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A Synthesis of Evaluation Monitoring Projects Sponsored by the Forest Health Monitoring Program (1998-2007)

**Edited by William A. Bechtold, Michael J. Bohne, Barbara L.
Conkling, Dana L. Friedman, and Borys M. Tkacz**

Forest Insects

Forest Diseases

Invasive Plants

Lichens

Tree Crown Conditions

Tree Declines

Down Woody Material

Drought and Climate

Fire Effects

Ozone

Soil Conditions

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Abstract

The national Forest Health Monitoring Program of the Forest Service, U.S. Department of Agriculture, has funded over 200 Evaluation Monitoring projects. Evaluation Monitoring is designed to verify and define the extent of deterioration in forest ecosystems where potential problems have been identified. This report is a synthesis of results from over 150 Evaluation Monitoring projects initiated between 1998 and 2007. The purpose of this synthesis is to document results, provide material for a planned online database, and establish priorities for future Evaluation Monitoring projects.

Keywords: Down woody material, evaluation monitoring, fire, forest health, insects and disease, lichens, ozone, soils.

Introduction

The national Forest Health Monitoring (FHM) Program of the Forest Service, U.S. Department of Agriculture, has three main objectives (Riitters and Tkacz 2004): (1) to identify forest ecosystems where conditions might be deteriorating in subtle ways over large areas; (2) to verify and define the extent of deterioration in forest ecosystems where potential problems are identified; and (3) to understand the processes that cause forest health problems so strategies can be developed for problem mitigation and prevention.

The FHM program uses a three-tiered approach to accomplish these objectives, whereby progressively more detailed studies are conducted to investigate forest health issues. The studies are Detection Monitoring (DM), Evaluation Monitoring (EM), and Intensive Site Monitoring.

Detection Monitoring relies on systematic sampling across the landscape in both space and over time, where measurements of forest health indicators are monitored for adverse change. Detection Monitoring is accomplished through the phase 3 plot network implemented by the Forest Inventory and Analysis (FIA) Program of the Forest Service (Bechtold and Patterson 2005). Phase 3 plots were originally established by the FHM program between 1990 and 1999. These plots were integrated into the FIA plot network in 2000, at which time they were designated as phase 3 plots, and FIA standard inventory plots were identified as phase 2 plots. Phase 3 plots include all of the measurements obtained from phase 2 plots, plus additional data associated with more specialized forest health indicators. Detection Monitoring also includes the aerial detection surveys conducted by the Forest Health Protection (FHP) Program of the Forest Service (Ciesla 2006), as well as special surveys designed to monitor particular threats (Coulston and others 2008). Evaluation Monitoring then focuses on potentially important problems that have attracted attention through DM.

Intensive site monitoring, intended for even more rigorous analysis, links forest health issues that defy explanation to process-level research at long-term research sites (Bechtold and others 2007). A comprehensive description of FHM program history, organization, and implementation is provided by Riitters and Tkacz (2004) and Bechtold and

others (2007). Additional details are available on the FHM Web site at www.fs.fed.us/foresthealth/fhm/.

The objective of this report is to collect and synthesize the results of nationally funded EM projects initiated between 1998 and 2007. The impetus for this project is from a review of the FHM Program in 2006 by the State and Private Forestry Branch of the Forest Service (http://www.fs.fed.us/foresthealth/fhm/pubs/misc/fhm_review/FHM_review06.pdf). In addition to documenting lessons learned and value gained, this synthesis is expected to provide material for a planned online EM database as well as guidance for future project selection and overall program priorities for EM projects.

Although the FHM program funded a few projects in 1996 and 1997, EM project selection and funding protocols were not formalized until 1998. Since then, project selection has been a collaborative regional and national panel process. A request for proposals (appendix A) is distributed nationally each year. Projects are chosen through separate competitions involving two different funding sources: Base EM and Fire Plan EM.

The purpose of Base EM is to investigate issues or concerns identified in the Detection Monitoring phase of forest health monitoring. Proposed projects are 1 to 3 years in duration and devised to explain the extent, severity, and/or cause of a phenomenon observed during DM. General target areas include forest insects and diseases, climatic events (e.g., drought, ice storms, hurricanes, frost), air pollution, soil conditions, and other factors influencing forest health.

The purpose of Fire Plan EM is to investigate and explain the extent, severity, and cause of a fire-related phenomenon observed in DM. General target areas include risk reduction, fuel loading, ecological impacts of fires, invasive species, and restoration or fire-damaged ecosystems. Fire Plan funding for EM projects did not become available until after the 2000 fire season, when the EM system was recognized as a useful mechanism for studying the aftermath of large disturbance events associated with fire. In addition to Base and Fire Plan funding, regional FHM offices have limited funding for local-scale EM studies; the local projects are not included in this synthesis.

Introduction

After EM proposals are submitted, each of five FHM regional managers (West Coast, Interior West, North Central, Northeast, and South) identifies which funding category is most appropriate, subsequently ranking the projects in each category for their region. Regional results are submitted to the National FHM Program Manager, and individual proposals are then evaluated by a national panel for either Base or Fire Plan funding (as specified in the packages received from the regional managers). Each region may submit up to five Base EM and five Fire Plan proposals. Ongoing multi-year proposals are counted among the annual submissions, receiving priority if sufficient progress has been documented. Proposals are evaluated using the following criteria:

1. Linkage to DM (and linkage to the National Fire Plan <http://www.forestsandrangelands.gov/> in the case of Fire Plan funding)
2. Significance in terms of geographic scale
3. Biological impact and/or political importance of the issue
4. Scientific basis/feasibility—probability of successful completion in 1-3 years
5. Priority issues (as specified in the annual request for proposals).

The principal investigators of funded projects are expected to submit annual progress reports and present posters summarizing results at annual FHM working group meetings (posters can be viewed by visiting the FHM Web site <http://www.fs.fed.us/foresthealth/fhm>). A final report is due upon project completion. Starting in 2010, investigators also have been required to publish summaries of completed projects in the annual FHM national technical reports. However, the summaries will begin appearing in the Forest Health Monitoring 2008 National Technical Report (Potter and Conkling 2012). In addition to these minimal requirements, results of many projects have been published in other outlets such as peer-reviewed journals. Material for this synthesis has been drawn from all of these sources.

Appendix B lists over 150 nationally funded Base and Fire Plan Projects initiated between 1998 and 2007 for which results are available at this writing. These projects were subsequently sorted into the forest health-related topic areas listed below. Note that these topic areas are not necessarily mutually exclusive because forest health problems often interact, so projects selected for one topic area might also fit into another.

- Forest Insects (by region)
- Forest Diseases (by region)
- Other Biotic Stresses and Indicators
 - Invasive Plants
 - Lichens
 - Tree Crown Condition
 - Tree Mortality
- Abiotic Stresses and Indicators
 - Down Woody Material
 - Drought and Climate
 - Fire Effects
 - Ozone
 - Soil Conditions

Subject matter specialists, many of whom have received EM funding, were then invited to synthesize the information available for completed projects and write a chapter for each topic area to describe individual projects, summarize the key findings, and make suggestions for further investigations.

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CHAPTER 1

Interior West Forest Insects

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This chapter provides a synthesis and brief review of 11 Base Evaluation Monitoring (EM) projects and 7 Fire Plan projects in Arizona, Colorado, Idaho, New Mexico, Utah, and Wyoming. Base projects were distributed among the primary coniferous forest types in this region: spruce-fir, piñon-juniper, Douglas-fir, lodgepole pine, limber pine, and ponderosa pine. All but two of the Base projects were associated with bark beetle-caused tree mortality, the exceptions being a study examining the effects of a defoliating insect, *Nepytia janetae*, and a study assessing the occurrence, severity, and expanding distribution of the nonnative balsam woolly adelgid. Fire Plan funded projects were spread among Engelmann spruce, lodgepole pine, Douglas-fir, ponderosa pine, and piñon-juniper types. Six of these projects examined relationships between tree mortality, fuel accumulation, and fire modeling. The remaining project investigated the effects of prescribed burning on bark beetle populations.

An Overview of Base Evaluation Monitoring Projects

Insect defoliator and bark beetle outbreaks have had significant impacts on forests of the Intermountain West over the last decade. The principle factor responsible for the initiation and spread of these outbreaks is not always clear, but stand conditions, disturbance events, and climate are typically important contributors (Fettig and others 2007). Most of the defoliator impacts have occurred in mixed conifer and spruce-fir forest types. Although the importance of a few defoliators (e.g., western spruce budworm, Douglas-fir tussock moth) has been recognized for several decades, impacts of other forest defoliators (e.g., *Nepytia janetae*, spruce aphid in

the Southwest) have been studied only recently. Because there was no previous record of an outbreak by *Nepytia janetae* or information on its basic biology, Projects INT-EM-99-05 and INT-EM-00-05 were funded to document the biology and associated impacts of this insect in Arizona. Nonnative insect species such as the balsam woolly adelgid continue to pose serious threats to forest ecosystems. Project INT-EM-07-02 documents a range expansion of balsam woolly adelgid in Idaho, providing valuable information on distribution, severity, and expansion rates.

Bark beetle outbreaks in the West have recently occurred across all major conifer forest types (Negrón and others 2008). In the Southwest, bark beetle outbreaks were most intense and widespread in ponderosa pine forests and piñon-juniper woodlands (Allen-Reid and others 2008, McMillin and others 2008, Negrón and others 2009). Outbreaks have also been occurring throughout many areas of mid- and high-elevation forest types in the Rocky Mountains (USDA Forest Service 2009). Although large bark beetle outbreaks have occurred historically throughout the West, recent interactions between climate effects and susceptible forests may have greatly increased the extent and severity of these outbreaks. Aerial detection surveys and special mission flights by the national Forest Health Monitoring (FHM) Program of the Forest Service, U.S. Department of Agriculture, assist in mapping the extent of these events, but more specific information on the impacts at the stand and landscape levels is lacking. Most of these Base EM projects were funded to quantify impacts associated with stand structure and to look for correlations between stand structure, site conditions, tree mortality or other stand-level impacts. In addition, one project (INT-EM-07-04) developed protocols to monitor the effects of silvicultural treatments on spruce beetle impacts. The documentation of insect associated impacts under different forest conditions supplies important information to land managers.

An Overview of Fire Plan Projects

Tree mortality caused by bark beetles can influence attributes associated with fire behavior through increases in ignition probability and fuel loads, and through changes in stand

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Forest Insects

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structure leading to increased wind speeds and drying of fuels (reviewed in Jenkins and others 2008). Although not all forest types have been studied, recent results from mid- to high-elevation forest types (spruce-fir, lodgepole, Douglas-fir) suggest that effects are largely dependent on time since beetle-caused tree mortality and severity of the outbreak (Jenkins and others 2008, Lynch and others 2006). For example, during and shortly after outbreaks, probability of crown fire initiation is thought to increase because living canopy fuels have been converted into dryer dead canopy fuels. After dead needles are shed, it is thought that crown fire ignition and spread through the canopy are both temporarily reduced. Once branches and whole trees begin to fall, and regeneration occurs, risk of crown fire ignition and spread may begin to increase. Because rates of needle drop, tree fall, and surface fuel decomposition vary across forest types, elevation and latitudinal gradients, it is critical to quantify relationships between bark beetle outbreaks and potential fire behavior across this variability. Because few empirical studies have examined these relationships in lower elevation forest types (e.g., ponderosa pine, piñon-juniper) (Jenkins and others 2008) two projects (INT-F-06-02, INT-F-07-01) were funded to provide information on how bark beetle outbreaks in lower elevation forest types affect fuel loading and predicted fire behavior.

Past management practices have left many forests and woodlands in the Southwest with high tree densities that are particularly susceptible to bark beetle outbreaks and stand-replacing wildfires. Consequently, forest managers have been conducting understory burning in conjunction with overstory thinning to reduce stand density. Prescribed fires, however, may cause unwanted mortality of large residual trees because trees damaged during these burns have increased vulnerability to beetle attack. Project INT-F-07-02 examines these relationships, which have important implications for land management policies, especially for communities near the wildland-urban interface.

Descriptions of Specific Base Projects

Project INT-EM-99-03: Stand Level Impact of Douglas-Fir Beetle Infestations in the Greater Yellowstone Area—The focus of this study was to evaluate changes in the forest overstory and understory following a Douglas-fir beetle (*Dendroctonus pseudotsugae*) infestation in northwestern Wyoming on the Shoshone National Forest. Specifically, the study was designed to document significant effects of the Douglas-fir beetle in three general categories: (1) overstory effects, (2) regeneration effects, and (3) understory effects. The study evaluated forest condition changes in areas with high levels of mortality 5 or more years post-outbreak and quantified changes in the understory of previously infested

stands. Line transects with a variable radius plot every 10 chains and a comparison of paired infested and uninfested plots were used to assess bark beetle impacts in affected sites.

Douglas-fir beetle caused significant changes in forest condition in the transect portion of the study (McMillin and Allen 2003). Douglas-fir basal area decreased by 46 percent, pre-outbreak basal area for all species decreased 43 percent and average stand diameter by 8 percent [1 inch (2.5 cm) reduction]. Statistically significant relationships were observed between Douglas-fir mortality and percentage of Douglas-fir stems, pre-outbreak basal area for all tree species, and Douglas-fir basal area.

Significant differences in forest overstory conditions were found between paired infested and uninfested plots. Douglas-fir basal area was reduced by 80 percent in the infested plots. Post-outbreak tree diameters averaged 4.3 inches (11 cm) less in infested plots and a relative increase occurred in the percentage of other tree species (Engelmann spruce, white pine and lodgepole pine).

Douglas-fir beetle had a significant effect on understory (grass, forbs, and shrubs) abundance. Infested plots averaged a three-fold increase in total abundance compared to uninfested plots. Forbs were the most prevalent in both infested and uninfested plots; grass species had the largest percent increase (nearly 12-fold) among the three groups. Average understory height tripled in infested plots. The relatively low coefficient of determination for each understory component suggests that there are other important, but unexplained sources of variation accounting for differences between uninfested and infested plots. Variation could be associated with timing of measurement (plots with older mortality), grazing pressure, short-term and long-term fire effects, aspect, and moisture.

Regeneration in infested plots was more than three times greater than in uninfested plots. Approximately 90 percent of the regeneration was Douglas-fir in both plot types. The other 10 percent included Engelmann spruce, subalpine fir, and lodgepole pine.

Projects INT-EM-99-05, INT-EM-00-05: Impact Assessment of *Nepytia Janetae* (Lepidoptera, Geometrida) on Engelmann Spruce-Subalpine Fir Forests on Mt. Graham, Coronado National Forest and on Fort Apache Indian Reservation—*Nepytia janetae* severely defoliated over 4 000 ha of spruce-fir forests between 1996 and 1999 in the White and Pinaleno Mountains of eastern Arizona, defoliating both corkbark fir and Engelmann spruce (USDA Forest Service Region 3, Insect & Disease Conditions Reports). The objectives of this project were to determine the impacts of defoliation by *N. janetae* and

to more fully understand the biology of the insect. Permanent plots were established throughout impacted areas to collect mensurational information, levels of defoliation, and tree mortality data.

Based on two separate outbreaks in Arizona, investigators concluded that *N. janetae* is a univoltine, winter-feeding looper with 3- to 4-year long outbreaks in high elevation spruce-fir forests (Lynch 2005) (Lynch and Fitzgibbon).⁵ Both Engelmann spruce and corkbark fir were found to be highly susceptible to defoliation, while Douglas-fir and southwestern white pine were not defoliated. Both defoliation intensity (74 versus 32 percent) and tree mortality (76 versus 5 percent) was higher in the Pinaleno Mountains than in the White Mountains. Differences in impact severity between the two sites were caused in part by the Pinaleno outbreak lasting one year longer. Defoliation was found to increase tree susceptibility to spruce beetle and western balsam bark beetle in the Pinaleno Mountains, with most of the mortality attributed to the combined effects of defoliation and bark beetle attack.

Project INT-EM-99-04, INT-EM-00-04: GIS-Based Landscape-Scale Prediction System for Piñon Pine Decline in the Southwestern United States—

This project focused on preparing a predictive model for piñon mortality from piñon ips and black stain root disease in southwestern Colorado. Modeling included the use of aerial photos to define the extent of the piñon mortality in combination with ground surveys and soil information from GIS-based data provided by the Forest Service and the U.S. Geologic Survey. The aerial photos were taken in 1998 followed by 14 months of photo interpretation. Geo-rectifying of the photos was time-consuming and, therefore, was not completed. The field survey was completed and combined with soil data to develop mortality models.

In recently formed tree mortality centers, 68 percent of all piñon were dead, 76 percent of piñon were affected by black stain root disease, and 70 percent had evidence of piñon ips attack (Kearns and Jacobi 2005). Incidence of mortality was highest in piñon stands characterized by high densities of small diameter trees with below average amounts of non-piñon vegetative cover. Relationships between tree mortality and topography were inconclusive, as were relationships between mortality and site disturbance by humans. This study also provided information on insects associated with black stain root disease (Bishop and Jacobi 2003) and persistence of piñon snags and logs (Kearns and others 2005).

⁵ Lynch, A.M.; Fitzgibbon, R.A. In preparation. Biology and impact of *Nepytia janetae* (Lepidoptera: Geometridae) in spruce-fir forests in Arizona, U.S.A.

Project INT-EM-00-01: Stand Level Impact of Subalpine Fir Decline in Spruce-Fir Forest Type of the North-Central Rocky Mountains—

Western balsam bark beetle caused widespread mortality of subalpine fir in western North America throughout the 1990s. The objectives of this study were to document the effects of this mortality, relate mortality to preexisting stand conditions, and investigate the role of storm-damaged fir to beetle population dynamics in north central Wyoming. Transect cruise lines and pairs of infested and uninfested plots were installed to detect changes in the forest overstory and understory and to determine associations between stand conditions and beetle-caused fir mortality.

On average, western balsam bark beetle killed more than 70 trees per acre (28 trees per hectare) over 5 years in the Bighorn Mountains of Wyoming (McMillin and others 2003). This mortality resulted in significant decreases in subalpine fir basal area, trees per acre, stand density index, and the percentage of subalpine fir stems in the overstory. Small, but significant increases were detected in the understory; herbaceous plant abundance increased in the infested plots compared to noninfested plots. Moreover, significant positive linear relationships existed between the amount of fir mortality and the percentage of subalpine fir trees in a stand, subalpine fir basal area, and subalpine fir stand density index.

Western balsam bark beetle successfully colonized down trees. A significant positive linear relationship was observed between the percentage of wind-caused downed fir logs in an area and the percentage of logs utilized by western balsam bark beetle. The blowdown events that occurred in the mid-1990s in combination with a high percentage of subalpine fir in the overstory provided ideal conditions for continued beetle expansion.

Projects INT-EM-01-05: Subalpine Fir Mortality Caused by Western Balsam Bark Beetle: the Importance of Blowdown in Beetle Population Increase—

The objectives of this project were to determine (1) if western balsam bark beetle successfully attacked and produced brood in downed subalpine fir, (2) if attaching beetle attractants to downed trees increased attack densities and subsequent brood production, and (3) if successful brood production varies by location on the tree bole; and (4) to examine the lifecycle of western balsam bark beetle in downed subalpine fir.

The Bighorn and Shoshone National Forests in north central Wyoming were selected as study sites. Five subalpine firs were felled at four locations on each Forest. In two of the study sites on each Forest, felled trees were baited with attractants and on the other two sites, no baits were attached to the downed trees.

Forest Insects

1. Interior West Forest Insects

In September of 2001, trees were sampled to determine life stage and brood production from the top and bottom aspects of the trees, at diameter at breast height (d.b.h.), at mid-bole, and in the upper crown. Brood sampling was repeated in the spring, summer, and fall of 2002.

Results indicate western balsam bark beetle does attack and produce successful brood in downed trees (Allen and others 2002, 2003) and suggest a 2-year life cycle in north central Wyoming. The use of attractant baits did not increase brood production in the felled trees. Rather, bark beetle populations were almost double in the trees where no attractants were used in 2001 and 2002. A higher percentage of brood was produced in the mid portion of the bole compared to successful brood production at d.b.h. and in the upper portion of the tree bole. More beetles were produced in the bottom aspect of the bole than the top surface. Higher brood production occurred in felled trees located on the Shoshone National Forest than on the Bighorn National Forest.

Based on this analysis, it was suggested that resource managers employ management strategies in downed subalpine fir to mitigate western balsam bark beetle population increases. Prompt removal or chipping of the down material should be conducted within 2 years of a blowdown event. Downed trees may also serve as trap trees to concentrate local populations of the insect as part of a management strategy to suppress western bark beetle populations.

Project INT-EM-03-01: Stand Level Impacts of Ips and Dendroctonus Bark Beetles in Pine Forest Types of Northern Arizona—Landscape-level bark beetle outbreaks in ponderosa pine forests and piñon-juniper woodlands occurred throughout the Southwest between 2002 and 2004 in response to severe drought and susceptible forests conditions. FHM aerial detection surveys found more than 3 million acres of ponderosa and piñon impacted by bark beetles during 2002 and 2003 (USDA Forest Service Region 3, Insect & Disease Condition Reports). Several bark beetles worked in concert to kill the ponderosa pine: *Ips* spp., western pine beetle, and roundheaded pine beetle. Piñon was killed primarily by pinyon ips and twig beetles. Investigators established over 1,100 permanent plots across five national forests in Arizona during 2003 and 2004, which were designed to quantify overstory impacts (reductions in trees per acre and basal area) and correlations with preexisting stand conditions.

Tree mortality resulted in significant reductions in basal area, tree density, stand density index, and mean tree diameter for ponderosa and piñon pine (McMillin and others 2008, Negrón and others 2009). Ponderosa pine mortality was positively correlated with tree density and negatively correlated with

elevation (all national forests combined) and reduced tree diameter (Prescott National Forest). Most of the observed ponderosa pine mortality was in the 10-35 cm diameter class, which comprise much of the increase in tree density over the last 100 years as a result of fire suppression and grazing practices.

Piñon mortality was found to range from 0 to 48 percent on the national forests, with mortality positively correlated with tree density and negatively correlated with elevation on most forests (McMillin and others).⁶ Piñon mortality occurred across all diameter classes; however, a higher percent of trees were killed in the largest diameter classes. In addition, up to 40 percent of piñon that died between 2002 and 2003 had already fallen to the ground based on plot remeasurement in 2005.

Project INT-EM-04-03: Severity and Extent of Douglas-Fir Beetle Infestations in Northern Wyoming

The project was designed to evaluate the extent and severity of Douglas-fir beetle infestations at the stand level in the Bighorn Mountains of northern Wyoming. Objectives included determining the effects of outbreaks on residual stand structure and understory vegetation following an outbreak. Fifty-six fixed-radius plots were installed on the west side of the Bighorn National Forest. In each plot, the following measurements were recorded for all trees larger than 4 inches (10.1 cm) d.b.h.: tree species, crown class, and condition/damage class. Plots were installed in Douglas-fir beetle infested sites and uninfested stands of Douglas-fir. Year of attack was determined for infested/dead Douglas-fir. Number and species of seedlings greater than 6 inches (15.2 cm) in height were counted in 11.8-foot (3.6-m) fixed-radius plots around plot center. Along a 10-foot (3-m) transect line in cardinal directions from plot center, grass, forb, and shrub cover was measured in centimeters. Understory canopy height was measured at its highest point along transects in each cardinal direction.

Summary statistics indicate that Douglas-fir beetle was significantly impacting forest overstory conditions (Allen and others 2006). Basal area was reduced by 82 percent in the infested plots. Live d.b.h. in the infested plots averaged 6.4 inches (16.2 cm) compared to uninfested plots where d.b.h. averaged 9.4 inches (23.8 cm). Infestations caused a 33 percent reduction of Douglas-fir tree density in infested plots compared to the pre-outbreak Douglas-fir percentage.

Understory vegetation (shrubs, forbs, and grasses) increased within the infested plots as a result of overstory Douglas-fir mortality. The largest response in understory vegetation

⁶ McMillin, J.D.; Negrón, J.F.; Anhold, J.A. Stand level impacts of *Ips confusus* on piñon-juniper woodlands of southwestern United States and northern Mexico. In preparation.

occurred in the shrub component where ground cover increased by 7 percent.

Project INT-EM-05-01: Piñon and Juniper Mortality—Extent, Severity, and Causal Agents—This work examined tree mortality levels and their causes in piñon-juniper woodlands in Arizona, Colorado, Utah, and Nevada. The study analyzed data from the Annual Inventory Program conducted by the Forest Inventory and Analysis (FIA) Program of the Forest Service.

Investigators concluded that widespread mortality in the piñon-juniper forest type is associated with several years of drought in the Southwestern United States (Shaw and others 2005). A complex of drought, insects, and disease was responsible for piñon mortality rates approaching 100 percent in some areas, while other areas experienced little or no mortality. Implementation of FIA annual inventory in several States coincided with the onset of elevated mortality rates.

Project INT-EM-05-04: Monitoring Host Selection Behavior and Progression of Infestation by the Mountain Pine Beetle in Mixed Stands of Limber and Lodgepole Pine—This project examined the host selection behavior of mountain pine beetle in mixed stands of limber and lodgepole pines in southeastern Wyoming (Medicine Bow National Forest). Investigators monitored the parameters of the life cycle, phenology, and host selection behavior of mountain pine beetle using ten 0.32 acre (0.13 ha) plots with the following objectives: (1) to determine the phenology of main developmental stages and developmental success in hosts of mountain pine beetle; (2) to assess the course of infestation progression in mixed stands of lodgepole and limber pines; and (3) to identify the host of origin of mountain pine beetle in mixed stands.

In May 2004, sampling from research plots demonstrated that a higher proportion of limber pines and a lower proportion of lodgepole were colonized by mountain pine beetle; suggesting that limber pine was the preferred host in the mixed stands of limber/lodgepole (Dean 2007, Dean and others 2007). Intermediate and large-diameter size classes of limber were almost eliminated from these mixed stands. This study suggests a possible shift in host preference from limber pine to lodgepole pine, but a longer term study would clarify the progress of the infestation. In 7 out of 10 cases more mountain pine beetle emerged from limber than from lodgepole. Mountain pine beetle emergence periods varied between limber and lodgepole, but peak emergence was identical.

Project INT-EM-07-02: Ground-Based Distribution Surveys for Exotic Balsam Woolly Adelgid (*Adelges piceae*) in Idaho—Balsam woolly adelgid has been

spreading rapidly in Idaho since it was first discovered there in 1983. In 2006, Idaho Department of Lands personnel found balsam woolly adelgid infestations on sites well outside the area previously reported from ground and aerial surveys conducted in 1997-98, indicating a dramatic range increase in the State. These discoveries highlighted the need for another survey to determine the current extent of balsam woolly adelgid infestation across Idaho. Ground surveys were considered necessary to fully capture the current extent, as trees may be infested for many years before a signature is detectable from the air.

Project objectives were to identify factors contributing to the decline of subalpine fir and other true firs in Idaho, determine the current distribution and severity of balsam woolly adelgid in subalpine fir, determine the extent to which balsam woolly adelgid was infesting grand fir in areas where it was also infesting subalpine fir, and examine the relative utility of balsam woolly adelgid distribution maps generated from ground versus aerial detection surveys. Trained crews conducted a roadside survey in 2006 and 2007. Survey plots were located along roads at 1- or 2-mile intervals in subalpine fir stands. Plots were georeferenced, and presence/absence data were collected for each true fir species present. A plot was considered infested when gouting was present or at least one balsam woolly adelgid was found after 10 minutes of searching.

Field crews sampled a total of 1,016 plots distributed throughout the roaded portions of the subalpine fir vegetation type and also in many urban areas, finding about 58 percent of them infested with balsam woolly adelgid. Balsam woolly adelgid was present on 73 percent of the plots located below 4,500 feet (1 375 m) elevation, while 53 percent of the plots located above this elevation were infested. During the approximately 10 years elapsing since the previous ground survey, balsam woolly adelgid advanced 91 miles (146 km) north to the Canada border, 26 miles (42 km) east to the Montana border, 10 miles (16 km) west to the Washington border, and about 111 miles (178 km) south.

Project INT-EM-07-04: The Effects of Silvicultural Manipulations on Spruce Beetle Populations—The project was designed to monitor the extent, severity and causes of spruce beetle caused mortality in southwestern Colorado. Evaluations of previous silvicultural treatments were conducted to determine if these treatments mitigated spruce beetle activity and impacts. The project was also designed to examine the interactions of current stand conditions and high levels of spruce beetle activity to subsequent tree mortality.

The project was funded for 3 years beginning in 2007 to quantify spruce beetle impacts in areas where recent activity was evident. Candidate stands were selected on five national forests using two criteria: (1) at least 50 percent of the stand's

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total basal area is spruce, and (2) some type of silvicultural manipulation occurred within the stand previously. In 2007, candidate stands were selected using “most similar neighbor” GIS analysis (Moeur and Stage 1995). The GIS exercise selected stands based on stand conditions, previous silvicultural management and spruce beetle activity. In 2008, data collection began on the five national forests with data collection continuing through the 2009 field season. Managed stands will be compared to unmanaged stands in areas with current and recent spruce beetle activity for degree and cause of tree mortality (Eager and Mask 2008).

Descriptions of Specific Fire Plan Projects

Project INT-F-04-02: Characterization of Fuel Complexes in Stands Affected by the Spruce Beetle

The original project title was later changed to Bark Beetle Induced Changes in Conifer Fuel Complexes in the Intermountain Region. Fuel complexes in mature stands of spruce-fir, Douglas-fir, and lodgepole pine were compared under different levels of bark beetle activity (endemic, epidemic, and post-epidemic) to quantify bark beetle-caused changes to the fuel complexes. Study sites were selected using FHM aerial detection survey data in conjunction with FIA data. Survey data were used to delineate stands with endemic, epidemic, and post-epidemic beetle populations. Variable-radius plots were systemically established within each selected stand. From plot center, a Brown’s (1974) planar transect method was used to determine 1-, 10-, 100- and 1,000-hour fuel class sizes, duff, and litter. Data were also collected for shrubs, herbaceous vegetation, and regeneration from fixed micro-plots. Year since attack in addition to d.b.h. and proportion of needles remaining on the tree were recorded for all bark beetle attacked trees.

Results from this project (Jenkins and others 2008, Page and Jenkins 2007a, 2007b) demonstrated that fuels change over time, creating periods where the potential for high intensity, severe fires or both either increases or decreases. The net result of bark beetle epidemics was a substantial change in species composition and a highly altered fuel complex. Early in the epidemic there is an increase in the amount of fine surface fuels compared to endemic stands. In post-epidemic stands, large dead woody fuels and live surface fuels dominate. Results indicated that for surface fires both rates of fire spread and fireline intensities were higher in the current epidemic stands than in the endemic stands. Higher rates of spread and fireline intensities in epidemic stands were caused by decreased vegetative sheltering and its effect on mid-flame wind speed rather than changes in fuels. Passive crown fires were more likely in post-epidemic stands, but active crown fires were predicted to be less likely because of decreased aerial fuel continuity.

Results from this and related projects suggest that treatments to mitigate impacts caused by bark beetle outbreaks, such as moderate thinning, may result in less potential for extreme fire behavior compared with unmanaged stands. Greater fuel depths, mid-flame wind speeds, and lower fuel moisture might increase potential fire behavior compared to unmanaged stands. Bark beetle management strategies should be designed to address post-harvest fuel treatments that reduce surface fuels to lower the risk of severe wildfire. Management plans that consider bark beetle/fire interactions can provide resource managers with better guidance for meeting important resource objectives, reducing treatment costs, minimizing adverse ecological impacts, and avoiding potential controversy. The mitigation of potentially adverse bark beetle and fire effects is maximized when treatments occur at landscape scales and integrate the spatial arrangement of forest types and stand conditions.

Project INT-F-06-02: Potential Fire Hazard Following Bark Beetle Outbreak in Piñon-Juniper Woodlands

An extensive, drought-driven pinyon ips epidemic occurred in New Mexico from 2000 to 2004. Special FHM aerial detection surveys conducted in New Mexico mapped significant piñon mortality on more than 770,000 acres, with an estimated 44 million piñon killed in year 2003 alone. Objectives were to quantify the extent, severity, and impact of bark beetles on piñon throughout the 14,000 acre woodland type on the Santa Clara Pueblo. In addition, the project was designed to examine effects of the outbreak on fuel loading and potential fire hazard, and to relate site and stand factors (e.g., elevation, stand density, and dwarf mistletoe infection) to outbreak intensity. Forty-nine 0.05-acre impact plots were installed in 1995 on a 750 x 750 m grid throughout the Tribe’s 14,000 acre “commercial” woodlands. Plots were revisited in 2006 to collect mensurational and fuels data.

No results or reports from this study were available at the time of this review. However, the collected data will be used to provide information on impacts to assist the Pueblo in their forest management planning activities.

Project INT-F-06-03: Mountain Pine Beetle in Lodgepole Pine: Mortality and Fire Implications

Objectives for this project were to (1) characterize changes and extent of tree mortality in stands attacked by mountain pine beetle during an epidemic, (2) describe stand conditions associated with mountain pine beetle in lodgepole pine forests of north central Colorado, and (3) use fire simulation models to portray fire behavior and potential for crown fire in stands affected by mountain pine beetle. FHM aerial survey data and data collected on the Sulphur Ranger District were used to identify areas where mountain pine beetle populations were active from 2000 to 2007. Fixed-radius plots (1/20th acre)

were established in infested and uninfested stands with data collected on diameter class, basal area, trees per acre, and stand density index. Brown's (1974) fuel transects were used to quantify downed woody debris and regeneration data were collected from a 1/500th acre in 2007. Potential fire behavior and effects were modeled using Forest Vegetation Simulator-Fuels and Fire Extension (FVS-FFE) (Reinhardt and Crookston 2003) under severe fire weather for lodgepole pine stands infested with mountain pine beetle and for uninfested stands. Modeled tree fall rate was used to project potential fuel loads when 10 percent and 80 percent of the trees were down.

Results from this project include the finding that mountain pine beetle-infested plots had significantly higher lodgepole pine basal area and stand density index compared to uninfested plots prior to the outbreak. There were reductions in lodgepole pine of 42 percent, 69 percent, and 34 percent in tree density, basal area, and quadratic mean diameter, respectively, between 2000 and 2007. Density of total regeneration was significantly higher in uninfested plots compared to infested plots (West and others 2008).

Surface fine and coarse woody debris fuel loads were not different among categories of infested plots and uninfested plots. The median litter depth was significantly greater in plots in the 2000-03 category compared to plots in the 2004-07 category and uninfested plots. Modeling of future downed woody debris accumulations indicated no differences for downed woody debris at 10 percent tree fall. However significant increases in downed woody debris classes are anticipated when 80 percent of the trees are down.

Active fires were modeled as the most frequent fire type to occur in uninfested plots, while in mountain pine beetle infested plots, passive fires were modeled. For infested plots, torching index (wind speed required for a fire to move from a surface to a crown fire) was not different than uninfested plots, but crowning index (wind speed required for a fire to move from tree crown to tree crown) was greater. However, for stands projected to have 80 percent tree fall, the torching index was greater in uninfested plots compared to infested plots. The percent of basal area killed from a fire was modeled to be > 95 percent, with uninfested plots projected to have greater mortality than infested plots.

Project INT-F-07-01: Contribution of Landscape Level Bark Beetle Outbreaks to Fuel Loading and Fire Behavior in Pine Forests of the Southwest—

Bark beetle outbreaks in ponderosa pine forests and piñon-juniper woodlands occurred throughout the Southwest from 2002 through 2004 in response to severe drought and susceptible forests conditions. An FHM-funded project (INT-EM-03-01) resulted in the establishment of over 1,100

permanent plots across Arizona during 2003 and 2004, which were designed to quantify overstory impacts (reductions in trees per acre, basal area) and correlations with preexisting ponderosa and piñon stand conditions. Using a subsample of the previously established plots, investigators collected data on canopy and surface fuels using Brown's (1974) planar intercept methods 4 to 5 years after the bark beetle outbreak collapsed. In 2007, data were collected from 133 plots in ponderosa pine forests on the Prescott, Kaibab, Coconino, Apache-Sitgreaves, and Tonto National Forests. For statistical purposes, plots containing ponderosa pine mortality were paired with plots having no mortality with respect to site (elevation, topography) and percent ponderosa pine in the stand.

Investigators found that, in comparison to plots with no ponderosa pine mortality, bark beetle-caused tree mortality resulted in significantly decreased tree density, basal area, and live canopy fuel loadings; and also resulted in increased crown base height, fuel bed depth, and surface fuels in all size classes (Hoffman and others 2008; Hoffman and others, in review).⁷ Torching and crowning indices were found to increase due to increased crown base height when weather, topographic, and surface fuel loading were held constant; when differences in surface fuels and basal areas were added, there was no difference in torching index. These findings suggest that there may be a trade-off between elevated canopy base height and reduced live canopy fuel (both decreasing fire hazard) with increased surface fuel loading and wind speed (both increasing fire hazard) as a consequence of bark beetle outbreaks in ponderosa pine 4 to 5 years post-tree mortality.

In 2008, investigators used similar methodology for collecting fuels in piñon-juniper woodlands of Arizona (McMillin and others 2009). Data on canopy and surface fuels were collected from 40 pairs of tree mortality and no mortality plots on the Coconino, Kaibab, and Apache-Sitgreaves National Forests. In addition to collecting the standard Brown's fuels intercept data, investigators measured fine fuels (grass, forbs), mid-canopy fuels, and the spatial arrangement of canopy and surface fuels. These additional data were collected because little is known about fire modeling and fuel models in piñon-juniper woodlands, and because of the spatial heterogeneity of fuels in these woodlands. Results from data collected in 2008 were still being analyzed at the time of this review.

Project INT-F-07-02: Bugs and Burns: Effects of Fire on Ponderosa Pine Bark Beetles—

This study is a continuation and expansion of a previous study (Breece and others 2008) and was ongoing at the time of review.

⁷ Hoffman, C.; McMillin, J.D.; Sieg C.H.; Fulé, P.Z. Influence of bark beetle-caused tree mortality on fuel loadings and crown fire hazard in southwestern ponderosa pine forests. In review.

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The objectives of the study were to (1) quantify long-term effects of operational prescribed fire on bark beetle attacks in ponderosa pine-dominated stands of Arizona and New Mexico, (2) identify species of bark beetles attacking ponderosa pine damaged by prescribed burns in Arizona and New Mexico, and (3) assess the utility of using measures of pre-fire bark beetle populations as predictors of future bark beetle-caused tree mortality at prescribed fire sites. In the previous study, four sites in Arizona and New Mexico were burned in the fall of 2003 or spring of 2004 and then monitored in 2004, 2005, and 2006 for bark beetle-induced mortality (Breece and others 2008). Four additional sites composed of a paired treatment and control (~300 ha each) were established in ponderosa pine forests in northern Arizona in the summer of 2007. Controlled burning occurred in the fall of 2007, with the exception of one site that was burned in July 2007. All sites were revisited in 2008 to record crown scorch and consumption, tree mortality, and sample bark beetle attack activity by removing bark samples from dead trees. In addition, bark beetle activity was monitored using funnel traps baited with lures for Scolytinae commonly found in ponderosa pine forests of Arizona (*Ips pini*, *I. lecontei*, *Dendroctonus brevicomis*).

Preliminary findings by the investigators suggest that under endemic beetle population levels, bark beetle-induced tree mortality levels may be expected to return to background levels within 4 years after burning (Hayes and others 2008). Based on funnel trap catches, bark beetle activity was greater in burn plots compared with control in three of the study sites. *Ips pini*, *D. frontalis*, and *D. valens* were the most commonly trapped beetle species in the burned plots. The investigators also found differences in the ratio of predators to bark beetles between study sites. This finding presents an opportunity to study the importance of such relationships on post-fire beetle-induced tree mortality. This project was completed in 2009.

Project INT-F-07-03: Monitoring Bark Beetle-Caused Mortality and Relation to Fire Occurrence—The primary objective of this project was to determine if there is a relationship between bark beetle outbreaks and subsequent ignition of forest fires. To test this relationship a number of factors needed to occur concurrently. Fuels accumulated from bark beetle-caused mortality needed to be present along with signs of a subsequent fire. This study identified locations of historic mountain pine beetle (MPB) outbreaks having occurred from 1980 through 1987 by converting 176 hardcopy aerial detection survey maps (Arapaho, Roosevelt, Routt, White River, Uncompahgre National Forests) into a digital format (TIFF images and GIS shape files). Locations in three national forests (Arapaho, White River, and Uncompahgre) were identified from 68 of 176 scanned aerial detection maps as having experienced MPB outbreaks beginning in 1980 through 1990. Fire point records from 1980 through 2007 were overlaid

in a geographic information system with the historic mountain pine beetle outbreak locations. Sixty-nine fire ignitions in combination with the mapped historic mountain pine beetle-caused mortality were identified for field assessment from June to August 2008. Mountain pine beetle-caused lodgepole pine mortality and fire presence were recorded at each location. Ignitions from the Arapaho and White River National Forests are currently under analysis while ignitions from the Uncompahgre National Forest were not clearly identifiable in the field due to post-fire forest management practices. Temperature and precipitation data from weather stations close to the fire points and historic mountain pine beetle outbreaks have been gathered and annual departures from a 30-year average have been calculated.

Preliminary findings include approximately 22 700 ha and 71 900 ha mapped as mountain pine beetle-caused lodgepole pine mortality on the Arapaho and White River National Forests, respectively, from 1980 through 1987. Fifty-seven fire ignitions were located in the field from the Arapaho and White River National Forests. Twelve fire ignitions were not evaluated due to erroneous point data, private property boundaries, adverse mountainous terrain, or excessive travel distance. Two fire ignitions were identified as having occurred with older mountain pine beetle-caused lodgepole pine mortality.

Project INT-F-07-05: Modeling Fire Spread and Intensity Across Bark Beetle-Affected Landscapes

—The objectives of this project were to use custom fuel models and landscape scale fire behavior models FARSITE and FlamMap (Finney 1998) to simulate fire spread across bark beetle-affected landscapes. Bark beetle impacted areas were identified using FHM Detection Monitoring (DM) tools and data from the LANDFIRE project (Landscape Fire and Resource Management Planning Tools Project) (Rollins and Frame 2006). The study quantified changes in three forest fuel complexes (lodgepole pine, Engelmann spruce/subalpine fir and Douglas-fir) caused by bark beetle-induced tree mortality and developed custom fuel models to make more accurate estimates of fire behavior.

Aerial detection maps, custom fuel models, historic weather data, and data from the LANDFIRE project were used to create FARSITE/FlamMap fire growth and intensity simulations in a lodgepole pine forest on the Sawtooth National Forest, ID, prior to a mountain pine beetle outbreak and currently infested with epidemic populations. Historic weather data input consisted of 30 three-day weather windows within the fire season that were randomly selected. Similar ignitions and FARSITE options were used in each simulation. Model simulations were also run in a post-outbreak, lodgepole pine forest on the Ashley National Forest, UT. Historic weather data input consisted of 60 five-day weather windows within the fire

season that were randomly selected. These simulations were calibrated with actual fire events that occurred in lodgepole pine types on the Sawtooth and Boise National Forests in 2006.

Preliminary conclusions generated from this project indicate that the probability was greater for larger fire sizes throughout the range of historic fire weather conditions in lodgepole pine forests during the mountain pine beetle epidemic. The greatest change in fire size, however, occurred under the most extreme fire weather conditions. This result is probably due to the greater likelihood of fires transitioning from surface to crown fires under extreme fire weather conditions. Extreme fire weather conditions, largely attributed to higher wind speed, were more prevalent in landscapes modeled on the Sawtooth National Forest. However, moderate fire weather conditions, such as those characterizing the landscape modeled on the Ashley National Forest, provided better comparisons of differences in fire behavior attributed to fuels. Interpretation of these FARSITE model simulations should consider the weather windows used and limitations inherent in conventional surface fire spread models (i.e., live canopy fuel moisture). All else being equal, the collection of fuels data in bark beetle-affected forests should prioritize those geographic locations more prone to extreme fire weather conditions. These simulations also can provide land managers with other information necessary to evaluate the ecological impacts of bark beetle activity and associated fire risk, intensity, and spread.

Summary of Key Findings from Base Projects

INT-EM-99-03, INT-EM-04-03—Douglas-fir beetle outbreaks in Wyoming changed both overstory and understory conditions of the forest (Allen and others 2006, McMillin and Allen 2003). Significant reductions in the forest overstory resulted in subsequent increases in the understory (grass, forbs). Magnitude of bark beetle-caused impacts was correlated with pre-outbreak stand conditions such as measures of stand density.

INT-EM-99-05, INT-EM-00-05—*Nepytia janetae* outbreaks in Arizona last 3 to 4 years and seem to be limited to mature spruce-fir stands near the top of mountains [Lynch and Fitzgibbon (see footnote 5)]. Defoliation was found to increase tree susceptibility to spruce beetle and western balsam bark beetle in the Pinaleno Mountains, and most of the mortality occurred from the combined effects of defoliation and bark beetle attack.

