease was reported for the first time on Rocky Mountain bristlecone pine (*Pinus aristata*). These new findings heightened concerns about the status of high elevation white pines of the northern, central, and southern Rocky Mountains and clarified the need for more in-depth, long-term monitoring to gain a better understanding of the status of these species and ecological impacts of the disease. Consequently, several more EM projects were initiated.

Results have been useful to land managers needing to manage, protect, and restore white pine stands. Furthermore, each of these EM projects was coordinated with and complemented other research efforts leading to a more thorough understanding of the disease in the region. For example, EM data were used to model the potential distribution of blister rust in Colorado, to develop a rapid system for surveying

blister rust severity in whitebark pine (*Pinus albicaulis*), and to develop and implement genetic conservation strategies in Yellowstone and Rocky Mountain national parks and several national forests in the Northern and Rocky Mountain Regions. Long-term monitoring plots were established in Colorado, Wyoming, Montana, and Nebraska to assess the ecological impacts of the disease and ultimately to refine management and restoration efforts.

Project INT-EM-01-04: Monitoring White Pine Blister Rust Spread and Establishment in the Central Rocky Mountains

The purpose of this project was to monitor the distribution and status of WPBR in previously unsurveyed areas of Colorado, southern Wyoming, northern New Mexico, and portions of the Greater Yellowstone Ecosystem (GYE) encompassing Forest Service Regions 1, 2, 3, and 4. To accomplish this, several projects were synchronized using compatible survey methods to gain a better understanding of the status of the disease throughout this broad region. Coordinated projects included a study of the role of *Ribes* spp. in the intensification and distribution of blister rust in the GYE (Newcomb 2003, Newcomb and Six 2003); the development of a rapid system for rating WPBR incidence, severity and within-tree distribution in whitebark pine (Six and Newcomb 2005); and a dissertation on the current status and potential impacts of white pine blister rust in the central Rocky Mountains (Kearns 2005). Surveys were completed in 2002 and 2003.

Most plots in the GYE (85 percent) had infected trees, and the average disease intensity on infected plots was 35 percent. The incidence of disease was still relatively low in Colorado and southern Wyoming, and no rust was found in northern New Mexico. Overall, only 15 percent of plots in this area had infected trees, and the average intensity on infected plots was 14 percent. No infected trees were observed within Rocky Mountain National Park (RMNP) and at the same time the disease front was estimated to be only 13 miles (21 km) away to the north (Burns 2005). (Infected trees were observed in RMNP in 2009.) Isolated infestations in the Sangre de Cristo and Wet Mountains of south-central Colorado were discovered. Most infected trees were limber pine, although infected Rocky Mountain bristlecone pines were discovered for the first time in their native range within the Great Sand Dunes National Park and Preserve, Sangre de Cristo Mountains.

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Project INT-EM-04-05: Monitoring White Pine Blister Rust Spread and Establishment in the Central Rocky Mountains, Stage 2—A more in-depth survey was initiated in the Sangre de Cristo and Wet Mountains in light of the newly discovered infestations. Specific objectives were to delimit the geographic extent and intensity of the new infestations, determine the incidence of disease on Rocky Mountain bristlecone pine, install monitoring plots in the Sangre de Cristo Mountains, and map the current distribution of WPBR in the southern and central Rocky Mountains. Work was coordinated with and complemented other studies including a Special Technology Development Project (STDP) to develop a WPBR hazard-rating system and a rust resistance study in Rocky Mountain bristlecone pine.

Thirty-six long-term monitoring plots were established in the Sangre de Cristo Mountains and 56 plots were established in the Wet Mountains. The incidence of WPBR is generally low in both ranges and infected trees were not observed above 10,100 feet (3081 m) in elevation. However, white pines and *Ribes spp.* coexist in both mountain ranges, and therefore, it is likely that the disease will continue to spread and intensify. Infected bristlecone pines were only observed near Mosca Creek in the Great Sand Dunes National Park and Preserve. Overall, small trees had a significantly higher frequency of severe infections. Impacts to larger trees were evident throughout the crowns. A GIS database was created and is updated yearly to map the current distribution of white pine blister rust in the central and southern Rocky Mountains.

Project INT-EM-06-03: Monitoring Limber Pine Health in the Rocky Mountains—This study was conducted to assess the ecological impacts of WPBR on limber pine (*Pinus flexilis*) within the central and southern Rocky Mountains. Intensive measurements were taken to quantify impacts to crown structure, reproductive capability, stand structure, and species composition of tree and plant species. Eighty-three monitoring plots were installed in 4 study areas, including northern Colorado and southern Wyoming (36 plots together), central and western Wyoming (29 plots), central Montana (16 plots), and southwestern North Dakota (2 plots). Plots will be revisited every 5 years. This project was coordinated with an STDP project developing and refining operational guidelines for cone collections and seed tree collections to streamline restoration projects in limber pine.

No blister rust was detected in the North Dakota plots. Infected trees occurred in 81 percent of plots in each of the other three study areas. The average disease incidence of infected plots was 35 percent in northern Colorado/southern Wyoming and central/western Wyoming, and 60 percent in central Montana. WPBR was observed 5 miles (8 km) southeast of Rocky Mountain National Park in 2005. Long-term monitoring plots

were established in this new infection area and within the park. These data have been used to develop and implement genetic conservation strategies in Rocky Mountain National Park and on the Arapaho-Roosevelt and Medicine Bow National Forests. This project was ongoing in 2009.

Project INT-EM-00-03: Determining the Condition of Whitebark Pine in the Northern Region—Data collected by the Forest Inventory and Analysis (FIA) Program of the Forest Service, U.S. Department of Agriculture, from 1994 to 1998 were analyzed in order to characterize whitebark pine and its forest health condition. Although the original intent was to use data from both Montana and Idaho, only the Montana data were conducive to this analysis. Most white bark pine plots are in subalpine fir vegetation types, and will succeed to fir in the absence of fire. Whitebark pines are generally larger than 5 inches (12.7 cm) diameter at breast height (d.b.h.), with little regeneration. Mortality was concentrated in groups of trees larger than 10 inches (25 cm) d.b.h., likely attributable to mountain pine beetle (*Dendroctonus ponderosae*). WPBR infection was recorded on 16 percent of the FIA plots, was lower than expected, and believed to be inaccurate. The authors concluded that FIA plots are best used to flag plots of concern and that it is unrealistic to expect intensive insect and disease information from FIA plots.

Project INT-EM-03-03: Monitoring West-Wide Distribution and Condition of Whitebark Pine and Limber Pine—The focus of this project was to create an interactive database of all off-plot monitoring data collected on whitebark and limber pine throughout their ranges. Previous efforts at compiling data resulted in maps that could not be adequately used at a sub-regional or sub-watershed level. There is a need to have readily accessible data for all interested individuals.

An interactive plot-level database with a GIS component was developed and released on CD and is now available as a downloadable version on the Region 1 Web site at <http://www.fs.fed.us/r1-r4/spf/fhp/prog/programs2.html>. This Whitebark Limber Pine Information System (WLIS) consists of a limited number of critical fields representing key plot data variables that can be queried and GIS-linked via a user-friendly interface. The application connects to the underlying Microsoft Access Database using Microsoft Jet Database Engine technology. The application inserts, modifies and deletes values in the database using industry Standard Query Language (SQL) statements.

WLIS is a database of survey plots established for whitebark and limber pines in the United States and Canada. Data were assembled from researchers, surveyors, and literature sources and compiled in a standard format. In addition, data from

FIA plots with whitebark or limber pine were included, which provided the distribution of the two species. Data can be viewed for any of the plots in the system. The data can also be queried to refine the dataset to meet the user's needs. Plot locations can be spatially depicted through an interactive mapping system. The interactive database provides a user-friendly interface for the addition of new plots or updating data for plots already in the system. A users manual is included as part of the system and should be referenced for details on using the system.

Project INT-EM-04-02: Monitoring the Status and Condition of Whitebark Pine in the Greater Yellowstone Ecosystem—

The Whitebark Pine Monitoring Working Group, made up of representatives from the Forest Service, National Park Service, U.S. Geological Survey, and Montana State University, saw a need for a long-term assessment of whitebark pine in the Greater Yellowstone Ecosystem (GYE) (Greater Yellowstone Whitebark Pine Monitoring Working Group 2005, 2006). The intent of this project was to estimate current status of whitebark pine relative to white pine blister rust infection and to determine the probability of whitebark pines persisting in the GYE. This project started in 2004, and is ongoing. In years one and two (2004 and 2005), the project was funded by the national Forest Health Monitoring (FHM) Program of the Forest Service, U.S. Department of Agriculture, specifically with Evaluation Monitoring (EM) program dollars. It was funded with Regional FHM EM dollars in year three (2006), and it is continuing on dollars acquired annually outside of FHM EM.