INT-EM-99-04, INT-EM-00-04—In recently formed piñon mortality centers, the majority of piñon was affected by black stain root disease and had evidence of pinyon ips attack (Kearns and Jacobi 2005). Incidence of tree mortality was highest in piñon stands characterized by high densities

of small diameter trees with below average amounts of non-piñon vegetative cover.

INT-EM-00-01, INT-EM-01-05—A western balsam bark beetle outbreak significantly altered forest overstory and understory conditions in Wyoming (McMillin and others 2003). Based on the relationships between the amount of subalpine fir killed and fir stand density index, fir basal area, and the percentage of fir found in a stand, manipulating these stand components should reduce stand susceptibility to western balsam bark beetle. Blowdown events may play an important role in initiating western balsam bark beetle outbreaks (Allen and others 2002, 2003; McMillin and others 2003). Salvaging blowdown quickly and entirely may prevent epidemics.

INT-EM-03-01, INT-EM-05-01—Impacts caused by bark beetle outbreaks in ponderosa pine forests and piñon-juniper woodlands of the Southwest were highly variable at the stand level; tree mortality levels ranged from 0 to 100 percent [McMillin and others 2008, Negrón and others 2009, McMillin and others (see footnote 6), Shaw and others 2005]. Tree mortality in both pine types was correlated with stand and site characteristics that are indicative of stress. Mortality was typically greatest in areas near the lower elevation distribution of each pine species, stands with relatively high tree densities, and areas of poor site quality (rocky, south-facing slopes).

INT-EM-05-04—Limber pine seemed to be the preferred host during initial stages of a mountain pine beetle outbreak in mixed conifer stands in Wyoming (Dean 2007, Dean and others 2007). As the outbreak progressed, however, there may have been a shift towards lodgepole pine being favored. In general, there was greater beetle emergence from limber pine than lodgepole pine hosts.

INT-EM-07-02—The range of balsam woolly adelgid in Idaho dramatically increased during a 10-year period. Balsam woolly adelgid was found on more than half of the sample plots, and was more frequently encountered below 4,500 feet elevation. Range expansions to the north and south were significantly greater than expansions to the east and west.

Summary of Key Findings from Fire Plan Projects

INT-F-04-02—The net result of bark beetle epidemics in Douglas-fir, lodgepole pine, and spruce-fir forests was a substantial change in species composition and a highly altered fuel complex (Jenkins and others 2008, Page and Jenkins 2007a, 2007b). Fuel complexes change over time, creating periods where the potential for high intensity and/or severe fires either increases or decreases.

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INT-F-06-03—Based on mountain pine beetle outbreaks in lodgepole pine forests in Colorado, active crown fires were modeled as the most frequent fire type to occur in uninfested plots, while passive fires were modeled to occur in mountain pine beetle infested plots (West and others 2008). For stands projected to have 80 percent tree fall, the torching index (wind speed required for fire to transition from surface to crown fire) was greater in uninfested plots compared to infested plots.

INT-F-06-02, INT-F-07-01—Four to five years after bark beetle outbreaks in ponderosa pine forests of Arizona, there seems to be a trade-off between increased surface fuel loadings and increased canopy base heights [Hoffman and others (see footnote 7)]. The end result of this exchange is predicted to be the same: a surface fire can transition into the canopy; however, the physical properties driving this mechanism have switched from low surface fuels and low crown base heights to higher surface fuels and higher crown base heights. Data from piñon-juniper studies on the Santa Clara Pueblo in New Mexico (INT-F-06-02) and in Arizona are forthcoming. Results from these studies will have important implications for forest management and restoration.

INT-F-07-02—In the Southwest under endemic beetle population levels, bark beetle-induced ponderosa pine mortality levels may be expected to return to background levels within 4 years after burning (Hayes and others 2008).

INT-F-07-03—This project is continuing and data analysis has not been completed. Preliminary findings include: 57 fire ignitions were located in the field from the Arapaho and White River National Forests, and 2 fire ignitions were identified as having occurred with MPB-caused lodgepole pine mortality.

INT-F-07-05—Probability of achieving larger fire sizes throughout the range of historic fire weather conditions in lodgepole pine forests of Idaho and Utah was greater during mountain pine beetle epidemics (Jenkins and others 2008). Collection of fuels data in bark beetle-affected forests should prioritize those geographic locations more prone to extreme fire weather conditions.

Utilization of Project Results

While it is difficult to track how project results have been utilized by land managers and forest health practitioners, we assume that most have been used in a variety of forest management decisions, strategic planning, and monitoring activities. For example, two Base EM projects focused on Douglas-fir beetle impacts in Wyoming influenced National Environmental Policy Act decisions regarding sanitation and salvage treatments on the North Fork Project (Shoshone

National Forest) and the Bench Project (Bighorn National Forest). In addition, these same projects plus those centered on western balsam bark beetle have been integrated into recent Forest Plan Revisions on both the Bighorn and Shoshone National Forests in Wyoming. Specifically, because western balsam bark beetle has caused dramatic changes to stand conditions in the spruce-fir type on the Bighorn National Forest, and this forest type provides critical wildlife habitat, results emanating from EM projects provided vital input in the Forest Plan Revision process. Similarly, results from projects on bark beetle and defoliator impacts in the Southwest have been incorporated in the Forest Plan Revision process on five national forests in Arizona. Results are also routinely used in project level specialist's reports by defining potential impacts and focusing silvicultural treatments to reduce stand susceptibility.

Results from Fire Plan EM projects have and will continue to be used by resource managers. For instance, EM projects examining relationships between bark beetle outbreaks and fuel loading generated custom fuel models that have been incorporated into the FARSITE and FlamMap fire behavior models. Thus, these projects are providing fire and fuels specialists with better guidance for meeting important resource objectives, reducing treatment costs, minimizing adverse ecological impacts, and ultimately avoiding potential controversy. In addition, these projects have supplied baseline data on temporal and spatial patterns of fuel loading that will be critical when projecting future impacts and fire risk under different climatic conditions.

Suggestions for Further Investigation from Base Projects

Long-term effects of bark beetle outbreaks have really never been measured. Long-term effects could be evaluated through permanent plots measured at 5-year intervals for the next 20 to 25 years, or perhaps using old aerial survey maps to locate beetle impacted areas that occurred from 20 to 50 years ago.

If trap trees are used by resource managers to suppress local populations of western balsam bark beetle, there are many questions associated with this recommended strategy. Further research should be undertaken to determine if brood production is significantly different between down (felled) versus standing trees. Also, would baiting standing uninfested trees produce more brood than downed trees? If trees are intentionally felled to serve as trap trees, how many, what size, and how should they be spatially distributed on the landscape? Western balsam bark beetle studies were conducted only in north central Wyoming; results may differ in other portions of the Interior West.

Future monitoring projects in the Southwest could focus on the interaction of insects and climate in creating disturbance events in mixed conifer forest types. For example, FHM aerial detection surveys recorded extensive mortality of white fir and Douglas-fir during the severe drought of 2002-04, but on-the-ground impact studies have not been conducted. Mortality has been caused by a complex of defoliators (budworm, tussock moth, loopers, needleminers) and bark beetles (fir engraver, Douglas-fir beetle).

Although INT-EM-07-04 is continuing, it will complement the results from a similar study conducted in adjacent States and in other portions of Colorado. This evaluation (A Retrospective Assessment of Partial Cutting to Reduce Spruce Beetle-related Mortality in Southern Rocky Mountains) by Matt Hansen (Forest Service, Rocky Mountain Research Station) and others is in the final stages of completion for journal submission.

As the range of balsam woolly adelgid continues to expand throughout Idaho, additional periodic ground surveys to document changes in extent, occurrence, and severity on subalpine fir and grand fir would be warranted. Future studies documenting and evaluating changes in fire risk and behavior, wildlife habitat, and hydrologic function associated with balsam woolly adelgid establishment in new areas would provide basic impact information that is currently lacking. Other worthwhile topics for investigation are how balsam woolly adelgid interacts with the recognized insect, disease, and drought complex associated with subalpine fir decline, or with climate change.

Suggestions for Further Investigation from Fire Plan Projects

Because spatial arrangement and distribution of bark beetle-caused tree mortality and associated fuel accumulations vary considerably across the landscape, further development of fire spread models in various bark beetle affected landscapes may help land managers to identify high priority stands for treatment. Fuel appraisals and estimated fire prediction models are currently being used to develop photo appraisal guides for bark beetle-affected fuels, which will facilitate collecting large amounts of actual surface fuels data for modeling purposes. This information will be used to model fire spread and predict probable fire size (FARSITE) through bark beetle affected forests. The resulting models will be similar to those generated and used in the Wildland Fire Decision Support System.

Monitoring studies in the Southwest could examine the effects of multiple causal agents on spruce-fir and mixed

conifer tree mortality on subsequent fuel loading and fire behavior. For example, in the White Mountains and Pinaleno Mountains of Arizona, and in the Sacramento Mountains of New Mexico, defoliator and bark beetle outbreaks in combination with drought have resulted in dramatic ecosystem alterations within these forest types. How these multiple disturbance events influence spatial and temporal patterns of surface and canopy fuels and future fire behavior remains unknown.

Future studies examining interactions between prescribed burns and bark beetles could focus on other forest types besides ponderosa pine, and should be conducted during periods of higher bark beetle populations.

Recently, entomologists (in the Forest Health Protection Program of the Forest Service) from all western regions met with research entomologists from the western research stations of the Forest Service to discuss western bark beetles research priorities for the future (Negrón and others 2008). Future research is recommended to be focused in the following areas: vegetation management; ecological, economic, and social consequences of bark beetle outbreaks; fire and bark beetle interactions; climate change; and chemical ecology.

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CHAPTER 2

North Central Forest Insects

Steven A. Katovich¹

This chapter describes three projects. One project addressed the impacts on American basswood (*Tilia americana*) from an exotic species, the introduced basswood thrips (*Thrips calcaratus*). As with many exotic species, little was known about the biology and behavior of this insect, and little was known concerning the possible negative impacts on the basswood resource in the North Central region. The project clarified the importance of *Thrips calcaratus* in a regional basswood decline episode. It also provided a great deal of basic biological information on the insect. The second project studied the responses of sub-boreal forest insect communities to a large windstorm and subsequent salvage activities and prescribed burning in northeastern Minnesota. Study results indicated that subcortical insect numbers and activity increased initially in the wind-disturbed areas, and contributed to the mortality of live residual trees after the windstorm, but subcortical insect numbers declined dramatically 4 years after the windstorm, and a widespread epidemic of bark and woodboring insects did not occur in these sub-boreal forests. The third study revolved around the evaluation of survey methodology for forest defoliators. This project proposed the development of a multi-scale approach to monitor defoliation extent and severity using high-resolution satellite imagery. Specific objectives were to link image-derived estimates of defoliation to measures derived from current forest health Detection Monitoring (DM) efforts (i.e., aerial survey). This research could pave the way towards standardized defoliation mapping using satellite-based methods.

Project NE-F-01-02: Impact of an Invasive Species on Forest Health: Phenological Differences as a Possible Explanation of Impacts on American Basswood in the Great Lakes Region

The objectives of this project were to (1) compare relative abundance and phenology of native and introduced insect herbivores and predators associated with American basswood, (2) evaluate reasons for differential damage of introduced

basswood thrips in its native and introduced range, and (3) assess basswood crown condition.

Introduced basswood thrips was first observed causing damage to American basswood in the Great Lakes region in the 1980s. This insect is not native to North America, and little was known about its biology or its ability to damage the basswood resource. This project clearly identified *Thrips calcaratus* as a significant cause of extensive dieback and decline in basswood stands in Wisconsin, Michigan, and Minnesota. However, there were other factors also involved in the ongoing regional basswood decline episode.

The project also evaluated several survey techniques. No technique was obviously better; tree size and cost and availability of tree climbers were key factors in selecting an appropriate survey method.

Utilization of project results—Peer reviewed publications and a thesis were developed from this project (Werner and Raffa 2004, Werner and others 2005). These have greatly increased our background knowledge on the behavior and impact of introduced basswood thrips and our ability to survey for the insect.

Suggestions for further investigation—No further evaluation on the health of the basswood resource has been conducted despite the continuing presence of introduced basswood thrips. A regional evaluation on basswood growth, regeneration, and overall health would be warranted. This has special significance since the eventual loss of ash (*Fraxinus* spp.) due to emerald ash borer (*Agrilus planipennis*) will require renewed emphasis on basswood as a major component in many Great Lakes forest stands.

Project NE-F-01-08: Prescribed Fire as a Management Tool for Curbing Potential Epidemics of Bark Beetles and Woodborers in a Forest Blowdown

The initial objective of this project was to evaluate if fire could be used as an important tool to control potential outbreaks of phloem and wood-dependent insects in disturbed stands to

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better achieve forest sustainability goals. This objective was broadened as discussed below.

The project investigators studied the responses of sub-boreal forest insect communities to a July 4, 1999, severe windstorm and subsequent salvaging and prescribed burning in northeastern Minnesota. Study results indicate that (1) subcortical insect numbers and activity increased initially in the wind-disturbed areas and contributed to the mortality of live residual trees after the windstorm; (2) these subcortical insect numbers declined dramatically 4 years after the windstorm, and a wide-spread epidemic of bark and woodboring insects did not occur in these sub-boreal forests; and (3) a woodboring *Monochamus* beetle instead of a bark beetle species became a more significant contributor to tree mortality in the wind-disturbed areas.

In regards to prescribed fire, results indicate that (1) both salvaging and burning altered populations and communities of forest insects; (2) burning resulted in increased invasion by an exotic ground beetle; (3) burning resulted in greater populations of both ground and subcortical insects at least for a short-term; (4) burning can maintain populations of fire-adapted ground beetles; (5) large-scale conversion of pine to aspen/birch forest may be problematic for some ground beetle species adapted to pine forests; and (6) subcortical insect populations in the wind-disturbed sub-boreal forests may decline naturally without the use of fuel-reduction activities.

Utilization of project results—The following peer reviewed publications were developed through this project: Gandhi and others 2007, and Gandhi and others 2008. Land managers have a better understanding of ecosystem response following a large scale wind disturbance in northern boreal forests. A key finding was that subcortical insect numbers declined dramatically 4 years after the windstorm, and a widespread epidemic of bark and woodboring insects did not occur in these sub-boreal forests. This information provides a context for future responses to large scale disturbances.

Suggestions for further investigation—Future studies should focus on comparing insect communities between naturally burned and prescribed burned sites. Wildfires were virtually absent during the duration of the study, but there have been a number of fires since 2003 in the wind-disturbed areas in the Superior National Forest. Also, this study did not evaluate the fate of live residual trees in salvaged and burned areas. Would we expect bark and woodboring beetles to contribute to tree mortality of residual live trees in these two fuel-reduction treatments, and would it be similar to trends observed in the wind-disturbed forests?

Large-scale forest disturbance events are not uncommon in the Great Lakes region. This study in a sub-boreal forest type cannot clarify what is likely to occur following similar events in other forest types. For that reason, repeated observations (studies) should be done following future disturbance events so that a better understanding of insect and pathogen behavior can be developed.

Project NC-EM-05-04: A Multi-Scale Remote-sensing Approach for Quantifying Regional Impacts of Insect Defoliators

This project proposed the development of a multi-scale approach to monitor defoliation extent and severity using Moderate Resolution Imaging Spectroradiometer (MODIS), Landsat (or similar), and high-resolution imagery (hyperspectral imagery). Specific objectives were to link image-derived estimates of defoliation to measures derived from current forest health DM efforts (i.e., aerial survey and plot-level forest health data) to predict impacts across two representative regions of North America (Upper Midwest and adjacent Canada, and the Mid-Atlantic Highlands) at the resolution of the National Aeronautics and Space Administration's MODIS imagery (250 m). The long-term goal of this work was to standardize defoliation mapping using satellite-based methods.

Development of the multi-scale mapping approach centered on multi-temporal Landsat imagery. Two late-summer Landsat images for each Landsat scene and year of disturbance were used. One image was from the year of interest for defoliation, and the second image was from a base year, in which no defoliation occurred at the sites of interest. The investigators calculated a Moisture Stress Index (MSI), which has been shown to be strongly related to forest stress and vegetation loss. They calculated a pixel-wise simple difference of MSI between years which represented the probability of change, where change was defined as disturbance, defoliation, or clearing. They then mapped percent defoliation as a simple regression model.

Utilization of project results—Articles by McNeil and others (2007) and deBeurs and Townsend (2008) describe the application of MODIS data to map defoliation across large regions. A key conclusion from this research is that “daily MODIS data can be used with confidence to monitor insect defoliation on an annual time scale, at least for larger patches ($> 0.63 \text{ km}^2$)” (deBeurs and Townsend 2008). This research could pave the way towards standardized defoliation mapping using satellite-based methods. Additional peer reviewed publications developed through this project were Wolter and others (2008), and Wolter and others (2009).

Suggestions for further investigation—Insect defoliation has been traditionally collected using labor and time intensive sketch map surveys. Field trials with the techniques described previously could provide a basis for comparing traditional defoliation data collection to a system relying on a multiscale approach as described earlier.

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CHAPTER 3

Northeast Forest Insects

Bradley P. Onken,¹ Allison M. Kanoti,² Dave Struble³

The hemlock woolly adelgid (*Adelges tsugae*) (HWA) is a serious nonnative pest of eastern (*Tsuga canadensis*) and Carolina hemlocks (*T. caroliniana*). The insect is currently found in 17 eastern States from southern Maine to northeastern Georgia and west to eastern Kentucky and Tennessee. On average, HWA spreads about 12.5 km per year, HWA dispersing naturally by wind and birds, and artificially on hemlock nursery stock. Infested nursery stock has resulted in isolated infestations in Michigan, Ohio, Vermont, New Hampshire, and Maine. Such isolated infestations are eradicated when possible. HWA feeds on stored nutrients in the ray parenchyma cells of the xylem by inserting its stylet bundle through the leaf cushion where needles attach to the twig. Abundant adelgids soon deplete nutrients vital to shoot growth the next growing season. Damage occurs over 4 to 10 years, and includes stunted shoot growth or no growth at all, graying needles, branch dieback, and eventually tree mortality. All ages of hemlock are susceptible from seedlings to mature trees. Other biotic and abiotic stress agents like the elongate hemlock scale (*Fiorinia externa*) and drought hasten tree decline. Extensive tree mortality has been reported throughout the infested region of the Eastern United States.

The balsam woolly adelgid (*Adelges piceae*) (BWA) is a serious nonnative pest of true firs, (*Abies* spp.) including balsam (*A. balsamea*) in the Northeast, Fraser (*A. fraseri*) in the Southeast, and noble and shasta firs (*A. procera* and *A. shastensis*, respectively) in the Pacific Northwest. Native to central Europe, this insect was first discovered in North America in the early 1900s near Brunswick, ME, and in the Southern Appalachian Mountains in the 1950s. BWA has caused extensive damage to native fir stands throughout the eastern landscape in addition to serious economic losses to both Christmas tree and seed cone industries. This pest attacks all ages of fir trees but damage is often minimal until trees are about 30 years old. In the Northeast, BWA populations can build rapidly following consecutive years of

mild winter temperatures. Susceptible fir trees often succumb to BWA infestations within 2 to 8 years depending on other insect or disease stressors or droughty conditions during the period of attack. Extensive decline and tree mortality have been reported throughout the coastal region in Maine in recent years and a series of off-frame plots—styled after plots by the Forest Inventory and Analysis (FIA) Program of the Forest Service, U.S. Department of Agriculture—was established to assess the relationship of recent weather patterns, climatic regions, and site conditions to BWA populations and impact trends.

Project NE-EM-03-01: Mapping Susceptibility and Spread Associated with Hemlock Woolly Adelgid

This project used GIS technology and available datasets to model the predicted spread of HWA over 25 years. Forest susceptibility was first assessed through interpolation of host species abundance estimated from more than 93,000 FIA plots throughout the Eastern United States. Host abundance was measured as basal area/ha of eastern hemlock. A geostatistical method called kriging was used to interpolate an unbiased estimate of hemlock basal area between plots to produce a surface basal area of eastern hemlock. Maps were then generated using the plot data and kriging estimates based on a grid of 1 km² cells.

This forest susceptibility map was then adjusted for forest density using National Land Cover Data acquired from the Multi-Resolution Land Characteristics Consortium as a raster matrix of 30 x 30 m cells coded for land use. These data were aggregated to 1 km² to estimate the forest cover for each cell. The forest susceptibility map layer could then be multiplied by the forest density map to generate the forest susceptibility map adjusted for percent forest cover.

The third dataset used in this analysis was the predicted spread of HWA, which was derived from county-level historical records that documented the year a county was first known to become infested. A GIS was used to calculate the minimum distance in the x and y direction from each county to the area first infested. A predicted spread map

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representing years of expected presence (between 2001 and 2025) was then generated using the estimated spread rate. The number of years of expected presence was then divided by the years of possible infestation (25 years) to produce a proportion of expected years of presence between 2001 and 2025. Areas with higher proportion of years infested are likely to see greater overall impact. The proportion map was then multiplied by the adjusted forest susceptibility map to create a map of HWA risk through 2025.

Utilization of project results—The conclusion of this analysis indicates that (1) HWA has only recently begun to move into areas with a large hemlock component; (2) the estimated risk of HWA was highest in a large proportion of New York and northern Pennsylvania; and (3) Vermont, New Hampshire, and New York are the highest risk areas that are currently uninfested.

The results of this analysis give land managers a planning tool to determine when HWA is first likely to appear in a specific geographical area where HWA is likely to have the greatest impact over a 25-year period, based on a measure of hemlock abundance.

Suggestions for further investigation—The risk model should be validated and updated periodically as HWA continues to spread to new areas. This approach may be used to examine the progression of hemlock decline and mortality following the introduction and build-up of HWA to improve the predictive value of risk map projections of significant mortality events associated with HWA. The model also could be improved if climatic information is used to weight regions with cold temperatures in addition to considering the number years infested.

Project NE-EM-03-02: The Impact of Balsam Woolly Adelgid (*Adelges piceae*) on Balsam Fir (*Abies balsamea*) Stands in New England

The objectives of this project were to (1) determine the magnitude of loss of the balsam fir resource in Maine; (2) analyze the associated BWA populations and damage patterns; and (3) develop a predictive risk model to map infestation

susceptibility and vulnerability based on stand and site characteristics that could be applied regionally.

Maine Forest Service (MFS) crews developed a field assessment protocol to quantify BWA impacts on candidate stands. Vetted data fields and categories were adapted to FIA plot data protocols at a tree-level basis in the southeastern quadrant of the State to allow analysis for site and tree health conditions. Analysis by biophysical region of the data collected on the FIA plots revealed a distinct trend of decreasing damage levels moving inland from the coast. This gradient represents a gradient in climate as well, and increased levels of damage further inland can be expected with warming temperatures.

An analysis of tree ring chronology revealed that impacts caused by BWA began in the late 1980s and continued to about 2003 in the study area. An analysis of climate data indicates infrequent lethal temperatures for BWA have occurred since the 1940s and the drought of 2001 coincided with a spike of fir mortality. This correlation of BWA impact with warmer winters suggests that the footprint of BWA economic damage and the severity of damage in currently affected areas will increase with climate warming.

Utilization of project results—The MFS-developed field assessment protocol for quantifying BWA impacts continues to be the local standard for assessing current and future conditions on candidate stands. Consulting and industry foresters are using the hazard rating system to prioritize stands for treatment. MFS-Forest Policy and Management Division field staff use the protocol to approve harvest variance requests. Vetted data fields and categories adapted to FIA field plot protocols are being used to collect tree-level baseline and remeasurement data from 6.4 million acres of eastern and central Maine.

Suggestions for further investigation—Potential BWA range expansion and population/impact intensification should continue to be monitored using FIA plots. The developed risk model should now be validated for its utility elsewhere in the Northeast. Developing silvicultural prescriptions to mitigate impacts from BWA would be a useful tool for the forest management sector.

CHAPTER 4

Southern Forest Insects

Donald A. Duerr¹, Robert J. Rabaglia², Bradley P. Onken³

Between 1998 and 2008, five Evaluation Monitoring (EM) projects under the national Forest Health Monitoring (FHM) Program of the Forest Service, U.S. Department of Agriculture, studied insects of the Southern United States. The projects reflected expanded survey efforts related to various nonnative bark and ambrosia beetles. Two of the projects conducted preliminary surveys of the Southeast to determine the occurrence of exotic ambrosia beetles, and two projects addressed mortality surveys and survey methodology for the nonnative redbay ambrosia beetle and associated laurel wilt fungus. The fifth project investigated risk of initial hemlock woolly adelgid (HWA) infestations to hemlock stands in the Southern Appalachian Mountains region. The emphases of these projects reflect the growing impacts that nonnative insects are having on southern forested ecosystems. The first four projects discussed increased our knowledge of the extent and distribution of nonnative bark/ambrosia beetles, improved detection methods, helped to focus current and future survey efforts, and formed the basis for impact studies. The last project focused on identifying areas at risk of initial HWA infestations, and the site variables that are important in modeling which areas may be at greatest risk.

Projects SO-EM-00-01 and SO-EM-01-02: Exotic Ambrosia Beetle Survey of the Southeastern United States, 2000–2001

The purpose of these projects was to conduct preliminary and follow-up surveys in the Southeast to detect and confirm the distribution of exotic ambrosia beetles in the region. Information from these 2 years was used as a baseline for current and future surveys and has helped form the basis for impact studies. Ethanol was used as the attractant in Lindgren-funnel traps. One 250 ml Nalgene® bottle was

used per trap. Ethanol (75 to 95 percent) was released from the bottle through a cotton wick placed through a hole in a closed top and was replenished as needed. Nine States (27 trapping sites) participated in this survey in 2000. Ten States (28 trapping sites) participated in 2001. The trap catches were collected weekly for 8 weeks and sent to Dr. Robert Rabaglia for identification and tally.

Previous to the 2000 survey, 150 species of scolytids had been recorded in the nine States in the region (species occurring only in southern Florida and south or west Texas were not included). During the 2000 survey, 48 species were identified from the 8,273 specimens collected. The exotic ambrosia beetle (*Xyleborus pelliculosus*), collected in Tennessee, was the first record of this species in the southeast. During the 2001 survey, 52 species were identified from the 5,358 specimens collected. Eleven species were collected in 2001 that were not collected in 2000, whereas seven species that were collected in 2000 were not collected in 2001. Four of the species collected for the first time in 2001 were ambrosia beetles that are native to the region.

Collection of such a large percentage (90 percent) of ambrosia beetles indicates that these species are likely to have an impact on tree health, even if the impact is only on dying or weakened trees. Infrequent reports implicate several of these ambrosia beetles in attacks on healthy trees.

During the 2001 survey, 5,358 scolytids were collected. Ambrosia beetles accounted for 4,880 of these specimens (91 percent). The most common species was *Xyleborinus saxeseni*, accounting for 57 percent (3,043) of all specimens. As in the 2000 survey, this exotic ambrosia beetle was found in every State and dominated most trap samples. A native of Europe, it has been in North America for over 100 years and occurs throughout most of the United States. It is often found attacking weakened, injured, or dying trees as well as fresh-cut logs (Solomon 1995).

Members of the tribe Xyleborini made up 71 percent of the species collected. This is the most common and often most damaging group of ambrosia beetles worldwide. In the United States, there are currently 34 species of xyleborines; 14 of these are exotics. Within this tribe five

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different genera were collected: *Ambrosiodmus*, *Euwallacea*, *Xyleborus*, *Xyleborinus*, and *Xylosandrus*. The three species of *Xylosandrus* are potentially the most damaging (Wood 1977). *Xylosandrus compactus* (Eichhoff), an aggressive primary borer in twigs of a wide variety of hosts, has been reported killing twigs of dogwood along the Gulf Coast and from Florida through the Carolinas. *Xylosandrus germanus* (Blandford) and *X. crassiusculus* (Motschulsky) both breed in branches and stems of weakened hosts, and there is concern that these species are attacking and killing nursery stock and young trees that are only slightly stressed; in 2001, there were reports from Richmond, VA, that *X. crassiusculus* was aggressively attacking landscape trees.

Atkinson and others (1990) and Wood (1977) pointed out the preponderance of east-Asian xyleborines in eastern North America. All of these exotic species have inbred polygyny as their mating system. Newly matured females mate with siblings before emerging from host trees. With a skewed female to male ratio of at least 10 to 1, individual females, which are also polyphagous, are able to quickly establish new populations.

The fungal associates of ambrosia beetles have been well documented (Roepke 1996), but few studies have investigated the impacts and aggressiveness of these fungi (Anderson and Hoffard 1978, Kessler 1974). In a new environment, the host-beetle-fungus interaction can change and negatively affect the susceptible host tree.

The increasing rate of establishment of exotic ambrosia beetles should be of concern. Of the 10 species collected in the 2001 survey, five have been reported for the first time in the Southeast in the past 10 years. Most of these new introductions are from Asia, and in this study, eight of the 11 exotics were from Asia.

During the 2 years covered by these projects, numerous new State records were documented. The distribution of ambrosia beetles, and in particular exotic ambrosia beetles in the southeast, is now better known.

Project SO-EM-06-01 Redbay Mortality Survey in the Coastal Region of Georgia; Project SO-EM-06-02: Redbay Mortality Survey in the Southeastern Coastal Region of South Carolina

Laurel wilt (LW), caused by the fungus *Raffaelea lauricola*, is a new disease of plants in the Lauraceae family in the United States that is vectored by an introduced Asian ambrosia beetle, *Xyleborus glabratus* (Fraedrich and others 2008, Harrington and others 2008). Since the capture of the first *X. glabratus* in a monitoring trap near the Port of Savannah in 2002 and the

first reports of dying redbay trees (*Persea borbonia*) in 2003 and 2004, this disease has spread rapidly through the abundant redbay in the maritime and coastal plain forests northward into South Carolina and south into Florida, killing most of the redbay trees in its path. Other plants in the laurel family known to be susceptible to varying degrees include: sassafras (*Sassafras albidum*), avocado (*Persea americana*), pondspice (*Litsea aestivalis*), and pondberry (*Lindera melissifolia*), the latter two on Federal lists as threatened and endangered species, respectively (Fraedrich and others 2008).

This exotic disease episode is particularly noteworthy because it is caused by a previously unknown pathogen vectored by an ambrosia beetle that was not expected to be a serious threat to forests or wood products in the United States. Yet in under 10 years, it has essentially eliminated redbay from a large portion of the South Atlantic Coastal Plain and maritime forests. This disease will likely continue to expand throughout coastal plain forests from Virginia to Texas and is a threat to the avocado industry in south Florida and elsewhere. Ambrosia beetles generally attack dead and dying hosts and do not vector important diseases. The redbay ambrosia beetle is not known to be an important pest in its native range in Southeast Asia, but was known to be associated with members of the Lauraceae (laurel) family (Rabaglia 2003). However, the unique association between insect, pathogen and host in which *X. glabratus* conveys the *R. lauricola* fungus into highly susceptible redbay trees has proven to be exceptionally fatal. The fungus spreads through the vascular system, blocking water transport, and causes redbay trees to wilt and die within months after initial infection.

Although redbay is a species of minor importance for forest products, it plays an important ecological role. Various birds and animals feed on its fruit and one species of butterfly, the Palamedes swallowtail, feeds almost exclusively on its foliage during the larval stage (Coder 2007). This new disease may eventually become much more widely distributed if it continues to spread in sassafras, which is found in much of the eastern half of the United States. There are many additional genera and species in the laurel family, concentrated mainly in the tropical and subtropical areas in Central and South America, which may also be susceptible to LW disease. Thus, it is important to document the advance of this disease both in geographic distribution and species affected; this was the main purpose of both of these EM projects. Parallel surveys have also been carried out in Florida, although these surveys were supported outside of FHM EM.

To track the geographic distribution and rate of spread of the disease in a more comprehensive and systematic fashion, surveys were conducted in Georgia and South Carolina in 2006/2007 (2006 survey) and 2007/2008 (2007 survey). The objectives of the surveys included the following:

1. Systematically document the distribution of LW disease on a grid pattern over the area known to be infected and beyond the apparent advancing front.
2. Determine the severity of infection within the range of distribution of the disease.
3. Document the rate and direction of spread and elucidate possible causes of varying rates of spread in Georgia.
4. Investigate the symptoms and incidence of LW disease in sassafras and other species in the laurel family in Georgia.
5. Lay the foundation for future monitoring projects.

Via these projects, over 400 plots have been evaluated for LW-caused mortality to redbay, sassafras, and other susceptible species. Many new affected areas/counties were documented, the severity of mortality was recorded according to standardized damage classes, effective survey methods were identified and enhanced, and information was gained regarding the rate and means of spread and possible future expansion of this devastating disease. To view the current distribution, visit: http://www.fs.fed.us/r8/foresthealth/laurelwilt/dist_map.shtml.

Project SO-EM-03-01: Early Warning System for Hemlock Woolly Adelgid in the Southern Appalachians

This project was also funded in 2003. The principle investigators include Frank Koch, Heather Cheshire, and Hugh Devine from North Carolina State University. The goals of this project were to develop a protocol for mapping hemlock stands, and to develop a model for predicting areas at greatest risk to initial HWA infestations in the Southern Appalachian Mountains.

The Great Smoky Mountains National Park served as the study area for this project. The technique for mapping hemlock forest stands used selected Landsat 7 and ASTER multispectral images acquired of the west and east sides of the park during leaf on and leaf off periods between 2000 and 2003. A 15-m resolution was used and the images were geometrically corrected using polynomial equations as well as topographically normalized. Evergreen and non-evergreen maps were then created from the winter images, and non-evergreen areas were eventually masked out from the summer images. Stratified random sample points collected from the masked images were compared to a vegetation map (derived from an aerial photograph) of the park and used in creating a “training” dataset to construct a decision-rules-based “expert” classifier. The expert classifier was then used to create output hemlock maps from the western and eastern study areas that included hemlock, non-hemlock evergreen and non-evergreen map layers. Field surveys and or aerial photographs were then

used to assess the accuracy of the generated maps and resulted in better than 85 percent accuracy in the eastern study area, and 69 percent in the western study area.

The risk to initial HWA infestations was assessed by using GIS technology to calculate values for a suite of site related variables on 56 infested and 45 noninfested sites within the park. Some of the variables included: elevation; aspect; geology; vegetation type; disturbance history; and proximity to roads, trails, and streams. Resulting logistic regression equations using four variables—proximity to trails, elevation, slope, and aspect—correctly classified 83 percent of the input sample and 75 percent of the sites set aside for testing. Other procedures also used proximity to roads as an additional variable and had similar results indicating that between 16 to 38 percent of hemlock areas in the Great Smoky Mountains National Park are at risk to early HWA infestation. Areas near roads and trailheads are at high risk.

Summary of Key Findings

- Greatly increased knowledge was obtained about the number of species, rate of introduction, distribution, and abundance of exotic bark and ambrosia beetles in southeastern forests. Numerous new State records of exotic ambrosia and bark beetles were documented.
- Over 400 plots were evaluated for LW-caused mortality to redbay, sassafras, and other susceptible species, and produced the following results:
 - Many new affected areas/counties were documented.
 - The severity of mortality was recorded according to standardized damage classes.
 - Effective survey methods were identified and enhanced.
 - Insights were gained regarding the rate and means of spread and possible future expansion of this devastating disease.
- A protocol was developed for mapping hemlock stands and models for predicting the areas at greatest risk to initial HWA infestations in the Southern Appalachian Mountains region. Models including proximity to roads indicated that between 16 to 38 percent of hemlock areas in the Great Smokey Mountains National park are at risk to early HWA infestation.

Utilization of Project Results

The survey methods developed and honed via the first four projects above have been used to standardize nonnative bark/ambrosia beetle detection surveys and LW surveys. The trapping protocols refined by the exotic ambrosia beetle survey projects have been used in the national Bark Beetle

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Early Detection and Rapid Response Program (of the Forest Health Protection Program, Forest Service). The exotic ambrosia beetle survey projects raised awareness among land managers regarding the number and impacts of nonnative bark/ambrosia beetles occurring on their lands. Similarly, the LW survey projects educated land managers and the general public about the spread and impact of LW. The LW survey methods developed by these projects are used by Federal, State, and private land managers to measure the spread and impacts of LW as it moves into new areas.

Suggestions for Further Investigation

Future work on exotic bark and ambrosia beetles should include expanded monitoring of forested areas near high-risk sites for new introductions. New detection methods and introduction risk assessments could be evaluated and improved to increase the efficiency and effectiveness of detecting new exotic bark and ambrosia beetles. Evaluation studies should be conducted to determine the aggressiveness of new exotic bark and ambrosia beetle species, the pathogenicity of their fungal associates, and ultimately, their impact on the long-term health of forests in the southeast.

Mortality of various species (redbay, sassafras, avocado, pondspice, pondberry, etc.) due to LW should continue to be documented and measured. Lessons learned and survey methods developed should be used as a starting point in evaluating future tree mortality caused by nonnative species. In addition, the following areas should be explored: improved detection and evaluation techniques for LW, possible use of remote sensing methods, better traps/lures, and more efficient visual surveys.

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CHAPTER 5

West Coast Forest Insects

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This chapter describes seven projects focusing on the effects of defoliators, bark beetles, and the balsam woolly adelgid. Two of the defoliator projects addressed the effects of defoliation by the western spruce budworm (*Choristoneura occidentalis*), while a third developed methods for using satellite imagery to assess distribution of the aspen leaf miner (*Phyllocnistis populiella*) in Alaska. The budworm-related projects considered the effects on fire potential and on the unstable habitat of the northern spotted owl east of the Cascade Mountains. Three bark beetle projects dealt with the Douglas-fir beetle (*Dendroctonus pseudotsugae*), spruce beetle (*D. rufipennis*), and pine beetles in southern California. The Douglas-fir beetle project examined the accuracy of the Cooperative Aerial Detection Survey using the bark beetle as a test case for evaluating survey mapping. A spruce beetle outbreak led to significant changes in vegetation on the Kenai Peninsula, and its effects were studied by using data from forest inventory plots. In another project, bark beetle mortality in southern California was measured from plots of the Forest Inventory and Analysis (FIA) Program of the Forest Service, U.S. Department of Agriculture, and compared to mortality mapped from aerial survey and other sources. One project used a ground survey approach to document current distribution and impacts of the nonnative balsam woolly adelgid (*Adelges piceae*) across Oregon and Washington.

Project WC-F-01-07: Changes in Fire Hazard Associated with Western Spruce Budworm Defoliation in the Eastern Cascades

Late Successional Reserves (LSRs) were established by the Northwest Forest Plan in order to provide habitat for late-seral species associated with the northern spotted owl. Many of these LSRs contain stands that are very dynamic and are vulnerable to various disturbances such as insects, disease, and wildfire. As such, land managers face large challenges

in carrying out the mandate to provide habitat under these unstable conditions.

The purpose of this 2-year project (2000-2001) was to examine the effects of defoliation by the western spruce budworm on changes in fire hazard within northern spotted owl habitat. The study was carried out on Smith Butte in the Gotchen Late Successional Reserve (Gifford Pinchot National Forest) where the budworm had been in outbreak status since 1995. The author measured several stand attributes including canopy cover, levels of down wood, and basal area of budworm host species. Specific fire parameters being evaluated included severity of surface fire, torching potential, and crown fire potential at the stand and landscape levels.

Sources of data included the Continuous Vegetation Survey (CVS) plots (1992), a local Research Natural Area, and Region 6 Timber Stand Exam procedures. These data sources represented pre-outbreak and during-outbreak information that could be compared to identify changes brought about by the budworm infestation. The data from these sources were also loaded into the Forest Vegetation Simulator (FVS) and the Fire and Fuels Extension to FVS (FFE-FVS) in order to model the contribution of each stand attribute to various aspects of wildfire.

Results from the first year indicated that canopy cover in defoliated stands was reduced by roughly half and that down wood levels doubled between 1992 and 2000 (from 18 to 35 tons per acre).

In the second year of the study, the data were processed through a number of fire models (FFE-FVS, BEHAVE, FOFEM) in order to describe how several aspects of wildfire would be affected by the budworm outbreak. The predicted average flame length derived from fire models increased from 4.5 to 6 feet given 95 percent weather [95 percent percentile of extreme weather conditions and perhaps footnote those elements that go into the equation (humidity, fuel moisture, temperature, wind)], while changes in torching potential and independent crown fire behavior were not significant. Current debris loads, although quite high, were not predicted to result in stand replacement fires. In fact, even though absolute stand density and basal areas were greater in 1992 than in 2000, the proportional loss to fire did not differ between the two periods.

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Utilization of project results—The peer-reviewed paper resulting from this study (Hummel and Agee 2003) has been cited in at least three District Environmental Impact Statement/Environmental Assessment planning documents in Region 6 and a dozen other scientific papers (with a geographic range across the Western United States and Canada). Results from this FHM-supported study were incorporated, for example, in the Gotchen Risk Reduction and Restoration Final Environmental Impact Statement (2004). Landscape-scale treatments began in 2005.

Suggestions for further investigation—The authors (Hummel and Agee 2003) pointed out that the predictions of fire behavior were derived from the best fire models available, but that each of these contains certain assumptions and therefore the results should be applied with caution. Their work described the stand conditions following 6 years of outbreak and as they appropriately suggest, additional work should be done in later years once the full effect of the budworm outbreak has been expressed. In the coming years, there will be more fuels accumulated as the small dead trees fall and add to the surface fuel bed. Other vegetative changes will occur over time and may alter the predicted fire behavior even more than suggested in this study. Another important avenue of study is how to manage these ephemeral habitats over time and across the landscape in such a way that they can be buffered from large-scale disturbances, be they insects, diseases, or fire. Research that evaluates various treatment alternatives for maintenance and/or recruitment of certain vegetative conditions associated with late-successional species would be very appropriate.

The Cold Springs wildfire burned through the northern portion of the Gotchen LSR in summer 2008. It stopped north of the Smith Butte plots measured for this project of the national Forest Health Monitoring (FHM) Program of the Forest Service, U.S. Department of Agriculture. But the fire burned through some that were remeasured in 2005 as part of a different FHM project (McDonald Ridge). The 2008 Cold Springs wildfire comprised stand-replacement, mixed-severity fire effects, and low-severity fire effects. It would be timely to remeasure both the Smith Butte (unburned) and the McDonald Ridge (burned or re-burned) plots to validate the earlier fire behavior model predictions.

Projects WC-EM-05-02, WC-EM-06-01: Effects of Western Spruce Budworm Defoliation on the Northern Spotted Owl and its Habitat in South Central Washington

The objective of the project was to investigate the landscape-level effects of a lengthy western spruce budworm outbreak (*Choristoneura occidentalis*) on the quality of habitat and

demography of the northern spotted owl (*Strix occidentalis caurina*). Issues are extremely complex in this dry forest setting, with owls occupying habitats that are prone to rapid deterioration yet expected to be managed for sustained late-successional conditions under the Northwest Forest Plan. The spruce budworm represents one of the important disturbance agents that make management of LSRs in dry forest ecosystems extremely challenging.

The study was designed to utilize numerous tools and procedures including satellite imagery of vegetation for the area (LANDSAT 5 TM), annual aerial survey maps of budworm defoliation, data from the CVS and FIA plots, remeasurement of spruce budworm impact plot data collected over several years, Washington forest permit application data, and owl demographic data from field monitoring surveys. Ground validation and remeasurement work was time-consuming due to difficult access of remote locations across multiple ownerships, and, therefore, the study was extended to include a second season of field work.

The study area was defined by using GIS overlays of northern spotted owl habitat, aerial survey maps of budworm defoliation, and topographic features of southwestern Washington. The satellite imagery, available for pre-outbreak (1985) and ongoing or post-outbreak (2003) conditions, was used for change detection. To verify the satellite classifications of defoliation levels, 219 ground sample points (1/4-acre fixed-area plots) were used (112 defoliated points and 107 undefoliated points). Post-outbreak defoliation impact data were collected from sites previously measured during early- or mid-outbreak periods to assess stand-level changes. Owl populations were to be assessed using assorted demographic data gathered since 1985. Finally, the trends and associations would be evaluated among severity of budworm defoliation and vegetative conditions, owl demography, and other disturbances.

In the first year of the study, preliminary work included sampling 88 ground plots. In the second year, an additional 131 fixed-area ground plots were sampled and results were summarized into three categories: (1) host-type with defoliation, (2) host-type with no defoliation, and (3) non-host with no defoliation. Plots were rated as host plots if they contained more than 30 percent trees per acre of true firs, Douglas-fir, and spruce. Preliminary results indicated a strong association between western spruce budworm defoliation and subsequent tree mortality. The tree mortality for host-defoliation plots averaged about twice as much as for host-no defoliation plots. Canopy cover, an important component of owl habitat, was also substantially reduced in the host-defoliation plots.

In the third year, the ground verification plot data were applied in geospatial models creating preliminary study area surfaces for

basal area, stem count, tree mortality, and owl habitat (modeled as a function of basal area standard deviation). Study area CVS/FIA plot data were summarized, and data on budworm suppression and harvest activities were compiled for use in further refining and expanding the models and examining relationships to owl demographics. Preliminary analysis of the CVS/FIA inventory data showed higher levels of crown cover and stocking, and of larger-diameter live and dead trees on forested plots categorized as budworm host type as opposed to non-host type plots. Further results from this ongoing project were still being analyzed at the time of this review.