Nearly 5,000 whitebark pine trees have been tagged along 181 transects within the GYE. Eighty percent of the transects have WPBR infected whitebark pine, and infestation levels range from 14 to 22 percent of whitebark pines infected. Bole cankers, which are considered lethal, occur on 14 percent of the trees. Thirty-five transects established in 2004 were remeasured in 2007. Approximately 4 percent whitebark pine mortality was observed, some of which was attributed to mountain pine beetle activity. Information from this survey has been incorporated into the development of protocols for monitoring whitebark pine in the GYE.

Project INT-EM-05-02: Evaluation and Monitoring of Whitebark Pine Regeneration after Fire in the Frank Church River of No Return Wilderness—This study was initiated in 2005 to provide information on fuel loadings, forest health, disease incidence, mortality, and reproduction of whitebark pine in the Frank Church River of No Return Wilderness Area. Permanent plots were established in four whitebark pine populations, across three habitat type classes and three burn classes. The objectives of the project were to evaluate the dynamics of stand composition and health, examine the

influence of habitat type and fire history on the composition and health of whitebark pine stands, and assess the risk of whitebark pine population losses to wildland fire. Potentially rust resistant individuals were also identified for inclusion in the Forest Service's rust resistance testing and breeding program.

Data are currently housed at the Department of Forest Resources in the College of Natural Resources at the University of Idaho. Copies of all data will be provided to Region 1, Forest Health Protection (FHP) Program of the Forest Service for archiving and reference for future monitoring once the final report is complete.

WPBR and mountain pine beetles are active on whitebark pine in Frank Church River of No Return Wilderness Area. The apparent decline of mountain pine beetle attacks in one of the four survey areas may be due to an initial overestimation of mountain pine beetle attack. Blister rust infection and mortality did not change significantly between measurement years, but was significantly different between populations. Mountain pine beetle attack was positively correlated with slope and inversely correlated with elevation. Coarse woody debris was greater in the recently burned population than in the other populations and less in the early seral phases than in late seral or climax phases.

Utilization of project results—

- A rapid system for rating WPBR incidence, severity and within-tree distribution in whitebark pine was developed (Six and Newcomb 2005) and is being evaluated for use in limber pine.
- Genetic conservation strategies are being developed and implemented within Rocky Mountain National Park and on the Arapaho-Roosevelt and Medicine Bow National Forests of the Rocky Mountain Region.
- A GIS database that provides the current distribution of WPBR in the central and southern Rocky Mountains is updated annually to guide surveys, monitoring, and management activities.
- Long-term monitoring plots are providing baseline information on current ecological conditions in limber pine stands in the Rocky Mountains and North Dakota. Future measurements will provide a better understanding of the ecological implications of blister rust.
- The WLIS is an interactive database of inventory data from plots established in whitebark and limber pine forests in the Western United States and Canada. WLIS is on CD and available in a downloadable version from the Northern Region, FHP Web site (USDA Forest Service 2006).

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- An interactive plot-level database with a GIS component was developed and released on CD and is now available as a downloadable version on the Region 1 Web site at <http://www.fs.fed.us/r1-r4/spf/fhp/prog/programs2.html>.
- Protocols for monitoring whitebark pine in the GYE (Greater Yellowstone Whitebark Pine Monitoring Working Group 2006) were developed from EM studies.