Suggestions for further investigation—Greater understanding is needed of the effects and interactions of natural and human-influenced disturbance in unstable forests. Resource managers who deal with lands on the eastern slope of the Cascade Mountains are faced with the challenge of managing unstable forest conditions, most of which are considered critical habitat for species such as the northern spotted owl. As portions of these unstable conditions change due to various disturbance agents, similar conditions need to be recruited to replace what has been lost. The trade-off between managing these forest conditions versus leaving them alone is a fertile topic for investigation. Future studies would need to take a landscape level approach, as this one has done, to address ever changing conditions over the landscape and over time, and how to manage for those changes.

Project WC-EM-07-02: Assessment of Aspen Leaf Miner Distribution in Alaska Using Satellite Imagery

Due to the immense size of the State of Alaska, yearly comprehensive aerial forest pest detection surveys using fixed-wing aircraft are impractical. Annual aerial detection surveys typically cover a relatively small percentage of Alaska's total forested acres, providing only a partial indicator of insect occurrence and severity in any given year. If conditions in unsurveyed areas could be consistently assessed using another complementary method, annual pest impact and trend assessments would be greatly improved because they would more closely reflect total insect activity for the State.

The objective of this project was to develop a technique for using satellite imagery to predict pest presence and severity in areas not covered by aerial detection surveys. It focused on assessing the distribution of a single insect species within a delimited study area. Spatial statistical methods previously developed in studies of bark beetles and diseases in South Dakota (Reich and others 2004), Colorado, and New Mexico (Lundquist and Reich 2006) were applied to the aspen leaf miner in a 19 981 ha study area near Fairbanks, AK. The

aspen leaf miner is a widely distributed, native defoliating insect. Larvae tunnel through quaking aspen leaf tissues, causing the foliage of affected trees to turn a distinctive grayish-silver color that is visible from the air. Population levels of aspen leaf miner in Alaska increased dramatically over the 5- to 10-year period prior to 2007.

Within the study area, 206 ground verification plots were sampled in five vegetation types: spruce, birch, noninfested aspen, infested aspen, and open areas. Verification plot data, high-resolution Quickbird satellite imagery, and various other existing spatially referenced auxiliary data were used to develop predictive spatial models for basal area, canopy closure, and vegetation type. Healthy aspen and birch vegetation types were ultimately combined into a birch/noninfested aspen vegetation type, as the scarcity of noninfested aspen stands in the study area resulted in insufficient data to successfully differentiate the two. The resulting models generated probability maps of the distribution and severity of the aspen leaf miner over the study area. The final model mapped aspen infested with leaf miner (i.e., "infested aspen" vegetation type) at an 80 percent accuracy level, accounted for 45 percent of the variability in canopy closure, provided unbiased variance estimates, and yielded prediction and confidence coverage rates close to 0.95.

Suggestions for further investigation—With continued refinement and expansion to include other disturbance agents, the methods and models initiated in this project could enable comprehensive assessment of insect (and some disease) activity across the entire State of Alaska. Further work could be done in this regard to accurately predict the total array of vegetation types and disturbance agent activity in Alaska. New types of satellite imagery and spatial statistical techniques could be tested and incorporated as they become available. Future studies utilizing the refined and expanded methods and models could focus upon the effects of climate change on disturbance agents and forest conditions in Alaska.

Project WC-EM-01-02: Ground Checking Aerial Survey Polygons Identified as Douglas-Fir Beetle Caused Damage in Washington in 2001 and 2002

Each year, the Pacific Northwest Region conducts an aerial detection survey to map insect damage that occurred in the previous year. These map products are important tools for resource managers, and they provide an important historical perspective on insect activity. Ground checks are typically carried out to assess the accuracy of the mapping effort, but these checks have usually been random and not necessarily focused or comprehensive.

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The objective of this project was to conduct a systematic ground survey of aerial survey polygons in order to evaluate their accuracy and provide feedback to the aerial observers. The ground survey concentrated on polygons mapped as mortality caused by the Douglas-fir beetle, an important and commonly identified damage agent in the aerial survey.

The project concentrated on a Douglas-fir beetle (DFB) outbreak that began in 1998 around Republic, WA. This area was chosen because of good road access and a high likelihood that the outbreak would be mapped in 2001 and 2002 aerial surveys. In the summers of 2001 and 2002, aerial surveyors sketchmapped insect and disease activity in the project area using a digitally assisted sketchmapping system with GeoLink software while flying the standard four-mile grid pattern.³ In the autumns of 2001 and 2002, 117 DFB polygons were evaluated, either chosen from that season's map and then visited on the ground, or located on the ground and then sought on the most current map. The evaluator recorded how the polygon was selected (from the map or from the ground); how it was evaluated (from a distance, from the perimeter, from within); the number, species and size of trees of affected trees; and actual mortality causal agent. Fifty-three of the plots were located on the aerial survey map and then visited on the ground; fifty-three areas of damage were viewed from the road and then matched to a polygon on the map; four polygons were located with a combination of methods; and the locating method was not recorded for seven polygons.

Of the polygons evaluated, 60 were mapped in the correct place and 14 mapped polygons were less than half of a mile from the damage on the ground. One polygon depicted on the map (covering 30 acres with 10 trees per acre affected) could not be located; no dead trees were in the nearby area. Three mapped polygons were shown more than half of a mile from the damage on the ground. Thirty-nine damaged areas viewed from the ground did not correspond to mapped polygons. The polygons seen from the ground but unmapped were fairly small, discrete groups of trees (the average number of trees per polygon was 21.64). When only polygons with more than 100 dead trees indicated on the survey map ($n = 27$) are considered, 22 were in the correct location, four were mapped within half a mile of the correct location, and one could not be found at all.

The success rate (i.e., correctly mapping damage polygons within half a mile of the actual damage) identified in this study is 63 percent. Groups of more than 100 dead trees were successfully mapped 96 percent of the time. Success rates

were high for mapping of polygon shapes (74 percent accurate) and causal agent (96 percent correct).

Direct numbers of dead trees were compared between the maps and ground surveys. For smaller polygons (where actual numbers of trees are usually indicated) there was a tendency to overcount dead trees on the aerial survey map as compared to the ground survey. This could have been related to accumulations of older dead trees in the area making an impression on the aerial surveyors, in contrast to challenges in seeing even all the most recent "current" dead trees in the vicinity from a ground vantage.

The authors identified certain challenges associated with ground verification of mapped polygons. Complex topography and the limitations of a partial view from the ground make assessment of an aerial view difficult. Polygons attributed as "trees per acre" are also extremely difficult to evaluate.

Suggestions for further investigation—The aerial detection survey gathers an extraordinary amount of information at a relatively small cost. The 100 percent coverage of forested lands in the region means that there are potentially many users of this information and many types of questions that can be answered. Further work could be done along the same lines of accuracy assessment, but with other species of trees and other damage agents. A calibration of the recorded tree mortality under different conditions could produce a good index of the reliability of different attributes that are mapped in the aerial survey and conclusions could be drawn about the utility of these data in the management of our forests.

Project WC-F-01-09: Broad-Scale Spruce Forest Change, Kenai Peninsula, Alaska 1987-2000

Researchers reported on a number of vegetative changes that have occurred in the forests of the Kenai Peninsula as a result of a long-term spruce beetle epidemic. In 1987, FIA conducted a special inventory designed to assess the impact of the spruce beetle on the timberland resources of the Kenai Peninsula. This inventory provided the baseline for a remeasurement conducted in 1999-2000 after the spruce beetle had affected most of the stands on the Peninsula.

This project involved the resampling of 127 ground plots from a pool of 1,216 FIA plots classified as productive forest in 1987. Five-point variable-radius cluster plots were used to collect tree information. Understory vegetation and seedlings were sampled from small fixed-radius plots. Down woody material was determined from 11.3-m transects.

³ Personal communication. 2009. Julie Johnson, GIS Analyst, U.S. Forest Service, Pacific Northwest Region, 333 SW First Street, Portland, OR 97204.

Results for vegetative changes differed between the four distinct forested zones of the Kenai Peninsula (southern lowlands, Kenai Mountains, coastal forests, mid- to northern Kenai). The forests of the southern lowlands experienced the greatest change in vegetative composition, with high spruce mortality and increases in bluejoint grass and fireweed. Other significant vegetation changes occurred in the Kenai Mountains where mountain hemlock, tall blueberry, and rusty menziesia all increased over 1987 levels. The coastal and mid-northern Kenai forests showed no consistent changes in vegetative composition between the 1987 inventory and the revisit in 2000.

Tree mortality was greatest in the southern Kenai lowlands within the white spruce forest type. These stands experienced a substantial reduction in size class; poletimber was reduced to a smaller size (or to non-stocked) on 36,000 acres and sawtimber was down to pole-sized or smaller size class on 136,000 acres. During the period between 1987 and 2000, cubic foot volumes were reduced by half on productive forest land and mortality exceeded growth by a ratio of more than 2 to 1. Spruce reproduction (as measured by presence of seedlings) either improved or stayed the same on most sample plots.

Down woody material of all size classes increased during the sampling period. Fuels averaged slightly less than 5 tons per acre for all plots. Salvage logging of dead spruce did not significantly reduce large sound fuels; in fact, 10- and 100-hour fuels increased after harvest.

Suggestions for further investigation—A logical next step would be to identify resource issues that have arisen from these dramatic landscape-level changes in forest structure. Effects on recreation, hydrology, wildlife habitat, and perhaps wildfire risk might be expected. Clearly, not all resources are likely to be affected in the same way, but a quantification of the most dramatic effects or impacts might enable managers to evaluate mitigative measures for future events that will surely occur in other mature spruce stands.

Project WC-F-04-03: Southern California Forest Health Assessment—Analysis of Status and Trend, Post Drought-Induced Bark Beetle Mortality Events of 2002-2003

The study area covered more than 980,000 acres of forested lands on the San Bernardino, Angeles, and Cleveland National Forests in southern California. This project involved the remeasurement of FIA plots within areas affected by bark beetles in 2002 and 2003 in order to develop statistical estimates of tree mortality by species, size and volume. Recent tree mortality was determined using several data sources

including recent aerial photography, Landsat Thematic Mapper satellite imagery and aerial survey data. One hundred FIA plots were remeasured, and mortality was recorded by tree species and size class. This plot information was stratified by mortality level and vegetation type using remote sensing and aerial survey data. Statistical analyses of the FIA data provided information on the levels of beetle-caused mortality by forest type, tree size, and ownership.

Suggestions for further investigation—A comparison of aerial survey data with FIA ground plot data could be a useful calibration of the survey in order to generate timely reports of tree mortality that could be applicable to current issues.

Projects WC-EM-98-02, WC-EM-99-03, WC-EM-00-02: Balsam Woolly Adelgid Survey for Occurrence and Impacts

The first documented incidence of balsam woolly adelgid in Oregon or Washington occurred in Oregon's Willamette Valley in 1930. By the late 1950s and 1960s, the balsam woolly adelgid was causing extensive and fairly rapid tree mortality in the region, primarily in the Cascade Mountains. By the late 1970s, it had colonized most of the available sites in the western valleys and along the Cascade and Coast ranges of Oregon, Washington, and British Columbia. The initial wave of mortality was distinctive and well-recorded in annual aerial detection surveys. Since that time, an apparent shift from bole infestations that cause rapid and obvious tree death towards chronic crown infestations that cause a slow decline and can eventually kill trees has resulted in an associated shift towards a more subtle and less identifiable detection signature. As a result, balsam woolly adelgid occurrence and damage have often been missed or misidentified during annual aerial detection and ground surveys.

The primary objectives of this 3-year project were to conduct a ground-based survey in Oregon and Washington for the presence of balsam woolly adelgid, describe the current level of infestation in true fir species based on damage symptoms, and determine the effects of balsam woolly adelgid on host species and changes in local ecosystems (Overhulser and others 2004, Ragenovich and others 2002). In the ground survey, trained crews drove along roads adjacent to areas known to have true fir present and stopped to sample at 1-mile intervals. At each stop, 1 to 20 true fir trees were examined for indications of balsam woolly adelgid infestation. Only trees with gouts on branch tips, or with branch or stem infestations were counted as infested. Other plot data collected at each stop included damage type (gouting, abnormal crowns, balsam woolly adelgid-caused mortality) relative tree size, tree species, site characteristics, and location.

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Ground survey data were collected on 1,038 plots. About 44 percent of the plots were determined to be infested with balsam woolly adelgid. The majority of sites examined were forest lands, but some were located in urban areas and on agricultural lands. A major limitation of the roadside survey method was the inability to access unroaded high elevation sites, restricting sampling of the highly susceptible subalpine fir type. Nevertheless, the investigators found evidence that balsam woolly adelgid has spread into virtually all of the highly susceptible host type (subalpine fir, Pacific silver fir, and grand fir). Since the 1970s, it has spread rapidly through host stands in eastern Oregon. Distribution of detected infestations was spotty. Distinctive swellings on branch tips and nodes indicating balsam woolly adelgid infestation (called gouting) were found most commonly on Pacific silver fir and subalpine fir. Crown infestations that reduce tree vigor and can eventually kill trees was the most common form of infestation. Stem infestations that cause rapid tree mortality appeared to be relatively rare, but were more common in subalpine fir than in other species. Survey results confirmed the general resistance of noble fir, white fir and Shasta red fir when growing in natural stands.

A series of seven trend plots established between 1959 and 1965 were revisited in 1998 to collect long-term trend information on infestation characteristics and mortality. Among their findings, investigators reported that tree damage had been most severe during the first decade of infestation; once present, the insect never seemed to disappear from a stand; higher mortality occurred on wet sites and at lower elevations; and grand fir and subalpine fir were being slowly eliminated from certain environments and landscapes within their respective ranges (Mitchell and Buffam 2001).

Suggestions for further investigation—This study's finding that balsam woolly adelgid has spread throughout much of the highly susceptible host type in Oregon and Washington is a matter of concern, due to the balsam woolly

adelgid's potential for causing significant long-term ecosystem effects. Further investigation of balsam woolly adelgid occurrence and impacts could be focused upon specific ecosystems, or expanded to areas not covered in this roadside survey, as the picture is not yet complete and may continue to change over time. Studies on the interactions of balsam woolly adelgid and other disturbance agents or management practices are lacking, and could provide some much needed insight for forest land managers. As warmer temperatures are known to favor balsam woolly adelgid infestations, another important topic for investigation would be potential effects of climate change upon the balsam woolly adelgid, its predators and hosts, and host ecosystems.

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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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CHAPTER 7

North Central Forest Diseases

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This chapter describes eight projects covering a wide range of disease issues in the region. Three of the projects involved investigations pertaining to decline syndromes or physiological problems in hardwoods (white oak, white ash and black ash), two were related to nonnative or organisms of unknown origin (*Diplodia pinea* and the organisms involved in the beech bark disease complex), and the others involved interactions of disease and prescribed fire, dwarf mistletoe in black spruce stands, and the native pinewood nematode.

Project NC-EM-02-02: Rapid Detection of Two Exotics in Michigan: Beech Bark Disease and Hemlock Woolly Adelgid

This project was proposed to determine the distribution of hemlock woolly adelgid and beech bark disease in the State of Michigan, and to lay the groundwork for risk modeling efforts that will be addressed in a future project.

This 3-year project ended in 2004. Results for the first 2 years were presented in a poster at the 2004 Working Group meeting held by the national Forest Health Monitoring (FHM) Program of the Forest Service, U.S. Department of Agriculture. Final results of the project were presented at the same forum in 2005. Hemlock woolly adelgid was introduced on landscape nursery stock into two nurseries in Michigan in 2001. Detection and eradication efforts were undertaken by the Michigan Department of Agriculture, and it was assumed that the insect was eradicated in the vicinity of the infested nurseries. During the current project, in 2002-03, the Michigan Department of Natural Resources (DNR) surveyed 34 forested stands or recreation areas in the Upper Peninsula and 25 in the Lower Peninsula, and detected no hemlock woolly adelgid infestations in the State.

Beech bark disease was recognized in Michigan in 2000, and scale infestations were found in both the Upper and

Lower Peninsulas. During the current project in 2002-03, no beech scale adelgids were detected outside the core area of previously documented beech scale infestations in either the Upper or Lower Peninsula.

Utilization of project results—Data from this project will be used to help generate risk criteria for inclusion in GIS-based risk models for hemlock woolly adelgid and beech bark disease. In addition, the methods developed for the surveys will be used in future surveys for exotic forest pests. The methods developed include a stratified, repeatable, fixed-plot system that uses host distribution and density information—based on data from the Forest Inventory and Analysis (FIA) Program of the Forest Service—to stratify sample plots. The survey methodology incorporates FHM crown indicators to assess tree vigor, and is organized and conducted relatively quickly with minimal training.

Suggestions for further investigation—None identified.

Project NC-F-03-03; NC-F-04-01: Interactions of Prescribed Fire and Insect and Disease Pests in Red Pine

The objectives of this project were to (1) determine the effects of fire and mechanical treatments, alone and in combination, on incidence and impact of forest insect pests and pathogens in mature red pine stands in the Lake States, and (2) document the effects of these treatments on forest vegetation and litter parameters, and relate these effects to the biology of forest pests. The site-intensive project was conducted in a single 17 ha stand in Luce County, in Michigan's Upper Peninsula.

Preliminary results of this project were presented in poster format at the 2006 FHM working group meeting. At the time of reporting, mechanical treatments had been completed, but the prescribed fire component had not been initiated (scheduled for 2006). Results comprised an evaluation of the species composition of the site, and spore trap data for the *Diplodia pinea* (syn. *Sphaeropsis sapinea*) and *Sirococcus conigenus* shoot blight pathogens. In the study area, 54.2 percent of trees were red pine, 16 percent were white pine,

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11.3 percent were jack pine, and 8.9 percent were red oak. Both *Diplodia pinea* and *Sirococcus conigenus* spores were trapped on the site in the summer months, but larger numbers of *S. conigenus* spores were found.

Utilization of project results—Final results of this project are not yet available. The efficacy of prescribed fire or mechanical treatments to control these diseases has not yet been determined, and recommendations for implementation have not been offered.

Suggestions for further investigation—Final results for this project are not yet available, and the development of final conclusions will likely require data collection and monitoring over several years to determine the ultimate effects of mechanical and prescribed fire on insect and disease incidence in this stand. If this project is successful, it may lead to additional experiments with these site-altering treatments and their effects on insects and pathogens in northern forests.

Project NC-EM-03-04: Evaluating Distribution and Structure of Epidemic Populations of *Sphaeropsis sapinea*

It has been proposed that the name of this pathogen should be changed back to *Diplodia pinea*, because it had been incorrectly changed to *Sphaeropsis sapinea*. Because most researchers working with this organism appear to support the change, it will subsequently be referred to as *Diplodia pinea*. The study had three goals: (1) to characterize *D. pinea* populations in epidemic situations, (2) to characterize *D. pinea* populations in non-epidemic situations, especially those beyond the range of historical reports of significant damage, and (3) to determine the potential for virulent populations to persist with asymptomatic hosts in Federal, State, and private conifer nurseries.

Results of this project were documented in a journal article in 2005 (Stanosz and others 2005) and in a poster presented at the 2006 FHM working group meeting. Results presented to date involve the third objective, determining “latency” in non-symptomatic hosts in tree nurseries. Incidence of symptomatic seedlings varied widely within and between the seven nurseries included in the study. Symptomatic seedlings were more frequent in beds near windbreaks including diseased trees. Symptomatic seedlings were infrequent in the three nurseries where red pines were not present (or were rare) or appeared healthy in windbreaks.

Frequency of identification of *D. pinea* from asymptomatic seedlings varied widely within and between nurseries. The pathogen was found more frequently from asymptomatic

seedlings in nurseries with windbreaks that included diseased pines, and more frequently near the infected windbreaks than from seedlings more distant from the windbreaks. Overall, in five of the seven nurseries in the study, the pathogen was recovered from asymptomatic seedlings at frequencies ranging from 0 to 88 percent. The pathogen was not recovered from asymptomatic seedlings from two Michigan nurseries, where red pines were not present or were rare in windbreaks.

Utilization of project results—Forest tree nurseries throughout the north central region have taken steps to eliminate red pine windbreaks from nurseries, to reduce the level of inoculum present.

Suggestions for further investigation—The authors do not propose any next steps or further research in their poster or paper, but the first two objectives of this study deserve examination. Latency in *Diplodia* species and the recent discovery that there is an additional *Diplodia* sp. present in the Lake States (*D. scrobiculata*) make it difficult to assess the risks posed by members of this genus. Because most red pine in the Lake States is in plantations, the disease has been spread from infected nurseries on asymptomatic, infected seedlings. The extent of distribution of *D. pinea* and *D. scrobiculata* has not been fully investigated, and there is increasing discussion that *D. pinea* may be a pathogen introduced into the United States in the last century.

Project NC-EM-04-02: Developing a Damage Threshold for Dwarf Mistletoe Infested Black Spruce Stands

Partial results of this project were presented at the 2005 FHM working group meeting, the 2005 Western International Forest Disease Work Conference, 2009 North Central Forest Pest Workshop, the 2009 Joint Statistical Meetings, and the 2009 International Association of Landscape Ecology. Results were recently published in the journal *Ecological Applications* (Hanks and others 2010), and another paper is in press in the *Northern Journal of Applied Forestry* (Baker and others, in press).

The authors proposed to use FIA and FHM plot information as a starting point, and to implement GPS-based surveys, using consumer-grade GPS units, in stands infested with black spruce dwarf mistletoe (*Arceuthobium pusillum*). The data were then to be used with a spatial model to project future disease losses. Projection results would be provided to forest managers and policymakers to help make informed decisions about management in infested stands.

Stated objectives of the project were (1) to develop field procedures for using GPS in surveys, (2) to evaluate the reliability of FIA dwarf mistletoe incidence, and (3) to identify infestation levels on FIA plots that indicate extensive stand damage.

The investigators surveyed parts of 202 stands, establishing plots that determined that 112, or 55 percent, had dwarf mistletoe. The plots were located near FIA plots, which could not be directly located because of privacy concerns. Of the 144 stands within 0.5 miles [0.8 km] of a plot which FIA considered infested, 67 percent were actually infested. Conversely, of the 58 stands examined within 0.5 miles of an uninfested FIA plot, only 26 percent were infested. Of all the stands surveyed, the mistletoe status of 79 percent of stands agreed with that of the nearby FIA plot. Thus, the FIA plot probably does a good job of indicating the presence of dwarf mistletoe, but tends to underestimate the presence of dwarf mistletoe in surrounding stands. This might in part explain the reportedly low incidence of dwarf mistletoe based on FIA plots.

The Minnesota DNR inventory also records the presence of pests such as dwarf mistletoe. Analysis of those data showed that Minnesota DNR inventory crews recorded dwarf mistletoe in just 23 percent of 112 infested stands. This low level of detection is not likely due to miscoding the pests, as most of the incorrectly assessed stands were coded as “0” or no pest.

The investigators initially planned to project losses in infested stands, and then relate the magnitude of the losses to FIA plot infestation level. Given the difficulty of even categorizing dwarf mistletoe presence, they abandoned this approach. However, the data collected during the surveys permitted an analysis of the spatial autocorrelation of dwarf mistletoe occurrence on the landscape. The spatial autocorrelation model was used in a Bayesian Hierarchical model to improve the accuracy of dwarf mistletoe incidence based on the Minnesota DNR dataset, resulting in the prediction that 35 to 59 percent of black spruce stands in northern Minnesota are infested with dwarf mistletoe.

The investigators have developed a multi-stand, spatially explicit simulation model, written in Python, which projects dwarf mistletoe impact in infested stands. The model was designed to allow users to change spread rates and volume equations. This design was employed to allow using the model for any aggregated forest loss situation, such as that caused by root disease. The model will be shared with State, Federal, and international cooperators.

Another unique aspect of this model is that it will run backwards to help examine the importance of bird vectors in initiating dwarf mistletoe infestations. They plan to take existing infestations and shrink them over time (“un-spread

the parasite”). Some centers will remain at the time of stand initiation, others will disappear. Disease centers that disappear at some critical time, say 30 years, after stand initiation, clearly did not originate with the stand, and were probably started by birds.

The conclusions derived from this project include:

- Consumer grade GPS units can be used to record information for dwarf mistletoe surveys.
- Transect lines 200 m apart were adequate for detecting dwarf mistletoe in black spruce stands.
- FIA plots underestimate the incidence of dwarf mistletoe. The Minnesota DNR inventory, which has the primary goal of recording timber volumes, is even less effective at identifying dwarf mistletoe.
- FIA crews are not likely to code dwarf mistletoe (or witches’ brooms) each time they visit the plot, so information from all observations will give the best indication of the presence of dwarf mistletoe.
- Eleven percent of FIA plots are infested, but the proportion of infested plots observed in any year was usually less, ranging from 0 to 16 percent.
- In Koochiching County, MN, the relative proportion of black spruce represented in FIA plots is much less than in other surrounding counties.

Utilization of project results—The model derived from this project was still in preparation as of 2009. Eventually, the model will be made available to land managers to help predict dwarf mistletoe incidence and impacts in black spruce stands.

Suggestions for further investigation—The Bayesian Hierarchical model provides a unique tool to merge broad scale relatively inaccurate datasets with highly focused but accurate surveys and make inferences not possible from either dataset. These inferences (e.g., that between 35 and 59 percent of black spruce stands are infested) need to be evaluated. In addition, a larger sample of FIA plots needs to be examined, to demonstrate the utility of this technique for FIA. Finally, these observations were made only in stands older than 60 years where dwarf mistletoe is very obvious. Surveys of younger stands are needed to determine if the disease incidence is as great as it is in mature stands.

Project NC-EM-04-05: White Oak Decline

Partial results of this study were presented at the Iowa chapter of Society of American Foresters meeting in 2006. Forest health professionals have been observing tatters on leaves of declining oak trees in eastern Iowa and other Midwestern States since the 1990s. Beginning in 2004, initial work on this issue in Iowa examined relations to temperature (late frost) and the possibility of oak wilt fungus with no conclusive

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results. In 2006, work was planned in cooperation with the University of Iowa Hygienic Laboratory looking at the presence of low levels of ambient herbicide in air, rainwater and tree tissue samples as a possible explanation of the tatters phenomena. Oak wilt sampling was performed by the Forest Service in the fall of 2006 at White Pine Hollow with the results coming back from the Iowa State University (ISU) Plant Disease Clinic as negative for oak wilt. White oak seedlings were tested at ISU greenhouse for their reaction to volatile levels of acetochlor, atrazine, 2-4D and chlorine.

In cooperation with ISU field testing oak and hackberry seedlings with farm chemicals were ongoing in a volatilization experiment (Spring 2008). The findings of that initial study showed the acetochlor caused tatters on white oak at a rate 1/10 and 1/100th of the labeled application rate. This initial study, in conjunction with field findings, suggests that acetochlor is causing tattering on oak leaves.

Utilization of project results—No information is currently available regarding utilization of results derived from this project.

Suggestions for further investigation—Further investigation regarding levels of acetochlor sufficient to cause tatters on oak and hackberry are warranted. Timing of the physiological effects of acetochlor on leaf development also should be examined.

Project NC-EM-06-01: Assessment of Decline and Contributing Diseases in White Ash Stands in Michigan

Ash decline was a notable issue in white ash stands before the arrival of the emerald ash borer. The intent of this project was to assess the roles of various factors potentially involved in the ash decline syndrome in stands not yet affected by emerald ash borer. The project was designed to assess the role of various factors in the expression of decline symptoms in white ash. The primary biotic factors involved were ash yellows and several root and butt rot organisms that were identified during a preliminary study. Other risk factors in the analysis included abiotic influences, including stand dynamics, climatic, physiographic and edaphic site factors, and stand management history. Particular attention was given to ash yellows, including quantification of the relationships between ash decline, ash yellows, and various field symptoms, including deliquescent branching, witches' brooms, basal bark cracks, and epicormic sprouts.

Preliminary results from this project were presented in poster format at the 2008 FHM working group meeting. The study found that distribution of the ash yellows phytoplasma

(AshY) is statewide in Michigan. The frequency of AshY in woodlands with white ash varied from 0 to 40 percent. Crown decline was not correlated with the presence of AshY in forests. Mean radial growth (mean diameter at breast height) was identical for white ash trees whether they were positive or negative for AshY, in a 65-year-old stand. Preliminary observations suggest that white ash decline in Michigan forests may be due, in part, to several root and butt rots.

Final results from this project are not yet available. Plans for field work in 2008 included collecting tree-ring data from 80 white ash that were to be evaluated to determine whether ash decline appeared following successive years of drought. Tree-ring data were to be used to try to determine whether AshY affects white ash recovery from drought. White ash with basal cracks (a common phenomenon) were to be assayed to determine whether the cracks are correlated with the presence of AshY. Real-time polymerase chain reaction and transmission electron microscopy assays were to be compared to DAPI fluorescence microscopy to determine the efficiency of these techniques in identifying AshY infected trees.

Utilization of project results—None identified. When completed, the project may inform silvicultural prescriptions for dealing with AshY-infected ash in forest stands.

Suggestions for further investigation—None noted. This project was incomplete at the time this document was prepared.

Project NC-EM-07-02: Relating Black Ash (*Fraxinus nigra*) Decline and Regeneration to Tree Age and Site Hydrology

Black ash decline is a widespread phenomenon throughout the upper Midwest and Northeast. Several factors have been implicated in the onset of black ash decline, including drought, disease, soil, and hydrologic factors. The goals of this 2-year project were to develop an assessment of decline and mortality severity within black ash ecosystems in Minnesota that appear to be heavily impacted based on FIA data, and to prepare a quantitative assessment of the relationships between site hydrology and soil moisture, tree age, and decline.

Preliminary results of this project were reported in a poster at the 2008 FHM working group meeting. The study found that, across the 21 sites examined in Minnesota, black ash stands showed marked differences in frequency of declining trees (from less than 20 percent to more than 60 percent). The investigators were able to group the stands into heavily impacted ("susceptible") stands with substantial decline, and generally "healthy" stands. Decline of overstory trees in

susceptible stands may be related to tree age, since healthy trees in these stands averaged 20 years younger than declining trees in the same stands. Tree age was unrelated to decline in healthy stands. Both declining and healthy stands contained seemingly healthy regeneration cohorts, but densities were higher in healthy stands. The authors observed no obvious causal insect or disease organisms on declining trees. Decline appears to be positively correlated with wetter conditions and deeper depth to a mineral layer, indicating that the site is more prone to anoxic, saturated conditions.

Final results are not yet available for this project, which was completed in 2008. The investigators sampled an additional 31 stands in Lake, St. Louis, Carlton, Aitkin, and Itasca counties in Minnesota, but results have not yet been made available. The investigators are also examining successional trends in declining stands.

Utilization of project results—None noted.

Recommendations for improving ash silviculture may be forthcoming when the project analysis is completed.

Suggestions for further investigation—None noted.

This project was incomplete at the time this document was prepared.

Project INT-EM-04-06: Pine Wilt in the Central Great Plains: Differences in Pinewood Nematode Populations and Identification of Insect Vectors

Pine wilt caused by the nematode *Bursaphelenchus xylophilus* is a severe problem throughout the Midwest primarily on Scot Pine (*Pinus sylvestris*) though it can be found in other pine species. The pine wilt disease was identified for the first time in the United States in Columbia, MO, in 1979 (Powers 2004). Since that first report, *Bursaphelenchus xylophilus* has been found in 36 states, including all the Great Plains states except for North Dakota. The widespread distribution of the pinewood nematode suggests that it is native to the United States. In North America, investigators have confirmed the disease on 27 species of *Pinus* (pine), one each of *Abies* (balsam) and *Pseudotsuya* (fir), and two each of *Cedrus* (cedar), *Larix* (larch), and *Picea* (spruce). The disease is unique in its complexity, since it involves a plant-parasitic nematode, one or more insect vectors (primarily pine sawyers), wood-staining fungi, and possible other organisms (Gleason and others 2000). Incidence of the disease appears to be greater during periods of drought impacting aesthetics, high-value windbreaks, and Christmas tree plantations. An

EM project funded in 2004 was set up to compare nematode populations found in Scot and Ponderosa pine. In addition, the project was designed to look at the pine sawyer beetle (*Monochamus* spp.) and other potential insect vectors involved in the spread of pine wilt.

Virulence of populations of *Bursaphelenchus* spp. associated with conifers varies throughout the range of this nematode in the United States. Pathogenicity of Pine Wilt Nematode (PWN) in the United States depends on the interaction of the pine species with different PWN populations, the physiological status of the infected pine, and environmental conditions. Mating and reproductive potential, virulence, DNA sequence differences determined by restriction fragment length polymorphisms, and isozyme differences are useful criteria for studying population biology and genetics of PWN. When used together, these factors can elucidate speciation of *Bursaphelenchus* associated with conifers (Kiyohara and Bolla 1990).

Utilization of project results—Results of this EM project were utilized and incorporated into the Plant and Insect Parasitic Nematode website: <http://nematode.unl.edu>.

Suggestions for further investigation—

- Host specificity within *Bursaphelenchus xylophilus* in the Midwest needs further investigation.
- More information is needed about how other insect carriers of PWN influence spread of the disease.

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CHAPTER 8

Northeast Forest Diseases

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The national Forest Health Monitoring (FHM) Program of the Forest Service, U.S. Department of Agriculture, has provided a means to address important forest tree disease conditions that continue to threaten the survival and prevalence of valuable tree species. A range of Evaluation Monitoring (EM) projects has been conducted related to native and introduced diseases in the Eastern United States. The topics include various forest declines such as hickory, basswood, oak, northern white cedar, ash, and black ash; forest health conditions in the Allegheny and Ozark forests; Eastern dwarf mistletoe damage; butternut resource viability and canker progression; and beech bark disease impact, extent, and host resistance. The projects relating to beech bark disease and butternut canker have helped to provide information to evaluate the continued impact of these long-time established pathogens.

Beech bark disease is a complex tree disease involving an introduced scale insect, *Cryptococcus fagisuga*, and specific species of the *Nectria* (*Neonectria*) fungus. Millions of board feet of the American beech (*Fagus grandifolia*) have been lost due to mortality from the pathogen that gains entry through feeding wounds caused by the scale (Miller-Weeks 1983). The scale was first introduced on imported European beech in Halifax, Nova Scotia, in the Canadian Maritimes, in the 1890s (Ehrlich 1934). By the early 1900s, mortality was occurring in eastern Maine. The insect spread naturally through New England, into New York and Pennsylvania, and southward to Virginia, West Virginia, North Carolina, and Tennessee, and now also occurs in eastern Ohio and northern Michigan (Houston 1994a, 1994b, Heyd 2005). Tree mortality, caused by the *Nectria* spp., has followed close behind in the areas where the scale has infested, and continues throughout the range of the insect (Lohman and Watson 1943). The areas affected are referred to as the “advancing front,” “killing front,” and “aftermath zone” (Shigo 1972).

For many years, numerous research and biological evaluation projects have been conducted to determine the extent and impact of this disease on the beech resource, along with

possible host resistance. The ongoing effects of beech bark disease, including dieback and tree mortality, have been recorded during the detection phase of the FHM program, both within the extensive permanent plot network and during the annual aerial and ground surveys conducted by both State and Federal forest health specialists. Several projects were recently funded through the EM aspect of the FHM program. The range of projects included current and future impact and extent of the disease, along with host resistance.

The beech bark disease studies focus on impacts and management guidelines, provide further evaluation of the associated insect and pathogen, along with the disease progression, and help to provide a model to assess impact on forest composition from an introduced species. The projects also help to determine needs for future research (e.g., resistance studies and trials). One project looked at the advancement of the disease at the edge of the killing front, finding that there were twice as many standing dead trees within the disease-affected areas. Another looked at forest composition in the aftermath zone and influences of site factors on host tree sustainability, noting that beech was still a significant component of the forest stands, although there were larger numbers of smaller trees. Another project reviewed the historical records to predict future mortality and define areas most at risk, determining that the disease would continue to expand south and west throughout the range of American beech. The most recent project allowed for development and testing of a technique to assess individual tree resistance, and found that resistance is heritable and that seedlings resulting from experimental crosses can be challenged to test that resistance.

Butternut (*Juglans cinerea*) has a native range from eastern Canada west to Minnesota and south to Arkansas, Alabama, Georgia, and Mississippi. First reported in 1967, butternut canker caused by the fungus *Ophiognomonia clavigignenti-juglandacearum* (syn *Sirococcus clavigignenti-juglandacearum*) is killing butternut throughout its range (Nair and others 1979). Extensive tree mortality has resulted in butternut being a “species of concern” or a “sensitive species” in many States, a Regional Forester Sensitive Species in the Eastern Region on 13 of the 16 national forests, and is listed as endangered in Canada (Schultz 2003). Butternut

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is not a common tree but occurs as widely dispersed small groups with many other tree species in several hardwood forest types. The current health status and prospects for the future of the species in much of its range is poorly known.

The FHM program has coordinated butternut conservation and restoration activities among private landowners, universities, State and Federal agencies and Native American tribes to raise awareness of the issues. EM-funded projects related to the butternut resource in the Midwestern and Northeastern United States have focused on obtaining the frequency of butternut occurrence within different habitats, incidence and severity of disease, disease progression, rate of tree mortality, status of tree regeneration, silvicultural prescriptions for butternut retention and regeneration, and locating, collecting, and propagating potentially canker resistant trees (Ostry and others 1994, Woeste and others 2009). Based on these projects, a map and a predictive model of the probability of butternut occurrence was developed that can be used for intensive surveys of butternut to identify candidate trees with possible canker resistance. Another project helped to determine the rate of expected mortality in Vermont, noting that almost all of the butternut would succumb to the pathogen by 2011.

It is important to continue supporting efforts to evaluate and understand exotic disease impact, progression, and resistance. Studies of established introduced diseases yield valuable information that can be applied to pathogens that are newly introduced or may be introduced in the future.

Project NE-EM-02-01: Forest Health Conditions and Analysis of the Allegheny National Forest

The study was initiated on the Allegheny National Forest in response to concerns regarding forest condition following 15 to 20 years of damage associated with drought, insect defoliation by the gypsy moth and various native pests, and the progression of beech bark disease. Comparisons were made between disturbed and undisturbed sites, including the effects of beech bark disease within and outside the “killing front.”

The FHM plot grid was intensified across the Forest in 1998 to 168 plots, to facilitate forest health monitoring and implement forest management practices based on plot data analysis. This approach serves as a model for implementing monitoring systems on other national forests to support forest management planning, monitoring, and plan revision. The analysis of the initial data was conducted in 2000. This EM project provided an opportunity to continue the analysis to provide a more extensive look at the various damage factors

affecting the forest including beech bark disease. Beech bark disease was first detected in northeastern Pennsylvania in 1958, a half-century after it was introduced into Nova Scotia on European beech. The “killing front” was determined to be moving across the northeast section of the Forest. The intensified FHM grid provided a network to evaluate the impact of the disease. A map of the forest was developed to show the area where the front was located, indicating that 58 monitoring plots were within the “killing front” zone and 64 plots outside.

Results indicated that, by 2001, 9.9 percent of basal area of American beech within the “killing front” zone were standing dead, in contrast to only 4 percent of the basal area of standing dead outside of that zone (Morin and others 2006). The percentage of standing dead beech was more than twice as great inside the “killing front” as opposed to outside the front. It is probable that the beech mortality has been even higher since dead beech trees often quickly decay and snap off. Eastern hemlock showed the greatest increase in relative dominance following the loss of beech to the disease.

Project NE-EM-02-03: Health and Sustainability of the New York Forest in Relation to the Destructive Exotic Beech Bark Disease System

The overall objective was to examine variation in disease severity in relation to forest health and sustainability of northern hardwood forest systems. It was hypothesized that in the “aftermath zone” where the disease has already been established for some time, the system would have reached equilibrium and the disease would no longer be a threat to sustainability of the forest. The study incorporated data from established plots to study the disease on a landscape scale in New York.

Since the sustainable equilibrium may not have been reached on all sites, researchers hoped to look at the parameters that defined sustainability, along with determining the influence of site factors and forest composition. The State University of New York College of Environmental Science and Forestry conducted the survey using data from 286 plots throughout the State, to obtain a wide range of variation in beech and site conditions (Manion and Griffin 2001). To assess forest health on State-owned lands, a portion of the plots were established in the Adirondacks after the 1998 ice storm and other storms in 2000 and 2001.

The dataset was used to assess effects of slope and aspect, stand composition, disease incidence, and mortality on forest composition. Beech bark disease was present in all sampled sites and was the leading cause of beech mortality. Beech scale

was present across all diameter classes; however, most of the smaller diameter beech trees were disease-free, as were some larger trees, suggesting that these individuals may be resistant to the scale or disease. Fewer trees were infested with the scale on eastern and southeastern eastern slopes; however, a larger proportion of trees on eastern slopes > 16 percent were infected with *Neonectria* spp. (Munck and Manion 2006).

Within the forest stands in these “aftermath zones” the impact of beech bark disease mortality and beech snap resulted in a shift in size classes with a larger number of small diameter stems and low numbers of large stems, due to the ongoing impact from the disease. Although the host species will take a long time to reestablish, the extirpation and extinction of beech is not likely, as a certain portion of the population is retained to sustain forest structure in the aftermath of the disease. This model may be useful to assess other introduced diseases and their expected impacts on forest sustainability and resiliency.

Project NE-EM-04-02: Historical and Regional Analysis of Beech Bark Disease Impacts

The intent of this study was to predict spread to estimate the expected geographical distribution of the disease through 2025 and develop a mortality model to determine which areas would be most at risk. This study looked at historical information describing the progress of the disease since it was introduced in the Canadian Maritimes and mapped the geographical distribution of the suitable habitat based on 93,611 forest inventory plots in the Eastern United States. A forest susceptibility map was then developed based on the basal area/ha of American beech and adjusted for percent cover type.

The future range of expansion of beech bark disease was predicted by applying estimates of past spread rates derived from historical records. These records consisted of the year each county became infested and the distance of each county from the area initially infested to determine the rate of infection. Then a predicted spread map representing years of expected presence from 2001 to 2025 was generated on a 1- by 1-km grid based on the estimated rate of spread. This map was overlaid with the forest susceptibility map to create the disease risk map through 2025.

The results indicated that the beech bark disease has spread through much of the range of American beech, the host tree is most abundant in the Adirondack and Southern Appalachian Mountains, and that Kentucky is the highest risk area that is currently uninfested. Over the next 50 years, it is likely that the disease will continue to expand its range in the United States. Analysis of current inventory data suggests that the

disease has already invaded most of the areas with high densities of beech and caused a temporary decrease in the dominance of American beech regionally. It has not caused the elimination of the species, although in the aftermath forests beech stems are smaller and have a reduced quality.

This study is important in that it addressed the possible future impact from the disease. It serves as a model for risk assessment for management of exotic invasive species before and after their arrival in new habitats. For beech bark disease this includes further spread in the Lake States and also the Southern States, where beech is a component of the hardwood forest and where the disease is likely to occur in the future.

Project NE-EM-04-01: Development of a Challenge Protocol to Identify Young American Beech Trees that are Resistant to the Beech Scale Insect

A percentage of American beech trees remain disease-free in stands long affected by beech bark disease, and challenge trials have shown that they are resistant to the scale insect. It is thought that the best management approach to reduce the impact from the disease is to increase the number of resistant beech trees, while reducing the proportion of susceptible trees. David Houston conducted years of research on this disease and developed a technique to artificially inoculate trees to test resistance (Houston 1982).

This study was designed to determine if this technique was effective in distinguishing resistant from susceptible American beech trees (Koch and Carey 2004). Three different tree sources were employed: natural and artificial root grafts; grafted material; and seedlings from pollinated sources (either open or controlled cross-pollination). It is hoped that eventually superior resistant progeny can be selected and used to develop seed orchards to provide an enriched source of resistant beech for plantings. These trees would be planted ahead of the “advancing front” to minimize the impact of beech scale and beech bark disease, to introduce resistant genetic material for restoration of beech across the forest landscape where this species is prevalent.

Traps were set for egg collection in Ohio, Michigan, and Pennsylvania for use in scale insect challenge experiments. Putative resistant root sprouts were identified with control susceptible areas nearby. Eggs were placed in 2003, and colonization was scored in 2004. Scion material from resistant and susceptible trees was collected in Maine and Michigan for grafting onto seedling root stock. Controlled cross-pollinations were successfully performed and 1,200 seeds collected, along with 5,000 open pollinated seeds.

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Inoculations were conducted by wrapping insect eggs around seedlings to determine hereditary resistance.

The tests were successful to distinguish between resistance and susceptible seedlings, with a higher proportion of resistance from the resistant X resistant crosses, suggesting that the trait is heritable and not a single gene trait. This test also appears to be successful in a variety of age classes, as demonstrated by test sites on the Allegheny National Forest.

Project Number NE-EM-01-03, NC-EM-02-01: Evaluation of the Viability of the Butternut Resource

Butternut distribution was evaluated using the Eastwide database of the Forest Inventory and Analysis (FIA) Program of the Forest Service, and a hierarchical ecological classification system of ecoregion provinces and sections. Although relatively few butternut occur on FIA phase 3 plots, this technique enabled construction of a map of the probability of butternut occurrence that can be used for intensive surveys of butternut to identify candidate trees with possible canker resistance and to locate suitable sites for future reintroduction of the species.