Summary of key findings —

- Evaluation Monitoring projects have improved understanding of the distribution of WPBR in the central and southern Rocky Mountains (Burns 2005, Burns 2006, Burns and others 2008, Geils and others 2003, Howell and others 2006, Kearns and others 2004, Newcomb 2003, Newcomb and Six 2003). Generally, the incidence of disease is greatest to the north and west where the rust has been present for decades, decreasing to the south and east in more recently infected areas.
- White pines and *Ribes* species coexist throughout the central and southern Rocky Mountains, and, therefore, the disease likely will continue to spread and intensify (Burns 2006, Newcomb 2003, Newcomb and Six 2003).
- Project INT-EM-01-04 led to the first report of natural WPBR infection in Rocky Mountain bristlecone pine (Blodgett and Sullivan 2004a, 2004b).
- Disease incidence is low in Rocky Mountain bristlecone pine; infected trees were only observed near Mosca Creek in the Great Sand Dunes National Park and Preserve (Burns 2006).
- The incidence of WPBR was inversely related to elevation in southern Colorado and no infected trees were observed above 10,076 feet (3073 m) (Burns 2006).
- Analysis of FIA plot data in Montana demonstrates that whitebark pine regeneration is scant, mortality is concentrated in larger size classes, most stands will succeed to subalpine fir in the absence of fire, and WPBR infection may be underrepresented.
- Eighty percent of transects installed in the GYE in whitebark pine habitat are infected with WPBR. Infection levels ranged from 14 to 22 percent of whitebark trees infected (Greater Yellowstone Whitebark Pine Monitoring Working Group 2008).
- WPBR and mountain pine beetles are active in whitebark pine in Frank Church River of No Return Wilderness Area. Mountain pine beetle attack is positively correlated with slope and inversely correlated with elevation.
- Intensive insect and disease information is not obtained from FIA plot surveys, but the survey information can suggest the presence of certain agents.
- Observer variability needs to be considered during surveys of WPBR. Differences in infection rates observed over time should not be confounded with observer differences. Management needs to address the issues concerning observer-to-observer variability and its effect on the quality and reliability of estimation (Greater Yellowstone Whitebark Pine Monitoring Working Group 2007, Huang 2006).

Suggestions for further investigation—

- Develop accurate, multi-ownership white pine vegetation coverages.
- Study the epidemiology of *Cronartium ribicola* and the susceptibility of other *Ribes* species in the more arid forests of the central and southern Rocky Mountains.
- Explore resistance mechanisms and adaptive traits in high elevation white pine species of the Rocky Mountain Region.
- Identify or develop silvicultural techniques for restoring stands impacted by blister rust, mountain pine beetle, and fire.
- Assess the combined impacts of WPBR and mountain pine beetle in limber and bristlecone pine.
- Identify resistant stands of whitebark, limber, and bristlecone pine and protect them from mountain pine beetle.
- Establish more long-term monitoring plots to gain a better understanding of the spread and intensification timeline in limber pine stands and its effects on ecosystems services such as wildlife, reproduction, and hydrology.
- In cooperation with other Forest Service Regions and Washington Office FHP Staff, initiate a contingency plan of action with Mexican forestry officials for the likely introduction of WPBR disease into white pine stands in Mexico.
- Place WLIS in a corporate databank where updates can be made automatically.
- Determine the ability of whitebark pine to be reproductively viable. A current effort by the Whitebark Pine Monitoring Working Group is underway to develop the necessary protocol for determining the recruitment of immature trees into the cone-producing population.

- Analyze the data from the Frank Church River of No Return Wilderness project slated for 2009. The final report will include analysis of whitebark pine regeneration following fire and fire risk associated with varying levels of WPBR and mountain pine beetle.
- Collect seed from whitebark pine in the Frank Church River of No Return Wilderness and archive the seed in a genetic conservation bank and make available for any future restoration efforts, genetic studies, and breeding activities that focus on resistance to WPBR.

Aspen Dieback and Mortality Projects

Beginning about 2002, large scale and rapid aspen mortality occurred in the interior West, especially in Arizona, Colorado, and southern Utah in association with severe drought and warmer than usual temperatures. Symptoms of sudden aspen decline (or SAD, as it was named in Colorado), include excessive branch and twig dieback; high levels of mortality; and in some areas poor regeneration success. This rapid decline was preceded in several areas of the Interior West by a slow and gradual loss of aspen-dominated forests during the 20th century, due in large part to fire suppression that allowed seral stands to succeed to more climax conifer species (Margolis 2007). Severe browse by both domestic livestock and wild game in specific areas also contributed to the decline of aspen by limiting the ability of aspen to regenerate successfully over the last century.

Four EM Projects were funded from 2003 to 2007 to quantify aspen mortality, dieback, causal agents, and regeneration response, and describe stand and site variables contributing to decline. The EM program allowed a quick assessment of aspen health across several States of the interior West. Surveys were conducted in Arizona, Colorado, Idaho, Montana, Nevada, and Utah. Although each project had a unique approach, focus, and plot design, the results indicate there was a synchronized mortality event, with slight variations in timing and degree of impacts, starting in the southern latitudes and extending to the mid-latitudes of the Interior West.

Project INT-EM-03-02: Impacts to Aspen

Communities in Northern Arizona—Monitoring plots were established in 2003 and 2004 on two national forests in Arizona, following the severe dieback and decline of aspen detected during aerial surveys. Estimates of tree death allowed stand reconstruction back to 2000 and 2001. This was important because although the severe drought and warm temperatures of 2002 were a major factor in aspen mortality, a June 1999 frost event was believed to have contributed to decline. Annual plot remeasurement continued through

2007 to assess further decline or recovery and record browse impacts on regeneration.

Overall, 52 percent of the aspen over 5 inches (12.7 cm) d.b.h. died between 2000 and 2007 across the sampled area. On the Coconino National Forest, aspen mortality varied from a high of 95 percent on low-elevation xeric sites (< 2286 m), 61 percent in mid-elevation sites (2286–2590 m), and 16 percent on more mesic high-elevation sites (> 2590 m). On the Apache-Sitgreaves NF mortality rates in mid and high elevation sites were similar at 46 percent.⁴ The lower elevation sites found on the Coconino NF are rare on the Apache-Sitgreaves NF, where none were selected in random sampling.

Diameter distributions showed mortality was not skewed to any particular size class, but trees with diameters smaller than 5 inches (12.7 cm) died more rapidly than larger trees. Several insects and pathogens were associated with aspen mortality, but predominance varied by site. These agents include *Cytospora* canker (*Valsa spp.*), aspen bark beetles (*Trypophloeus populi* and *Procryphalus mucronatus*), bronze poplar borer (*Agrilus liragus*), and poplar borer (*Saperda calcarata*). Western tent caterpillar defoliated aspen throughout Arizona in 2004, 2005, and 2007, and may have contributed to further decline.

Although aspen ramet production occurred to some degree on all sites with the death of mature trees, aspen sprouts were nearly nonexistent by the summer of 2007 due to browsing by wild ungulates, particularly elk. Most aspen sites were not recently grazed by domestic cattle. Widespread mortality of mature aspen trees, chronic browsing by ungulates, and advanced conifer reproduction are expected to result in rapid vegetation change of many ecologically unique and important sites.

Project INT-EM-06-01: The Influence of Wolves on Decline in Aspen Communities in Northern Arizona

—Elk exclusion fences are necessary in many areas across Arizona to protect developing aspen. Aspen regeneration (ramets) was monitored for ungulate browse impacts in recent wildfire areas. Since the Mexican grey wolf was reintroduced into eastern Arizona in the mid-1990s, wolf home range maps were acquired by U.S. Fish and Wildlife Service to see if ungulate browsing was negatively correlated with wolf use.

Aspen ramet densities were high (~124,000 per acre (50 000/ha) and similar to densities found in studies of successfully regenerated clearcut stands in the West. Browse damage was estimated based on the presence or absence of forked stems.

⁴ Personal communication. 2009. Mary L. Fairweather, Plant Pathologist, U.S. Forest Service, Forest Health Protection, Flagstaff, AZ 86001.

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Although 75 percent of sampled ramets were forked, the average height after 3 years of growth was 5.2 feet (1.6 m), which is good growth for young aspen. Differences in browse impacts were not detected between low- and high-use wolf areas, nor were there differences in stems per acre or biomass. Other methodologies are likely necessary to determine wolf impact on elk browse behavior; perhaps monitoring elk activity with radial collars is necessary to assess wolf-elk interactions. Aspen ramets apparently are growing well in these recently burned areas. However, elk browsing pressure is ongoing and further monitoring is essential to determine the success or failure of regeneration over time.