An investigation of silvicultural options for retention and recruitment of butternut to maintain viable populations revealed several critical requirements for natural or artificial regeneration systems. Most important is opening stands to promote regeneration but not to the extent that it will be to the detriment of the residual butternut seed source trees (Ostry and others 2003). Continued loss of butternut regeneration was attributed as much to competing vegetation and damage from deer as was caused by canker. A large proportion of the marked, healthy butternut that was retained in the stand at the start of the study was still healthy after 13 years. Grafted copies of these source trees have been placed into archive plantings and breeding orchards and the trees are being tested for canker resistance.

Project NE-EM-02-02: Assessment of the Rate of Progression of Butternut Canker Disease

This study of butternut canker progression in Vermont based on a small number of plots revealed that disease incidence and tree mortality was 94 percent and 12 percent, respectively, in 1996. In 2002, disease incidence increased to 96 percent and tree mortality to 41 percent. A larger sample size from additional plots throughout Vermont in 2004 resulted in finding 86 percent of trees diseased and 45 percent killed by butternut canker. Based on these data, it was projected that 85 percent of all butternut in Vermont would be dead by 2011.

Project NE-EM-06-03: Assessment of the Butternut Canker on Public and Private Lands in the Eastern U.S.

An assessment of butternut health on public and private lands in the Eastern United States revealed that butternut mortality in Maine and New Hampshire was 28 percent in 2007. Butternut inventories are continuing in many States, and a GPS/GIS database is being compiled. Surveys have shown that butternut crown dieback from disease and shading is reducing seed production, and butternut regeneration is either lacking or sparse. Diseased and suppressed trees are often affected by decay fungi and killed by *Armillaria* root rot. Stump sprouts are not common and often are diseased or have been killed by butternut canker. A GIS-based predictive model was developed and is being used to locate healthy butternut trees and to delineate sites that are optimum for butternut growth.

Utilization of Project Results

The beech bark disease and butternut EM projects have provided information that has heightened the general public's awareness of the plight of the American beech and butternut resource in North America. Results of the various studies have been developed into guidelines for the assessment, management, and conservation of beech and butternut, which are being used by land management agencies in the United States and Canada.

Suggestions for Further Investigation

In 2008 a working group was formed to address research needs related to beech bark disease in the Eastern United States. This effort followed a 2004 symposium of research, pest management specialists, and forest managers. Based on the overall importance of American beech as a component of the extensive hardwood forest, it was prudent to readdress the research needs related to the impact from this forest disease by forming the Beech Bark Disease Initiative.

The major focus of the Initiative is to consolidate information, provide spatial analysis, identify putative resistance, and then enhance this through management. As a result of the group discussions, several research proposals were developed in regards to:

- Ecological factors that influence incidence and severity
- DNA-based markers to screen for resistance
- Enhanced propagation methods to develop seed orchard
- Silvicultural treatments to enhance resistance
- Spread rates

- Abundance and distribution of resistant trees following harvesting
- Scale intensity related to biogeoclimatic zones
- Locating and mapping resistance

Future research that would address reducing susceptibility of beech trees in advance of the scale, identifying and managing for scale resistant trees, and restoring affected forests would be appropriate.

EM-funded projects have increased understanding of the extent that butternut canker has impacted the butternut resource, revealed habitat requirements critical for butternut conservation and restoration, and resulted in locating potentially canker resistant trees for breeding and restoration efforts. These projects have also revealed several important gaps in our knowledge that require further investigation.

Critical information needs include determining the level of genetic diversity remaining among populations of butternut to guide future germplasm collection. This information will result in conserving an adequate level of genetic diversity across the species range.

Evidence from current collections of butternut has revealed the presence of butternut hybrids that complicate the identification of potentially resistant pure butternut. This will require the investigation of the extent of hybridization with Japanese walnut (*Juglans ailantifolia*) within the range of butternut and the development of techniques to accurately distinguish pure species.

Finally, evaluating the extent of site and environmental influences on disease severity and on the success of natural and artificial butternut regeneration will greatly contribute to the success of future butternut conservation and restoration projects.

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CHAPTER 9

Southern Forest Diseases

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This chapter describes projects on three diseases impacting Southern forests: oak decline in the Ozark Mountains, loblolly pine decline, and dogwood anthracnose.

Projects on Oak Decline in the Ozark Mountains

Adverse effects of oak decline in the Ozark Mountains of Arkansas, Oklahoma, and Missouri, and to a lesser extent in the Ouachita Mountains of Arkansas and Oklahoma, have been of interest to forest health experts for several decades. Oak decline was thought to be associated with the advancing age of large blocks of second-growth oak-hickory forests in the region, the loss of some species that were close to their biological maturity in these forests, and possibly to changes in ecological conditions such as the exclusion of fire in oak-hickory ecosystems across the region.

An episodic drought in the early 1980s affected stands in the region through reduced vigor of some oaks and scattered tree mortality. However, the major change attracting the immediate attention of forest health experts was an unusual outbreak of the red oak borer [*Enaphalodes rufulus* Haldeman (Coleoptera: Cerambycidae)] in the late 1990s. The outbreak was centered in the Boston Mountains on the southern part of the main division of the Ozark-St. Francis National Forest in Johnson, Franklin, Pope, Madison, and Newton counties in northwest Arkansas. The outbreak was unprecedented in the literature because, while previous outbreaks had recorded perhaps a dozen attacks per tree, this outbreak showed attacks that were two orders of magnitude greater than previously observed; some trees dissected during this outbreak showed an average of 2,250 attacks per tree. By 2001, advanced stages of oak decline and mortality, and an assumed relationship related to red oak borer, were reported from the Ouachita Mountains in eastern Oklahoma and western Arkansas, across the Boston

Mountains in Arkansas, and extending to the Springfield Plateau subsection of the Ozark Mountains in Missouri.

A series of Evaluation Monitoring (EM) projects through the national Forest Health Monitoring (FHM) Program of the Forest Service, U.S. Department of Agriculture, was established in Regions 8 and 9. Forest Service scientists and academic cooperators in the region studied these dual questions about oak decline in general, the red oak borer in particular, and the question of whether there was a causal relationship between these events.

As quickly as the red oak borer outbreak arose, by 2007 there was virtually no red oak borer activity in the region. This makes the questions of oak decline and epidemiology of red oak borer all the more interesting. Largely through research funded by the FHM and the Forest Health Protection programs of the Forest Service, as well as through the Southern Research Station and the Northern Research Station of the Forest Service, scientists have learned a great deal about the relationship between oak decline and forest health, ecosystem restoration, and management activity; similarly, in the past few years, scientific understanding of red oak borer has grown exponentially.

But there is still no direct link between oak decline and red oak borer. A variety of insects and pathogens are normally considered contributing factors to oak decline. However, despite more than 100 oak decline events reported in the literature, red oak borer has never before been seen as a contributing factor. The reasons for the unusual population increase of the red oak borer and the equally rapid population decrease are not clear. And, the general health of Midsouth oak-hickory forests remains a cause for concern not only because of advancing age and homogeneity of age of oak stands across the landscape but also because of added impacts of ecological forcing factors (such as the widespread ice storm affecting the Ozarks in February 2009). Scientists interested in the health of oak-hickory forests in the Ouachitas and Ozarks of Arkansas, Oklahoma, and Missouri will continue to have interesting opportunities for monitoring and research activities in the region for the foreseeable future.

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Project SO-EM-06-04: Regional Oak Decline-Related and Regular Oak Mortality Predictions of Extent and Severity

In the Ozark Highlands of southeast Missouri and northern Arkansas, there is considerable concern about oak decline (Oak and others 2004, Starkey and others 2004, Spetich 2004). Red oak group species appear to be particularly susceptible, especially those that are large or physiologically mature, in dense stands, and growing on droughty sites (Law and Gott 1987, Starkey and Oak 1989, Starkey and others 2004, Johnson and others 2002).

Forests of the Ozark Highland ecoregion (Ecological section 222A) (Keys and others 1995) are highly susceptible to oak decline in the coming decades (Lawrence and others 2002). Approximately 98 percent of all scarlet oak (*Quercus coccinea* Muenchh.) volume, 83 percent of all black oak (*Q. velutina* Lam.) volume, and 54 percent of all northern red oak (*Q. rubra* L.) volume in Missouri and Arkansas occurs in this ecoregion. Oaks as a major component of the upland oak-hickory forests represent 70 percent of stand basal area in the Ozark Highlands in southern Missouri. Episodic oak decline/crown dieback has been a chronic problem, and since in the late 1970s has resulted in high mortality, particularly for black and scarlet oaks. Recent research on oak mortality from the Missouri Ozark Forest Ecosystem Project (MOFEP) (Brookshire and Shifley 1997, Shifley and Brookshire 2000, Shifley and Kabrick 2002) has demonstrated that species, crown class, and tree size are significant indicators of the probability of oak mortality (Kabrick and others 2004). Those results are based on a time period covering approximately 1991 to 2002. However, oak decline is a periodic event and recent oak mortality rates may or may not be consistent for earlier decades.

In this monitoring project, most of the oaks in the study area had healthy crowns and only about 10 percent of the black and scarlet oaks and 6 percent of the white oak (*Q. alba* L.) trees exhibited moderate crown dieback (34 to 66 percent) or severe crown dieback (> 66 percent). Other factors being equal, mortality rates were highest for black oak, followed by scarlet oak and least for white oak. Most of the oaks examined showed evidence of attack by oak borers, even those that had healthy crowns and otherwise appeared to be healthy. Analysis showed that oaks exhibiting borer exit wounds were not especially prone to moderate or severe crown dieback or accelerated mortality, suggesting that oak borer damage is not particularly useful for predicting tree mortality in the short term. However, oak mortality was predominantly related to crown dieback class and to crown width or to diameter at breast height (d.b.h.) (i.e., a surrogate for crown width). Logistic regression models that were developed through our analyses can be used to estimate mortality from knowledge of species, d.b.h., and crown dieback class, information that

is routinely collected during forest inventories. These models can be used to guide marking prescriptions during thinning and harvesting operations.

Project SO-EM-02-01: Ground Truth Assessments of Oak Decline and Red Oak Borer in the Interior Highlands of Arkansas, Oklahoma, and Missouri

When this EM program was initiated, forests of the Interior Highlands of Arkansas, Oklahoma, and Missouri were in the midst of an outbreak of red oak borer. The FHM monitoring network had not detected the red oak borer outbreak in the Interior Highlands. But visual evidence of problems with oaks in the Ozark and Ouachita Mountains was readily apparent from ground observations and aerial flights. In the absence of concrete estimates of the problem based on field surveys across the region, all three national forests in the Interior Highlands developed plans to respond to observed conditions resulting from this outbreak.

Ground surveys are useful in situations such as this to establish the extent and severity of this outbreak. These data were nested as strata according to the plot polygon approach used in the national FHM ozone program. Polygons equal to the number of plots to be installed were identified, and an oak decline/borer plot was located at random. In Oklahoma, Arkansas, and Missouri, 225 plots were located over two field seasons; installation of a larger number of plots was complicated by issues of access to private lands.

The condition class variable shows differences in tree health by species group in the region. In general, trees in the red oak group were in poor condition. Fewer than half of the red oak trees in this sample were healthy, and more than 30 percent of red oaks were in severe decline or at the point of mortality. The data also suggest that white oaks are in relatively good condition across the study area relative to the red oak group; nearly 70 percent of white oaks were evaluated as healthy, and fewer than 10 percent were in severe decline or at the point of mortality. No State had better condition in the red oak group than the others; concerns about red oak health exist in all three States in the study. The percentage of healthy red oaks in the sample ranges between 35 to 40 percent in each State.

The monitoring study confirmed that oak decline and red oak borer infestation were widespread and distributed widely across the Interior Highlands. Unhealthy red oaks were found in roughly similar proportions in each of the three States, comprising 22 to 36 percent of stem density and 24 to 31 percent of basal area of the red oak group. White oaks were affected but at levels roughly one-third that of red oaks in each State. Unhealthy white oaks constitute 8 to 13 percent of white oak stem density and 7 to 19 percent of white oak basal area. Geographic information system-based inverse distance

weighting analysis found hotspots in the southwestern and northern parts of the Interior Highlands, which had not been identified as more adversely affected than stands in northwest Arkansas where the tree mortality was first reported.

Project NC-F-06-02: Effects of Prescribed Fire on Upland Oak Forest Ecosystems in Missouri Ozarks

—Initially funded to study the effects of prescribed fire on ecosystem structure and function, this work has evolved to more closely study species-site relationships that underlie problems with oak decline. Work has been completed on posters relating oak decline to fire effects and timber effects, and more work is under way to relate oak decline and drought effect.

Analysis of existing datasets on prescribed burning in Missouri oak forests shows that woody species (or groups) responded differently to prescribed burning in terms of stem density change within different size classes. Among other findings, data showed that red oak was the only species group with decreasing stem density for all size classes under prescribed burning prescriptions; white oak stem density increased in the overstory but decreased in the mid- and understory. Hickories, shortleaf pine, and other species had an increasing stem density in the overstory and on the ground but a decreasing density in the mid- and understory. These results imply that prescribed burns gradually change not only forest size structure but also species composition. As the prescribed burn treatments continue on the study sites, it is expected that continued responses will be observed.

A related study (Kabrick and others 2008) was conducted to determine whether oak decline severity in oak-dominated Missouri Ozark forests is related to factors strongly influencing site quality, including soil, landform position, slope, and aspect. Analysis confirmed that red oak group species had more crown dieback and greater mortality than did white oak group species. Authors also reported more red oak mortality on upper slope positions and where soils were gravelly and low in base cations. However, if the initial abundance of red oaks was included as a covariate in the model, the site factors no longer were significant effects related to oak mortality; moreover, the authors found that frequency of oaks exhibiting crown dieback was the same or sometimes greater on high quality sites. These findings show that red oak mortality is more prevalent on droughty and nutrient-deficient sites because red oak group species are more abundant there. Rather than simply predisposing oaks to decline, droughty and nutrient-deficient site conditions most likely favored the establishment and growth of red oaks following the extensive logging during the early 1900s. The extensive oak decline occurring on droughty and nutrient-deficient soils today appears due to the high abundance of mature red oak group species on these sites.

Work is needed to continue our understanding of oak decline in relation to stand conditions and climate. We need to spatially quantify the lag and perpetual-effect of drought and extreme temperature on oak decline and mortality. A gap in understanding still exists on how climate extremes (drought, temperature) interact as inciting factors with stand/tree factors (predisposing factors) and insects/diseases (contributing factors).

Project SO-EM-02-02: A GIS-based System for Quantifying, Assessing, and Predicting Impact of Oak in the Ozark Mountains

—The authors developed an innovative whole-tree sampling procedure that provides accurate data on within-tree populations (Fierke and others 2005a), but this is a time-consuming and expensive process. Follow-up work showed that extensive sampling, using subsamples taken proportionally along the tree bole, is acceptably accurate; statistical analyses indicate that seven subsamples is the optimal number, considering both accuracy and efficiency.

The authors also developed a rapid estimation procedure (REP) to quickly, non-destructively, and economically assess current density and infestation history of red oak borer in northern red oaks under outbreak conditions in the Ozark National Forest (Fierke and others 2005b). The REP is a survey method for classifying individual trees that takes under 2 minutes per tree and uses two variables: crown condition and number of emergence holes on the basal 2 meters of a tree. Data obtained through intensive and extensive population sampling validate classification of trees into three REP infestation classes that exhibit significantly different densities of measured red oak borer population variables. The REP is an efficient sampling procedure as it facilitates greatly increased sample sizes, thus allowing estimation of red oak borer populations at the stand, area, and landscape levels. Information provided by this kind of survey method may be vital to understand causes and extent of the current outbreak as well as predict future outbreaks and design silvicultural treatments for enhancing forest health.

The authors conducted an additional study using the REP approach to determine infestation histories of northern red oaks in a series of forest stands. To predict REP classes for stands containing northern red oak in the Ozark National Forest, 26 variables, both biotic and abiotic, were analyzed for possible inclusion in a model. With 364 plots evaluated, a model was generated using the following significant variables: percent northern red oak, basal area of northern red oak, stand density, easting or longitude, soil clay content, and the Forest Service designators of compartment, stand, and land class.

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An automated GIS approach, developed for extracting whether or not each plot is located on a ridgetop, was developed for use in the Ozark Mountains. The ridgetop variable was shown to be an important contributor to a machine learning decision tree model used to predict rapid estimation classes. This model is a first step in generating a more precise and detailed model for determining susceptibility of forest stands to red oak borer outbreaks.

Sampling immediately prior to adult emergence in 2003 and again in 2005 allowed evaluation of emerging adult populations and confirmed extremely high populations as well as documenting a population crash in the 2005 emerging red oak borer cohort. Sampling also added to our knowledge of red oak borer biology (Kelley and others 2006), including life stages and emergence period as well as documenting mortality agents, e.g., intra/interguild predation (Ware and Stephen 2006), pathogens, and parasitoids. Adult flight has been investigated with results indicating that optimum trap placement for monitoring should be near the canopy. Investigations of preferential landing, tree volatiles associated with host selection, and beetle pheromones have not been conclusive, but baseline data are available and will be used for further research. Other potential mortality influences/agents include stand and tree conditions associated with differentially infested trees, occurrence of *Armillaria* root disease (*Armillaria* spp.) and presence of black carpenter ants [*Camponotus pennsylvanicus* DeGeer (Hymenoptera: Formicidae)].

Project SO-EM-04-02: Assessing the Extent and Severity of Oak Decline in an Ozark Mountain Watershed—Beginning in 1999, oak decline in the Ozark Mountains of northern Arkansas and southern Missouri resulted in high mortality of red oaks, primarily northern red oak, black oak, and southern red oak (*Q. falcata* Michx. var. *falcata*). Factors associated with this decline included a preponderance of mature and susceptible red oaks (predisposing factor); a regional drought from 1998 to 2000 (inciting factor); and a large increase in the population of red oak borer, a native wood-boring insect (contributing factor). Field observations indicated red oak mortality was not uniformly distributed throughout the district. Instead, some stands were heavily damaged while others suffered little to no mortality.

In the summer of 2006, a study was installed on the most heavily affected region in the Boston Mountains subsection of the Ozark Mountains in northwest Arkansas. It was thought that the most heavily infested stands would be relatively old and highly dense on low site indices and steep slopes, but this was not the case. Although severely damaged stands occurred most frequently on southerly-facing aspects and upper slopes,

so did stands with low damage. This study suggests there is little evidence that red oak stands severely damaged by oak decline are older, denser, or grow on poorer sites than stands with lower levels of damage. Although the severely damaged stands in the study grew on relatively xeric sites, not all xeric sites are associated with moderate or high levels of oak decline. Other factors, such as crown position or species composition, are also important determinants for predicting oak decline.

In the severely impacted stands in the study, red oak was more affected than white oak. Other studies of this decline and previous declines also reported a greater susceptibility of red oak to decline (Starkey and Oak 1989, Stringer and others 1989, Kabrick and others 2004). The reduction in red oak has shifted these formerly red oak-dominated stands toward a more mixed assemblage of white oak, hickory (*Carya* spp.), red oak, blackgum (*Nyssa sylvatica* Marsh. var. *sylvatica*), and red maple (*Acer rubrum* L.). Given the complex species composition and densities of understory trees and seedlings and the relatively short time since the stands were disturbed, it is difficult to predict whether decline-associated mortality will stimulate oak regeneration or accelerate a transition to nonoak forest types. Long-term monitoring of regeneration is needed to determine if and how decline is influencing the development of a new age class.

Project SO-EM-04-03: Development of Geospatial Techniques for Prediction and Assessment of Red Oak Decline Due to Red Oak Borer—Research under this monitoring project and others shows that, from 1940 until 1992, red oak borer populations were present in red oak trees at consistently low levels. The current outbreak on the Ozark National Forest appears to have begun in 1994 and then peaked in 2000 and 2002, when population levels reached more than 100 times higher than that of the beginning of the outbreak. Populations began to crash in 2004 and are now nearly as low as they were in 1994 at the beginning of the outbreak. We are not certain that the outbreak is over, but it now appears that this is the case.

Throughout the forests and among the different oak species, northern red oaks experienced the greatest mortality and that mortality was higher in dense stands on ridges than on north-, east-, west-, and south-facing benches or in forests with lower densities of northern red oak. Red oak borer populations were also highest on ridges.

Work under this project demonstrated that adult red oak borers fly over a period of approximately 6 weeks from late June through early August in odd-numbered years only, and that adult beetles fly near the tree canopy rather than close to the ground. Analysis of bark and phloem tissues was conducted

to analyze northern red oak chemical defense mechanisms against red oak borer invasion, and no difference was observed between healthy and unhealthy trees. When wounded, however, healthy trees were able to recover faster than unhealthy trees and thus may better tolerate invasion.

Because the immature stages of these beetles have few distinguishing physical features, molecular techniques were developed to identify red oak borer larvae. The principal investigator and associates also developed molecular methods to survey for *Armillaria spp.*, root rot fungi thought to be additional potential contributors to oak mortality, and determined that three species of these root decay pathogens are present in the Ozarks, the first confirmation of this fact. It is not yet clear whether the presence of *Armillaria spp.* is significant in relation to tree mortality and the red oak borer outbreak.

This research confirmed that the ubiquitous black carpenter ants common throughout the Ozark and Ouachita Highlands forests will eat red oak borer eggs and small larvae, and molecular techniques were used to confirm that, even when populations of red oak borer were very low, these ants were finding and eating them.

Finally, in conjunction with other research projects funded by State and Private Forestry and the Southern Research Station, the principal investigator and colleagues have begun to develop GIS-based hazard models to help predict forest conditions most susceptible to future red oak borer outbreaks.

Project NE-F-01-06: Evaluating Forest Health and Fire History of Ozark Oak Forests—Repeated oak decline and mortality events have occurred in the Missouri Ozark region for decades and probably longer. In work under this monitoring project, a pulse of mortality was reported immediately subsequent to the most recent drought, although decline often started decades previously. Decline appeared to be incited by one or two drought-related step-changes in growth and variance. For example, data indicate that a large increase in the frequency of borer wounds occurred in the mid- to late 1970s, preceding a prominent drought in the early 1980s.

Surviving oaks growing in high-mortality stands had poorer crown conditions and grew more slowly than trees in low-mortality stands. When recently dead trees were accounted for, the same high-mortality stands had significantly greater predecline basal area and stocking than low-mortality stands. Thus, a less competitive growth environment may afford some buffer to drought stress before oak decline but does not appear to help afflicted stands improve their growth and vigor. Correlation analyses indicate that temperature, ring width, and stand age were most strongly related to the frequency of borer attacks.

Research under this project also showed that increases in minimum temperature are strongly related to the frequency of red oak borer wounds. This is important because mean minimum monthly temperatures play a role in controlling the range of species (as illustrated in the U.S. Department of Agriculture Plant Hardiness Zone mapping), and have also been hypothesized as a significant effect likely to occur under climate change. Although the magnitude of increase in mean maximum temperatures has been modest in the Missouri Ozarks, the change in mean minimum temperature has been much larger. In the region of the case study, minimum temperatures have increased about 2.8 °F (1.5 °C) since the 1960s. Minimum temperatures could be most limiting to borer development, growth, reproduction, and fecundity (Galford 1974). Further research will provide greater information about these and other factors that may ultimately assist in developing predictive models and influence management activity.

Summary of key findings—

- The red oak borer outbreak in the Interior Highlands of Arkansas, Oklahoma, and Missouri began in earnest in the mid-1990s, with several insect generations emerging before coming to the attention of land managers. The underlying reason for the increase is not yet clear.
- By 2005, red oak borer populations had apparently returned to endemic levels. The underlying reason for the population decrease is also not clear.
- Factors positively correlated to oak decline include lower crown class, smaller d.b.h., and a high degree of competition from neighboring trees that reflects incipient density-dependent mortality, expressed either as stagnation from trees of similar size or suppression from larger trees.
- Drought was a major determinant of oak decline and mortality regionally. Drought condition from May to October (growing season) of both the current and previous years contributed to oak decline and mortality. Oak mortality during decline events was mainly related to crown width and dieback but also to the number of oak borer emergence holes.
- The current oak decline/red oak borer event is widespread and appears to be distributed across the range of the Interior Highlands. Unhealthy red oaks are found in roughly similar proportions in each of the three States, comprising 22 to 36 percent of stem density and 24 to 31 percent of basal area of the red oak group. White oaks have also been affected but at levels roughly one-third that of red oaks in each State.

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- Ground truth assessments show that unhealthy white oaks occurred disproportionately in either the smaller or larger diameter classes, whereas unhealthy red oaks were relatively uniformly distributed in roughly equal proportions across the diameter distribution.
- Field observations in the Interior Highlands indicated that oak decline seemed to be most severe on ridgetops and xeric aspects, but not all forests on ridgetops and xeric aspects were in decline. Thus, severity of the current oak decline in the Interior Highlands is influenced by a combination of individual tree, stand, and site variables.
- Multiple prescribed fires in Missouri oak stands significantly reduced stem basal area in the mid- and understory compared to the “one fire” treatment but had no effect on overstory stem density. Thus, prescribed burns gradually change not only forest size structure but also species composition, especially in the lower canopy strata.
- Red oak mortality in declining stands in Missouri is more prevalent on droughty and nutrient-deficient sites because red oak group species are more abundant there. Droughty and nutrient-deficient site conditions most likely favored the establishment and growth of red oaks following the extensive logging during the early 1900s.
- The extensive oak decline occurring on droughty and nutrient-deficient soils today appears to be due to the high abundance of mature red oak group species on these sites. These findings suggest that high-risk stands are those where mature red oaks are most abundant, regardless of site conditions.
- A rapid estimation procedure has been developed for red oak borer. It is an effective tool for classifying infestation history of northern red oaks under outbreak conditions with misclassification of < 15 percent of sampled trees.
- The red oak borer outbreak of 1999-2005 exceeded all historical records. Counts of current generation borers per tree during this outbreak (> 75) exceeded previous reports (approximately 1.5) by nearly two orders of magnitude, and attacks per tree in this outbreak (> 2,000) exceeded previous reports (~3) by two and a half orders of magnitude.
- Molecular diagnostics, with polymerase chain reaction-restriction fragment length polymorphism (PCR-RFLP), were successfully used to distinguish red oak borer from other closely related species of cerambycids during all life stages.
- Although the primary food of red oak borer is red oak phloem and xylem, experiments showed that red oak borer will exhibit cannibalistic behavior under laboratory conditions. Cannibalistic behavior has been reported among other cerambycids.
- In the Boston Mountains of Arkansas, stands in the throes of decline and mortality are changing from formerly red oak-dominated stands toward a more mixed assemblage of white oak, hickory, red oak, blackgum, and red maple. It remains unclear whether oaks will compete successfully for these resources and eventually replace dead oaks in upper canopy positions.
- In the Boston Mountains of Arkansas, stands affected by decline and mortality are in the midst of a change in regeneration dynamics. On the one hand, smaller oaks are greatly outnumbered by faster growing species, such as blackgum, red maple, and black cherry. On the other, oak sapling abundance on these poor sites exceeds that suggested for regenerating oaks under clearcutting. Long-term monitoring of regeneration will be needed to determine if and how the sapling cohort of oaks succeeds to the midstory and overstory.
- Cumulative indices of red oak borer degrade indicate that stand devaluation often begins one to two or more decades before typical rotation lengths of 65 to 85 years. Also, this devaluation often goes unnoticed until cutting begins. These data underscore the need to consider insect damage in infested stands when determining optimal rotation length.
- Data suggest that lower stand densities maintained through early and repeated thinning may help some stands from experiencing undue drought stress and decline. In addition, any shift away from red oak dominance will be sure to incur fewer oak decline-related losses. This is a preliminary hypothesis and is yet to be experimentally tested.

Utilization of project results—There are three primary user groups taking advantage of the EM work for oak decline funded over the past decade under the FHM program.

Federal agency land managers in the Interior Highlands have been key users of this information. Work funded at the height of the outbreak was instrumental in helping the Ouachita, Ozark-St. Francis, and Mark Twain National Forests decide how extensive the problem was, which areas were most severely affected, and how to prioritize funds for control and salvage efforts in stands affected by the decline event generally and red oak borer in particular. These decisions affected the expenditure of millions of dollars of national forest management appropriations on thousands of acres of national forest land in the three States.

State agencies and private landowners have also reaped the benefits of this work. Early in the outbreak, hysteria about the demise of oaks throughout the region was especially pronounced among nonindustrial private forest landowners. There is no way to estimate how many landowners liquidated oaks or sold oaks prematurely from their property under the advice of loggers warning that their oaks were doomed. Scientists involved with these EM projects conducted special training sessions for State forestry professionals, advising them through a continuing education and field tour format on state-of-the-art findings about oak decline and red oak borer. The scientists involved with the EM projects developed an extensive array of facts, informed opinions, dedicated Web sites, and subjective decision models devoted to silvicultural alternatives for stands threatened by oak decline and red oak borer. These tools gave the State resource managers a factual basis upon which to advise landowners based on best available science rather than hysterical overreaction. Some landowners still decided to harvest their oaks, but they did so as part of an informed decision under the guidance of county service foresters and forestry consultants rather than in response to a logger dropping cash on the kitchen table.

The resource management profession was a primary beneficiary of these EM projects. Some two dozen graduate and doctoral research projects were funded under this program at the University of Arkansas, the University of Missouri, and the Arkansas Forest Resources Center at the University of Arkansas in Monticello, AR. Many of these graduates went on to university faculty positions, jobs with non-governmental organizations devoted to conservation, and employment with State and Federal land management agencies, including the FHP program. With the forest science profession concerned about maintaining competence in light of a retiring old guard and insufficient funds for a new guard, these projects went a long way to place qualified young professionals on the front lines of future forest health issues, both in research and in management.

Finally, the scientific community also received substantial benefit from these projects. This is not so much with respect to oak decline per se, which remains a complicated and elusive forest health concern. But rather, this unprecedented outbreak of the red oak borer spurred a multitude of interrelated studies that have advanced our scientific understanding of the insect far beyond that which was known at the turn of the century. The initial triggering mechanism for the red oak borer outbreak, and the sudden collapse of it, remain a mystery. But the scientific literature pertaining to this particular insect has been advanced substantially through the hard work of scientists and students in elucidating the underlying biology and ecological dynamics of this Cerambycid beetle.

Suggestions for further investigation—

- Continue to monitor the correlative relationship between oak decline and associated insect and disease pests such as the Cerambycid beetles, *Armillaria* root rot fungi, and other insects and diseases as they arise.
- Continue to study the historic occurrence of red oak borer from 1997 to 2005 as well as earlier, and test alternative hypotheses on population expansion and reduction of the most recent red oak borer infestation in the Interior Highlands.
- Study the effects of oak woodland restoration, including overstory thinning, midstory reduction or removal, and repeated prescribed burning, on oak decline and incidence of the associated complex of insects and pathogens found in these stands.
- Work is needed to quantify the effects of climatic factors, especially drought and climate change, that predispose forest stands and trees to the associated complex of insects and pathogens in oak ecosystems.
- Continue the biennial monitoring of red oak borer populations, and respond to observed increases with not only continued monitoring of ecophysiological conditions within individual trees but also cumulative ecological effects within and among stands.
- Monitor regeneration dynamics in oak stands in Arkansas and Missouri that suffered significant overstory mortality in the 1997-2005 red oak borer outbreak, to quantify the species composition and dominance probability of red and white oaks relative to non-oak pines and hardwoods in the new regeneration cohort occupying these disturbed stands.
- Develop and test chemical attractants to permit monitoring of native and invasive insect populations in oak-hickory and oak-pine ecosystems.
- Define chemical and physical tree defense mechanisms against stem invasion by common insect pests in oak ecosystems.
- Gain knowledge on the natural enemies and abiotic agents that normally keep native insects such as red oak borer at endemic levels.
- Quantify the prevalence of different species of *Armillaria* on red and white oaks in the Interior Highlands, and estimate the pathogenicity of the various species on different sites in the context of oak decline.

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- Expand on the interesting concept of molecular diagnostics in the entomological food web on upland oak ecosystems
- Expand the relationships of oak decline and the factors that contribute to oak decline under silvicultural practices designed for ecosystem restoration, specifically including oak and oak-pine woodland restoration involving prescribed burning.
- Refine GIS-based hazard and risk modeling for oak decline in the Ozark and Ouachita Highlands.
- Continue research on stand reconstruction to better quantify the historic population of red oak borer across a range of sites having varying hazard for red oak borer incidence.
- Quantify whether simple reductions in oak stocking can reduce hazard of oak decline.
- Develop a broad network of intensive oak monitoring sites upon which fundamental meteorological measurements can be regularly collected, the better to answer questions about observed insect and disease conditions in oak-dominated forest ecosystems in light of observed changes in climatic conditions.
- Develop state-of-the-art public GIS capability to have information about oak decline and oak ecosystem productivity and health available to the public on a georeferenced landscape.
- Develop silvicultural decision support models to optimize stand resistance and/or resilience to any suspected adverse influence on forest health, diversity, productivity, and sustainability in Interior Highlands oak-dominated ecosystems.

Project on Loblolly Pine Decline

Loblolly pine (*Pinus taeda* L.) is a common species found in upland sites in central Alabama that has been declining since 1960. The decline condition was initially referred to as “loblolly pine die-off,” and was most frequent in sawtimber-size trees over 50 years old (Hess and others 2002a, 2002b). During the 1960s and 1970s, studies were initiated to determine the cause of the die-off and the rate of spread. Soil and root samples were analyzed for the presence of root pathogens including *Phytophthora cinnamomi*, a primary factor in the development of littleleaf disease. There was some recovery of *P. cinnamomi* from the decline plots, but it was reported that root system deterioration of the die-off trees was more extensive than that found in littleleaf diseased

trees (Brown and McDowell 1968). Although a specific cause was not determined, further investigation was warranted. To determine the correlation between reduced growth and its possible connection to *P. cinnamomi* and a *Leptographium* spp. in decline, FHM standards and protocols with root health evaluations relative to the crown, stem, and site measurements were studied. This EM project was funded in 2000.

Project SO-EM-00-02: Assessment of Loblolly Pine Decline—

The evaluation of site variables, including soil classification, bulk density, soil porosity and moisture capacity, and soil nutrient analysis, was thought to be a key to assessing the influence of soil and root pathogens recovered from these sites and their relationship to crown characteristics of symptomatic loblolly pines. The results of this preliminary study indicate:

1. On public lands, damage and mortality increase with age of the stands, especially after age 40.
2. Loblolly pine decline symptoms are the same as littleleaf disease of shortleaf pine (*Pinus echinata* Mill.), and preliminary results of our evaluation show a correlation between reduced radial growth, reduced basal area, declining crowns, root damage, and recovery of *P. cinnamomi* and *Leptographium* spp.
3. Loblolly pine decline is prevalent on sites within the historic range of littleleaf disease and is associated with sites and soils other than the heavy clay soils of the Piedmont Province.

Utilization of project results—

- Damage and mortality increases with age of the stands. Suggested management might include conducting precommercial thinning to improve growth of remaining trees. It might be appropriate to consider reduced rotation ages on some sites as well.
- Consider management for other pines or hardwoods instead of loblolly, especially in areas that have historically been impacted by littleleaf disease.

Suggestions for further investigation—

- Investigate how edaphic factors such as soil classification, bulk density analyses, and soil porosity play into declines in central Alabama.
- Determine if these soil variables could be incorporated into or linked to an overall analysis of management regimes and root pathogen

Project on Dogwood Anthracnose

Since its discovery in the late 1970s, *Discula destructiva*, the causal agent of dogwood anthracnose (Redlin 1991), has produced severe impacts to flowering dogwood (*Cornus florida* L.). However, researchers began documenting reduced disease severity as early as 1988. Disease progression of dogwood anthracnose is known to be affected by various physiological and physiographic factors, such as drought stress, light level, crown exposure, host density, topography, and timber harvesting practice (Daughtrey and others 1996). Most of the mortality has been on high elevation, moist and humid sites. Elevations of 3,000 to 5,000 feet (914 to 1529 m) are considered most at risk, as are north-facing slopes and sites within 100 feet (30 m) of water under a full forest canopy. In 2005, EM work was undertaken to use data from the FHM program and from the Forest Inventory and Analysis (FIA) Program of the Forest Service to predict dogwood occurrence based on the development of a hazard risk rating system using many of these factors. The goal of the work was to link three databases in order to establish on a regional scale the effects of dogwood anthracnose after approximately 25 years since its discovery, and from the process, to develop new guidelines for disease management. The project found, through use of FIA/FHM data, the occurrence of significant differences in relation to current and past conditions in the population structures of flowering dogwoods.

Project SO-EM-05-01: Validation of FIA/FHM Data for Predicting Dogwood Occurrence in Conjunction with a Dogwood Anthracnose Hazard Risk Rating System—Over the past 20 years, flowering dogwood populations have been reduced by approximately 50 percent, in stark contrast to early predictions of 90 to 100 percent. Analysis of the FIA data indicated that slope and increasing percent openness of canopy cover explained a significant portion of where dogwoods occur. This analysis corresponded with results from transects that showed most of the dogwoods occurred in proximity to crown openings. By mining the three databases, researchers found that, across its natural range, flowering dogwood growth habits have been significantly impacted. Shifts were seen from a small tree that thrived in shade-conditions to an impaired, short-lived tree found only in close relation to a significant canopy opening(s). Though incomplete, this project is already yielding novel findings relating to current and past conditions on the population structures of flowering dogwood.

Utilization of project results—Has application toward ongoing FHM risk mapping efforts in providing some justification for the goodness-of-fit in models on dogwood anthracnose.

Suggestions for further investigation—

- Determine if the observed trends will amount to further reductions and increased mortality during favorable climates for the disease.
- Investigate whether FIA data can be used to meaningfully predict changes in dogwood prevalence using risk based analysis.

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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 km²) 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 m²) 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 m²) each] in mixed evergreen forests across a 106-square-mile (275 km²) area in Sonoma County; and by Phytosphere Research, approximately 400 plots [239 square yards (200 m²) 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

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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

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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.

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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

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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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CHAPTER 11

Invasive Plants

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The national Forest Health Monitoring (FHM) Program of the Forest Service, U.S. Department of Agriculture, funded six Evaluation Monitoring (EM) projects on invasive plants. The projects belong to one of two broad groups: the effects of management actions on the distribution of invasive plants, and investigating the use of remote sensing or existing data from the Forest Inventory and Analysis (FIA) Program of the Forest Service or from local inventory as a means of gathering distribution or inventory information on invasive plant species.

Critical to the successful management of invasive plants is determining a baseline of existing infestation levels, understanding how management activities can influence the spread of invasives, and early detection and rapid response. The first three of the six FHM projects on invasive plants deal with management effects, specifically management associated with fire use or fire suppression, and look at the utility of existing inventory systems to assist in invasive plant inventory and population change. A fourth project investigates a method of aerial remote sensing techniques to determine the location and extent of annual invasive grasses in Hawaii, with the goal of providing land managers with a risk map of especially fire prone areas. A fifth project uses FIA data to predict vulnerability to successful invasion by exotic plant species on the Allegheny National Forest. The last project, based in Virginia and North Carolina, uses survey data to determine why some invasive plant species are more likely than others to move off roadsides into the interior forest lands adjacent to the roads.

Project INT-F-04-01: Understanding the Effects of Fire Management Practices on Forest Health: Implications for Weeds and Vegetation Structure

There were two primary objectives of this study. The first objective was to determine whether certain fire management tactics (e.g., fireline construction, spike camps, and helispots) increased short-term post-fire weed establishment as compared to burned areas in same fire.

The second primary objective was to determine whether the intensity of fire suppression tactics (from wildland fire use through containment to suppression) would cause long-term differences in post-fire patterns in vegetation structure. This was to be accomplished through the comparison of actively suppressed fires, contained fires, and wildland fire use fires. The authors intended to test two hypotheses: (1) that suppressed fires have a simpler shape than natural fires; and (2) that there is less internal heterogeneity in suppressed fires than in natural fires. Simpler landscape shapes could provide a more conducive environment for future forest health issues through large-scale heterogeneity. Less internal heterogeneity within fire areas could result in more invasive plants as a result of increased areas of suitable seedbed and less vegetative competition over a larger area.

Another objective was to assess the opportunity to use FIA data and more-intensive, locally collected data to assist in monitoring these effects. Invasive plant data collected from existing FIA survey methods was compared to a more intensive survey method incorporating linear transects using the same plot center. The intent was to determine whether the FIA method or the more intensive method would be more accurate in locating invasive plant species. It was determined that neither method was more accurate overall and that neither method detected all species of invasive plants known to be present. When topographic variation was higher, the linear transects showed an improved ability to detect invasive plant species. Current landscape sampling methods, such as those by FIA, that use widely spaced plot designs are useful for landscape vegetation sampling but are not of fine enough scale to resolve the heterogeneous distribution of many invasive plant occurrences.

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Other Biotic Stresses and Indicators

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The study showed that different fire management tactics increase short-term post-fire weed establishment. Fire suppression activities that disturb the ground increase the risk of invasive plant spread. Firelines have more invasive species than surrounding burned areas. Handlines had more occurrences of invasive plants at the beginning of the handline. This increase was most notable near the “anchor-point” (where the handline is anchored to another feature that prevents fire movement), most likely because of the proximity of this location to previously disturbed areas. Over time, the handline may serve as a corridor for the dispersal and establishment of nonnative invasive plants as they move along the length of the handline. Firefighter spike camps had more invasive plant species and more occurrences than the surrounding areas. Fewer nonnative plants were detected on bulldozer lines as compared to handlines, but there were more than in control areas.

The portion of the study that was to determine whether actively suppressed fires would cause landscape-level effects different than wildland use fires or containment fires was hampered by the lack of consistent datasets involving fire perimeter shape and location. Fire perimeter data were inconsistently developed, missing, were not digitized, or did not reflect final fire shape and size. The authors settled on the use of Burned Area Rehabilitation Classification maps developed by the Remote Sensing and Applications Center because they are developed using a consistent methodology. Due to missing data, only fires from 2003 and 2005 were sampled. There were no significant differences found between suppressed and wildland fire use fires, i.e., perimeters were not more simplified in suppressed fires. There was a correlation between the size of the fire and the complexity of the fire shape; the larger the fire, the more complex the shape, regardless of management method. As to the question of whether suppressed fires resulted in less internal heterogeneity, the study could not answer this conclusively. It appeared that wildland fire use fires had more internal heterogeneity, but this difference was lost as fire size increased or if individual fire years were considered.

Project Number: WC-F-05-02: Ecological Impacts of Invasive Species After Fire

This study was intended to inventory and record new noxious weed populations associated with disturbance caused by wildland fires and associated activities, focusing on high disturbance areas such as heliports, staging areas, firelines, and travel routes. The study focused on the bluebunch wheatgrass and Idaho fescue plant communities on the Wallowa-Whitman National Forest. The study was to determine the extent and severity of noxious weed sites in

relation to extent and severity of fire. Finally, the study was to compare new data to existing data of known sites and survey plots—a local current vegetation survey (CVS).

Monitoring began on the Tryon Fire Complex immediately after it burned in 2005 and continued twice a year for 2 more years (2006 and 2007). The study could not use the grid-established CVS plot data for monitoring invasive plants as these particular species were not included in the data collection and the grid-based design was not conducive to sampling invasive plants. One of the results of this study was a modification of local CVS plot procedures to include invasive plant species. The initial CVS plots were revisited and invasive plant information was recorded and additional weed monitoring plots were established using a combination of transects and 100 percent sampling circular plots within the Tryon Complex, centered on known invasive plant populations. There was an increase in both the number of invasive plant species and the percent cover of these species in the Tryon Fire Complex as a result of the fire.

Project Number: WC-F-06-06: Ecological Impacts of Invasive Species After Fire

This project is a follow-up to WC-F-05-02. Using plots established in the previous project within the 2005 Tryon Complex, the intent was to (1) determine the extent and the direction of spread of known noxious weed sites located within the Tryon Complex fire perimeters; (2) survey for new noxious weed sites within 2005 fire perimeters; (3) evaluate the relationship between weed response and fire intensity/severity; (4) monitor CVS plots within the Tryon Complex fire perimeters for noxious weeds; and, (5) monitor for survival of biological agents released within the area but prior to 2005 fires.

The invasive plant monitoring plots and the CVS plots demonstrated that there was an overall increase in weed densities within the plots during the initial green-up stage following a fire. Fires of low to medium severity, such as the fires monitored in this study, result in the removal of approximately 95 percent of the aboveground vegetation, but do not harm underground root or seed banks of existing vegetation. Invasive plants are the first to take advantage of the exposed surface, enhanced nutrients, and increased light that result from fire and thus increase seed germination. The study concluded that treatment of weeds during the initial green-up stage after a fire is essential, as it provides excellent visibility of invasive species and increased treatment efficiency. Invasive plants were found to have an accelerated rate of spread post-fire. This is likely due to the removal of competing vegetation. The original objectives of determining responses of invasive plants to fire were not discussed in the conclusions, probably because the

invasive plants found during these post-fire surveys were treated with herbicides about a year after the fire, in September 2006. The herbicide treatments resulted in a decrease in invasive plants 2 years post fire and subsequent successful restoration of native bunchgrasses. Monitoring of biological agents concluded that stem weevils on Dalmatian toadflax and seed feeders on yellow starthistle can survive late summer, low severity burns that move quickly through grasslands, but numbers may be significantly reduced. Therefore, biological treatment effectiveness is initially reduced as a result of fire.