Project INT-F-06-01: Monitoring the Condition of Aspen in the Northern and Intermountain Regions—

This project was implemented to describe impacts and stand and site conditions related to dieback and/or decline of aspen stands in the Intermountain and Northern Regions. Previous aerial detection surveys and FIA data had documented aspen mortality and/or defoliation. In particular, this project was designed to address the impacts of fire suppression, drought, and causes of tree and clone mortality. Plots were established in aspen stands in Utah, Nevada, Idaho, and Montana. Large tree mortality averaged 29 percent in the Utah and Nevada survey, 24 percent in southern Idaho, and 6 percent in Montana and Northern Idaho. Most trees died between 2005 and 2007. The most common insects and pathogens on larger trees were poplar borer (*Saperda calcarata*), bronze poplar borer (*Agrilus liragus*), Cytospora canker, (*Valsa spp*), sooty-bark canker (*Encoelia pruinosa*), and various defoliating insects such as the large aspen tortrix (*Choristoneura conflictana*) and aspen leaf tiers (*Sciaphila duplex* and *Enargia decolor*). Forest tent caterpillars (*Malacosoma disstria*) had been considered the principle defoliating insect in aspen forests in the Intermountain Region, but they were not recorded on any plot in 2006.

Aspen sprout [larger than 2 inches (5.1 cm) d.b.h.] density varied from fewer than 1,236 trees per ha (TPH) to 13,590 TPH. Ungulate browsing was common, occurring on 15 to 23 percent of all sprouts. Defoliating insects also played a significant role in several sites (St. Clair and others 2010), defoliating and killing many sprouts even in the absence of ungulate damage.

Project INT-EM-07-01: Recent, Rapid, Severe Aspen Mortality in the Rocky Mountain Region—This project surveyed healthy and damaged aspen forests aerially and from ground plots in southern Colorado. Aerial detection surveys were obtained with aerial sketch mapping techniques, and the geographic data were used to calculate the percent of aspen cover type damaged. Concentrated patches of recent trembling aspen (*Populus tremuloides*) mortality covered 56 091 ha of

Colorado forests in 2006. Area affected increased 58 percent between 2005 and 2006 on the Mancos-Dolores Ranger District, San Juan National Forest, where it equaled nearly 10 percent of the aspen cover type.

Randomly selected plots with crown loss damages exceeding 25 percent were paired with nearby randomly selected healthy plots. This project examined root systems, collected increment cores, and analyzed soil pits. Mortality generally decreased with increasing elevation and occurred on less steep slopes than healthy aspen. Mortality was generally greatest on southern to western aspects. In damaged plots, mean aspen mortality of trees smaller than 5 inches (12.7 cm) was 45.2 percent, and mean aspen crown loss was 52.9 percent (Worrall and others 2008). Stands in decline had lower basal areas than healthy stands. There are differences in crown loss between different vegetation types, but no relationship was observed between mean d.b.h. and stand age. Smaller size classes suffered significantly less mortality than the larger trees.

Regeneration response was not related to crown loss and mortality. Some stands responded to mortality, but no overall trend. Suckering response occurred on plots with a large volume of healthy roots and/or on mollic and especially pachic mollic soils. Density of regeneration was more typical of undisturbed stands and did not increase with overstory mortality.

Root mortality ranged from less than 10 percent to more than 90 percent in damaged stands, and there were more dead roots and fewer live roots than healthy stands. Percent root mortality was correlated with recent crown loss. The average diameter of live and dead roots in damaged plots was larger than in healthy plots, but may be due to quick decomposition of smaller roots.

Trees in damaged plots were attacked by the poplar borer more frequently than in healthy plots, but it was independent of crown loss within the plot. As crown loss of a tree increased, those in damaged plots were more likely to have beetles than those in healthy plots. Local contagion is probably more important for the bark beetles than for the other agents. Cytospora canker occurred in all d.b.h. size classes of trees.

Utilization of project results—

- Data from these projects are available to land managers and the general public on Forest Service Web sites:
 - http://www.fs.fed.us/r2/fhm/downloads/sad_faqs.pdf
 - http://www.fs.fed.us/r3/resources/health/aspen_decline.shtml
- Information from these projects has appeared in dozens of local and national newspapers, magazines, radio, and televised news casts.