Project WC-F-01-06: Evaluating Fire Fuel Loads for Nonnative Grasses in Hawaii from Hyperspectral Reflectance Data

The natural fire regime in Hawaii has been altered markedly by the rapid spread of alien grasses. The disturbance of alien grasslands and adjacent forests by fire often encourages invasions of additional introduced plants. The intent of this project was to develop a remote sensing methodology capable of quantifying the fire fuel load of nonnative fine fuels (grasses) that threaten forest health in Hawaii. This would be accomplished through a combination of vegetation analysis, imaging spectroscopy, and radiative inverse transfer modeling techniques. If successful, the same techniques could be applied to airborne imaging spectrometer data collected over the entire Hawaiian archipelago to map both the spatial extent of dry vegetation cover and the biomass density of these fuels.

The study documents an automated method of analyzing high-altitude aerial spectral imagery to determine the percent cover of photosynthetic (PV) and non-photosynthetic (NPV) vegetation and bare ground in a cross-section of habitat types on the island of Hawaii. Field analysis determined that NPV is primarily made up of senescent nonnative grasses; therefore, for this study's objective, the determination of NPV is critical, as these areas would be considered fire prone and are often adjacent to native woodlands.

An important initial step in the project involved the analysis of reflectance spectra data to determine the unique wavelength indicators for PV, NPV, and bare ground. Once the digital signature of these three classes was determined, imagery representing a cross section of rainfall, elevation, and vegetation types was analyzed to determine the relative amounts of PV, NPV, and bare ground. This remotely sensed data was then field verified through vegetation transects. The resulting correlations between field measurements and remote measurements were very high (all three classifications had correlation coefficients ≥ 0.89).

The percentage of NPV peaked in the subtropical dry and thorn forest and lower montane thorn steppe life zones. The subtropical systems had particularly high percentages of NPV and also low levels of bare ground, suggesting these areas may be fire prone, as the data suggest a high cover of dry grass with little to stop a fire. In contrast, the upper montane moist and wet forests had high NPV values (30 to 42 percent) but also high bare ground cover, indicating an open, depauperate structure with a lower fire risk. When combined with precipitation data, NPV cover was consistently high when the mean annual precipitation was less than 59 inches (1 500 mm). In the range of mean annual precipitation between 29.5 to 39.4 inches per year (750 to 1 000 mm/year), the combination of low levels of bare ground (15 to 26 percent) combined with high levels of NPV (49 to 55 percent) would indicate the most fire prone areas, and the areas that should be the focus for land managers.

The authors conclude that this method of remote sensing allowed for high precision estimates of live and senescent vegetation and bare ground, and was as accurate as more expensive field surveys. Unique combinations of PV, NPV, and bare ground quantify fundamental differences in ecosystem structure.

Project NE-EM-05-01: Evaluating Environmental and Disturbance Conditions Associated with Invasive Plants Using the Allegheny National Forest Intensive Plot Data

This project was designed to evaluate the applicability of using FIA data to predict vulnerability of the Allegheny National Forest to successful invasion by exotic plants, then to develop a forest health indicator of potential invasion and test the indicator using other FHM data from Pennsylvania.

The project selected three types of variables: biotic, abiotic, and disturbance or landscape features related to disturbance. Seven biotic, ten abiotic, and nine disturbance variables were considered. Native species richness was the only important biotic variable for predicting the presence of invasive species; the presence of invasive species was more likely with high native species richness. Soil pH was the only abiotic factor showing any relationship to the presence of invasive exotic species, but the positive relationship between alkaline sites and the presence of invasive exotics was only marginally important and did not hold for all species evaluated. Stand age (younger stands were more likely to be invaded), the presence of nonforest land, and distance to the nearest exotic species planting were the only disturbance variables significantly associated with the presence of invasive exotic plant species.

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Combining all variable types with $p \leq 0.1$ and presence of invasive species as the response variable, native species richness, presence of nonforest land, and stand age were significantly associated with the presence of invasive species. This model was the strongest of all the combined models with an adjusted R^2 of 0.43.

Project SO-F-05-04: Locate, Map, and Establish Long-term Monitoring of Exotic Invasive Plant Species in the Southern Appalachian Mountains

This project started with previously collected survey data of nonnative invasive plants from alongside roads, railways, powerlines, and other right-of-ways (ROW) in three areas of the Southern Appalachian Mountains in Virginia and North Carolina. The study investigated (1) development of a consistent and reliable method to survey forest interiors once invasive plants were found along an adjacent ROW; (2) capability of the surveys to detect the movement of invasive plants off the ROWs; and (3) the biotic or abiotic factors most associated with successful invasions of these invasive plants into the interior forest.

The project utilized three types of surveys, called L1, L2, and L3 in this study. L1 surveys were uncontrolled ROW surveys that were linear in design and conducted by “citizen-scientists” and where the presence or absence of nonnative invasive species (NNIS) was recorded. L2 surveys were plots based on the occurrence of NNIS from the L1 surveys, and, combined with information about the individual NNIS, were located in forest interiors in areas where conditions would allow for the NNIS to exist. L3 surveys were based on FIA protocols (FIA version 4.0 field guide) and were to be used to determine rates of spread of NNIS; however, the study authors determined that the timeframe for measuring rate of spread using this method would be much longer than the study parameters, and, therefore, the authors did not complete this part of the study.

One of the more important findings of the study was that the number of NNIS found along ROWs was not indicative of NNIS in interior forests; relatively few of the species found in L1 surveys were detected in L2 surveys. Although the study determined that there were some broad similarities in the biotic/abiotic factors associated with NNIS presence, there was also high variability in these numbers. Overall, NNIS presence in interior forests was more commonly associated with mesic conditions and disturbed areas (e.g., old roads, alluvial fans, etc.).

Summary of Key Findings

- The number of species found during roadside surveys or surveys along other types of ROWs do not necessarily indicate that all of these species would be found within forested lands adjacent to the ROW.
- Grid-based circular sampling plots tend to detect more invasive plant occurrences when the terrain is more uniform, while a more intensive survey could better detect occurrences in more variable terrain. Often nonnative invasive plants, based on their sporadic distribution, cannot be detected well by either method. One of the challenges of inventory and early detection of invasive plants is the difficulty in finding the individual plants, especially when recently introduced, within the background of existing vegetation. Fixed plot designs or a more intensive project-level fixed plot method such as considered in INT-F-04-01 are not well designed to sample for non-continuous species distributions as are common with invasive plants. Intuitive surveys, such as the surveys conducted under SO-F-05-04, are better suited for early detection purposes.
- Aerial or satellite remote sensing may provide the invasive plant manager with a method of detection that is both quick and relatively inexpensive. However, remote sensing studies must resolve the unique characteristics of the invasive species against the existing vegetation; this can be a formidable challenge. The challenge is to find those characteristics of a plant species unique to that particular species and the environment it is in. New techniques must be developed for each environment and invasive plant species.
- In the Interior West, invasive plants show a quick positive response to fire, while native bunchgrasses do not respond as quickly. It appears that the rate of spread of invasive plants increases within the fire area when compared to unburned areas.
- Low- to medium-severity fires remove 95 percent of the aboveground vegetation but do not harm underground roots or seed banks of existing vegetation. Both invasive plants and native bunchgrasses reestablish after fire.
- Immediate survey and treatment of invasive plants after a fire, during the initial green-up stage, is critical to effective control and to the reestablishment of native bunchgrasses. These early surveys and treatments can eliminate the need for re-seeding of native bunchgrasses, assuming the native bunchgrasses made up a significant proportion of pre-fire vegetation (> 30 percent cover).

- Although invasive plant biological control agents may survive a fire, their numbers may be greatly reduced. Biological control effectiveness is therefore initially reduced after a fire.

Utilization of Project Results

- The study on hyperspectral imaging data being used to determine nonnative grass invasions in Hawaii (WC-F-01-06) has led to additional studies by the lead author and others in which the methods from the study were combined with newer Light Detection and Ranging (LiDAR) technology to further improve the remote sensing of invasive plants (Asner and others 2005, Elmore and others 2005, Varga and Asner 2008).
- The National Environmental Modeling and Analysis Center (NEMAC) at the University of North Carolina at Asheville is collaborating with the Eastern Forest Environmental Threat Assessment Center (EFETAC) of the Forest Service to develop Web-enabled tools in risk assessment and decision making processes. The results from project SO-F-05-04, which developed location information and abiotic/biotic factors affecting movement of invasive plants from ROW edges into interior forests, were used by these organizations to develop a risk model for interior forest invasion by Japanese stiltgrass in the Hot Springs area of the Pisgah National Forest in North Carolina.

Suggested Further Evaluation

- Further research to develop a statistically valid sampling design that incorporates a linear sampling component (“walking and observing”) that is both quick and inexpensive is needed if we want to be able to monitor the effectiveness of treatments or rates of spread.
- Continued research into remote sensing methodology that would allow for more efficient use of limited funding would be fruitful, although some priority of invasive species may be desirable. Other agencies and organizations are also doing work in this area; a review of existing studies should be done so that we do not duplicate efforts made elsewhere.

- Evaluate the applicability of remote sensing and GIS analysis methods such as kriging to supplant the tedious and expensive collection of field data for spatially heterogeneous variables such as the presence of invasive plant species in a variable landscape.
- There is an assumption that over time, as native vegetation is established in a fire area, the disturbed areas that provided an initial post-fire environment for invasion would become less hospitable to those invasive plants. Monitoring burned-over areas with similar fire intensity regimes over time would answer this question, and would be useful in determining whether these disturbed sites remain an invasive plant seed-source.
- The observation that handlines often had more invasives at the point where their construction began led to the conclusion that this was due to the anchoring points of these handlines being along roads, trails, or other disturbed areas, which provided a seed source. More intensive monitoring of these anchor sites and monitoring these handlines over a longer period may shed light on this hypothesis and determine whether existing plant occurrences or new sources (e.g., fire equipment) could be the cause.
- More studies that compare significant biotic, abiotic, and disturbance variables associated with native plants, exotic plants, and invasive exotic plants may help to determine if certain variables can be of general use in predicting risk of invasion or spread of invasive plant species.

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CHAPTER 12

Lichens

Sarah E. Jovan¹

The status of epiphytic (i.e., tree-dwelling) lichen communities is systematically tracked by the Forest Inventory and Analysis (FIA) and national Forest Health Monitoring (FHM) programs of the Forest Service, U.S. Department of Agriculture (<http://fia.fs.fed.us/lichen/default.asp>). Lichens are highly sensitive to climatic and chemical perturbations, and can be used for early detection of changes in climate and air quality (Jovan 2008). This forewarning gives land and air managers the opportunity to attempt mitigation before less sensitive organisms and ecosystem processes are affected. Monitoring to ensure maintenance of intact lichen communities likewise has direct consequence for forest health due to the ecological linkages of the lichen communities to other forest flora and fauna (<http://www.lichen.com/fauna.html>). Such linkages include provision of critical winter forage for ungulates, camouflaging nesting material for many species of bird and rodent, and fixation of atmospheric nitrogen (N) into a form useable by plants (Nash III 1996).

Several common pollutants affect lichens although relationships to sulfur dioxide (SO₂; Hawksworth and Rose 1970), N-containing pollutants (van Herk 1999, 2001; van Herk and others 2003), and acidic deposition (Gilbert 1986) are the best understood. Sensitivity to a particular pollutant is species-specific, and therefore, the better we understand responses of individual species, the more precisely we can use information on lichen distribution and abundance to map and quantitatively estimate air quality risks.

Core data of the FIA/FHM Lichen Communities Indicator are surveys of permanent 0.4 ha forested plots wherein the mixture and abundance of each species is recorded. Traditional Detection Monitoring (DM) activities for a particular region (e.g., a State or distinct ecoregion) involve analyzing these community data with a multivariate model. Large-scale assessments of air quality are produced (Jovan 2008), which often result in detection of one or more pollution hotspots (i.e., high risk areas) per region.

Both lichen projects—supported by Evaluation Monitoring (EM) funds through the FHM program—provide integral support for the air quality application of the FIA/FHM Lichen Communities Indicator. Controlled studies—such as those under the EM-funded project of Riddell and others (2008)—that link physiological response to pollutant dose are in short supply yet are among the most valuable research contributions in the field of lichen-air quality bioindication. The second EM-funded project by Petersen and Neitlich (2001) was an in-depth investigation of a pollution hotspot identified by DM activities in Colorado (McCune and others 1998). Smaller-scale inspection of such high-risk areas is essential to a thorough forest health inventory.

Project WC-EM-07-05: Improving the Interpretation of Lichen Biomonitoring for Nitric Acid and Ozone Air Pollution in the Detection Monitoring Program

Riddell and others (2008) measure the physiological effects of a highly phytotoxic vapor found in photochemical smog, nitric acid (HNO₃), on pollution-sensitive lichen. Scientists recently discovered the predominance of HNO₃ in the Los Angeles Basin where arid forest ecosystems receive exceptionally high N loading. Growing anecdotal evidence suggests HNO₃ has played a large role in degradation of lichen communities in the basin, which experienced a 50 percent loss in species since the flora was characterized at the end of the 19th century (Riddell and others 2008). Until recently, this role was attributed to ozone (O₃).

The research of Riddell and others (2008) is the first to measure experimentally the physiological effects of HNO₃ on lichens and demonstrate the high toxicity of HNO₃. Results directly inform nascent DM activities of the FIA/FHM Lichen Communities Indicator in southern California (due for publication in 2011). Results likewise provide an essential empirical basis for determining a HNO₃ critical load for lichens. Critical loads are pollutant loading thresholds below which sensitive species, like lichens, are unharmed; information about these loads increasingly is sought by policymakers for establishing air quality guidelines that preserve ecosystem integrity (Fenn and others 2008, Porter and others 2005).

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Transplants of the lichen *Ramalina menziesii* were subjected to month-long fumigations in growth chambers. This formerly abundant species is now nearly extinct in the Los Angeles Basin. Besides in controls, nitric acid levels were varied in each chamber over 24 hours to simulate daily fluctuations experienced in the basin. Thus, each nitric acid treatment is described by a concentration range; chambers received dosages ranging from 7-25 $\mu\text{g m}^{-3}$ to 26.4-35.3 $\mu\text{g m}^{-3}$, resembling moderate to high concentrations. Potential interactive effects of climate also were tested by simulating humid conditions in some chambers and dry conditions in others.

Results were dramatic. Photosynthetic ability was swiftly impaired in all lichens treated with HNO_3 as indicated by decreased chlorophyll content and carbon exchange capacity. Thalli became bleached. By about 28 days, both photosynthesis and respiration were arrested to near zero in lichens exposed to even the lowest HNO_3 dose. When rinsed, fumigated lichens became increasingly “leaky” over time, meaning their cells lost ions due to damage at the cell membrane. Riddell and others (2008) further demonstrated that HNO_3 toxicity seems more acute under dry conditions, a result that is particularly notable for the FIA/FHM Lichen Communities Indicator and associated critical load research.

Work on this project continues. For the second phase, investigators conducted a field study in summer 2009 to link lichen community composition to N measurements in the LA Basin (estimated completion: 2011); a main objective is to describe ecological effects of N and, if possible, parse out the influence of HNO_3 on community structure. Also under way is a second round of fumigations to determine if O_3 levels affect how HNO_3 affects lichen physiology and survivorship (estimated for completion in 2011).

Project INT-EM-99-01: Impacts of Two Coal-fired Power Plants on Lichen Communities in Northwestern Colorado

Peterson and Neitlich’s (2001) EM-funded project was a follow-up to DM efforts in Colorado. McCune and others (1998) used survey data from the FIA/FHM Lichen Communities Indicator ($n = 185$ plots) to summarize large-scale air quality patterns across Colorado. They identified the Steamboat Springs area of the Park Range as a potential pollution hotspot based on composition of the lichen communities there. Other lines of evidence specifically pointed to an SO_2 problem, as follows: (1) the Steamboat Springs area lies downwind of two coal-fired power plants in Yampa Valley, (2) high S was detected in lichen material collected from nearby Mt. Zirkel wilderness (Jackson and others 1996), and (3) relatively high nitrate and sulfate

deposition (for rural Colorado) was measured by National Atmospheric Deposition Program monitors.

Peterson and Neitlich surveyed lichens at additional plots ($n = 35$, a 7x intensification of the FIA/FHM inventory grid) in the problem region, roughly defined as the western and upper eastern slopes of the Park Range. Upon closer inspection, no unequivocal statistical evidence of pollution damage was uncovered. Major patterns in community structure were closely patterned on topographic gradients—which is not to say lichens were unaffected by air quality but it suggests that pollution effects are not acute.

Evidence of pollution impact was subtle, suggested by the negative correlation of a highly pollution sensitive species, *Bryoria fuscescens*, with proximity to the pollution point sources. Loss of *Bryoria* species is ecologically damaging due to their use by wildlife for forage and nesting material. Fortunately, stricter emissions controls were implemented around the time of this study in response to evidence of ecological damage in Mt. Zirkel. Thus, pollution stress should lessen, and *Bryoria* may be able to recolonize any habitats in which it was extirpated.

Relevance to Policy and Land Managers

The keystone work of Riddell and others (2008) on HNO_3 critical loads made a significant contribution to efforts of the Environmental Protection Agency to set a secondary standard for nitrogen oxides; their study was heavily cited in HNO_3 -focused parts of the Integrated Science Assessment (EPA 2008). The work of Peterson and Neitlich (2001) helped land managers assess whether Air Quality Related Values (AQRV) (i.e., pollution-sensitive resources) are being degraded in the Colorado Park Range. Managers are required by the Federal Clean Air Act to protect AQRVs in Mandatory Class I Federal areas, which include wilderness areas like Mt. Zirkel that exceed 5,000 acres in size.

Suggestions for Further Investigation

Any experimental investigation of the tolerances of individual lichen species to particular pollutants would be invaluable, as would experimental and observational studies that identify lichen critical loads for regions besides the well-studied Pacific Northwest. Moreover, the usefulness of the FIA/FHM Lichen Communities Indicator for monitoring climate change has been largely ignored in favor of air quality applications. At this early stage, we need more foundational work that elucidates reliable lichen indicator species of temperature and moisture shifts.

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CHAPTER 13

Tree Crown Condition

William A. Bechtold¹

The crown-condition indicator was originally developed in 1990 to monitor tree crown health. The indicator presently consists of seven “absolute” variables recorded in the field (sapling vigor class, uncompacted live crown ratio, crown light exposure, crown position, crown density, foliage transparency, and crown dieback), and four “composite” variables formulated from multiple crown dimensions (crown volume, crown surface area, crown shape, and crown efficiency). Detailed descriptions of the crown-condition indicator are available in Schomaker and others (2007) and on the Web at <http://srsfia2.fs.fed.us/crowns/>. Between 1990 and 1999, the national Forest Health Monitoring (FHM) Program of the Forest Service, U.S. Department of Agriculture, collected crown data as part of the FHM Detection Monitoring (DM) system (Riitters and Tkacz 2004). In 2000, upon integration of the FHM plot system with the phase 3 plot network (Bechtold and Patterson 2005) of the Forest Inventory and Analysis (FIA) Program of the Forest Service, FIA assumed responsibility for collecting crown data.

The FHM program funded four Evaluation Monitoring (EM) projects associated with the crown-condition indicator. All of these projects originated from potential problems noticed during analysis of DM plot data.

Project NE-EM-98-02: Evaluation of Unexplained Defoliation of Ash and Other Hardwoods

The 1997 FHM aerial detection survey in Vermont identified more than 20 sites (totaling about 17,000 acres) with trees exhibiting thin crowns, brown foliage, and leaf cast. White ash (*Fraxinus americana*) was the most severely affected species, but similar symptoms also were observed for white birch (*Betula papyrifera*), beech (*Fagus grandifolia*), sugar maple (*Acer saccharum*), striped maple (*Acer pennsylvanicum*), red oak (*Quercus rubra*), and ironwood (*Ostrya virginiana*).

EM Project NE-EM-98-02 was funded to monitor the situation more closely during the next 3 years. Seven of the problem

areas identified in 1997 were reexamined by ground crews in 1998, 1999, and 2000. The follow-up checks revealed that white ash crown dieback and foliage transparency levels were higher than average on these sites, but the foliage browning and defoliation observed in 1997 did not recur. No significant causal agents were detected on symptomatic tissue examined in the laboratory. In addition to improvements on sites defoliated in 1997, statewide aerial surveys conducted during the follow-up period did not detect defoliation at any new locations.

This project concluded that the symptoms observed in 1997 were likely related to poor water availability caused by dry weather, shallow soils, exposed sites, and tree wounding. White ash was affected more severely than other species because the sites exhibiting symptoms were located at the edge of its natural range, where the species is more vulnerable to stress.

Project NC-EM-03-01: Evaluation of Increased Crown Dieback and Reduced Foliage Transparency within the Laurentian Mixed Forest

Detection Monitoring plots were first established in the three Upper Great Lake (UGL) States of Michigan, Minnesota, and Wisconsin in 1994. Ambrose (2001) observed that foliage transparency and crown dieback data in northern Minnesota and Wisconsin were relatively high and became progressively worse between 1994 and 1998. He concluded that the observed changes were attributable to chronic stressors.

FHM aerial detection surveys identified 125,000 acres of mapped jack pine defoliation and 210,000 acres of spruce budworm defoliation in the UGL region in 1997. Because the crown analysis by Ambrose (2001) coincided with known episodes of insect defoliation, Project NC-EM-03-01 was launched to examine the conclusion that deteriorating crown conditions in UGL forests were attributable to chronic stressors rather than single insect or disease episodes. A Before-After-Control-Impact (BACI) analysis was conducted to identify effects associated with the two insect outbreaks.

The BACI design used for this study required measurements from before and after the time of impact on a set of impacted

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sites, as well as a set of non-impacted (control) sites. Because the study was intended to evaluate the effect of single-event episodes, the analysis was restricted to plots that experienced low levels of insect defoliation before and after the defoliation event in 1997. FHM plots located in or near the mapped defoliation areas were used to represent impact sites. Each impacted plot was then paired with a similar plot from outside the impact zones; plot cohorts selected from beyond the impact zone thus represented control plots. The year of outbreak (1997) was used to split the available data into before- and after-impact groups: 1994-96 versus 1997-99.

After the plot selection criteria were applied to the dataset, only two plots met the selection criteria. Because so few DM plots occurred in the defoliated areas, the BACI analysis was halted and the project concluded that the defoliation events mapped in 1997 were not responsible for any crown deterioration observed in DM plots in UGL forests between 1994 and 1999.

Project SO-EM-04-04: A Spatial Cluster of Poor Crown Conditions: Evaluating Results from Crown Indicators and Spatial Scan Statistics

The Kulldorff scan statistic (Kulldorff 1997) was originally developed to test for randomness of human disease occurrence in the spatial and temporal domains. When applied to FIA phase 3 crown data collected in 2000 and 2001, statistically significant clusters of trees with relatively small crown volumes were identified near Augusta, GA (Bechtold and Coulston 2005, Conner and others 2004). Project SO-EM-04-04 was funded to further investigate the situation through additional analysis of the plot data, combined with a field visit to search for physical evidence of a problem.

Additional testing to check individual crown dimensions (e.g., crown density, crown diameter, and crown length) for spatial patterns did not yield the consistent geographic clustering observed with crown volumes (Bechtold and others 2005). Further evaluation of the crown volumes in the original clusters with more conventional t-tests failed to confirm the results of the spatial scan statistic. The subsequent field inspection of sampled trees in the suspect area revealed no visual evidence of a problem.

The EM study concluded that statistically significant clustering detected in the original analysis most likely resulted from:

- the use of statistical thresholds (as opposed to biological thresholds) to identify trees with poor crowns. Trees with crown volumes in the bottom 5th percentile (after adjustment for species and diameter at breast height) were assumed to have a problem. Field inspection of these trees revealed no visual evidence of a problem.

- adaptation of the Kulldorff scan statistic to a forest health application. In particular, the data had to be transformed from continuous measurements to binary counts, and it was not clear whether tree-level or plot-level observations should be used. These modifications may have rendered the scan statistic prone to Type 1 error (i.e., false positives).
- the estimation of crown diameters with models. Crown diameters, which are needed to compute composite crown volumes, are not measured in the field. There is no guarantee that a model developed from one dataset will be unbiased for another, and the crown-diameter predictions used for this analysis were demonstrably biased for the trees in the study area. The lack of measured crown diameters hampers the use of composite crown variables.

Project Number NE-EM-07-01: Evaluating Elevated Levels of Crown Dieback Among Northern White-Cedar (*Thuja occidentalis*) Trees in Maine and Michigan

Spatial clusters of plots where the crown dieback of northern white cedars (*Thuja occidentalis*) averaged 10 percent or more were discovered in Maine and northern Michigan when analyzing FIA phase 3 crown data for the FHM 2006 national technical report (Randolph 2009). High averages for northern white cedar (NWC) were not necessarily accompanied by elevated averages among the hardwoods and other softwoods on the same plots.

The first stage of this EM study was accomplished during the summer of 2007, when some of the plots with elevated levels of NWC dieback were revisited and inspected for additional evidence of a problem (Randolph and others 2008). The field visits were successful in verifying elevated levels of NWC dieback, but no single cause was apparent. A variety of factors had contributed to elevated dieback including tree age, weather (e.g., wind, flooding), soil conditions, and past harvesting practices.

The second stage of this project involved the statistical analysis of NWC data collected by the FIA and FHM programs, ranging as far back as 1990. Analyses are ongoing at the time of this writing, but preliminary results (Randolph and others 2009) indicate that:

- when significant differences were found among species groups, NWC crown dieback was higher than dieback levels of other softwood species, and lower than the dieback levels of hardwood species.
- there has been no statistically significant increase in NWC crown dieback in either State during the timeframe examined in the study.

Additional questions about correlations between NWC dieback and stand and weather conditions continue to be investigated.

During this analysis, opportunities to improve the crown-condition indicator were noted. Many leaning trees were encountered during the field visit, but lean angle is not currently recorded on FIA plots. This metric could be used to identify stressed trees, especially with respect to damage after harvesting, hurricanes, tornados, floods, or ice storms. The measure of dieback is not cumulative, which could have a confounding effect on the analysis of temporal trends. As dead leaves, twigs, and branches disintegrate, they are no longer classified as dieback, and therefore, the measure of dieback on a given tree may actually improve as its crown deteriorates. Also, as trees with excessive dieback die and drop out of the inventory, average plot-level estimates of dieback could improve.

Utilization of Project Results

The EM projects discussed here found no unexplained or unusual problems affecting tree crown condition. Detection Monitoring identified phenomena deemed worthy of further evaluation, and these projects were in response to those detections. Had any of these phenomena been new or important issues, these evaluations would have provided confirmation and triggered further necessary actions. In addition, these investigations suggested where the sampling and analysis methodology associated with the crown-condition indicator might be improved. These suggestions, some of which can be applied to other DM indicators, are discussed in the next section.

Suggestions for Further Investigation

The primary research need for the crown-condition indicator is the establishment of biological thresholds. All the crown-related projects discussed above would have greatly benefited from this information, and at least some may not have been necessary. Unfortunately, the point at which a tree begins to decline is difficult to pinpoint. The task is further complicated because the thresholds are expected to vary by species. Schomaker and others (2007) have given some consideration as to how such research might proceed. This task will become

more feasible as individual trees are tracked further through time, and the crown conditions preceding their eventual decline and death are better known.

The further development of spatial scan tools is another fruitful area of research that would not only improve analyses of the crown-condition indicator, but most other FIA phase 3 indicators as well. Problems encountered with the Kulldorff scan statistic used in Project SO-EM-04-04 need to be rectified. Work in this area is currently proceeding with funding designated for FHM analysis and reporting (Coulston and others 2008). This line of research should be supported until suitable geographic surveillance tools are developed and transferred to FHM analysts.

Care must be exercised when using the DM plot network for EM studies involving small areas, such as those sometimes mapped during aerial detection surveys. At the base sampling intensity, each phase 3 FIA DM plot represents approximately 96,000 acres. It is therefore not surprising that only 2 plots were located in the 335,000 defoliated acres examined under Project NC-EM-03-01. As pointed out by the investigators, the coarseness of the aerial maps and the perturbation of plot coordinates (McRoberts and others 2005) also create uncertainty about whether or not a plot is actually located in an impact area. Investigators should plan on using auxiliary data and/or supplementary sampling (as was done for Project NE-EM-98-02) when focusing on small areas. Rough guidelines from statistical power analyses conducted by Bechtold and others (2009) suggest that crown studies depending on statistical analyses involving less than 100 plots (or 50 paired plots) should be scrutinized to ensure there are enough samples to conduct the analysis.

Finally, crown-condition data issues that have become apparent during analysis deserve further attention. Failure to measure crown diameters essentially precludes the use of composite crown indicators. As such, there is currently no reliable way to monitor changes in tree crown volumes. Bechtold and others (2002) discuss several techniques that yield acceptable crown-diameter data, including ocular estimation. The utility of a lean-angle variable, as suggested in Project NE-EM-07-01, deserves further investigation. Research into methods that yield cumulative measures of crown dieback, up to (and possibly including) the point of tree mortality, would also be worthwhile.

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CHAPTER 14

Tree Species “Declines” that May Be Associated with Large-scale Mortality

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Many of the Evaluation Monitoring (EM) projects funded by the national Forest Health Monitoring (FHM) Program of the Forest Service, U.S. Department of Agriculture, have been motivated by perceived regional declines in specific tree species (or groups of species). Sometimes data collected from the FHM program’s former Detection Monitoring (DM) plots [now Forest Inventory and Analysis (FIA) Program (Forest Service) phase 3 plots] have suggested that a species or group of species were experiencing decline. Sometimes concern developed based primarily on observations by foresters and researchers working in a particular region. Such projects have focused on determining the extent of these declines, the causal agents responsible, and whether the decline truly represents a serious forest health concern. Often the focus was also on determining if decline symptoms (such as crown dieback) were related to tree mortality. Some projects also considered the potential for forest management or land-use actions to mitigate the problems.

One of these studies focused on eastern white pine in Vermont. A number of other EM projects have focused on decline in hardwood species in the Midwest. Some EM projects have focused on declines leading to loss of forest. Concern over loss of coastal wetlands prompted a study of the health of forested wetlands in Louisiana.

Project NE-EM-01-01: Evaluation of the Condition of Eastern White Pine

Burns and others (2003a, 2003b) evaluated the health of eastern white pine (*Pinus strobus*) in Vermont. Their study was prompted by observations of unexplained white pine mortality, scattered occurrences of heavy Caliciopsis canker, and widespread needlecast. Similar observations in nearby States heightened concern that there might be a serious health problem affecting white pine. Also, there was an interest in currant and gooseberry (*Ribes* spp.) cultivation in Vermont, but a fear of the impact that increased numbers of these plants, which are the alternate host required for the spread of white pine blister rust, might have on the white pine health.

In this project, mature stands of white pine were located on randomly selected aerial photos from a statewide coverage obtained in 2000. In the summer of 2001, 21 stands were surveyed. Trees were evaluated on four 1/24th acre subplots in each stand [including symptoms of decline (branch mortality, twig dieback, and foliar discoloration)] and site conditions were rated (Vermont Department of Forests, Parks, and Recreation 2001). In addition, 10 young pines were evaluated in regenerating stands near each mature stand.

This study found that the most common pests and pathogens on white pine were not strongly associated with the observed poor condition of the trees. While white pine weevil was found on about two-thirds of trees sampled in mature stands, 91 percent of those trees were healthy. White pine adelgid was found on 16 percent of the sampled trees in mature stands, again with 91 percent of those affected trees healthy. White pine blister rust was found on only 3 percent of the trees, and 73 percent of the affected trees were healthy. Instead, unhealthy pine stands seemed to be associated with difficult site conditions (e.g., shallow soils, wet sites) or recent disturbance (e.g., logging). Overall, white pine decline was not found to be widespread in Vermont. Most trees (89 percent of the trees sampled in mature stands and 93 percent of the trees sampled in regenerating stands) had healthy crowns (Burns and others 2003a, 2003b, 2003c).

Project NC-EM-05-02: Evaluating Black Ash (*Fraxinus nigra*) Decline in the Upper Midwest

Palik and Ostry (2005) studied black ash (*Fraxinus nigra*) decline in the upper Midwest. Black ash decline had been noted with increasing frequency in the region from the mid-1990s. There was particular concern about the status of black ash because the tree species occupied many sites that had once supported American elm (*Ulmus americana*), and the loss of black ash as well could be ecologically significant. Also, the emerald ash borer, as it spreads, poses a threat, and there was a desire to better understand the status of black ash prior to any effects of emerald ash borer in order to better evaluate the risk to black ash associated with that pest.

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The project aimed to quantify black ash decline and mortality in stands across northeastern Minnesota. Another aim of the project was to relate decline and mortality pattern to factors affecting tree health, including tree and stand age, insects and diseases, and site hydrology, as well as mapped climatic, physiographic, and edaphic data. The project also aimed to quantify black ash regeneration patterns in both declining and healthy stands.

The researchers first used FIA and FHM data to assess the distribution of decline in Minnesota and relate decline occurrence and variation to mapped landscape-scale climatic, physiographic, and edaphic data (Ward and others 2007, 2008). Using FHM aerial sketchmapping data for Minnesota in 2004, they found that black ash decline was spatially concentrated and that declining stands were significantly closer to city, county, and State roads. Data from the FIA public database (1977-2005) were analyzed together with hydrology, wetlands, soils, climate, and roads data. The researchers found that ash survival and mean diameter at breast height (d.b.h.) both decreased over time and that survival varied greatly among counties. Both mean d.b.h. and survival were found to be greater on moist slopes than on flat, wet sites.

Analyses using FIA data with true geographic coordinates (1990-2003) were also performed to determine if the more accurate plot locations provided more information. From these analyses they found that the decline in mean d.b.h. was greater on drier than on wetter sites, that mortality levels differed among counties, climate divisions, and ecological subsections, and that soils, temperature, and precipitation data were associated with mortality and change in d.b.h., but they explained little of the variation.

Field evaluations confirmed some of the findings from the FIA data analyses and provided additional results. Trees growing on wetter plots were found to have greater decline symptoms than trees growing on drier plots. Trees growing closer to roads had more decline symptoms than those farther from roads. No biotic agent was found to be responsible for the decline. Black ash regeneration (seedling and sapling size classes) varied widely across sites but was generally greater on better drained plots. Amount of black ash regeneration was not related to degree of decline in a stand (Palik and others 2008; Palik and others, in press; Ward and others 2007).

Work on this project has continued. In 2007, an additional 31 stands were sampled in Lake, St. Louis, Carlton, Aitkin, and Itasca counties in Minnesota. Analysis is ongoing to verify the preliminary findings reported to date. Additional work also focuses on successional trends in declining ash stands.

Project NE-EM-98-01: Lake State Basswood Decline Evaluation

Werner and others (2001) studied basswood (*Tilia americana*) decline in the Midwest. Detection Monitoring projects in the Great Lakes Region recorded increases in crown dieback, foliage transparency, and mortality of American basswood in the 1990s. An EM project was initiated in 1998 to assess basswood condition and determine causal agents related to this problem.

Twenty-two sites were established in 1998 to monitor basswood condition, insects, soil, and other site factors. Sites and plots were chosen to maximize overlap with previously established monitoring networks. Basswood condition was monitored using the then-current FHM protocols to measure branch dieback, foliage transparency, and crown density in June and August from 1998 to 2000. In addition, insects were sampled from foliage and tree boles at each site in 1998, 1999, and 2000. Soil cores were collected from five random points per site in 1999. Samples were analyzed for relative site pH, organic matter, P, K, Ca, Mg, nitrate, and ammonium. Increment cores were taken from five basswood trees per site in 2000 (Werner and others 2001, 2005).

Both crown dieback and foliar transparency increased from 1998 to 2000. High variability in crown conditions and soil type was observed among sites. Disease symptoms were relatively rare. Nine species of Thysanoptera (thrips) were collected from foliage samples from 1998 through 1999. The introduced basswood thrips (*Thrips calcaratus*) dominated insect abundance, accounting for over 99 percent of total Thysanoptera, and introduced thrips species far outnumbered the native thrips, *Neohydatothrips tiliae* (Werner and others 2001). Weak associations between basswood dieback and *T. calcaratus* abundance suggest that it is a major component of basswood decline in the Great Lakes region, but that other factors, including lepidopteran herbivores and diseases, may also be contributing factors (Werner and others 2001, 2005).

Project NC-EM-07-01: Assessment and Etiology of Hickory (*Carya* spp.) Decline in the Midwest and the Northeastern Regions

Hickory (*Carya* sp.) decline, particularly the decline of smoothbark hickories, had been reported in several Midwestern States and in New York. Widespread hickory mortality had been linked to outbreaks of the hickory bark beetle (*Scolytus quadrosiposus*) during or immediately after periods of drought, and, in the early 1990s, a fungus (*Ceratocystis* sp.) was linked to stem-discoloring and sunken cankers associated with beetle outbreaks. Site factors such as soil fertility and land use, as well as the flatheaded woodborer

(*A. tiosus*), also have been associated with hickory decline. Juzwik and Haugen (2007) studied hickory decline in the Midwest to determine the extent of hickory decline and mortality and quantify the relationships between decline incidence and severity and pathogen and/or insect presence, stand basal area, soil type, elevation, land use, and drought history.

Fourteen sites in thirteen counties across three States (Iowa, Minnesota, and Wisconsin) were surveyed and sampled in the summer of 2007. At each site, total live stand basal area and number of hickory stems across four size classes were recorded on nine fixed-radius, 1/15th acre plots. The frequencies of hickory decline and mortality (decline was defined as >20 percent crown dieback), decline severity based on crown ratings, and evidence of damage on trees from fungi, insects, fire, or mechanical damage were gathered at 30 point plots per site. Soil, topographical, and elevation data were gathered through use of GIS. At each site, four 2-foot long log sections also were taken from each of three declining trees for insect and pathogen evaluation. Two log sections from each declining tree were placed in insect emergence chambers. Total number and type of insects that emerged were recorded weekly over 6 weeks. After 6 weeks, the bark on each log was removed and presence and type of galleries recorded. Small cubes of discolored wood underneath cankers were taken from each 2-foot log section and used to isolate suspected pathogens. Additional sites were surveyed and sampled in 2008, including two new sites each in Wisconsin and Iowa, three sites in Indiana and Ohio, and six sites in New York (Juzwik and others 2008c).

Hickory decline and mortality were found to be widely distributed in the Central and Northeastern United States, but only in portions of affected States. For example, in New York, the problem was most severe in the Finger Lakes region. Also, decline and mortality were often localized within larger stands, and stands within a few miles of severely affected stands could have low incidence of the problem.

Preliminary results were presented in 2008 (Juzwik and others 2008c). Several different types of damage were found on declining hickories (from most to least common): insect holes (associated with hickory bark borer, flatheaded woodborer, and ambrosia beetles), sunken annual and diffuse cankers, galls, black leaf spotting, sapsucker and woodpecker damage, decay fungi, mechanical and fire damage, broken tops, and human-induced girdling.

Further analyses identified three major patterns of damage/decline and associated damage-causing agents (Juzwik and others 2009; Park and others 2009). Globose galls, caused by *Phomopsis* sp., occurred on branches in tree crowns and/

or main stems. Mortality can result from heavy infections. This was the least common of the three damage types (USDA Forest Service 2009).

The second major damage pattern identified was top dieback. Affected bitternut hickories have numerous annual cankers on the upper main stem or on a major branch resulting in dieback. The fungus, *Fusarium solani*, was most commonly isolated from the cankered tissues. *Ceratocystis smalleyi*, a recently discovered fungus, was also commonly isolated. Field inoculation studies showed both fungi can cause annual cankers on bitternut hickory (Juzwik and others 2008b, USDA Forest Service 2009).

The third damage/decline pattern observed was a relatively rapid crown decline followed by mortality. This was characterized by progressive deterioration of crown (e.g., small, chlorotic leaves, thin crowns, usually dying from top down, diffuse cankers sometimes with obvious bleeding spots, insect attacks). Hickory bark beetles (*Scolytus quadrispinosus*) and hickory timber beetles (*Xyleborus celsus*) accounted for 91 percent and 8 percent, respectively, of the insects attacking trees with crown decline in the 2008 survey (Juzwik and others 2009). *Ceratocystis smalleyi*, a canker pathogen of bitternut hickory, was commonly isolated from diffuse cankers (Park and others 2009, Park and others 2010, USDA Forest Service 2009). Hundreds of such cankers may be associated with an affected tree (Juzwik and others 2010).

It is hypothesized that stressed (due to drought, overstocking, flooding, or other causes) hickories are attacked by beetles carrying fungal spores on their bodies. The fungal spores are dislodged, germinate, and infect the attacked host. Diffuse cankers and sapwood infections resulting from the fungal colonization further stress the tree, leading to more beetle attacks (Juzwik and others 2009, USDA Forest Service 2009). The role of the fungus *C. smalleyi* in the decline is the subject of ongoing research.

Juzwik and Haugen (2007) developed management guidelines for dealing with hickory decline. These included management of stand density to reduce stress on trees, management of the abundance of hickory in mixed stands to lessen susceptibility to bark beetle attacks, and phytosanitary practices to control bark beetle levels.²

² These guidelines were presented at a meeting of the Wisconsin DNR (DNR Forest Health Protection Work Planning Meeting—January 30, 2009; 3911 Fish Hatchery Rd. SCR Headquarters, Fitchburg, WI) and were also provided in a letter to the landowners who participated in the 2008 landowner survey. Personal communication. 2009. Jennifer Juzwik, Research Plant Pathologist, U.S. Department of Agriculture Forest Service, Northern Research Station, 1561 Lindig St., St. Paul, MN 55108, and Adjunct Associate Professor, Department of Plant Pathology, University of Minnesota.

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Decline mostly affected trees larger than 5 inches d.b.h. Incidence and severity of decline were positively correlated with basal area in sampled stands on all but one site. Hickory bark beetles and/or their galleries were found at all sites, exceeding occurrences of other damage on declining trees. *Ceratocystis* and *Fusarium* fungi were both obtained from log sections from declining trees with hickory bark beetles and/or galleries (Juzwik and others 2008a, 2008b, 2008c). Work continues on this project.

Project NC-EM-04-01: Forest Health Evaluation of Reported Yellow-poplar, Ash, and Bitternut Hickory Decline

This project aimed to link off-plot and on-plot monitoring of forest health. In particular, the project focused on explaining the extent and severity of tree mortality and decline (as expressed through crown conditions) of drought-sensitive species in Indiana following the 1999 and 2002 droughts (Fischer and Marshall 2004).

The project results focused on observed yellow-poplar (*Liriodendron tulipifera*) decline. Yellow-poplar is an important component of Indiana’s hardwood forests. The species grows best on rich, mesic sites and has been long regarded as a drought-sensitive forest species. Indiana foresters reported pockets of declining yellow-poplar in southeastern parts of the State following substantial, prolonged droughts in 1999 and 2002. Decline symptoms include chlorosis of leaves, sparse crown, dieback, trunk and branch cankers, and root sprouts, as well as epicormic sprouting.

Field observations were made in 2004 on yellow-poplar trees at 12 locations in southeastern Indiana in order to identify factors associated with yellow-poplar decline and evaluate the effectiveness of FHM/FIA data and methods in detecting yellow-poplar decline (Krecik and Marshall 2006).

Yellow-poplar decline was found to be strongly associated with prolonged drought events. Decline symptoms were most pronounced on exposed slopes, and first appeared after the 1999 and 2002 droughts. Several FHM crown condition parameters were strongly correlated with yellow-poplar decline. However, insufficient Indiana phase 3 crown condition data restricted use of the then-current on-plot data set to extrapolate the extent of yellow-poplar decline statewide. Plotting of FIA mortality data (1985-2005) showed that yellow-poplar mortality followed both the distribution of drought-vulnerable soils and areas of the State with reported decline, further indicating yellow-poplar decline to be drought-associated. Mortality was also significantly correlated with smaller diameter classes (Krecik and Marshall 2006).

Being a more drought-sensitive species, yellow-poplar trees reduced incremental growth during the drought years of 1999 and 2002, while less drought-sensitive species, such as oaks, did not significantly vary in incremental growth (Krecik and Marshall 2006).

Project SO-EM-99-01: Factors Affecting Tree Health in Forested Wetlands of Louisiana

The main focus of this project was to determine the extent of previously observed decline in the health of trees in forested wetlands in southern Louisiana as well as to determine the causal agents responsible for the decline. The study area was the oak-gum-cypress bottomland forest of the Mississippi River delta. Existing historical data were used together with new air and ground surveys to document the extent and severity of the problem.