- Results have been presented to Forest Service line officers and are affecting land management planning efforts.
 - In Colorado, test treatments are under way to identify conditions under which clones may regenerate.
 - A landscape planning effort and environmental impact statement on the San Juan National Forest is using project results.
 - A landscape scale assessment focusing on restoration of aspen forests in north central Arizona is using results from EM projects.
 - A district in Arizona with little aspen forest type is assessing aspen health and prioritizing areas for treatment.
- The Forest Service is cooperating with Federal and State agencies, legislators, and local governments to share information on sudden aspen decline and its management implications, and to look for opportunities for partnerships, collaboration, and funding.
- In Arizona, results were presented to the State Game and Fish agency and hunter groups, resulting in proposed reductions in elk populations in some parts of the State.
- Countless presentations have been given to other public and scientific groups.
- All studies report some level of ungulate browse on aspen ramets (Fairweather and others 2008, Guyon and others 2007, Worrall and others 2008). In Arizona, ramet numbers decreased over a 5-year period, and no surviving ramet grew above 3 feet in height.
- The widespread mortality and crown loss event fits the model of a decline disease because predisposing, inciting, and contributing factors are readily apparent. Predisposing factors include elevation, aspect, and stand history (e.g., fire suppression). Inciting factors include drought and warmer temperatures, and in Arizona, a 1999 frost event. The contributing factors include cytospora canker, bark beetles, woodborers, and other normally secondary agents that were more aggressive on trees weakened by drought and warmer temperatures.
- In mixed conifer stands disturbed by fire in eastern Arizona, ramet densities were considered excellent (124,000/acre (50,000/ha)) and ungulate browse impacts light (Hayes and others 2008). The average height after 3 years of growth was 1.6 m, good growth for young aspen.
- Soil type analysis of Colorado plots suggests differences in crown loss between soil type suborders with drier suborders having greater crown loss.

Summary of key findings—

- Evaluation Monitoring projects have improved the understanding of aspen dieback and decline across much of the Interior West (Worrall and others 2008, Fairweather and others 2008, Guyon and others 2007, Hoffman and others 2008, Steed and Kearns 2008, Worrall 2010). Generally, recent and rapid aspen mortality was greatest in Arizona and southwestern Colorado, and more modest levels of mortality were observed in Utah, Nevada, Idaho, and Montana.
- In decline areas in Colorado, aspen trees larger than 5 inches (12.7 cm) sustained greater damage than smaller trees (Worrall and others 2008).
- In low elevation aspen-ponderosa pine sites in Arizona, all size classes were impacted and smaller trees died at a faster rate than larger trees (Fairweather and others 2008).
- Damage decreased with increasing elevation (Worrall and others 2008, Fairweather and others 2008). Damage tended to be greater on south and west aspects (Guyon and others 2007, Worrall and others 2008), with the exception of the lowest elevation sites that are located on north facing slopes (Fairweather and others 2008).
- Regeneration response was not related to crown loss and mortality in Colorado (Worrall and others 2008).

Suggestions for further investigation—

- Complete aspen decline data analysis in Arizona, Colorado, Utah, Nevada, Idaho and Montana, examining the role of elevation, slope position, and relative importance of damage agents.
- Quantify browse impacts on aspen regeneration across central Arizona, in both decline and wildfire areas, and compare areas with and without significant populations of the introduced Rocky Mountain elk.
- Summarize 100 years of research on severe browse impacts in central Arizona.
- Describe life cycles of aspen bark beetles.
- Investigate the fire history of healthy and unhealthy aspen forests.
- Continue monitoring aspen health, particularly in more northern forests where decline impacts were more moderate or nonexistent.
- Monitor elk activity with radio collars to assess wolf-elk interactions.

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Alder Dieback and Mortality Projects

Project INT-EM-04-01: Alder Dieback and Mortality in the Southern and Central Rocky Mountains:

Extent, Severity, and Cause—Dieback and mortality of thinleaf alder, *Alnus incana* subsp. *tenuifolia*, was first observed in the southern Rocky Mountains beginning in the late 1980s. Dieback and mortality intensified so that by 2000, land managers inquired as to the cause. The goals of this project were to quantify the extent and severity of dieback and mortality from southern Wyoming to northern New Mexico, and to assess potential direct and indirect causal factors. Two surveys were conducted to quantify the extent and severity of dieback and mortality; an extensive survey was conducted over randomly selected, fourth-level watersheds from southern Wyoming to northern New Mexico, and a more intensive survey was conducted within the upper Gunnison River Basin in Colorado. In total, over 10,000 alder stems were evaluated on 100 transects. The condition of stems was classified as live, diseased (i.e., stem dieback), and dead. Dead stems were the most abundant condition class recorded in both surveys, with 37 percent dead in the extensive survey and 40 percent dead in the intensive survey (Worrall 2009).

Genets are dying and not replacing themselves successfully through vegetative reproduction. Live sprout abundance decreased as dieback and mortality increased. Genets with higher sprout quantities had significantly better stem condition than those with fewer sprouts. Canopy dieback and mortality was strongly correlated with percentage of sprouts that were dead at both the transect level and the genet level. Alder damage was not related to elevation, animal browsing, or distance to nearest road.

Cytospora canker, caused by *Valsa melanodiscus*, was consistently associated with dieback and mortality of thinleaf alder. The period of rapid canker growth was the hottest part of summer, from late June through late July. Drought is not considered a factor, since dieback and mortality of thinleaf alder occurred previous to the 2000-05 drought.

Utilization of project results—

- Information has been presented to land managers.
- Published reports (Worrall 2009, 2010) are useful to land managers facing similar alder mortality events.

Summary of key findings—

- Over one-third of standing alder stems were dead, and one-third had dieback in the southern Rocky Mountains.
- Genets with dying and dead stems have fewer live sprouts and higher sprout mortality than healthy genets.

- Genets appear to be dying rather than replacing themselves vegetatively.
- Cytospora canker, caused by *Valsa melanodiscus*, is the proximate cause of the dieback and mortality.
- Except on stems near death, cankers grow only during the hottest part of summer.
- A spectral analysis of long-term climate data revealed a 21-year cycle of summer heat, but the frequency has slowed and amplitude has weakened since the late 1970s.
- During periods with high summer temperatures, alder is apparently stressed and becomes susceptible to Cytospora canker. The canker grows and kills very quickly during warm periods. During cool phases, cankers do not develop and alder can recover and regenerate. With the dampened cycle in recent decades, periods of consecutive cool summers may not be long enough to permit recovery.
- If climate change leads to an increase in maximum and mean summer temperatures in the southern Rocky Mountains, more severe epidemics of Cytospora canker are expected.
- *Phytophthora alni* was not found on dying thinleaf alder in the southern Rocky Mountains.

Suggestions for further investigation—Although *V. melanodiscus* is associated with the thinleaf alder dieback and mortality in the southern Rocky Mountains and other alder forest systems in the West, it is not a primary pathogen of vigorous trees. The factors that lead to host stress are not well understood and need to be explored.

Armillaria Root Disease Project

Project INT-EM-04-04: Distribution, Species, and Ecology of *Armillaria* Fungi in Wyoming—

The geographic distribution of various *armillaria* species were investigated in Wyoming, and relationships among hosts and site conditions characterized. The investigators took this much further and documented common diseases, insects, and damage agents associated with all major forest cover types (including aspen) in Wyoming. *Armillaria* was found in 30 percent of surveyed sites. Four *Armillaria* species have been identified, with *A. solidipes* (synonym *A. ostoyae*) the most common followed by *A. sinapina*, *A. gallica*, and *A. cepistipes*. Soil and stand condition analysis will develop coarse-scale distribution of different *armillaria* species and hazard maps, including precipitation and climate data.

The canker pathogen *Cytospora spp.* and root pathogens *Ganoderma applanatum* and *Armillaria spp.* are responsible for much of the observed aspen mortality in Wyoming. *Armillaria spp.* were detected in 27 percent of aspen stands and confirmed to cause root disease in 13 percent of surveyed sites. Stands and trees have multiple causal agents, and root diseases and cankers often occur in the same stand.

Utilization of project results—Results have been presented to colleagues at various conferences.

Summary of key findings—

- Baseline information on geographic and site factors related to *Armillaria* disease incidence in Wyoming.
- *Armillaria* was found in 30 percent of surveyed sites in Wyoming.
- Four *Armillaria* species have been identified, with *A. solidipes* (synonym *A. ostoyae*) being the most common, followed by *A. sinapina*, *A. gallica*, and *A. cepistipes* (Blodgett and Lundquist 2006).

Suggestions for further investigation—Investigate pathogenicity of *Armillaria* species on quaking aspen.

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