The study found that a variety of forest health issues are affecting the forested wetlands of southern Louisiana. The most significant factor appears to be saltwater intrusion. The increased salinity makes wetlands unsuitable for the tree species of the oak-gum-cypress forest type, leading ultimately to a loss in forested wetlands. The saltwater intrusion is related to reduced flows of freshwater, which also carry nutrients and sediments necessary to sustain these wetland systems. The reduced freshwater flows are often due to human impacts on the landscape. Navigation channels have allowed saltwater to reach farther inland. Spoil banks from dredging channels have created impoundments that permanently flood some areas while cutting off freshwater to others. Levees and elevated roadways have also affected hydrology (Goyer 2002, Goyer and Lenhard, no date).

Other factors have added stress to these forests, sometimes killing trees that cannot regenerate under the altered hydrology. These include herbivory from mammals (e.g., nutria and beaver) and insects (e.g., forest tent caterpillar and cypress leaf roller) (Goyer 2002, Goyer and Lenhard, no date).

Goyer (2002) recommends several actions to restore degraded wetlands and stop the further loss of forested wetlands. The most important action is to engineer changes to the hydrology to provide or restore freshwater inputs and reduce or stop saltwater encroachment.³ Goyer also suggests addressing some of the biological stressors affecting these forested wetlands. Suggested actions include controlling the exotic

³ The closing of the Mississippi River Gulf Outlet (MRGO), which began in early 2009, is one major project that may ameliorate the hydrological conditions.

nutria, use of biological insecticides on high-value cypress stands, and selection of salt tolerant genotypes of baldcypress for regenerating stands.

Summary of Key Findings

Most of the findings of these various EM projects are unique to particular regions or forest types. Nevertheless, some general trends can be found. Key findings include:

- Unhealthy white pine stands in Vermont were associated with difficult site conditions (such as shallow soils or wet sites).
- The most common pests and pathogens on white pine were not strongly associated with the observed poor condition of the trees.
- Black ash trees growing on wetter plots were found to have greater decline symptoms than trees growing on drier plots, and trees growing closer to roads had more decline symptoms than those farther from roads.
- No biotic agent was found to be responsible for the black ash decline.
- An introduced insect pest, *Thrips calcaratus*, appears to be a major cause of basswood decline in the Lake States.
- A number of pathogens, including the fungus *Ceratocystis smalleyi*, have been identified as being related to hickory decline. It is hypothesized that the hickory bark beetle (*Scolytus quadrospinosus*) helps to spread the spores of these organisms.
- Yellow-poplar decline was found to be strongly associated with prolonged drought events.
- Altered hydrology, which reduced freshwater inputs to forested wetlands in southern Louisiana, is the major factor leading to decline and loss of those forests.
- Both native and exotic insects and mammal species contribute to the loss of forested wetlands in southern Louisiana.

Several of these studies indicate that maintaining site quality and, in particular, the original hydrology of forested sites is important for maintaining the forest health. Disturbances at a variety of scales may affect forest hydrology and have negative impact on the forest. White pine decline was associated with site conditions and site disturbance. Black ash decline was related to site hydrology and, possibly, to

alteration of that hydrology from road construction. Yellow-poplar decline was found to be related to drought, but site factors affected the severity of drought impact. Large-scale changes to the hydrology of wetland forests in Louisiana are leading to loss of those forests.

Biotic factors played a relatively small role in several decline situations studied in these projects. The most common pests and pathogens on white pine were not strongly associated with the observed poor condition of the trees. No biotic agent was found to be responsible for the black ash decline. However, hickory bark beetle (*Scolytus quadrospinosus*) as well as several fungi seem to play a role in hickory decline. An introduced insect pest, *Thrips calcaratus*, appears to be a major cause of basswood decline in the Lake States. Also, both native and exotic insects and mammal species contribute to the loss of forested wetlands in southern Louisiana.

Utilization of Project Results

The researchers working on several of these EM projects have used various means to disseminate their results to landowners and forest managers. Sometimes the project results enabled the researchers to develop specific guidelines for forest management. In other cases, the project results enabled landowners to make more informed management decisions relating to particular species on difficult sites.

- Results of the white pine study were shared with over 200 forest managers at the New England Society of American Foresters meeting and over 100 foresters at the 2003 Forest Health Information Meeting. Forest managers were made aware that managing white pine on marginal sites is risky, but that otherwise, there was not widespread decline on white pine. This information allowed forest managers to continue to manage it for maximum growth and timber yield.⁴
- Results from black ash study have increased awareness of the extent of black ash decline among landowners and managers of the region. Landowners have been made aware of possible linkages between ash decline and site factors related to soil moisture. Results also allow managers to place the anticipated invasion of the black ash forest by emerald ash borer in proper perspective, since many of these forests are already experiencing significant decline and mortality.⁵

⁴ Personal communication. 2009. Barbara Burns, Forest Health Program Manager, Vermont Department of Forests, Parks, & Recreation, 100 Mineral Street, Suite 304, Springfield, VT 05156.

⁵ Personal communication. 2009. Brian Palik, Research Ecologist, U.S. Department of Agriculture Forest Service, Northern Research Station, 1831 Hwy. 169 E, Grand Rapids, MN 55744.

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14. Tree Species “Declines” that May Be Associated with Large-scale Mortality

- Information about the extent and causes of hickory decline were communicated to forest landowners and managers (Allen and others 2009; USDA Forest Service 2009; Wisconsin Department of Natural Resources 2006, 2007), and management guidelines for hickory based on the hickory decline research have been published (see footnote 2).

The results of some projects helped form the basis for further research or have led to tree breeding programs to obtain better survival in the face of particular insects, pathogens, or other stressors.

- Based on the black ash study, the researchers are now examining field plots across northern Minnesota to investigate the influence of finer scale site (soil moisture-drainage), tree age, and road influences on incidence and severity of decline.
- The black ash project provides a starting point for future studies on the potential impact of emerald ash borer on black ash in Minnesota. Researchers plan to use some of the same study sites and will use their previous assessments of black ash health as a baseline. The future research effort will involve an expanded team of hydrologists, plant ecologists, entomologists, and foresters from the University of Minnesota, the Northern Research Station of the Forest Service, and the Minnesota Department of Natural Resources.⁶
- The Louisiana Department of Agriculture and Forestry has established a baldcypress tree improvement program, has acres of genetic material being cultured for salt tolerance and insect tolerance as well, and uses progeny of cypress trees shown to survive better in saline/insect environments for much of the department’s coastal reforestation efforts after hurricanes.⁷

Suggestions for Further Investigation

Future research should continue to look at the relationships of decline to tree mortality and try to determine the causal relationships. Useful research may aim to determine the factors related to decline and mortality that can be affected by human management of forest systems in order to prevent or reduce the severity of forest decline. Another goal of future research may be to determine which decline symptoms

indicate situations so severe that radical intervention (such as harvest and replanting) is warranted.

The results of these projects suggest that future research should not only focus on biotic factors related to forest decline. Research also must consider factors relating to site quality and how humans may have altered site characteristics.

FHM must continue to conduct in depth investigations when observations suggest that there may be forest health issues that might lead to large scale mortality with a species or group of species. At the same time, it is important that data about tree species reactions to stressors be compiled over longer time periods so that we have a better idea of the natural variation that occurs both in stressors (such as climate or insects and pathogens) and in the responses of forests to those stressors. Such data will allow future researchers to better determine which phenomena truly warrant in depth investigations and which are related to natural cycles.

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⁶ Personal communication. 2009. Robert Venette, Research Biologist, U.S. Department of Agriculture Forest Service, Northern Research Station, 1561 Lindig Street, St. Paul, MN 55108.

⁷ Personal communication. 2009. Richard Goyer. Professor (retired), Louisiana State University, Department of Entomology. 404 Life Sciences Building, Louisiana State University, Baton Rouge, LA 70803-1710.

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CHAPTER 15

Down Woody Material

Christopher W. Woodall¹

The full range of possible down woody material (DWM) research includes wildlife, nutrient cycling, fungi, fuels, carbon, biomass, water cycling/stream structures, and stand structural diversity. Of studies on DWM by the national Forest Health Monitoring (FHM) Program of the Forest Service, U.S. Department of Agriculture, 80 percent primarily focused on fire-related objectives. The only two remaining studies not focused on fire dealt with the mapping of snags and coarse woody debris, close to the topic of mapping DWM found in many fire studies. The explicit request for Evaluation Monitoring (EM) projects under the Fire EM umbrella has resulted in a dominance of fire-related studies to the exclusion of all other DWM topics. There have been no completed FHM studies explicitly and primarily focused on the DWM topics of wildlife, carbon, or structural diversity (for detailed description of dead wood ecology, please see Harmon and others 1986).

Project INT-EM-99-02; INT-EM-00-02; INT-F-01-03: Fire Risk Rating of FIA/FHM Plots

The Forest Vegetation Simulator (FVS) (Reinhardt and Crookston 2003), with the Fuels and Fire Effects (FFE) and Insect and Pathogen (I&P) extensions, was used to characterize forest fire hazards in Montana. Data from the Forest Inventory Analysis (FIA) Program of the Forest Service were processed through the FVS to characterize current and future fire hazards in Montana. The potential for wildfires to put lives, property, and environmental services at risk is a much discussed and debated topic in recent years, especially in communities across Montana. This study had two main objectives: (1) to develop methods of using FIA data and the FVS, incorporating its FFE and I&P extensions, to characterize current and simulated future forest conditions in Montana, and (2) to use the methods developed to describe the conditions of Montana forests now and in 50 years. Following analysis of all model outputs, a number of conclusions were stated. First, there is an abundance of comingled small- and medium-diameter stands creating an abundance of ladder fuels. Second, there is an abundance of stands with a high

potential for crowning fires, especially in extreme fire weather conditions. Third, the stand attributes that resulted in reduced wildfire mortality were fire-resistant species (e.g., ponderosa pine), larger diameter trees, lower crown bulk density, and less stand layering (e.g., complex crown architecture). Future modeling improvements to refine modeling estimates are suggested, such as adding tree species and recalculating growth and mortality functions. For further details, please refer to Atkins and Lundberg (2002).

Project SO-F-01-04: Evaluating Critical Fuel Loading in the Wildland/Urban Interface

Located in coastal Georgia adjacent to the Florida border, Camden County covers more than 403,000 acres, two-thirds of which is forest land. Interstate 95 and U.S. Highway 17 are routed through the middle of the county. Camden County is home to the Kings Bay Naval Base and the Cumberland Island National Seashore, with a number of communities in the interface between suburban/urban development and natural fuel complexes in forest ecosystems. The Georgia Forestry Commission initiated a pilot study to address several wildland/urban interface issues unique to this county. A study was undertaken with the specific objective to develop forest fuel loading values for the palmetto/gallberry fuel type that is the dominant fuel type in the county. The study methods followed a number of logical steps. First, the fire history (e.g., cause, number, and acreage burned) of Camden County (1996-2001) was determined. Second, the forestry commission developed a series of wildfire occurrence maps. Third, forest statistics concerning forest density and extent were developed from FIA data. Finally, all the data layers were combined with a fire hazard rating index for urban interfaces. It was found that wildland fires could occur anywhere in Camden County where forests adjoin grasslands with fire ignition coming from human activities along roadways or lightning strikes. On average, nearly 99 fires occur annually in Camden County. The population of Camden County has more than tripled since 1980, causing a tremendous increase in wildland/urban interfaces and associated increases in fire hazards. Recommendations based on the results of the risk assessment were presented to fire departments, emergency management agencies, the American Red Cross, County Commissioners, and University of Georgia Cooperative Extension Service.

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Projects SO-F-01-03; NE-F-01-05: Assessing Contribution of Down and Standing Deadwood Biomass and Decay on Fuels and Wildland Fire Risk Across the Southeastern and Northeastern United States

The study summarized fuel biomass/carbon for Eastern States based on preliminary 2001 and 2002 DWM plots sampled by the FIA program (for details regarding the FIA program's DWM indicator, please see Woodall and Monleon 2008). As this was one of the first regional summaries of DWM based on phase 3 DWM indicators, it found that linkages between the DWM biomass models (estimators) and the FIA database offer a methodology for monitoring DWM that is beneficial for establishing carbon credits, assessing wildlife habitat, managing fire fuels, and understanding other forest health issues related to dead wood and the forest floor. The primary objective of this study was to explore use of the Eastwide FIA database, remotely sensed landcover data, a coarse woody debris model, and a productivity model (PnET) as the basis for developing estimates of live and deadwood biomass for producing fire fuel maps for eastern forests. The study used both FIA phase 2 and phase 3 plots. On average, mass of each DWM component was less than 4.5 tons per acre (10 tonnes/ha). Generally, Northern States had greater amounts per plot than Southern States. An objective was to use these DWM data to estimate DWM for all plots in the eastern half of the FIA database. This was done by developing regression models to predict DWM from available FIA measurements collected on their phase 2 plots.

Project Number NC-F-03-01: Supporting the National Fire Plan with Maps and Digital Data Layers Derived from FIA and FHM Plot Observations

This study brought together phase 2 and phase 3 data, along with pertinent ancillary data (forest/non-forest maps), to map down woody material fuels at large scales (McRoberts and others 2004). This was one of the first studies to postulate and examine using an entire suite of forest monitoring data to produce continuous coverages of fuel loadings. Specific objectives were to (1) construct models of the relationships between phase 3 down wood material observations and the suite of phase 2 observations, (2) determine if augmentation of phase 3 plot observations with phase 2 plot predictions improves fuel maps, and (3) determine if fuel maps are improved by masking out non-forest areas. The following conclusions were derived from this study: (1) augmenting phase 3 plot observations with phase 2 plot predictions improves fuel maps, (2) masking out non-forest portions of

the landscape improves fuel maps, and (3) map-based mean per acre fuel tonnage estimates are not significantly different than plot-based estimates, suggesting that the map is unbiased at the spatial scale of most of Bailey's Ecological Provinces (Bailey 1995).

Project Number: NC-F-04-03: Fire Season "Real Time" Estimation of Fuel Moisture Fluctuations in Regional Down Woody Material Inventories During a Fire Season

Although regional-scale forest fuel maps are essential to wildfire management and fire risk mitigation efforts, forest fuel conditions are not static. Regionally assessing the fire season fluctuations of fuel moisture levels has never been undertaken using extensive fuels inventory and mesoscale models. Such effort is crucial to tracking weather-dependent fire hazards across regional forest fuels during critical fire seasons. This study examined the concept of meshing phase 3 DWM data with real-time meteorological data for real-time assessment of fire hazards. This study was one of the first to suggest linking static estimates of fuel loadings with mesoscale models for prediction of real-time fuel moisture to aid rapid response to wildfires. Specific objectives were to (1) employ mesoscale atmospheric numerical model output to modify FIA down woody material data to produce higher temporal resolution information on fuel moisture, (2) produce an assessment of the variations in fuel moisture over the course of a fire season, (3) assess the extent to which fire activity correlates with these simulated fuel moisture variations, and (4) determine if this system can be employed to produce real-time predictions of fuel moisture conditions based on the simulated variations in fuel moisture from the previous year. Products delivered by this study were (1) regional-scale map of fuel moisture weekly/daily/hourly variations across multiple North Central States for a past fire season, (2) assessment of how past fire behavior correlates with the study's fuel moisture maps, and (3) regional-scale real-time prediction and subsequent map production of fuel moisture conditions. For further details, please refer to Woodall and others (2005).

Project SO-F-05-01: Models for Using FIA Data to Assess Impacts of Fire and Fuel Loading on Water Quality

Preliminary analyses have indicated a possible causality between dead and live forest structure and stream pH—particularly for western U.S. forests. DWM in forest ecosystems provide structure and, therefore, may impact water quality. This study had several objectives, including (1) linking

FIA phase 2 data with national Water Quality Assessment (NAWQA) data at the watershed-basin scale (HUC-6), (2) establishing baseline relationships between live and dead forest structure and water quality (i.e., dissolved oxygen, suspended sediment, water temperature, and electrical conductivity), and (3) demonstrating model ability when applied to FIA data to assess impacts of fire and fuels on water quality. Study results indicated that between 7 and 25 percent of examined counties exceed one or more standard deviations from a regional mean for dissolved oxygen, temperature, electrical conductivity, pH, or sediment variables. The Southern United States had the largest percentage of counties with >1 standard deviation from the regional mean for almost all water quality variables. The ordered ranking of variables within each study region demonstrated varying patterns. For example, sediment and winter temperature are upper and lower extremes in the Southern United States, but these variables are opposite in other regions. Overall, it was feasible to merge U.S. Geologic Survey NAWQA data and FIA data for assessing water-quality across large-scales for sustainability assessments. The greatest value for this type of analysis is to establish a 1990s baseline for comparing future deviations. Although this study did not explicitly relate water quality to DWM structure (only biomass), it has established relationships between regional water quality and large-scale estimates of forest standing live tree structure (FIA phase 2 data).

Project WC-F-05-05: Pre- and Post-Fire Fuel Loads: Empirical Versus Simulated Results for Mixed-Conifer Forests of the Cascade Range

This FHM-funded study took advantage of an opportunity created by the 2004 McDonald Ridge wildfire on the Gifford Pinchot National Forest in Washington. The McDonald fire burned more than 200 acres through a research area where forest vegetation and fuels had previously been measured (in 2001) as part of a larger, landscape silviculture study in the Gotchen Late Successional Reserve (LSR) (15,000 acres, 6 070 ha). The 2001 data were used to simulate forest structural dynamics associated with fire, insects, and pathogens, and with stand density reduction treatments over a 30-year period for LSR (e.g., Hummel and Calkin 2005). The objective of the 2005 FHM-funded study (WC-F-05-05) was to compare the simulated fire effects with those actually observed. This required remeasuring the burned and unburned plots within the perimeter of the 200-acre (81-ha) fire; the fieldwork was completed 1 year post-fire, in August 2005. Plot measurements included the height, diameter, and species of all live and standing dead trees, plus transects on which down fuels were tallied. Of the 20 original plots in the sample polygon, 10 were within the fire perimeter and, of these 10, three were burned.

A comparison of predicted and actual fire effects was done using the east Cascades variant of a forest vegetation and fire/fuels simulation model (U.S. Department of Agriculture Forest Vegetation Simulator-Fire and Fuels Extension models; Reinhardt and Crookston, 2003). Study results were the subject of a poster displayed at the 2006 International Association of Wildland Fire (IAWF) conference in Portland, OR (Hummel and Bouchard 2006). Results suggest that the FVS-FFE model did well in the plots that burned, but that on an area basis (when plots were pooled), it over-predicted fire-related tree mortality.

Project NC-F-05-03: Multi-Scale Modeling and Mapping Coarse Woody Debris

FIA/FHM programs provide important data that have been used to map dead and down woody material for multi-state regions. The dead and down woody material maps generated based on FIA/FHM plots are too coarse to describe variation at small spatial scales because of the low sampling intensity [about 1 phase 2 and phase 3 plot per 6,178 acres (2 500 ha) and 98,840 acres (40 000 ha), respectively]. The resultant maps, therefore, are insufficient for regional resource management and planning to evaluate fire risk or wildlife habitat suitability (e.g., at the scale of a national forest or other sub-State region). Generally, dead and down woody material is relatively scarce and varies dramatically at small spatial scales such as plots/stands, even when the plots/stands are similar in many other respects (Shifley and Schlesinger 1994). This is due to the spatially stochastic nature of disturbance agents (Shifley and others 2000) and the resultant tree mortality and decay process. Research on other rare forest attributes (e.g., cavity trees) has indicated that they are predictable within a tolerable range of errors at relatively small spatial scales (e.g., 50-acre (20-ha) blocks). The prediction/estimation error of such models may be reduced by employing an ensemble of related models rather than individual component (e.g., height and diameter) models (e.g., simple linear regression models; Fan and others 2004). The scale-dependent statistical/computer models and ensembles of predictive models can be developed by using bootstrapping techniques to combine groups of FHM plots and create virtual landscapes of various sizes where the coarse woody debris (CWD) characteristics are known. These can be linked with other data sources such as remote sensed imagery, GIS layers, or other sources of existing data (e.g., Shifley and Brookshire 2000) to map dead and down woody material at finer scales than previously reported for the Midwest. Other sources of CWD data for the region (Spetich and others 1999, Shifley and others 1997) serve as an additional benchmark against which to compare findings from FHM data. Products delivered by this study were (1) an identified set of hierarchical stand and site factors and/or computed composite variables statistically

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associated with dead and down woody material, (2) a set of statistical/computer models applicable for estimating CWD at multiple spatial scales, and (3) dead and down woody material maps for Missouri based on models or ensembles applied at different scales. These also serve as prototypes for extension of the methods to other geographic regions.

Project Number: SO-F-06-01: Fuel Characteristics in the Southern Appalachian Mountains—A Test of FIA Down Woody Material Indicator for Regional Fuel Estimation

Both the National Fire Plan and the Healthy Forest Initiative call for reduction of hazardous fuels. Consequently, estimations of forest fuel loading at various scales become necessary. With objectives such as fuel reduction, site preparation, wildlife habitat improvement, and maintaining extant populations of threatened and endangered species, prescribed fire has become an increasingly widespread management tool in the Southern Appalachian Mountains. However, fuel loading information is not readily available to fire managers in this region. The FIA program is currently assessing the FHM indicators at its phase 3 plots. Within this assessment, DWM sampling occurs every 96,000 acres (38 851 ha). This study compared DWM estimates from two sources: extensively sampled FIA phase 3 plot data and more-intensively sampled fuels information collected specifically for this study. With estimates from two levels of sampling intensity, the study found a large discrepancy, with the FIA phase 3 estimates much smaller (by 47 to 73 percent, depending on study area). Differences in sampling methods were not the cause of the discrepancy observed between the two estimates. In addition, the two methods also used the same equations to determine DWM estimates from field data. Based on the new data collected in this study, total DWM estimates varied from 10.85 to 15.58 tons per acre among the four study areas (24.2 tonne/ha to 34.7 tonne/ha, respectively). Litter and duff accounted for 36.5 to 61.7 percent of the total DWM. Fine woody debris (FWD) (for definition, see Woodall and Monleon 2008) usually accounted for approximately 20 percent while coarse woody debris (CWD) (for definition see Woodall and Monleon 2008) accounted for 20 to 30 percent of the total DWM except for Tennessee (44 percent). Litter and FWD accounted for about 40 percent of the total DWM. Except for litter, the ranges for individual DWM attributes were quite large, particularly for CWD and duff. The study also examined whether regional fuel estimations derived from the FIA phase 3 plots could capture multiple and distinct fuel complexes of forests at its current sampling intensity [approximately one plot per 96,000 acres (38 851 ha)]. Results suggest that FIA phase 3 sampling intensity is appropriate at

regional scale when fuel loading is averaged over a large area [more than 2 million acres (809 388 ha)]. However, fire events often occur at a much smaller spatial scale. Fuel estimates obtained over such a large area may not provide much useful information for fire management decisions that have to be made at stand or landscape level. At a smaller scale (i.e., individual county or individual national forest/park scale), the FIA phase 3 sampling intensity would likely be too sparse to generate reliable fuel loading estimates.

Project WC-F-06-05: Estimating Snag Densities and Down Wood with Aerial Survey Data

An important aspect of dead wood analyses is ascertaining the current status (e.g., stage of decay, size, and presence/absence of cavities) of snags and down wood in the vicinity of the analysis area. Aerial survey data can aid managers in developing a picture of the current situation for the incidence and condition of snags and potentially down wood across a landscape. Recent development of the Decayed Wood Advisor (DecAID) has provided an important tool for analyses considering dead and decaying wood. DecAID is an Internet-based synthesis of published scientific literature, research data, wildlife databases, forest inventory databases and expert judgment and experience. It addresses current vegetative conditions (unharvested and managed); provides relevant summaries of snags and down wood; and presents information on wildlife use of snags and down wood. It also provides information on insects and pathogens and their role in creating and retaining dead wood. The following objectives were tackled in this study: (1) assess the impact of bark beetle-caused mortality on the accretion of standing dead and down fuels; (2) assess the ability of aerial surveys to estimate snag and large tree densities and distributions at watershed scales; (3) evaluate fuel loading for selected sub-watershed, and investigate possible correlations with aerial survey recorded mortality; and (4) develop and assess plot-based derived (FIA) conversion factors for aerial survey data relative to dead wood metrics identified in the DecAID. Annual cooperative insect and disease aerial detection surveys have recorded current year disturbance events since 1947. Forest land managers interested in managing for healthy forests in the context of ecosystem management may evaluate effects of forest conditions and existing or proposed management activities on organisms that use snags, down wood and other wood decay elements. Methods included user available spatial and tabular data summaries based on aerial survey data for intersection with hydrologic unit codes (i.e., watersheds) and user defined wildlife habitat types. Information will assist managers in forest and project planning by generating current conditions histograms for comparison with ideal unharvested

condition histograms generated from forest inventory plots. Study findings indicated that aerial survey data can provide an extremely conservative estimate of snag densities, sometimes < 10 percent of the actual snag densities. However, aerial data may provide cost effective methodology for snag surveys at fifth-order watersheds (i.e., county-level scale or larger) for some wildlife applications. Due to mapping thresholds and other environmental variables, estimates of snag densities in some habitat types based on aerial survey data are too variable.

Summary of Key Findings

- Fire behavior and stand growth models may be combined with FIA inventory data to inform landscape-scale fire hazard mitigation/management efforts.
- Western forests, such as those in Montana, have high probabilities of crowning fires as opposed to the mixed-severity fire regimes (e.g., torching/surface fires) typical of pre-European settlement forest ecosystems in this region.
- FIA data may be combined with fire burn history information and wildland/urban interface information at the county level to inform local emergency response planning efforts.
- Regression models may be used to estimate DWM attributes for all FIA phase 2 plots; however, continued research is suggested especially when applying models to assess carbon stocks and fuel loadings at local/State scales.
- Combining phase 2 information with phase 3 fuel information may reduce fuel estimate variance over using phase 3 fuels alone.
- Real-time fire weather assessments (e.g., wind and humidity) may be combined with regional assessments of forest fuels to provide real-time estimates of fluctuating fire hazards.
- The FVS-FFE model adequately predicts post-burn tree attributes, a modeling strategy used in numerous FHM studies. However, the model may overestimate fire-induced tree mortality in some cases.
- Data from FIA inventory phases may be combined with USGS water quality data for assessing impacts of fire/fuels on water quality.
- DWM data analysis results presents a conundrum: at large scales, it does not provide useful information for fire management decisions, while, at smaller scales, the sample density is so sparse as to disallow reliable local-scale fuel loading estimates.
- Only in the most optimum conditions can aerial surveys provide a reliable estimate of forest ecosystem snag densities.

Utilization of Project Results

As most studies investigated novel applications of FIA DWM inventory during its early implementation, there has been scant direct application of study results to on-the-ground management efforts. Instead, the avenues of dead wood research explored by the various EM projects have indirectly informed both State and National reporting efforts. At the State level, DWM analyses are routinely included in 5-year forest inventory reports. At the national level, DWM data are incorporated into National greenhouse gas inventory reports. Perhaps the greatest applied finding from EM projects on dead wood is that the strategic-scale FIA DWM inventory is best suited for State and National monitoring efforts, while forest health issues at sub-State scales requires inventory intensification, ancillary data, or well-developed models. As an example, the DWM inventory has found its greatest strength not in monitoring fuel loadings at county scales but in monitoring tenuous carbon pools at multi-State or National scales (see Woodall and Liknes 2008).

Suggestions for Further Investigation

To provide a more cohesive approach to filling the most relevant DWM knowledge gaps in the future through the FHM program EM grants, a number of items are suggested. First, perhaps more overall strategic goals for fire projects are needed. Are there overarching knowledge gaps we are trying to fill? Currently, past fire/fuels projects appear to be randomly assigned to random regions with little prioritization of topics or regions. Individually, these fire/fuels projects do fill certain knowledge gaps, but with holistic reflection do not serve to advance science at a national scale. Explicitly developing a fire/fuels FHM research plan might better allocate and recruit fire/fuels projects that synch with each other. Second, there is a lack of diversity regarding DWM studies. Perhaps the explicit fire focus of the FHM project is a reason; however, there are hardly any studies examining fungi, wildlife, or structural diversity. Third, there is a disconnect between DWM research as funded by FHM and phase 3 reporting in inventory reports/special analyses. Perhaps the most immediate method for applying research results might be to require principal investigators to facilitate incorporation of their study results into FHM national technical reports or 5-year FIA reports. Fourth, personnel retirements, lack of project reporting in earlier years (2001 or earlier), and lack of follow-up in project deliverables meant that information

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may have been lost or misplaced. Most projects demonstrated valid and timely study objectives; however, a preponderance of studies did not present their promised deliverables. Perhaps more oversight of study deliverables would ensure both study completion and dissemination of results. Overall, the capacity for worthwhile DWM research has been demonstrated by the reviewed studies. This capacity could be refined or enhanced through more robust study management and incorporation into program reporting requirements.

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CHAPTER 16

Drought and Climate

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In the time covered by this synthesis, researchers of six Evaluation Monitoring (EM) projects under the national Forest Health Monitoring (FHM) Program of the Forest Service, U.S. Department of Agriculture, presented findings on the effects of drought and other weather- or climate-related phenomena on specific aspects of forest health in the United States. (The term “weather” refers to the short-term behavior of the Earth’s atmosphere at the scale of minutes to months, while the term “climate” refers to long-term weather patterns.) One project mapped coastal forest mortality and change in the Big Bend region of Florida attributed to sea-level rise, a phenomenon that has been linked to climate change. Another project examined the predictability of forest health impacts caused by extreme weather events, which may in turn be linked to broader climatic trends. Two related projects investigated the different effects of drought on the health of distinct tree species groups in forests of the Southeastern United States, as well as the influence of drought on forest carbon balance. In addition, two projects analyzed the impact of climatic factors on the health of particular Alaskan tree species, with both of these projects considering the role of ongoing climate change in exacerbating these impacts.

Project SO-EM-98-01: Coastal Forest Health Monitoring Within the Big Bend Region of Florida

During the early 1990s, abundant and presumably recent mortality of cabbage palm (*Sabal palmetto*) and other tree species was observed in the Big Bend region of Florida, a greater than 155 mile (250 km) portion of the State’s north and central Gulf of Mexico coast (Barnard 1999). An in-depth study of forest replacement processes in this region (Williams and others 1999) linked coastal forest change to the effects of

ongoing sea-level rise, the rate of which has been predicted to increase due to climate change. In particular, this study found that increased exposure to tidal water and increasing groundwater salinity were associated with failed regeneration of cabbage palm and other tree species historically found in the region (e.g., redcedars, *Juniperus* spp.), ultimately leading to forest retreat inland as well as shifts in species composition.

In 1992, researchers in the Southern Region office of the Forest Health Protection (FHP) Program of the Forest Service performed an initial investigation of the observed mortality, procuring aerial photography of four flight lines within affected areas of the Big Bend region. As part of a 1998 EM project (E.L. Barnard, investigator), follow-up aerial photography was acquired for these flight lines. The primary objective of this study was to document any observed differences in forest type or condition between these two dates. In terms of methodology, vegetation types were mapped and compared for the two dates using a combination of photogrammetric, photointerpretive, and geographic information system (GIS) techniques. The classification scheme included “stressed vegetation” classes for describing areas with dead and/or fallen trees, stressed canopies, or other indications of damage or decline.

The most frequently observed vegetation change between 1992 and 1998 was a shift from the Mixed Forested (i.e., all healthy forest communities with cabbage palm comprising < 50 percent of forest cover) to the Stressed Mixed Forested category (Patterson 1999). Another relatively common change was a shift from the Mixed Forested to the Dominantly Palms forest category. A transition from the Dominantly Palms to the Stressed Palms category was less common. In all cases where vegetation change occurred, the percentages of affected acres were relatively modest. This apparently slow rate of change seems consistent with the observations of Williams and others (1999), who suggested that several decades may elapse between initial tree regeneration failure due to sea-level rise and the elimination of a species from affected sites. In any case, the described methodology could be applied for any future change analyses deemed to be necessary, with the resulting vegetation maps serving as a record of historic forest condition.

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Project NC-EM-01-01: Climate and Air Quality Indicators of Risk to Forest Health: An Online GIS for Integrating Climate and FHM Information

The investigators for this project (A.N.D. Auclair and W.E. Heilman) argued that field data, by themselves, are insufficient for real-time monitoring of forest health impacts because there is usually a time lag before distinct patterns emerge. Nonetheless, forest managers may be asked to anticipate when, where, and what type of impacts are likely to happen. Therefore, the investigators proposed the development of a comprehensive forest health decision support system. They outlined the concept of an archive of climate, air quality, and forest health indicator data, from which a series of statistical models could be constructed to relate historical observations of forest health impacts to explanatory factors. Under their concept, the system would also incorporate real-time data streams, such as recent weather forecasts and longer-term El Niño-Southern Oscillation (ENSO) forecasts, as well as available FHM/FIA phase 3 plot data. By combining historical models and real-time data, the system would thus provide managers with an early warning capability regarding forest health outcomes.

The researchers selected a small geographic area (the upper Midwest) as their initial test region. They selected crown dieback as a test forest health indicator, and selected two climate indices as explanatory variables: annual winter thaw-freeze occurrences [$+50^{\circ}\text{F}/-50^{\circ}\text{F}$ ($+10^{\circ}\text{C}/-10^{\circ}\text{C}$)] and annual occurrences of extreme cold temperatures [$<-22^{\circ}\text{F}$ ($<-30^{\circ}\text{C}$)]. In describing their early progress (Auclair and Heilman 2002), the researchers highlighted a particular example (Wisconsin in 1996) where above-normal dieback appeared to correlate with above-normal thaw-freeze and extreme cold frequencies. Noting evidence that forest dieback in the Northern United States is strongly affected by ENSO, they suggested that predictions of colder-than-normal winters or other anomalies based on ENSO forecasts could be used to forecast frequency of thaw-freeze and extreme cold events that could potentially impact forest health.

In subsequent work (Auclair and Heilman 2003), the researchers detailed their integration of GIS data on historic forest health-climate interactions into an on-line database, the Atmospheric Disturbance Climatology System. In addition, one of the researchers cataloged dieback events in northern hardwood forests from 1950 to 1995 based on Forest Service and State insect and disease surveys (Auclair 2005). When compared to ENSO data spanning the time period, two major dieback episodes (starting in 1954 and in 1976) in northern hardwood forests were found to have been preceded by extreme La Niña events. The researchers suggested that a La

Niña event around 2000-01 might predict another period of dieback for 2003 to 2015. They also looked at 23 historical dieback episodes in northern hardwood forests and explored whether these periods could be linked to various climate stresses; they discovered that decreasing snow-pack depth was consistently and significantly associated with onset of dieback, while increasing snow-pack depth was associated with recovery. The researchers asserted that this work provided the first model for projecting future dieback incidence in northern hardwood forests; more importantly, they argued that this simple model demonstrated the potential for archived climate and forest health data to provide effective decision support.

Project SO-EM-04-01: Drought Impact on Forest Health in the Southeast—An Analysis Based on FHM/FIA Data

The investigators for this project (G.G. Wang and W.L. Bauerle) noted that weather is a key contributing factor to tree mortality in the Southeastern United States. In particular, periods of severe drought in the latter half of the 20th century, especially during the 1950s and 1980s, had significant effects on tree growth and mortality in the region. Wang and Bauerle also remarked that periods of drought are predicted to occur more frequently, and with greater intensity, in the Southeastern United States under most global climate change models. To detail the relationship between drought and forest health at a regional scale, the researchers analyzed FHM/FIA phase 3 plot data from 1998 to 2001, another period of drought in the Southeastern United States, and assessed how drought severity affects patterns of tree growth, mortality, and crown condition (Klos and others 2007a). They used remeasurement data from plots in Alabama, Georgia, and Virginia to perform the analysis. The researchers employed mixed modeling to relate five dependent variables (annual growth rate, annual percent mortality rate, annual percent change in crown density, crown dieback, and foliar transparency) to a drought severity class (no drought versus mild, moderate, or severe drought) based on the Palmer Drought Severity Index. They included several variables to account for stand conditions: total basal area, tree density, tree species richness, percent slope, and stand age. They analyzed the dependent variables by tree species group (pine, oak, and mixed mesophytic species, including maple, birch, and yellow poplar) and drought severity class in order to identify, for each species group, any noteworthy differences between drought classes with respect to the dependent variables.

A key finding from the analysis was that the pine and mesophytic species groups displayed significant decreases in growth rate and increases in mortality rate with increasing drought severity, suggesting both groups are sensitive to

drought (Klos and others 2007a; Klos and others 2009). In contrast, the oak group exhibited no significant difference in growth or mortality rate due to drought severity, suggesting that the group is drought-tolerant. The analysis did not detect a significant change in crown condition due to drought, but the researchers described the difficulty in discerning a meaningful signal from the crown condition variables over a short measurement interval. Regardless, their results suggested that, if droughts are likely to be more common and/or intense in the Southeastern United States due to climate change, forest managers might anticipate a subsequent region-wide shift in species composition.

Project SO-EM-06-03: Modeling Drought Effects on Forest Health in the Southeast—An Analysis at the Sub-Regional and Regional Level

An associated study (W.L. Bauerle and G.G. Wang, investigators) examined the impact of drought on forest carbon balance in Southeastern United States forests using MAESTRA, a spatially explicit biological process model that integrates environmental, forest structure, and tree-level physiological variables to simulate a response to a factor of interest. The researchers again used remeasurement data from FHM/FIA phase 3 plots in Alabama, Georgia, and Virginia, this time for 1991-2005 and focusing on a single species, red maple (*Acer rubrum*). They again employed mixed modeling to relate drought severity class to annual growth rate and, in turn, identify any significant differences in mean growth rate between the drought classes. For the MAESTRA model, the researchers simulated a 100-tree stand of red maples in three size classes (small, medium, and large trees). They incorporated real-world hourly weather data for 1998-2005, and calibrated soil moisture deficit, a key model parameter, to drought severity class. The researchers then used MAESTRA to simulate the effects of droughts of different severity on annual growing season carbon gain.

The researchers found no significant difference in net carbon gain between the non-drought, mild drought, and moderate drought classes (Klos and others 2007b). However, carbon gain under severe drought was significantly lower than that seen with the other three classes, at approximately one-third of the gain observed under a condition of no drought. The results suggest that if droughts become more intense in the Southeast due to climate change, growth and productivity of some tree species could decline, with a detrimental effect on sequestered carbon. The researchers acknowledged that the MAESTRA model was calibrated for red maple as a test case, but argued that it could be similarly parameterized for other species to determine a regional response to climate change.

Project WC-EM-06-03: Ecological Impacts of Drought Stress in Alaska Birch Stands

Alaska has been experiencing a change in climate, with well-documented increases in mean annual temperatures, maximum daily temperatures, minimum daily temperatures, growing degree days, and duration of the frost-free season. The summer of 2004 in the south-central portion of the State was consistent with this observed warming trend, with record hot and dry weather across much of the region. Similarly, in August 2005, a massive high-pressure cell persisted over much of the State, causing record and near-record temperatures along with low precipitation levels. The result was two consecutive years of below-normal August rainfall. Forest health professionals believed they were beginning to observe effects of this continued warming and drying in Alaska's boreal forests. In 2003, numerous Alaska birch (*Betula neoalaskana*) trees in urban and suburban landscapes had begun to exhibit symptoms commonly associated with drought stress (e.g., scorched leaf margins, beginning in the tops of tree crowns; early leaf fall; mortality of individual trees and small groups of trees). In 2005, similar symptoms were observed for the first time on birch trees in native forest stands, and FHM aerial surveys documented substantial acreage of birch forest exhibiting crown thinning. Site visits indicated that these birch stands had produced leaves a fraction of their normal size or none at all, suggesting acute drought stress.

A 2006 EM project (R.A. Ott, investigator) explored the factors behind this documented crown dieback of Alaska birch. The study had three objectives: (1) to characterize site conditions where drought-stressed stands of Alaska birch were identified; (2) to characterize the nature of drought stress conditions in overstory trees in Alaska birch stands; and (3) to determine the extent to which insect pests may have been associated with drought stress conditions in these stands. Two days of aerial surveys were conducted in the early spring of 2006, the time of birch leaf-out in south-central Alaska. Aerial surveyors identified and mapped birch stands that had thin crowns or were not leafing out at all. These symptoms were assumed to be associated with drought stress, because significant defoliator activity would not have occurred so early in the season. A total of 622,400 acres (251 876 ha) were aerially surveyed, mostly in the vicinity of Anchorage and north along the Glenn Highway to the town of Wasilla, and 3,800 acres (1 538 ha, 0.6 percent) were classified as stressed. The majority of stressed forest stands were composed of Alaska birch. Site visits to stressed and adjacent healthy birch stands were conducted from mid-July through August 2006, and 18 birch stands (10 stressed, 8 healthy) were sampled.

Compared to healthy birch stands, unhealthy stands had larger diameter trees, lower tree densities, smaller basal areas, and

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less canopy cover. Unhealthy birch stands were older and many trees had extensive internal decay. In unhealthy stands, 86 percent of overstory trees exhibited dieback (>5 percent crown mortality); average mortality of those tree crowns was 46 percent. In healthy stands, 30 percent of overstory trees exhibited dieback; average mortality of those crowns was 6 percent. Drought stress was likely a factor in the apparent sudden decline of these birch forests, but stand age and history were also implicated as contributing variables to the overall decline of these stands. The apparent decline of open-canopied birch stands in response to warmer, drier summers is consistent with predictions of climate change impacts on Alaska's boreal forests.

Project WC-EM-07-01: Yellow-Cedar Decline: Evaluating Key Landscape Features of a Climate-Induced Forest Decline

Yellow-cedar (*Callitropsis nootkatensis*) is a culturally, economically, and ecologically important tree species in coastal Alaska. Widespread mortality of the species, known as yellow-cedar decline, has been occurring in the southeastern portion of the State for about 100 years. Annual FHM aerial detection surveys have delineated nearly the entire distribution of the problem, which totals over 500,000 acres (200 000 ha) in Alaska. While this broad-scale approach has been useful in determining the general occurrence of this forest decline, mapping from aircraft produces large polygons that are too coarse for practical evaluation of relevant landscape features. The investigators for this project (P.E. Hennon and D.T. Wittwer) argued that a finer spatial scale was required to test associations of the decline with factors such as slope, elevation, and aspect.

The researchers chose Mount Edgecumbe on Kruzof Island near Sitka, AK, as a location to conduct mid-scale analysis of yellow-cedar decline. Mount Edgecumbe is a dormant volcano with radial symmetry and wet plant communities that likely support abundant yellow-cedar at a range of elevations. The project had the following objectives: (1) to compare the occurrence of yellow-cedar decline as mapped by aerial survey and from aerial photographs; (2) to determine the association of elevation, aspect, and slope with the presence of yellow-cedar decline; and (3) to develop methods to detect healthy yellow-cedar populations. A secondary phase of the project modeled snow accumulations in order to identify future suitable habitat on Mount Edgecumbe for yellow-cedar.

Aerial survey methods and photo interpretation documented yellow-cedar decline in similar locations, but with widely different spatial results (Wittwer and others 2008). Photo interpretation produced about 25 times the number of

polygons of yellow-cedar decline, but only about 25 percent of the acreage compared to aerial survey. Thus, the two methods differed in their spatial resolution of the problem, with aerial photography producing a more resolute map, which was used for subsequent landscape analyses. Elevation, aspect, and slope were all associated with the occurrence of yellow-cedar decline. Foremost, the decline problem appeared to be largely restricted to low elevations, with considerably less decline above approximately 600 feet (183 m). The researchers also detected an elevation-aspect interaction, where yellow-cedar decline occurred at higher elevations on warmer, southerly aspects than on northerly aspects. In addition, decline was associated with gentle slopes compared to steep slopes.

Helicopter surveys produced a reliable method for detecting yellow-cedar in apparently healthy forests at higher elevations; this represented the first successful remote sensing approach for verifying the amount of yellow-cedar in healthy forests. A kriged map produced from the helicopter survey points indicated a substantial population of healthy yellow-cedar above the decline zones, and ground checks verified the results of the surveys. Thus, the researchers' sampling approach to detect live and dead yellow-cedar forests incorporated an increasingly detailed hierarchy of detection methods: aerial detection surveys (i.e., sketch mapping), air photo interpretation, helicopter surveys, and ground plots.

The project results supported the contention that patterns of snow accumulation dictate the health of yellow-cedar forests. In the second phase of the project, the researchers used GIS tools applied to gridded climate data, a new elevational adjustment technique, and general circulation models to produce snow accumulation models for Mount Edgecumbe (Wittwer and others 2009). Output maps included estimated snow patterns in the early 1900s to the present as well as future predictions to 2080. A conservative general circulation model (i.e., under a B2 emissions scenario, with greenhouse gas emission levels projected to increase continually but slowly) was used for future predictions. The amount of annual snow accumulation sufficient to protect yellow-cedar, using the current distribution of yellow-cedar decline as a benchmark, was determined and shown in each of the past, present, and future scenarios. The maps showed substantially more snow in the early 1900s, but shrinking zones of adequate snow to the present and into the future. By 2080, little of Mount Edgecumbe was projected to have sufficient snow to protect yellow-cedar from the root freezing injury, represented by only a small area near the cone of the dormant volcano. The principal investigators are now looking to extend these approaches to the entire distribution of yellow-cedar in coastal Alaska.

Summary of Key Findings

- Using aerial photography to map changes to coastal forest vegetation in the Big Bend region of Florida during a 6-year period, Barnard (SO-EM-98-01) found modest evidence of inland forest retreat and increased stress in some forest stands. While modest, the observed changes are consistent with expected impacts of sea-level rise, the rate of which has been predicted to increase due to climate change.
- Examining historical dieback episodes in northern hardwood forests, Auclair and Heilman (NE-F-01-01) discovered that snow-pack depth was consistently associated with onset of, and recovery from, dieback. Their work provided a simple model for projecting future dieback incidence in northern hardwoods, while also demonstrating the potential for archived climate and forest health data to provide effective forest management decision support.
- Evaluating forests in the Southeastern United States, Wang and Bauerle (SO-EM-04-01) determined that pine and mesophytic species are drought-sensitive, displaying decreased growth and increased mortality with increasing drought severity, while oak species are apparently drought-tolerant, exhibiting no significant difference in growth or mortality rate due to drought severity. Their results suggest that, if droughts are likely to be more common and/or intense in the Southeastern United States due to climate change, forest managers might anticipate a subsequent region-wide shift in species composition.
- Using red maple in the Southeastern United States as a test case, Bauerle and Wang (SO-EM-06-03) ascertained that annual growing season carbon gain was significantly lower under severe drought than under moderate, mild, or non-drought conditions. Their results suggest that if droughts become more intense in the Southeast due to climate change, growth and productivity of some tree species could decline, with a detrimental effect on sequestered carbon.
- Investigating sudden and widespread incidence of dieback in Alaska birch (*Betula neoalaskana*) forest stands, Ott (WC-EM-06-03) concluded that drought stress was likely a major factor, with stand age and history also implicated as contributing variables. Notably, this apparent decline in response to warmer, drier summers is consistent with predictions of climate change impacts on Alaska's boreal forests.
- Mapping and analyzing yellow-cedar decline in coastal Alaska, Hennon and Wittwer (WC-EM-07-01) found that decline was generally more prevalent at lower elevations and on gentler slopes, but also extended to higher elevations

on warm, southerly aspects. Their results support the contention that snow accumulation protects yellow-cedar forests, primarily by buffering soil temperatures and preventing fine-root freezing injury. However, the researchers projected that annual snow accumulation could diminish to insufficiently protective levels, for at least some Alaskan locations, under climate change.

Utilization of Project Results

These EM projects have yielded insights about climatic factors related to specific, regionally noteworthy forest health issues. Some of these insights have subsequently led to publications in peer-reviewed and widely cited academic journals (e.g., Auclair 2005, Klos and others 2009). Such information also may be critical for forest health decision makers charged with crafting short- and long-term policies and practices. For instance, a conservation and management strategy for yellow-cedar, developed in part from the study by Hennon and Wittwer, is currently being implemented at locations in coastal Alaska. Information from the Mount Edgecumbe project is providing guidance on where to favor yellow-cedar management (Hennon and others 2008). For example, the Tongass National Forest recently conducted a planting project for yellow-cedar regeneration near Yakutat, an area known for considerable late winter snowpack. Other planting projects at higher elevation are planned for the next few years.

Suggestions for Further Investigation

The six EM projects completed between 1998 and 2008 focused on specific climatic factors, weather events, or both as forest disturbance agents. This is logical in the context of climate change; in particular, if climate change will cause hurricanes, droughts, or other weather events to be more frequent and intense, then forest managers will need tools and techniques to project the impacts of these disturbances on forest resources and to predict when and where they will occur. The projects presented here, particularly the project evaluating yellow-cedar decline in Alaska, suggest what may be possible given current data resources. For instance, a wide variety of spatially referenced data are available that describe recent and historic trends in fundamental climatic variables (e.g., National Climatic Data Center daily summary of weather station observations) and extreme weather events (e.g., National Weather Service storm events data, National Oceanic and Atmospheric Administration historical hurricane track data). Although these data vary in quality, reliability, and spatial and temporal scales, by examining their associated metadata, it is possible to understand limiting assumptions pertinent to their analysis. Moreover, many of these data have

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been summarized and filtered into more refined data products by other groups (e.g., monthly climate variable maps available from the PRISM Climate Group at Oregon State University, drought maps from the National Drought Mitigation Center).

At the same time, the quantity of FIA phase 3 data, as well as remeasurement data on FIA phase 2 plots, is growing nationally. These diverse data streams suggest the potential to relate forest health indicators to patterns observed in many climate-related phenomena, whether extreme events (e.g., ice, wind, or lightning storms) or broad climatic trends (e.g., the ENSO patterns highlighted by Auclair and Heilman). The previously described EM projects illustrated a couple of ways to relate climate to forest health while also offering some predictive capabilities. However, there is a clear need to expand the scope of such analyses, not only in terms of quantity and time frame of the utilized data but also in their geographic areas of interest. Foremost, more climate-related EM projects could be completed in the western conterminous United States. For example, many parts of the West have experienced severe drought conditions for the last decade or longer; while it is generally understood that this has impacted pine-juniper woodlands severely, analyses about the effects in other forest types would be informative. Perhaps more critically, there may be potential to construct informative models of future climate-related disturbances simply by linking current and historic observations to trends anticipated under various climate change scenarios. The calibration of spatially explicit, high-resolution climate data (which typically span only about the last 120 years) using sparse but long-term data (e.g., dendrochronological data) may better enable such analyses.

Climatic conditions indirectly affect forest health through their influence on biotic (e.g., insects and diseases) as well as abiotic (e.g., wildfire, atmospheric pollution) disturbance agents. Although there have been recent EM projects relating emerging pest problems to climatic factors, there may be opportunity to expand the scope of such analyses given the available data streams. For instance, the several years of insect and disease aerial survey data compiled by the Forest Health Technology Enterprise Team might be analyzed nationally or regionally in relation to mapped drought data or storm events data. With respect to pollutants, it may be possible to construct better regional models of ozone injury to forests by including drought as a covariate. To cite another example, previous studies of climate-pest interactions have often employed variables that broadly summarize climatic conditions (e.g., annual means or extremes), thus inadvertently marginalizing important phenological (i.e., seasonal) patterns that, if included in new analyses, might enable better impact predictions. Regardless, as with analyses of climate or weather events as direct disturbance agents, there seems to be good potential for making projections with respect to future climate-pest or climate-pollution

interactions, or the combination of both, by linking historic and current data to patterns expected under likely climate change scenarios. Such work could be pertinent for initiatives such as the National Insect and Disease Risk Map, which does not currently incorporate climate change. Furthermore, since geographic patterns of forest disturbance might shift dramatically under climate change, it is also important to consider how cross-border analyses related to climate might fit within the EM mission.

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CHAPTER 17

Fire Effects

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In the time covered by this synthesis, researchers of five Evaluation Monitoring (EM) projects under the national Forest Health Monitoring (FHM) Program of the Forest Service, U.S. Department of Agriculture, explored approaches to better understand the role and effect of fire, specific targets for determining the ecological and economic effects of fire, and the relationship of fire to forest health conditions. Since fire is strongly related to forest health in ecological, social, cultural, and political ways, investigations of fire effects must also be multifaceted. Furthermore, quantifying the spatio-temporal association of fire and fire effects represents a constant work-in-progress. Changes in management activity, climate conditions, and stochastic patterns of disturbance in natural forests present challenges to the development of overarching predictive models. As fundamental and applied research efforts contribute results, models will improve and corresponding management decisions will rely on those advancements.

Project NE-F-01-07: An Interactive Web-Based Model for Estimating Fire-Related Characteristics Using FIA Data

The objective of this project was to develop a web-based model that allowed any user to produce estimates based on annualized data by the Forest Inventory and Analysis (FIA) Program of the Forest Service. The user could choose zone of interest, such as national forest or county, by accessing the tool through a web browser. The tool was intended to eventually apply to all areas of the United States with available annualized survey data. It was proposed that by the third year of the project, calculations were to include estimates of FHM phase 3 data, including both fine and coarse woody debris. Fine and coarse woody debris are of particular interest in studying fire behavior and understanding fire risk. These data were expected to be

available for public use by the third year of the project. We used open-source software to produce two versions of the tool named the Carbon OnLine Estimator (COLE).

Version 1.0 was based on Java, and, among other features, the graphical interface allowed the user to designate points by clicking on the screen (which featured a map) using their mouse. The user could either develop a polygon or designate the center of a circle, and estimates for all the plots within this defined area was calculated. The tool worked for all States for which data were available. This was an easy-to-use tool, but many users, especially within the U.S. Forest Service, had difficulties using it because of the relative newness of Java applets and relative slowness of Java-based numerical calculations. Because of these issues, version 2.0 was based around the R programming language for statistics with less use of Java. Additionally, a “COLE Lite” non-Java version was developed for those users who had difficulty accessing a Java-based web tool. The version 2.0 and Lite tools produce summary tables of volumes, biomass, and carbon, including carbon in coarse woody debris. Because these survey measurements were still not publicly available, estimates of total carbon (mass) of coarse woody debris were developed for each FIA plot. A version of COLE is available at <http://ncasi.umn.edu/COLE>. In 2009 COLE remained one of the most reliable, easy-to-use tools available on the web to produce carbon estimates from FIA data.

Project WC-F-03-01: Port-Orford-Cedar Mapping within the Biscuit Fire Area

Port-Orford-Cedar (POC), (*Chamaecyparis lawsoniana*), has a limited distribution, native to the Pacific coast in southwestern Oregon and northern California, within the area of the Biscuit Fire (2002). Much of the area burned experienced severe intensity fire, but the survival of POC had not been documented, and the specific locations of surviving populations of POC were not known. Further, a virulent root pathogen, *Phytophthora lateralis*, causes mortality of POC and can be introduced on firefighting equipment via infested soil or water. This project estimated the pre-fire extent of POC at 89,880 acres, and the amount purportedly infested with *P. lateralis* at 3,022 acres. The post fire extent of POC was

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21,273 acres (23.7 percent of pre-fire acreage), and *P. lateralis* was thought to infest 829 acres. Fire severity caused a stand replacement event on 46,000 acres occupied by healthy POC.

Project WC-F-05-06: Port-Orford-Cedar Mapping within the Biscuit Fire Area—Part 2, Follow-Up

This project followed the initial efforts of POC mapping in the area of the Biscuit Fire. The landscape pattern of fire severity and POC survival relative to soil was examined. According to post-fire mapping, POC was strongly associated with riparian areas. The pathogen *P. lateralis* can be most problematic in such areas where water drainage and transport can infect otherwise healthy POC. Areas of serpentine soils burned with greater severity than non-serpentine areas. Correspondingly, approximately 34 percent of POC acreage on serpentine soils was populated by dead trees, compared with 13 percent of POC acreage on non-serpentine soils.

Project NC-F-04-02: Effects of Prescribed Burning on Indicators of Forest Health in Oak Savannas and Woodlands of Iowa: Implications for Ecological Monitoring and Restoration

Oak savannas and woodlands represent ecologically valuable transition communities between the Eastern Deciduous Forests and the Great Plains. Land use change and alteration of the disturbance regime has compromised these oak and grassland communities. Today, < 1 percent of the original extent of savanna vegetation remains (Nuzzo 1986, Gobster and others 2000). Restoration typically has focused on reducing an encroaching overstory and instituting prescribed burning. This project aimed to establish a protocol for assessing the value of FIA Detection Monitoring (DM) on restoration based management activity. Specifically, the objective of this study was to evaluate the use of DM indicator measurements to quantify and monitor changes in soil quality, productivity, and forest health as influenced by thinning and burning degraded oak savanna ecosystems in central Iowa. Indicator variables identical to those collected on FHM phase 3 plots (i.e., understory vegetation, soils, overstory structure and mensuration growth, down woody material, crowns, damage) were monitored on DM plots following DM measurement protocols. Detection Monitoring and forest health indicators are described in the Introduction chapter of this document.

Restoration of oak woodlands requires opening the mid-story canopy through thinning and reintroduction of fire (McCarty 1998). Thinning and prescribed burning are expected to reduce

the presence of both shade-tolerant trees and exotic species and promote the establishment and maintenance of native savanna species in the understory. Long-term monitoring and evaluation are necessary to determine both the extent of these degraded woodlands and the effects of restoration practices on the structure, composition, and function of the targeted vegetation communities. However, little is known about the effectiveness of current indicator measurements to detect ecological responses to specific management practices and progress towards achieving short-term and long-term restoration goals. The investigation examined key ecological indicators of forest health and productivity (e.g., soil quality, growth rates, species composition, structure, water and nutrient cycling) to assess long-term ecosystem function, and to determine the extent of change by management. Variables range from the structural to the physiological for 6 years of regrowth following treatments. The project also aimed to determine the sensitivity of indicator variables to specific management practices in these ecosystems.

Project INT-F-06-04: Monitoring Tree Deterioration Following Stand-Destroying Wildfires

The project evaluated the process, rate, and causes of tree deterioration following stand-destroying wildfires in five tree species of the Rocky Mountain Region. The project evaluated losses of wood quality and economic value following fire-induced mortality associated with the exceptional fire year of 2002. Study areas were established in national forests in Wyoming, South Dakota, and Colorado. Species of interest were Engelmann spruce, subalpine fir, ponderosa pine, lodgepole pine, and Douglas-fir. The field methods included determining log weights for volume calculations, categorizing burn severity, taking samples for wood density determinations, and estimating wood boring beetle damage, amount of decay, and staining.

This 5-year effort provided an opportunity to study deterioration of wood quality and quantity over time. Emergence traps were placed in 2003 for quantification and identification of wood-boring insects. Sampling and isolation of decay-causing fungi important for each species took place in 2006 and 2007.

Decay as measured by decrease in block density from 2002 to 2004 varied among species and with fire. Greatest decrease in log weight was observed in ponderosa pine from the Bucktail Fire at the Uncompahgre National Forest. Log weight decreased the least in Douglas-fir from the Hayman Fire at the Pike National Forest. The decay fungus *Coniophora puteana* was the most frequently isolated fungus from the

wood samples. Area covered by visually detected sap rot was near zero in 2002 and 2003 but increased sharply in 2004 in Engelmann spruce, ponderosa pine, and Douglas-fir. Damage and evidence of wood boring beetles were apparent as early as 2002, and increased up to 4 years following fire.

Project NC-F-05-01: Effects of Prescribed Fire on Oak Pests and Invasive Plant Species

Fire in forests of the Missouri Ozarks has varied from long interval natural fire to prescribed frequent fires that were used as a management tool. Further confounding the role of fire as both a disturbance and as a tool are the years of oak decline, concomitant with or attributed to droughts, insects, and pathogens. Long-term mortality of oaks contributes to increasing fuel loads but an understanding of the etiology of oak decline generates questions about the potential use of prescribed fire (i.e., if prescribed fire had been used in the past, the predisposing factors of oak decline might have been avoided). This project addressed the biological impacts and political importance of fire and how the local landscape features influence fire characteristics. It also aimed to provide understanding of the related factors of hazardous fuel reduction and ecological restoration of the Ozark forest ecosystems.

Despite the use of prescribed fire to achieve various silvicultural goals, the practice of burning in upland Ozark forests raises many questions, (e.g., attaining objectives, indirect impacts, long-term effects and potential damage). This project examined the effects of prescribed burning at the individual species level and the stand/community level by examining fire scars, overstory tree vigor and damage, and ground flora vegetation in the Missouri Ozarks.

For determining the potential damage by prescribed fire, regression analysis revealed that stem bark char height, a proxy for fire intensity, is the most effective postfire predictor of percentage of trees scarred and extent of scarring. Landscape features such as aspect, fetch, and slope steepness were also important predictors of extent of scarring for some species.

Fire influenced structural components of the overstory vegetation primarily through differential tree scarring and losses of vigor. Insect activity, particularly red oak borer (*Enaphalodes rufulus*), was associated with stands that consisted of high density of suppressed trees. Understory vegetation was assessed in forests that had been subjected to prescribed burning. Grass cover was highest in burned stands, and tree seedling cover was highest in stands burned 1 year before sampling.

Summary of Key Findings

NE-F-01-07—The Carbon Online Estimator (COLE) was developed to allow any user to produce carbon and dead wood estimates based on FIA annualized data. It incorporates other ecological data to enhance accuracy. Reports can include statewide and county level summaries. With contributions of additional FIA phase 3 data, e.g., measured down woody debris, a more accurate examination of carbon stocks will be possible.

WC-F-05-06—It is possible to predict potential fire severity and damage to a species of concern (Port-Orford Cedar) based on soil type, i.e., serpentine versus non-serpentine. The project demonstrates the importance of integrated efforts by using GIS, fire date, pathology and botanical reconnaissance, to understand the range of fire effects while focusing on the fate of a species.

NC-F-04-02—Although thinning of oak woodlands modified the stand structure in woodland and savanna restoration, there was no positive effect on oak regeneration. Rather, non-desirable species encroached. Intervention management, e.g., eliminating encroaching species, would be possible but could only be verified by additionally monitoring the restoration status. A modified FIA sampling design was replicated across eight sites, but only then was it possible to document vegetation change. That level of replication was necessary for resolving differences in treatment. Direct effects of fires were not discernable using these methods.

NC-F-05-01—Fire intensity in the Ozark Highlands of Missouri can be inferred by examining bark char, and, therefore, the results can be used to related damage to specific levels of intensity. Post-fire examinations are facilitated through this approach, and bark char and damage can be suitable predictors of subsequent damage. Landscape characteristics also play an important role in extent of damage, presumably because of the influence of topography on fire behavior. Vegetation responses and influences of insect pests are strongly associated with type of fire and frequency of fire. Tree vigor in scarlet oak (*Quercus coccinea*) was negatively correlated with fire injury, but there was no difference in tree vigor in burned and unburned stands. Tree vigor of black oak (*Quercus velutina*) was higher in burned stands, although the difference may not be biologically significant.

INT-F-06-04—In Rocky Mountain tree species of commercial importance, density of wood boring beetles, although present at the time of wildfire, showed increasing trends up to 4 years following fire, when it reached a peak. Over a relatively short time following fire, i.e., under 5 years, up to 50 percent weight loss occurred in some tree species. The degree of deterioration, and consequently value loss, varied among the nine wildfires and with species.

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Utilization of Project Results

The interactive Web-based tool developed through this project was successful. In 2006, COLE was named in the Federal Register as the official U.S. Web tool for forest carbon estimates for the 1605b Voluntary Reporting Program Update, an Executive Branch effort led by the Department of Energy. In terms of usage, in November 2008, there were 588 hits on COLE and 100 hits on the COLE User Manual. COLE continues to be updated and used for estimating fire-related forest characteristics and for quantifying carbon stocks. The full version 2.0 and Lite tools produce summary tables, reports, and maps of volumes, biomass, and carbon, including carbon in down dead wood. Summary products from the simulator contribute to economic or ecological modeling and assessment as well as management scenarios.

The mapping of Port-Orford-Cedar within the Biscuit Fire Area revealed the value of using immediate post-fire aerial photos to evaluate the area of unburned forest. This approach created an opportunity to explore soil-fire relationships as well as location of species of limited distribution, providing a fundamental ecological picture of the species and system. Predictions of fire effects on uncommon species and associated pathogens have been rarely explored, and a careful, well-timed effort might enhance predictions. Potentially this approach could be used for the pathogen—host examination alone, even in the absence of fire.

There is critical research to be done in validating indicator variables and determining the sensitivity and utility of such variables. In practice, when using a national monitoring approach, validation needs to be conducted across habitat and vegetation types. The attempts to determine the sensitivity of indicator variables used in FIA data collection, and to validate these indicators for specific management practices in Midwestern oak savanna/woodlands represent one such approach. The findings reveal that standard FIA methodology is useful only if study area is sufficiently large to accommodate subplots.

Fire effects research has described specific losses of economic value of trees when a stand has been managed with prescribed fire. The resulting model includes identifying the trees that are likely to scar and potentially decay, based on species and topographic position (Stevenson and others 2008). Models developed from this study can aid managers in assessing potential injury to trees based on landscape features and fire intensity. Results of this project provide management recommendations for stand improvement thinning and harvesting guidelines. Finally, it contributes to fire effects literature by describing the response of vegetation to varying fire intervals.

Variability of tree deterioration and marketability following wildfire is great, and, therefore, these factors must be assessed on a species level and regional basis. The project examining deterioration of five species in the Rocky Mountains provides an understanding of the economic effects of fire of varying intensities over a wide area. This information provides managers a generalized time frame through which salvage activity can be conducted and a species level opportunity to focus post-fire management practices.

Suggestions for Further Investigation

Suggestions for continued improvement of the COLE web tool include: an outside review of current Web sites that provide access to FHM data to ensure user satisfaction; improved coordination with major partners to focus on timely access to the data and quality resulting estimates; augmentation of the COLE site to use FIA plot-based measurements of down woody data to produce estimates more directly useful about fuels loading; and development of a companion site that allows users to submit their own inventory data with the new tool producing useful statistics on fuels loading and carbon.

Findings from the fire effects field-based research underscore the importance of examining relationships that are not well established, but might be critical for species persistence or for overall forest vigor, e.g., productivity and maintenance of species diversity. Continued research into forest health-related issues, such as the root pathogen associated with Port-Orford Cedar, can be revealing about new perspectives on fire effects. There remains a need for more investigation into fire severity associated mortality and damage relationships.

Continued refinement of FIA-style protocol and indicator variables for non-closed canopy forest ecosystems should occur. Detailed analysis of soil carbon effects from restoration management could be included in these investigations. There is a need to specifically identify the effects of fires and the utility of the FIA style approach for plot design as well as the relevance of specific variables. The project represents only the first step in a long process of understanding the use of FIA or other monitoring data in various ecosystems and under varying practices or natural disturbances.

With increasing importance of prescribed fires, fuel reduction and long-term vigor of overstory trees, there is a need to develop site specific management guidelines, restoration approaches and continual assessment of economic and ecological effects of fire as a management tool. The value of empirical field data cannot be understated, when such data are central to the eventual development of robust models. Related research has yielded a theoretical rotation age

assessment based on insect activity that can strongly apply to much of the Ozark forest (Guyette and others 2007). If combined with fire effects on tree vigor, highly specific management recommendations could be made. Such models are necessary when evaluating fuel accumulation, establishing fuel management guidelines, and conducting fuel reduction practices. Long-term data are necessary for evaluation and demonstration purposes, and to understand larger scale consequences on forest productivity and ecological processes (Voelker and others 2006).

With regard to quality losses of timber caused by wood decay and general deterioration following fire, there are many opportunities to focus specific research efforts. Fungal isolation to determine the identity and colonization sequence of decay fungi would be highly valuable and provide bio-specific targets that can influence timing of salvage activity or can influence whether salvage should be considered. Similarly, continued examination of beetle species (the entire guild) and assessing which species account for population increases in the wood boring beetle community following fire should be conducted. Quantifying the value of resources and economic loss from all these factors would complete an integrated project on post-fire biodegradation and economic loss. Furthermore, a more broadly developed approach to determine species and regional differences with regard to fire effects on wood quality remains critical. There is ample economic and ecological justification for studying which agents of deterioration are active after fire and the duration

of their activity. Variation within and among regions is great and this variation might challenge refinement of scientific investigation; however, generalized findings that contribute to improved understanding and management are likely to result from further study.

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CHAPTER 18

Ozone

Anita K. Rose¹

Ozone is the product of chemical reactions that take place in the lower atmosphere when volatile organic compounds mix and react with nitrogen oxides in the presence of sunlight. Ozone exposure, uptake, and sensitivity all play important roles in the response of plants to ozone. Weather patterns and changes in emissions of precursors account for a majority of year-to-year variations in ozone exposure. The uptake of ozone by plants depends upon many things, including physiological age, climate, light availability, site characteristics, and available soil moisture (Peterson and others 1993, Bartholomay and others 1997, Samuelson and Kelly 2001). Sensitivity to ozone varies by species, genotype, physiological age, and leaf morphology. Several species, such as black cherry (*Prunus serotina* Ehrh.) and blackberry (*Rubus allegheniensis* Porter), are known to be sensitive to ozone and exhibit a visible foliar response. In addition, reduced growth and decreased species richness have been reported from studies of ozone impacts to plants (Arbaugh and others 1998, Barbo and others 1998, Bartholomay and others 1997, McLaughlin and Downing 1996, Rebbeck 1996, Reinert and others 1996, Samuelson and Edwards 1993, Somers and others 1998).

Despite the seemingly large amount of research on ozone exposure and ozone impacts to plants, there are still several key unknowns (see reviews by Bytnerowicz 2002, Chappelka and Samuelson 1998, Karnosky and others 2007, Kickert and Krupa 1990, Krupa and others 2000, Samuelson and Kelly 2001). The more elusive issues are the relationship between ambient ozone and foliar injury, the relationship between foliar injury and physiological response (i.e., reduction in photosynthesis), and the effect of ozone on growth. Complicating the exposure-response issue is the existence of multiple ozone exposure indices (i.e., SUM00, SUM06, W126) and the uncertainty surrounding variation in ozone exposure at the regional, local, and microsite scale. The SUM00 index is calculated by multiplying all hourly concentrations by time. Similarly, the SUM06 index is derived by multiplying the number of hours when the ozone concentrations stayed above 0.06 parts per million (ppm). The W126 is a weighted index with higher concentrations having higher weights (Bytnerowicz and others 2008).

Further complicating this issue is the questionable usefulness of ozone exposure indices to accurately reflect the effective ozone flux experienced by vegetation. While physiological responses in the form of reduced growth or biomass have been confirmed for some species, these studies have been mainly from controlled chamber studies, which may not directly translate to plant response in the natural environment. In addition, ozone sensitivity within species is quite variable and complicates interpreting results. The result is that cause and effect relationships have been difficult to confirm.

Between 1998 and 2008, seven ozone Evaluation Monitoring (EM) projects were funded under the national Forest Health Monitoring (FHM) Program of the Forest Service, U.S. Department of Agriculture. Five of them fell into the general category of ozone effects on plants. While many species have been tested for sensitivity to ozone, the list is far from comprehensive. Awareness of which species tend to exhibit consistent foliar injury is a key factor in successful large-scale biomonitoring surveys. One project (NE-EM-00-01) was initiated to determine the sensitivity of several species that were suspected to be sensitive based on field observations. Some studies have suggested that visible ozone injury and growth reductions are correlated in some species. The need to test this correlation *in situ* resulted in four of the EM projects (SO-EM-01-01; NE-EM-99-02; WC-EM-99-05; SO-EM-00-04). By comparing sensitive and tolerant individuals within the same species, three of the studies examined the genotypic variability that exists in ozone sensitivity (SO-EM-01-01; WC-EM-99-05; SO-EM-00-04). One study attempted to determine the impact of foliar injury on photosynthetic capacity (SO-EM-00-04).

Two of the EM projects addressed exposure issues. While a large network of ozone monitors currently exists across the United States, ozone varies across the landscape. Predicting the exposure at the regional level utilizing existing data was the topic of one of the funded projects (NE-EM-98-04). One way to better predict exposure at the local level is sometimes accomplished using passive ozone samplers, which were employed in another project (WC-EM-05-03).

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Project NE-EM-00-01: Determining the Ozone Sensitivity of New Bioindicator Species for the Biomonitoring Program

This study was part of a larger project at Pennsylvania State University to evaluate species for ozone sensitivity in controlled fumigation studies and determine validity of field observations. Demonstrating a linkage with the national ozone biomonitoring program of the Forest Inventory and Analysis (FIA) Program of the Forest Service, this project was initiated because field personnel were finding species with ozone-like injury that were not previously recognized as sensitive to ozone. This led the principal investigators to suspect that many more species than previously known develop ozone-induced foliar injury. This project is directly applicable to ozone biomonitoring data collection, because as the number of species increases, so does the likelihood that the crews will find and inspect the minimum number of species at a given site, and this, in turn, increases the number of potential biomonitoring sites.

Thirteen species native to the Northeastern United States were tested for ozone sensitivity in chambers utilizing four repetitions of four ozone exposure treatments [30, 60, 90, and 120 parts per billion (ppb)] and a control (Orendovici and others 2003). At 30 ppb little or no foliar injury was detected on any of the species tested. Ten species began showing symptoms at 60 ppb. Two of the 13 species became symptomatic at 90 ppb. Only one of the species tested did not become symptomatic until the 120 ppb level. Foliar injury was typically chlorotic spotting, upper leaf stippling (most reliable symptom), discoloration, dead patches, reddening, and early leaf death.

Two species, swamp milkweed (*Asclepias incarnate* L.) and winged sumac (*Rhus copallina* L.), showed the greatest potential to be ozone bioindicators. However, the authors caution that chamber studies do not always fully represent natural conditions, and these results may need further investigation. One species, pawpaw (*Asimina triloba* (L.) Dunal), was nonspecific for ozone injury and needs further investigation before drawing conclusions. Of particular note in this study was the variability among seedlings within species (i.e., several seedlings had severe injury, while others were asymptomatic). This may be the result of genetic variation in sensitivity. This project is particularly noteworthy, because the majority of the species tested are now on the FIA supplemental list of bioindicator species and are used to identify areas where ozone injury occurs.

Project SO-EM-01-01: Impact of Ground-Level Ozone on Trees in the Great Smoky Mountains National Park

This *in situ* research was conducted in the Great Smoky Mountains National Park, a Class I area. This designation, established in 1977 as an amendment to the Clean Air Act, affords greater protection to areas such as national parks that are greater than 5,930 acres (2 400 ha) in size. Building on an earlier study (Somers and others 1998), the principal investigator utilized black cherry and yellow-poplar (*Liriodendron tulipifera* L.) trees to determine if correlations exist (1) between ambient ozone concentrations and radial growth and (2) between ozone foliar injury and radial growth. To accomplish these goals, tree cores were taken from sensitive and nonsensitive individuals of the two species at three different locations within the park. Sensitivity was determined by the degree of foliar injury of each individual tree.

Growth differed significantly between locations for both species. Reasons for this may include site differences or differences in ozone exposure (Somers and others 1998). No growth differences for sensitive versus nonsensitive black cherry were detected. Growth differences between sensitive and nonsensitive individuals of yellow-poplar were not significant. This contrasts with a previous study (Somers and others 1998), when the growth differences between sensitive and nonsensitive yellow-poplar were significant. In that study, growth of sensitive yellow-poplar averaged 0.11 inches (0.27 cm) per year, while that of nonsensitive individuals averaged 0.13 inches (0.34 cm) per year. In the present study, sensitive individuals continued to have slower growth (0.16 inches (0.41 cm) per year) compared to nonsensitive individuals (0.17 inches (0.44 cm) per year), although the difference was not statistically significant. No location/sensitivity interactions were observed for either species.

Growth responses due to ozone exposure were only narrowly established with this study. However, one finding stands out: individuals of some species with foliar injury may respond with reduced growth when compared to uninjured (nonsensitive) individuals, while some species (e.g., black cherry) may not react in the same manner.

Projects NE-EM-99-02; NE-EM-00-02; NE-F-01-03: Ozone Effects on Plant Productivity and Population Dynamics in the Lake States; Ozone Effects on Common Milkweed and Black Cherry Productivity and Injury Dynamics in the Southern Lake States

Conducted in the southern Lake Michigan region, this *in situ* study demonstrated linkage to the FIA ozone biomonitoring program by utilizing the FIA ozone biomonitoring survey techniques and plots. The main objective was to assess whether ozone-induced foliar injury is correlated with productivity (branch elongation, plant height, or reproduction output) in black cherry and milkweed (*Asclepias syriaca* L.). This 3-year study utilized a network of 18 plots, with 9 located in an area of low ozone exposure (SUM06 <12 ppm-hours, average = 12.2, peak = 91 ppb) and 9 in an area of high ozone exposure (SUM06 >22 ppm-hours, average = 18.1, peak = 110 ppb). Ozone exposure was estimated using Environmental Protection Agency (EPA) hourly ozone data (Bennett and others 2006). To account for many confounding factors, several site and environmental variables, such as soil properties and rainfall, were included in the analyses.

Black cherry branch elongation was negatively affected by ozone exposure, while the number of seeds, height, and diameter were not, although this was not unexpected for the last two variables (Bennett and others 2006). For milkweed, the number of seedpods per plant was negatively affected by ozone, while plant height was not. The inclusion of the year-to-year and site-to-site variation in rainfall and temperature proved useful in explaining plant responses to ozone. Other variables, such as soil properties, varied significantly between the two ozone regions (especially percent nitrogen) and also were integral to the analyses. For black cherry, rainfall, percent soil nitrogen, and mean temperature departure were more important than ozone exposure for branch elongation. For milkweed, ozone exposure was more important than rainfall for percentage of stems with pods, but for height total soil nitrogen was more important, followed by ozone exposure.

This study emphasizes that different species have different ozone-responsive productivity measures, and that species respond to different environmental variables. In addition, rainfall and percent nitrogen in the soil proved to be possible interacting factors, highlighting the need to consider a wide variety of environmental variables when studying ozone exposure and productivity responses. Another important aspect of this study was the response to different ozone measures for the two species. Black cherry branch elongation responded to SUM06 ozone exposures greater than 13.3 ppm-hours. In comparison, milkweed height and pod formation responded to peak 1-hour

concentrations greater than 93 ppb and 98 ppb, respectively. The foliar ozone injury, which differed significantly between the low and high ozone sites, is the topic of a study currently in progress.

Project WC-EM-99-05: Evaluation of Ozone Foliar Injury and Bole Growth of Pines in Southern California

This study, located in the southern Sierra Nevada (Sequoia and Sierra National Forests), utilized data from plots that were installed in 1977 and 1978 and then measured every other year through 2000. The primary objective was to determine if trees with severe crown injury had different growth rates than trees with little or no crown injury. Both ponderosa pine (*Pinus ponderosa* Dougl. Ex Laws.) and Jeffrey pine (*P. jeffreyi* Grev. and Balf.) were studied. Presumably, these pines have similar ozone sensitivities, but there is some evidence that growth is correlated with ozone exposure for Jeffrey pine but not for ponderosa pine. Genetic differences, site, age, and stand dynamic differences may account for some of this. In California some ponderosa pine stands are located in areas with high nitrogen deposition, while Jeffrey pines tend to be located on sites with lower nitrogen deposition. This may partly explain the differences in growth response, as there is some evidence that the positive effects of nitrogen deposition can mask the negative effects of ozone exposure.² The analysis was done using data from cores that were obtained in 2000 from 15 pairs of trees (on 14 sites) based on historical and present crown position, present diameter at breast height, and average 20-year crown injury. Both severe and slight injury groups had significantly higher pre-pollution period basal area growth rates. Severely injured trees had significantly lower basal area growth after 1955 (relative to slightly injured trees), but changes in growth between time periods was not significantly different for the two groups of trees.

Project SO-EM-00-04: Ozone Impact on Sensitive Forest Tree Species

The objectives of this *in situ* project which took place in Giles County, VA, were to compare the photosynthetic capacity of tolerant and sensitive genotypes of black cherry exposed to ambient ozone concentrations and relate visible injury to carbon assimilation capacity. To achieve these goals, a variety of measurements were taken, including maximum net photosynthetic rate (Pn_{max}), stomatal conductance (gas exchange rates), chlorophyll fluorescence, chlorophyll content, and visible foliar injury.

² Personal communication. 2008. Andrzej Bytnerowicz, Senior Scientist, U.S. Department of Agriculture Forest Service, Pacific Southwest Research Station, 4955 Canyon Crest Drive, Riverside, CA 92507.

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Chlorophyll fluorescence revealed that ozone affected photosystem II (PSII) activity by reducing the maximum photochemical efficiency of PSII in sensitive black cherry by between 5 and 8 percent. In addition, the electron transport rate through PSII was significantly lower (28 to 55 percent) in sensitive trees compared to tolerant ones. Although chlorophyll content was the same between genotypes early in the season (June), by July, sensitive black cherry trees had 48 percent less chlorophyll than tolerant ones. In addition, as leaf injury increased, chlorophyll concentrations decreased ($R^2=0.95$) compared to noninjured leaves. At 25 percent leaf area injured, there was a 70 percent reduction in chlorophyll content.

Differences between gas exchange rates of sensitive versus tolerant trees were inconsistent across the study period. During 2001, stomatal conductance rates were the same for the two genotypes. In contrast, during 2003, conductance rates were 30 percent higher in tolerant black cherry in July but were 10 percent lower in August. This may, in part, have been due to the variation in weather and ozone exposure that occurred across the study period. In 2001, the early part of the summer was cool and relatively wet, while the later part was warmer than average and moderately dry; ozone concentrations were moderate. The year 2003, however, was extremely wet and cool with only moderate to low ozone exposure.

There was a significant progressive decline in Pn_{max} , of between 12 and 65 percent, in sensitive trees, compared to tolerant trees. In addition, Pn_{max} was correlated with leaf age and amount of visible injury. When young leaves were compared to mature leaves, Pn_{max} was reduced by 25 percent in tolerant trees and by 50 percent in sensitive trees. At 5.5 percent of leaf area with injury, Pn_{max} was reduced by 10 percent, and at 45 percent injury, it was reduced by 80 percent when compared to noninjured leaves.

In addition to reduction of Pn_{max} , both the quantum efficiency for CO_2 fixation and the carboxylation efficiency were significantly reduced between June and August for sensitive trees compared to tolerant ones, and thus both the light and dark reactions of photosynthesis were affected by ozone. Even in 2003, a year of fairly low ozone concentrations, carboxylation efficiency was 24 to 26 percent less in sensitive versus tolerant trees, highlighting the fact that under even low ozone concentrations carbon reduction processes may be affected substantially by oxidative stress. Early in the summer, maximum carboxylation was 25 percent higher in tolerant trees than in sensitive trees; however, by August, it was 250 percent higher, leading the author to conclude that the impact of ozone was much more severe on the dark reactions. In experiments conducted in 2003, under saturating CO_2 , the author determined that by late summer (August) there was 31 percent less ribulose biphosphate

regeneration capacity in sensitive versus tolerant trees. This means that sensitive trees had an approximately 25 percent less total capacity to fix CO_2 into sugars than tolerant trees. Although the implications are not yet fully understood, ozone-induced reductions of ribulose biphosphate and the enzyme that catalyzes carbon fixation (Rubisco) have been documented by other researchers (Bagard and others 2008).

The author concluded that ozone affected both the light and dark reactions of photosynthesis in sensitive black cherry. Although the impact to photosystem activity was substantial, the effect was greatest on carboxylation. The impact of ozone on photosynthetic activity could ultimately affect biomass accumulation, growth, and reproductive capacity.

Project WC-EM-05-03: Intensified Ozone Monitoring and Assessment of Ozone Impacts on Conifers in Southern California

To better understand ozone distribution and phytotoxic potential in the San Bernardino Mountains (SBM), this multi-year project used a variety of funding sources to install a network of passive samplers in the study area. These samplers allow ozone distribution to be characterized at the landscape or forest stand level. The linkage to the FIA ozone biomonitoring program presented the opportunity for the researchers to fill data gaps in areas where ozone biosites are scarce.

This study revealed that ozone concentrations in the SBM, although currently lower than in the 1960s and 1970s, are still some of the highest in the United States (Bytnerowicz and others 2008). Ozone concentrations increased from east to west. Ozone levels and distribution were fairly stable during the study period (2001-06). The ozone phytotoxic potential in the SBM, particularly in the Central and Eastern Transverse and Peninsular Mountain Ranges, is the highest among mountainous regions in the United States and Europe. The study also demonstrated that high elevation sites have a different diurnal pattern than low elevation sites. Ozone concentrations do not fall at night at the high elevation sites as they do at the low sites. This study also highlights the phytotoxic potential that currently exists in the SBM, despite decreasing levels of ozone.

Project NE-EM-98-04: Estimating Seasonal Exposures & Concentrations of Ozone for the Great Lakes Region

This study was initiated to aid in the determination of ozone exposures in the Great Lakes Region. Unfortunately, no

detailed information was available regarding this project. There was, however, reference to this project in the NE-EM-99-02 proposal: “ozone exposure studies conducted for the FHM program ... would be used to guide the site selection process.”

Summary of Key Findings

NE-EM-00-01—Many more species than previously known develop ozone-induced foliar injury under field conditions. Of particular note in this study was the variability among seedlings within species (i.e., several seedlings had severe injury, while others were asymptomatic). There was a strong association between cumulative ozone exposure and leaf injury; however, the amount of exposure required to cause symptoms and the progression of injury differed significantly between species.

SO-EM-01-01—No growth differences for sensitive versus non-sensitive black cherry were detected. Growth differences between sensitive and nonsensitive individuals of yellow poplar were not significant. Individuals of some species with foliar injury may respond with reduced growth when compared to uninjured (nonsensitive) individuals, while some species may not react in the same manner.

NE-EM-99-02; NE-EM-00-02; NE-F-01-03—This study emphasized that different species have different ozone-responsive productivity measures, and that species respond to different environmental variables. In addition, this study highlighted the need to consider a wide variety of environmental variables when studying ozone exposure and productivity responses. Another important aspect was the response to different ozone measures for the two species measured.

WC-EM-99-05—For the species tested, both the severe and slight injury groups had significantly higher pre-pollution period basal area growth rates. Severely injured trees had significantly lower basal area growth after 1955 (relative to slightly injured trees), but changes in growth between time periods was not significantly different for the two groups of trees.

SO-EM-00-04—Ozone affected both the light and dark reactions of photosynthesis in sensitive black cherry. Even under low ozone concentrations, carbon reduction processes may be affected substantially by oxidative stress. Although the impact to photosystem activity was substantial, the effect was greatest on carboxylation. The impact of ozone on photosynthetic activity could ultimately affect biomass accumulation, growth and reproductive capacity.

WC-EM-05-03—This study revealed that ozone concentrations in the San Bernardino Mountains, although currently lower than in the 1960s and 1970s, are still some of the highest in the United States. The study also demonstrated that high elevation sites have a different diurnal pattern than low elevation sites.

Utilization of Project Results

Project NE-EM-00-01 is particularly noteworthy, because 10 of the species tested are now on the FIA supplemental list of bioindicator species and are being used to identify areas where ozone injury is occurring. The confirmation of ozone sensitivity of these species under controlled exposure conditions proves cause and effect and validates the usefulness of these plants for biomonitoring practices. More species means more data records by plot and FIA region, thus improving the reliability of the plot-level injury index. The project findings were also used by researchers associated with the National Park Service to generate ozone sensitive plant lists for the assessment of foliar ozone injury on national parks (Porter 2003). From a policy perspective, FIA biomonitoring results, including data collected on the new species, helped to inform EPA staff in the most recent scientific review of the national ambient air quality standards for ozone. Furthermore, the Heinz Center for Science, Economics, and the Environment has used the biomonitoring data to develop quantitative tools for the benefit of natural resource managers responsible for the assessment of ecosystem response to changes in ozone air quality.

Suggestions for Further Investigation

Despite the wealth of knowledge that exists, and the obvious contribution that the funded EM projects have made, the effect of ozone on forest health is still not fully understood. As noted by investigators in project WC-EM-05-03, better biologically based indices of the phytotoxic potential of ozone are needed. The current network of ozone monitors does not adequately address the spatial and temporal variation in ozone exposure, particularly at the microsite scale (i.e., ozone exposure to trees in closed canopy forests). Another primary research need is a better understanding of the effective ozone flux to plants. Whether the primary issue is stomatal conductance, or other factors, as suggested in project SO-EM-00-04 and by Bagard and others (2008), needs investigation. Also needed are studies that measure the metabolic potential of plants to detoxify ozone and repair damage.

As suggested by EM project SO-EM-00-04, determining the effect of ozone on different aged leaves exposed to ozone for different amounts of time would improve estimates of ozone

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effects on canopy level photosynthesis and allow biomass loss estimates to be linked with visible injury. In addition, the increased impact of ozone to older leaves and the timing of episodes of high ozone exposure have implications for determining critical ozone levels.

EM projects NE-EM-99-02, NE-EM-00-02, and NE-F-01-03 underscore the need to include environmental variables in ozone studies. Their results suggest that studies investigating the role of rainfall and percent soil nitrogen in ozone injury are needed. In addition, they noted that the investigation of additional soil properties (i.e., magnesium, manganese, and copper) would be beneficial. The correlation between individual plant productivity and foliar ozone injury within a given ozone exposure also needs investigation. That black cherry responded to seasonal SUM06 values and milkweed to short-term peak values emphasizes the need to better understand the relative importance of long-term versus short-term ozone exposures, an issue that has been much debated.

Project SO-EM-01-01, which resulted in somewhat conflicting results from the previous study it was built on, emphasizes that long-term studies of ozone injury, exposure, and tree growth are needed. In addition, studies of growth rates in relation to ozone and climatic records should be conducted.

That chamber studies do not always fully represent natural conditions emphasizes the need for continued investigation of species sensitivities (NE-EM-00-01). In addition, there are many species that need further evaluation, such as pawpaw (as noted in NE-EM-00-01), while others, such as, southern red oak (*Quercus falcata* Michx.) and sweet birch (*Betula lenta* L.) have yet to be tested for ozone sensitivity.

The effect of the interaction between ozone and nitrogen is another area that needs investigation. Some research has shown that nitrogen may reduce sensitivity to ozone, while other studies have shown negative impacts, depending on the timing of exposure (i.e., sequential versus simultaneous) (Bytnerowicz 2002). In addition, whether nitrogen is supplied via the soil or the air as nitric acid vapor or ammonia could result in a different response.

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CHAPTER 19

Soil Conditions

Charles H. Perry¹

Soil scientists have evaluated linkages between forests and soils for many years (e.g., Alway and McMiller 1933). The traditional soil surveys of landscapes in the United States are purposive, selecting for analysis sites that are deemed representative “of an extensive mappable area” (USDA Soil Survey Division Staff 1993). By contrast, the Soil Quality Indicator by the Forest Service, U.S. Department of Agriculture, is a statistically-based survey of forest soils in the United States. The design and sampling strategy of the Soil Quality Indicator is powerful, and it lends itself to addressing questions at broader spatial scales than most other research programs. An additional benefit of the program is that field samples are archived for later and complementary analyses.

The Soil Quality Indicator collects information on several different aspects of the soil resource: compaction, erosion, physical properties, and chemical properties (O'Neill and others 2005). To investigate soils, five Evaluation Monitoring (EM) projects have been funded under the national Forest Health Monitoring (FHM) Program of the Forest Service. One project has evaluated soil compaction, three projects have examined variation in soil chemistry (including an assessment of soils in the archive), and one was a cross-indicator analysis with down woody materials (DWM) to quantify carbon stocks. There have been no funded investigations of erosion or soil physical properties.

Projects on Soil Compaction

NC-EM-03-02: Soil Compaction Effects on Site Productivity and Organic Matter Storage in Aspen Stands of the Great Lakes States—Visual evidences of compaction are reported on phase 3 plots, but links between soil physical properties, compactability, and observed levels of surface compaction do not exist. This project addressed the need to interpret the ecological significance of observed

compaction. Is sensitivity to compaction correlated with levels of compaction observed on phase 3 plots? Specific objectives initially included:

1. Identifying functional relationships between soil physical properties (e.g., texture, aggregate stability, soil organic matter, penetrability, shear strength) and levels of compaction reported on detection monitoring plots using digital soil survey data.
2. Developing spatial models of potential sensitivity to soil compaction based on soil physical characteristics, slope, and local hydrology by using digital models to stratify the region into soils that are at high and low risk for compaction.
3. Testing models by establishing experimental field plots on recently harvested and control plots within soils at high and low risk for compaction.

A review of the project's output (posters, interim reports, and manuscripts) indicates that objectives 1 and 3 were addressed.

Field crews installed FIA-like field plots on five national forests throughout the Lake States (Steber and others 2005, 2007;²). Plots in aspen (*Populus* spp.) clearcuts were paired with plots in adjacent unharvested landscapes. Field sampling occurred both on soils that are sensitive to compaction (loams, silts, and clays) and on those that are not (sands and sandy loams). The crews gathered visual evidence of compaction (USDA Forest Service 2007) and quantitative measurements of surface soil compression strength, bulk density, resistance to penetration, and saturated hydraulic conductivity [Steber and others 2005, 2007; (see footnote 2)]. Significantly, field procedures included both standard phase 3 protocols and additional methodologies for comparison.

The comparison of visual with quantitative measurements is particularly informative. Quantitative methods detected differences in compaction not discerned with visual observations collected with current phase 3 protocols (table 19.1). Steber and others (2007) also confirmed earlier observations by Amacher and O'Neill (2004) that an inexpensive pocket penetrometer measuring surface soil strength can be very effective at detecting compaction.

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² Kolka, R.K.; Steber, A.; Brooks, K.N.; Perry, C.H. In review. Harvest season, soil texture and landscape position influence soil compaction in northern Minnesota aspen harvests. *Canadian Journal of Soil Science*.

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Table 19.1—A comparison of plot condition group means based on soil risk level. ^{1, 2}

	Aspen clearcuts		Undisturbed stands	
	High	Low	High	Low
Visual assessment of compaction (percent)	63a	66a		
Surface soil strength (lbs/in ²)	33.6a	23.9b	5.3c	4.4c
Bulk density 0–4 inches (lb/ft ³)	103.0a	90.5b	78.0c	71.8c
Bulk density 4–8 inches (lb/ft ³)	103.0a	95.5a	88.0b	86.8b
Saturated hydraulic conductivity (ft/day)	9.45a	62.66b	28.61a,b	167.98c

¹ Adapted from Steber and others (2007).
² In each row values followed by different letters are significantly different at $\alpha = 0.05$.

The occurrence of compaction in the Minnesota’s aspen landscape is not limited to wetter toeslope positions. In fact, “both upper (summit) and lower (toeslope) topographic positions were susceptible to compaction in fine-textured soils when comparing summer versus winter harvesting” (see footnote 2). Landscape position does not have a similar influence on compaction in coarse-textured soils. Field research motivated by the compaction detected in the phase 3 plot network led the authors to recommend harvesting only in winter or on frozen ground for sites with fine-textured soils; coarse-textured soils would also benefit from these restrictions (see footnote 2).

Projects on Soil Chemical Properties

Project SO-EM-00-03: Examination of Nutrient Cation Status in Western Virginia Forests—The wet and dry deposition of chemicals from the atmosphere has a profound effect on the chemistry of forest soils. One of the principal effects is the depletion of exchangeable base cations from the soil profile (Lawrence and others 1999, Likens and others 1996). Continued calcium depletion in hardwood-dominated forests of the southeastern Piedmont will yield Ca stocks below those required for merchantable timber production in approximately 80 years (Huntington and others 2000), but quantitative studies of the base-cation status in forests of western Virginia are limited. Project SO-EM-00-03 addressed this gap in knowledge by examining linkages between the base status of forest soils, trees, and stream waters in western Virginia’s Shenandoah National Park.

Shenandoah National Park is underlain by three major geologies—siliciclastic (sandstones and shales), granitic, and basaltic—so sampling was stratified by bedrock lithology (Welsch and others 2001). Streamwater and soil samples were collected in 14 monitored watersheds. Tree cores of bole wood

were collected from northern red oak trees adjacent to the soil sampling pits; this was the most recent sample of wood tissue that did not contain active sapwood.

The effects of atmospheric deposition on soil chemistry varied with bedrock geology. The base saturation of surface and subsurface soil decreases across these lithologies: basaltic > granitic > siliciclastic (Webb and others 2002). Webb and others (2002) were among the first in southeastern forests to observe levels of Ca and Mg in wood tissue mimicking base cation availability in soil and export in streams. The observed levels of Ca and Mg indicate that the siliciclastic landscapes are especially sensitive to loss of base cations which poses particular concerns for forest and aquatic health in these areas (Cosby and others 2002).

Project NE-EM-04-03: Assessment of Forest Health and Forest Sensitivity to Nitrogen and Sulfur Deposition in New England—Project NE-EM-04-03 funded similar research but at a broader scale. The aerial survey program of FHM identifies areas of chronic defoliation, dieback, and mortality, and site-related factors may be involved, and project NE-EM-04-03 identified two objectives that would test this hypothesis:

- 1. Incorporating phase 3 plots into a regional assessment of forest sensitivity to atmospheric deposition of sulfur and nitrogen.
- 2. Evaluating current ecological indicators (crown health, growth, and mortality) at the plot level as a comparison between sensitivity and current health status.

No products exist to evaluate the outcomes of this funding support.

Project NC-F-05-04: The Distribution of Mercury in a Forest Floor Transect—In addition to acidifying cations, upland soils are sinks for the atmospheric deposition of mercury (Grigal and others 2000, Kolka and others 2001). Forest fires release mercury into the atmosphere when the forest floor is consumed while mercury concentration in the mineral soil may be unaffected (Amirbahman and others 2004). As industrial emissions come under increasing regulation, the contribution of forest fires to the mercury budget is an increasingly significant unknown. Project NC-F-05-04 funded the development of a spatial model of the mass of forest floor mercury on a transect spanning the Northern United States.

A transect across the northern coterminous United States was selected for two major regions because: (1) the investigators had relatively easy access to these data; the two soils Indicator Advisors are located in the North Central and Interior West regions, and (2) much of the deposition of mercury is believed to be related to industrial emissions which generally flow into the Northeastern region. The Interior West region should be relatively unaffected and the North Central Region should provide a transition.

Samples of the forest floor were collected as part of phase 3 sampling. The study team removed a small part of the archived sample (approximately 0.1 g) and determined the mercury concentration using cold-vapor atomic absorption. This concentration data was combined with the total mass and depth of the forest floor to estimate the mass of mercury stored in the forest floor.

Mercury amounts were highest in the northeastern part of the study region and the northern Rocky Mountains (Perry and others 2006, 2007a, 2007b). This bimodal distribution with high values in both the northern Rocky Mountains and the Great Lake States differs from earlier studies of Hg (Perry and others 2009a). Ecoprovince ($p < 0.001$) and latitude ($p = 0.006$) were both significant predictors of Hg concentration. Preliminary tests on subsets of the data suggested an important predictive role of forest-type groups.

Projects on Cross-Indicator Carbon Stocks

Project: SO-F-04-01: Duff and Litter Estimation for the Southeastern U. S.—Both the DWM and Soil Quality Indicators collect data on duff and litter accumulations. The DWM data are generally used for forest fuel analyses (Woodall and Monleon 2008) but scientifically credible estimators of bulk density are needed to best use DWM data for fire risk and fuel loading assessment. The original objective of this project was to obtain and summarize phase 3 soils data to develop needed auxiliary parameters to estimate

DWM for the Eastern United States. This objective was revised (Chojnacky and Amacher 2006, Chojnacky and others 2005) to developing a simple field technique for estimating forest floor carbon using litter depth.

Phase 3 soil sampling includes measurements of litter and forest floor thickness (USDA Forest Service 2007). After the accumulated thickness is measured, samples are collected and sent to a regional laboratory for chemical analysis. The result is a set of carbon concentration and soil depth values that can be combined to estimate carbon content per unit area.

The best model of carbon content ($R^2 = 0.56$) included duff and litter depth measurements, the geographic coordinates of the county center where the plot was located, dewpoint temperature, and ecological province (Chojnacky and others 2006). Unfortunately, this model could only be applied to the phase 3 plot network where duff and litter exist. A more widely applicable model was developed that included forest type (conifer versus deciduous forest), climatological data, and ecological province, but its performance was much reduced ($R^2 = 0.22$).

Utilization of Project Results

Three of the projects funded by the EM program were directly related to management, inventory programs, or both and as such, could be expected to influence future activities in the forest. The compaction project (NC-EM-03-02) was completed in partnership with five national forests: Chequamegon-Nicolet, Huron-Manistee, Ottawa, Chippewa, and Superior. The investigators shared their information with the forests and with the FIA program. Their recommendations to amend the Soil Quality Indicator's compaction protocols are under review. Early analyses of Hg are complete (Perry and others 2009a), but additional analyses will need to be completed and published before significant recommendations are available.

Additional soil/DWM cross-indicator analyses of carbon stocks have been published (Perry and others 2009b), but carbon estimation using the Soil Quality Indicator (SO-F-04-01) remains an open subject. The continued use of models to determine soil carbon stocks in national greenhouse gas reporting (US EPA 2009) illustrates the opportunities for research.

Summary of Key Findings

The research supported by EM funding generated several pieces of pragmatic knowledge.

Abiotic Stresses and Indicators

19. Soil Conditions

1. The phase 3 protocols for compaction assessment should be modified to include the use of a pocket penetrometer. This simple to use and inexpensive device detects significant soil compaction that is not detected with the current visual assessment protocols.
2. Soil compaction is related to the season of harvest, and this result is independent of landscape position in fine-texture soils. Aspen stands in Minnesota growing on fine-textured soils should only be harvested in winter when the ground is frozen.
3. Siliciclastic landscapes in Shenandoah National Park are especially sensitive to loss of base cations which poses particular concerns for forest and aquatic health in these areas.
4. Ecoprovince and latitude are significant predictors of Hg concentrations in the forest floor. Forest-type groups may also be significant predictors.
5. Carbon content in the forest floor may be roughly estimated from simple measurements of forest floor thickness and ancillary geospatial data.

Suggestions for Further Investigation

Surprisingly few projects have addressed the Soil Quality Indicator, so several methodological and science questions remain. From a methodological perspective, there are two broad categories of questions: (1) random versus purposive sampling designs, and (2) sampling protocols. The Soil Quality Indicator continues to be challenged in some professional circles: can a statistically-based soil inventory yield meaningful results? Increasingly, FIA-type plots are recommended at intensive research locations to facilitate extrapolation of local results to the wider landscape (Hollinger 2008). At the broadest scale, comparisons of the existing sampling design with other purposive approaches based upon expert opinion would be useful. Assessments of statistical power and detection limits would be informative as well. At fine scales, questions remain about the efficacy of the sampling protocols implemented on the plots. Is one mineral soil sample sufficient to define soil chemistry at the local site? Is 8 inches a sufficient sample depth to document soil carbon stocks and detect change? Bailey and others (2004) observed strong relationships between foliar chemistry and the B horizon, often found deeper than 8 inches. Relatedly, how does the answer to these questions change as the region of interest grows from the local site to the region and then the nation? Finally, the protocols need to be continually refined to address the pressing questions. Peatlands, for example,

store a tremendous amount of carbon (Batjes 1996, Gorham 1991), but the Soil Quality Indicator database does a poor job of representing peat soils because of shortcomings with the bulk density sampler. Current activity in the forest peat soils of Alaska will begin to address this omission, but additional protocol evaluation in critical areas of the northern United States (Minnesota, Michigan, and Maine) is essential.

Several science questions have been identified but not addressed during the EM proposal process. First, the Soil Quality Indicator samples plots at widely scattered locations in the landscape. Is it possible to fill the gaps between the plots, and how should this be accomplished? Second, roots are a significant carbon stock that varies across biomes (Jackson and others 1996), but they are not measured by the Soil Quality Indicator. Is there a method for measuring and/or estimating roots biomass on the plot network? Finally, what is the role of fire on soil carbon stocks? How does this vary across the many landscapes inventoried by the Soil Quality Indicator?

Five projects were reviewed to compile this summary. Of the five, the only projects with published outputs were those that included Indicator Advisors as collaborators. In fact, some funded projects did not submit posters to the annual Forest Health Monitoring Workshop. Clearly, the involvement of someone with a vested interest in EM increases the program's chances of receiving published research output. The ideas supported by EM funding are compelling and worthy of the resources dedicated to them. That said, the program frequently does not receive the outputs promised by investigators. Increased oversight from grant administrators might improve research output. In the absence of that, the collaboration of scientists with a professional interest in furthering the mission of the EM program results in published output.

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Summary

Borys M. Tkacz¹

Evaluation Monitoring (EM) has become a vital component of the national Forest Health Monitoring (FHM) Program of the Forest Service, U.S. Department of Agriculture. From the inception of the EM component in 1998 until 2007, over 150 projects were funded to address some of the most critical forest health issues facing the Nation's forest ecosystems. The projects funded by the EM program from 1998 until 2007 covered a broad range of forest health issues. Of the EM projects discussed in this report, 34 percent evaluated tree disease problems, and 27 percent dealt with insect problems; the remainder addressed abiotic stresses and indicators (25 percent) and other biotic stresses and indicators (14 percent) (fig. 1). Nearly a third of EM projects were completed by specialists in the Forest Health Protection Program of the Forest Service, with 20 percent by university scientists, 20 percent by Forest Service Research and Development scientists, 19 percent by State agency investigators, and the rest by investigators from other Federal agencies and tribes (fig. 2). The geographic distribution of the EM projects funded from 1998 until 2007 is presented in figure 3, with 26 percent of the projects being located in the Interior West, 26 percent in the West Coast, 17 percent in the Southern, 16 percent in the Northeastern, and 15 percent in North Central FHM Regions.

The projects funded through the EM program have contributed significantly to our understanding of some of the major forest health issues in the United States. Key findings detailed in previous chapters include the following:

- Bark beetle outbreaks in ponderosa pine forests and pinon-juniper woodlands of the Southwest led to tree mortality near the lower elevational distribution of each pine species in stands with relatively high tree densities and in areas of poor site quality.
- Mountain pine beetle epidemics increase the probability of achieving larger fire sizes throughout the range of historic fire weather conditions in lodgepole pine forests.
- Daily Moderate Resolution Imaging Spectroradiometer (MODIS) data can be used to monitor insect defoliation for large patches in the upper Midwest.

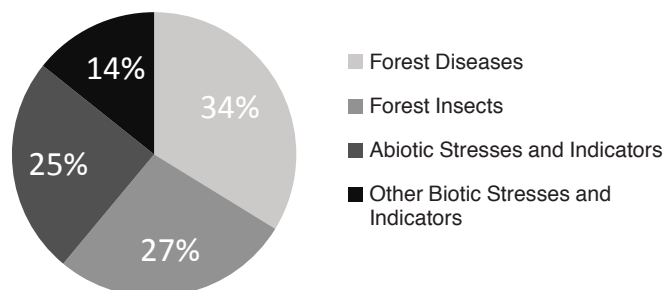


Figure 1—Proportion of evaluation monitoring projects by subject area.

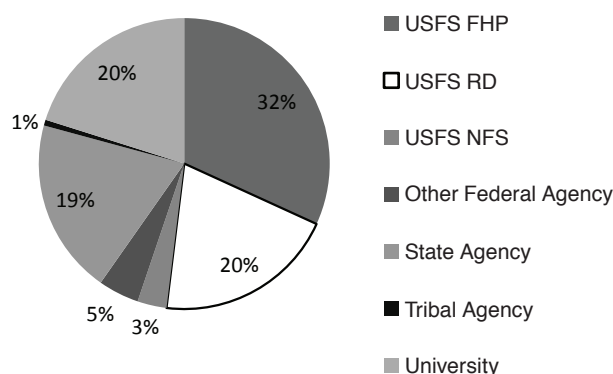


Figure 2—Proportion of evaluation monitoring projects by partner group. (USFS FHP = U.S. Forest Service Forest Health Protection; USFS RD = U.S. Forest Service Research and Development; USFS NFS = U.S. Forest Service National Forest System)

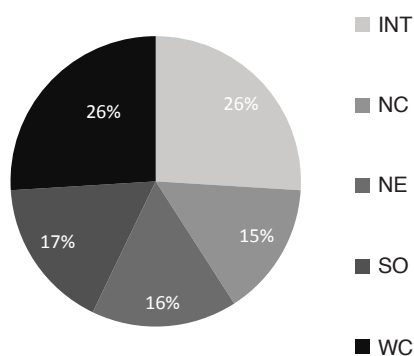


Figure 3—Proportion of evaluation monitoring projects by Forest Health Monitoring region. (INT = Interior West Region; NC = North Central Region; NE = Northeast Region; SO = South Region; WC = West Coast Region)

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Summary

- Incidence of white pine blister rust is greatest in the northern and western portions of the central Rocky Mountains where the disease has been present for decades. New locations were discovered in southern Colorado, including the first report on bristlecone pine.
- Recent and rapid mortality of aspen was greatest in the Southwest with more moderate losses further north.
- Surveys of butternut canker distribution and severity in Vermont projected that 85 percent of all butternut trees there would be dead by 2011.
- Drought was a major determinant of oak decline and mortality in the Southeast.
- The red oak borer outbreak of 1999-2005 in the Ozark Mountains exceeded all historical records in terms of area affected and attacks per tree.
- Early surveys for sudden oak death (2001) determined that (1) the pathogen *Phytophthora ramorum* was not confined to coastal California but had established in Curry County, OR, and (2) 10 percent of the land area in California coastal forests was infested within a few years of the pathogen's discovery.
- Fire suppression activities that disturb the ground increased the risk of invasive plant spread.
- Invasive plants respond to fires more quickly than native plants.
- An introduced insect pest, *Thrips calcaratus*, was found to be a major cause of basswood decline in the Lake States.
- Altered hydrology, which increased saltwater intrusion into forested wetlands, was a major factor leading to decline of oak-gum-cypress bottomland forests in southern Louisiana.
- Fire behavior and stand growth models may be combined with FIA inventory data on down woody material to inform landscape-scale fire hazard mitigation/management efforts.
- Snow-pack depth was consistently associated with onset of, and recovery from, dieback in northern hardwoods.
- Decreasing snow-pack depth was also associated with decline of yellow cedar in southeast Alaska.
- Nitric acid (HNO_3) was found to degrade lichen communities in the Los Angeles Basin.
- Ozone concentrations in the San Bernardino Mountains, although currently lower than in the 1960s and 1970s, are still some of the highest in the United States.
- Siliciclastic landscapes in Shenandoah National Park are especially sensitive to loss of base cations, due to atmospheric chemical deposition, which poses particular concerns for forest and aquatic health in these areas.
- Forest floor mercury was highest in the northeast and northern Rocky Mountains. Ecoprovince and latitude were significant predictors of Hg concentrations in the forest floor.
- Carbon content in the forest floor may be roughly estimated from simple measurements of forest floor thickness and ancillary geospatial data.

The results of EM projects have been used by land managers and forest health practitioners in a variety of ways. The following are some examples highlighted in the previous chapters:

- Impacts of bark beetles were considered in Forest Plan revisions and project-level environmental analyses in Wyoming.
- Information on relationships between bark beetle outbreaks and fuel loading was integrated into fire behavior models (FARSITE and FlamMap).
- The spread of hemlock woolly adelgid was predicted in the Northeast.
- Forest stands have been prioritized for treatment utilizing the hazard rating system for balsam woolly adelgid.
- A genetic conservation strategy is being developed and implemented for five-needle pines threatened by white pine blister rust.
- The Ouachita, Ozark-St. Francis, and Mark Twain National Forests prioritized control and salvage efforts in stands affected by the red oak borer in the Ozarks.
- The first detections of *P. ramorum* in Oregon triggered quarantines for the affected area and led to the development of an eradication effort.
- The evaluation of lichen communities downwind from two coal-fired power plants in Colorado was used in the assessment of Air Quality Related Values in Federal Clean Air Act Class I wilderness areas.
- The HNO_3 critical loads established for lichens were used by the Environmental Protection Agency in setting a secondary air quality standard for nitrogen oxides.
- A conservation and management strategy for yellow-cedar is currently being implemented at locations in coastal Alaska focusing regeneration efforts in areas with sufficient protective snow cover.
- The Carbon Online Estimator was developed to allow any user to produce carbon and dead wood estimates based on FIA Program annualized data. It has been named as an official U.S. carbon estimation tool for forests by the Department of Energy.
- Ten of the 14 species tested for ozone sensitivity are now on the FIA supplemental list of bioindicator species and are used to identify areas where ozone injury occurs.

While the results of completed EM projects have been impressive and useful, there are many unanswered questions that should be investigated in the future. The subject matter specialists who synthesized the preceding chapters suggested new lines of inquiry for the EM program, including the following:

- Long-term effects of bark beetle outbreaks should be evaluated through permanent plots remeasured at 5-year intervals for the next 20-25 years.

- Fire spread models should be further developed for various bark beetle affected landscapes.
- White pine blister rust resistance mechanisms and adaptive traits in high elevation white pine species of the Rocky Mountains should be evaluated.
- A better understanding of the genetic diversity remaining among populations of butternut will guide future germplasm collection.
- Developing a broad network of intensive oak monitoring sites will enhance understanding of insect, disease, and climate interactions.
- Compiling data on biotic and abiotic stressors over longer time periods will help elucidate natural variation in stressors and in the responses of forests to those stressors.
- There is a need for more investigation into fire severity associated mortality and damage relationships.
- Critical loads for lichen communities need to be determined for regions beside the well-studied Pacific Northwest.
- The usefulness of the Lichen Communities Indicator for monitoring climate change has largely been ignored in favor of air quality applications.
- The effects of short-term versus long-term exposure to ozone need further investigation.

Several chapter authors identified the need to target more evaluations on under-utilized indicators, including lichens, ozone, down woody material, and soils. Increased coverage and repeated measures will facilitate more detailed evaluations of these indicators in the near future. There is also a need for more evaluation of the extent and impact of invasive plant species as more data are collected on the phase 2 and phase 3 plots of the Forest Inventory and Analysis Program of the Forest Service. The FHM program should continue to encourage the use of additional sources of information, including aerial and ground detection surveys and other ancillary data in conducting EM projects.

In conclusion, EM is a vibrant component of the FHM program that has significantly enhanced our understanding of some of the most critical forest health issues facing the Nation's forests. Over the period from 1998 through 2007, the EM projects effectively addressed the second and third objectives of the FHM program—to verify and define the extent of deterioration in forest ecosystems and to understand the processes that cause forest health problems so that strategies can be developed for problem mitigation and prevention. Through the EM projects, the FHM program successfully engaged a broad spectrum of partners and collaborators in conducting forest health evaluations on a wide range of topics spanning forested ecosystem throughout the country. The EM approach of focused evaluations of current forest health concerns is effective in providing timely solutions to land managers as they are managed for sustainable, resilient forest ecosystems.

Acknowledgments

This report represents the work of many people. The authors and editors thank the scientists who conducted the Evaluation Monitoring projects for their assistance in preparation of this report. Thanks are also extended to the 22 scientists who reviewed one or more chapters of the report for their constructive comments. This research was supported in part through the project Forest Health Monitoring, Assessment and Analysis of research joint venture agreement 09-JV-11330146-087 (July 22, 2009 through March 21, 2011) and project Forest Health Monitoring, Analysis, and Assessment of research joint venture agreement 10-JV-11330146-064 (June 10, 2010 through February 28, 2012) and project Forest Health Monitoring, Assessment, and Analysis of research joint venture agreement 11-JV-11330146-090 (July 12, 2011 through October 31, 2012) between North Carolina State University (this institution is an equal opportunity provider) and the U.S. Department of Agriculture, Forest Service, Southern Research Station, Asheville, NC.

Appendix A

REQUEST FOR PROPOSALS AND INSTRUCTIONS (2009)

File Code: 3440

Date: August 27, 2008

Route To:

Subject: Requests for Forest Health Protection Special Project Proposals
for Fiscal Year 2009

To: Regional Foresters, Station Directors, Area Director, IITF Director, Deputy Chiefs
and WO Directors

**OPTIONAL REPLY DUE SEPTEMBER 30, 2008,
OCTOBER 15, 2008, AND NOVEMBER 14, 2008**

By this letter we are requesting fiscal year 2009 proposals for the following three special project programs administered by Forest Health Protection (FHP):

1. Forest Health Monitoring Program, Evaluation Monitoring (EM) - A component of the Forest Health Monitoring program designed to determine the extent, severity, and causes of undesirable changes in forest health.
2. Special Technology Development Program (STDP) - A program to help move research results into practice by developing cutting edge technologies and field operation methods to improve the ability of field specialists to restore and protect America's forests.
3. Forest Service-Pesticide Impact Assessment Program (FSPIAP) - A program to provide funding for evaluations of benefits and impacts of pesticide use in forest environments.

Please submit proposals for these programs according to the directions listed at the following websites: EM due September 30, 2008, STDP due October 15, 2008, and FSPIAP due November 14, 2008.

- EM—http://fhm.fs.fed.us/em/instructions/em_instructions09.pdf. Contact: Borys Tkacz, National Program Manager for Forest Health Monitoring EM, (703) 605-5343, btkacz@fs.fed.us.
- STDP—<http://svinetfc2.fs.fed.us/stdp/index.asp>. Contact: Marla Downing, Program Manager for stdp, (970) 295-5843, m Downing@fs.fed.us.
- FSPIAP—<http://www.fs.fed.us/foresthealth/pesticide/fspiap/>. Contact: Hank Appleton, Program Manager for FSPIAP, (703) 605-5346, happleton@fs.fed.us.

Thank you for your interest and cooperation in these important FHP programs.

/s/ James E. Hubbard
JAMES E. HUBBARD
Deputy Chief, State and Private Forestry

Appendix A

Request for Proposals and Instructions (2009)

Evaluation Monitoring New and Renewal Proposal Instructions for FY 2009

The Forest Health Monitoring (FHM) program is a cooperative program that enables the early detection and evaluation of changes in forest health conditions on all ownerships. The Evaluation Monitoring (EM) component of the FHM program is designed to determine the extent, severity, and causes of undesirable changes in forest health identified through Detection Monitoring using aerial and ground surveys, permanent plots, and other means (see: <http://fhm.fs.fed.us/em/index.shtml>). Projects funded through EM delve into the extent, severity, and/or causes of forest health problems.

Project Proposals for new and continuing projects should be submitted by **September 30, 2008** to the FHM Regional Managers: Jim Steinman for Northeast FHM Region (jsteinman@fs.fed.us), Manfred Mielke for Northcentral FHM Region (mmielke@fs.fed.us), Dale Starkey for Southern FHM Region (dstarkey@fs.fed.us), Jeri Lyn Harris for Interior West FHM Region (jharris@fs.fed.us), or Alison Nelson for West Coast FHM Region (asnelson@fs.fed.us). A template for project proposals is attached to this document.

Projects will be selected through two separate competitions reflecting funding source: Base EM and Fire Plan EM. Regional FHM Managers are responsible for ranking projects from their respective regions and submitting two separate proposal packages to Borys Tkacz, the National FHM Program Manager (btkacz@fs.fed.us). Individual proposals will be evaluated by a National Panel for either Base EM or Fire Plan EM, but not both, as specified in the packages received from Regional FHM Managers. While we do not have the final budget allocations at this time, anticipated funding levels will be: \$700,000 for Base EM (with approximately \$351,500 committed to continuing Base EM projects and \$150,000 being dedicated to Regional EM projects¹ leaving \$198,500 for new Base EM projects) and \$575,000 for Fire Plan EM (with approximately \$218,000 committed to continuing Fire Plan EM projects leaving \$357,000 for new Fire Plan EM projects).

Base EM Project Competition:

The purpose of a Base Evaluation Monitoring project is to investigate issues or concerns identified in the Detection Monitoring phase of FHM. Proposed projects should be 1-3 years in duration. Successful projects will help to explain the extent, severity, and/or cause of a phenomenon that has already been observed in the survey and/or permanent plot components of Detection Monitoring. Based on current analyses of forest health indicators tracked through the FHM program (see the FHM National Technical Reports and State Highlights posted on the FHM website at: <http://fhm.fs.fed.us>), we would be particularly interested in project proposals dealing with the following:

- Climate change—effects on forests or forest pests
- Drought—deviations from normal precipitation and related effects
- Validating or filling data gaps in insect & disease risk models
- Tree mortality—deviations from expected levels
- Poor crown conditions—deviations from normal
- Soil conditions—including forest floor depth, compaction, and erosion and chemistry
- Fragmentation—effects of fragmentation of forest cover
- Air Pollutants—effects of sulfate and nitrate deposition and ozone.

Information on specific Regional forest health issues and concerns is available from the Regional FHM Program Managers.

Each FHM Region may submit three to five Base EM proposals for consideration by the National EM Panel. Proposals will be evaluated using the following criteria:

1. Linkage to FHM Detection Monitoring—the need for the project should arise from an analysis of FHM survey data and/or Forest Inventory and Analysis (FIA) plot data;
2. Significance in terms of the geographic scale;
3. Biological impact and/or political importance of the issue;
4. Scientific basis/feasibility—likelihood that the project will be successfully completed.
5. Priority issues addressed as listed above.

Please make sure the criteria are addressed in your proposals.

¹ Each of the five FHM regions will receive \$30,000 allocated for Evaluation Monitoring for local projects. The Regional FHM Program Managers should work with Forest Health Protection (FHP) Leaders in their respective FS Regions to develop plans for using these funds.

Fire Plan EM Competition:

The purpose of a Fire Plan Evaluation Monitoring project is to investigate and explain the extent, severity, and/or cause of a fire-related phenomenon that has been observed in the Detection Monitoring components of FHM. General target areas are use of FHP survey or FIA plot data to address Fire Plan issues. The National Fire Plan is available online at <http://www.fireplan.gov/>. Proposed projects should be 1-3 years in duration. We encourage project proposals dealing with the following:

- Climate change—effects on frequency or severity of fires;
- Fire risk and fuel loading;
- Ecological impacts of fires;
- Invasive species—insects, diseases and plants (especially impacts on natural fire cycles and fire-adapted ecosystems);
- Restoration or fire-damaged ecosystems.

Each of the five FHM regions may submit three to five proposals Fire Plan EM proposals for consideration by the National EM Panel. Proposals will be evaluated using on the following criteria:

- Linkage to FHM Detection Monitoring- the need for the project should arise from an analysis of FHM survey data and/or Forest Inventory and Analysis (FIA) plot data relative to fire issues stated above or found in the National Fire Plan;
- Significance in terms of the geographic scale;
- Biological impact and/or political importance of the issue related to fire;
- Scientific basis/feasibility - likelihood that the project will be successfully completed within 1-3 years, with some immediate products in the first year and each year thereafter;
- Priority issues addressed as listed above.

Please make sure the criteria are addressed in your proposals and that there is a clear, obvious link to Fire Plan issues.

General Requirements:

Proposals should follow the attached template and be no longer than three pages (including cost information). Proposals should address data availability. Any projects requiring access to Forest Inventory and Analysis (FIA) plot coordinates should be discussed with Regional FIA work units or Liz LaPoint (email: elapoint@fs.fed.us) from the Spatial Data Services of FIA prior to submission of proposals. All overhead charges should be included in the project budget. The budget must include all overhead or other indirect costs going to the Region or Area, or to cooperating institutions. Projects on non-federal lands need to show non-federal contributions of 50% of the total project costs (1:1 match).

Continuing Proposals:

Previously funded, multi-year proposals from prior years will be given priority if the investigators have reported sufficient progress by submitting annual requests for continuation by September 30, 2008. Proposals for continued funding of multi-year projects should include a progress statement (within the three-page limit). The FHM Management Team requires that results and progress reports for all national competition EM projects be summarized in posters presented at the annual FHM Working Group meeting. Upon project completion, investigators will submit a final report, and an executive summary in FHM 'fact sheet' format.

TITLE:**LOCATION:** <Geographic location of project>**DATE:** <Of original submission and progress report>**DURATION:** Year X of X-year project **FUNDING SOURCE:** <Base or Fire Plan>**PROJECT LEADER:** <Name, affiliation, phone number, email address of principal investigator>**COOPERATORS:** <Names and affiliations>**FHP SPONSOR/CONTACT:** <Name, location, phone number and email address>**PROJECT OBJECTIVES:** <What are specific project objectives?>**JUSTIFICATION:** < How does the project address each of the following Evaluation Monitoring selection criteria?>

- Linkage to FHM Detection Monitoring- the need for the project should arise from an analysis of FHM survey data and/or Forest Inventory and Analysis (FIA) plot data;
- Significance in terms of the geographic scale;
- Biological impact and/or political importance of the issue;
- Scientific Basis/Feasibility - likelihood that the project will be successfully completed;
- Priority Issues addressed from Request for Proposals.

DESCRIPTION:

a. Background: <Brief description of the project including scientific basis.>

b. Methods: <Brief description of methods including data availability.>

c. Products: <Brief description of anticipated products.>

d. Schedule of Activities: <Listing of major activities & timelines>.

e. Progress/Accomplishments: <Brief description of progress/accomplishments or multi-year projects.>

Appendix B

EVALUATION MONITORING PROJECTS (1998-2007)

Project Number	Year Initiated	Project Title	Principal Investigator
NE-EM-98-01 ¹	1998	Lake State Basswood Decline Evaluation	Kenneth Raffa
NE-EM-98-02	1998	Evaluation of Unexplained Defoliation of Ash & Other Hardwoods	H. B. Teillon
NE-EM-98-04	1998	Estimating Seasonal Exposures & Concentrations of Ozone for the Great Lakes Region	Teague Prichard
SO-EM-98-01	1998	Coastal Forest Change—Florida	Ed Barnard
WC-EM-98-01	1998	OR/WA Swiss Needle Cast Survey	Alan Kanaskie
WC-EM-98-02	1998	Balsam Woolly Adelgid Survey for Occurrence & Impacts	Iral Ragenovich
WC-EM-98-03	1998	White Bark Pine Survey in Southwestern Oregon	Ellen Goheen
INT-EM-99-01	1999	Impacts to Lichen Communities Downwind of two Coal-Fired Power Plants in Colorado's Park Range: Evaluation Monitoring of Detected Impacts	Peter Neitlich
INT-EM-99-02	1999	Fire Risk Rating of FIA/FHM Plots	David Atkins
INT-EM-99-03	1999	Stand Level Impact of Douglas-fir Beetle Infestations in the Greater Yellowstone Area	Joel McMillin
INT-EM-99-04	1999	GIS-Based Landscape-Scale Prediction System for Pinyon Pine Decline in the Southwestern United States.	Roy Mask
INT-EM-99-05	1999	Impact Assessment of <i>Nepytia janetae</i> (Lepidoptera, Geometridae) on Engelmann Spruce–Subalpine Fir Forests on Mt. Graham, Coronado National Forest and on Fort Apache Indian Reservation.	Bobbe Fitzgibbon
NE-EM-99-02	1999	Ozone Effects on Plant Productivity and Population Dynamics in the Lake States	Ed Jepsen and James Bennett
SO-EM-99-01	1999	Factors Affecting Tree Health in Forested Wetlands of Louisiana	Richard Goyer
WC-EM-99-01	1999	WA Swiss Needle Cast Survey	Dan Omdal
WC-EM-99-02	1999	OR Swiss Needle Cast Survey	Alan Kanaskie
WC-EM-99-03	1999	Balsam Woolley Adelgid Survey for Occurrence & Impacts	Iral Ragenovich
WC-EM-99-04	1999	Geographic Distribution of Champion Mine Strain of White Pine Blister Rust	Rich Snieszko
WC-EM-99-05	1999	Evaluation of Ozone Foliar Injury and Bole Growth of Pines in Southern California	Michael Arbaugh and John Pronos
INT-EM-00-01	2000	Stand Level Impact of Subalpine Fir Decline in Spruce-fir	Joel McMillin
INT-EM-00-02	2000	Fire Risk Rating of FIA/FHM Plots	David Atkins
INT-EM-00-03	2000	Determining the Condition of Whitebark Pine in the Northern Region	David Atkins
INT-EM-00-04	2000	GIS-Based Landscape-Scale Prediction System for Pinyon Pine Decline in the Southwestern United States.	Roy Mask
INT-EM-00-05	2000	Impact Assessment of <i>Nepytia janetae</i> (Lepidoptera, Geometridae) on Engelmann Spruce–Subalpine Fir Forests on Mt. Graham, Coronado National Forest and on Fort Apache Indian Reservation.	Bobbe Fitzgibbon

¹ Project numbering convention is: Region-Project Type-Initial Year-Sequence (within region, project type, year). INT=Interior West; NC=North Central; NE=Northeast; SO=South; WC=West Coast; EM=Base Evaluation= Monitoring Project; F=Fire Plan Project.

Appendix B**Evaluation Monitoring Projects (1998-2007)**

Project Number	Year Initiated	Project Title	Principal Investigator
NE-EM-00-01	2000	Determining the Ozone Sensitivity of New Bioindicator Species for the FHM Biomonitoring Program	John Skelly and Gretchen Smith
NE-EM-00-02	2000	Ozone Effects on Common Milkweed & Black Cherry Productivity & Injury Dynamics in the Southern Lake States	Ed Jepsen and James Bennett
SO-EM-00-01	2000	Exotic Ambrosia Beetle Monitoring	Robert Rabaglia
SO-EM-00-02	2000	Assessment of Loblolly Pine Decline	Nolan Hess
SO-EM-00-03	2000	Examination of Nutrient Cation Status in Western Virginia Forests	Bernard Cosby
SO-EM-00-04	2000	Ozone Impact on Sensitive Forest Tree Species	Boris Chevone
WC-EM-00-01	2000	OR/WA Swiss Needle Cast Survey	Alan Kanaskie
WC-EM-00-02	2000	Balsam Woolley Adelgid Survey for Occurrence & Impacts	Iral Ragenovich
INT-EM-01-04	2001	Monitoring White Pine Blister Rust Spread and Establishment in Central Rocky Mountains	J.Harris and J.Hoffman
INT-EM-01-05	2001	Subalpine Fir Mortality Caused by Western Balsam Bark Beetle	Kurt Allen
INT-F-01-03	2001	Fire Effects Assessment Using FIA Data in the Northern and Rocky Mountains	David Atkins
NC-EM-01-01	2001	Climate and Air Quality Indicators of Risk to Forest Health: An On-line GIS for Integrating Climate and FHM Information	Allan Auclair
NE-EM-01-01	2001	Evaluation of the Condition of Eastern White Pine	Barbara Burns
NE-EM-01-03	2001	Evaluation of the Viability of the Butternut Resource	Kurt Gottschalk
NE-F-01-02	2001	Impact of an Invasive Species on Forest Health: Phenological Differences as a Possible Explanation of Impacts on American Basswood in the Great Lakes Region	Kenneth Raffa
NE-F-01-03	2001	Ozone Effects on Common Milkweed & Black Cherry Productivity & Injury Dynamics in the Southern Lake States	Ed Jepsen and James Bennett
NE-F-01-05	2001	Assessing the Contribution of Down and Standing Deadwood Biomass and Wildland Fire Risk	Linda Heath
NE-F-01-06	2001	Evaluating Forest Health and Fire History of Ozark Oak Forests	Rose-Marie Muzika
NE-F-01-07	2001	An Interactive Web-based Model for Estimating Fire-Related Characteristics Using FIA Data	Linda Heath
NE-F-01-08	2001	Prescribed Fire as a Management Tool for Curbing Potential Epidemics of Bark Beetles and Woodborers in a Forest Blowdown	Steven Seybold
SO-EM-01-01	2001	Impact of Ground-level Ozone on Trees in the Great Smoky Mountains National Park	Arthur Chappelka
SO-EM-01-02	2001	Exotic Ambrosia Beetle Survey	Bob Rabaglia
SO-F-01-03	2001	Assessing Contribution of Down and Standing Deadwood Biomass and Decay on Fuels and Wildland Fire Risk Across the Southeastern United States	Robert Mickler and Steve McNulty
SO-F-01-04	2001	Evaluating Critical Fuel Loading in the Wildland/Urban Interface	Terry Price
WC-EM-01-01	2001	Swiss Needle Cast in Cascades in Oregon	Floyd Freeman
WC-EM-01-02	2001	Ground Checking Aerial Survey Polygons Identified as Douglas-fir Beetle Caused Damage in Washington in 2001 and 2002	Karen Ripley
WC-EM-01-03	2001	Evaluation and Monitoring of Swiss Needle Cast in the Oregon Cascades	Floyd Freeman and Greg Filip
WC-F-01-05	2001	Monitoring Sudden Oak Death in Oregon (Ground Survey, Aerial Survey, and Aerial Photography)	Alan Kanaskie
WC-F-01-06	2001	Evaluating Fire Fuel Loads for Nonnative Grasses in Hawaii from Hyperspectral Reflectance Data.	F. Hughes

Project Number	Year Initiated	Project Title	Principal Investigator
WC-F-01-07	2001	Changes in Fire Hazard Associated with Western Spruce Budworm Defoliation in the Eastern Cascades.	S.Hummel
WC-F-01-08	2001	Monitoring Sudden Oak Death in Coastal CA: FIA Plot Remeasurement	Susan Frankel
WC-F-01-09	2001	Broad-scale Spruce Forest Change, Kenai Peninsula, Alaska 1987-2000	Beth Schultz
NC-EM-02-01	2002	Evaluation of the Viability of the Butternut Resource	Kurt Gottshalk and Mike Ostry
NC-EM-02-02	2002	Rapid Detection of Two Exotics in Michigan: Beech Bark Disease and Hemlock Woolly Adelgid	Roger Mech
NE-EM-02-01	2002	Forest Health Conditions and Analysis of the Allegheny National Forest	Kurt Gottschalk
NE-EM-02-02	2002	Assessment of the Rate of Progression of Butternut Canker Disease	Dale Bergdahl and Brent Teillon
NE-EM-02-03	2002	Health and Sustainability of New York Forests in Relation to the Destructive Exotic Beech Bark Disease System	P. Manion
SO-EM-02-01	2002	Ground Truth Assessments of Oak Decline and Red Oak Borer in the Interior Highlands of AR, OK, MI	James Guldin
SO-EM-02-02	2002	A GIS-based system for quantifying, assessing, and predicting impact of oak in the Ozark Mountains	Fred Stephen
WC-EM-02-02	2002	Evaluating the Health of 5-needle Pines in Washington and Southwestern Oregon	Ellen Goheen, Dan Omdal
WC-F-02-04	2002	Effect of Swiss Needle Cast on Crown Structure of Douglas-fir as it Relates to Fire Risk and Potential Fire Behavior in Western OR	Alan Kanaskie and Douglas Maguire
INT-EM-03-01	2003	Stand Level Impacts of Ips and Dendroctonus Bark Beetles in Pine Forest Types of Northern Arizona	John Anhold and Joel McMillin
INT-EM-03-02	2003	Impacts to Aspen Communities in Northern Arizona	Mary Lou Fairweather
INT-EM-03-03	2003	Monitoring Westwide Distribution and Condition of Whitebark Pine and Limber Pine	Blakey Lockman
NC-EM-03-01	2003	Evaluation of Increased Crown Dieback and Reduced Foliage Transparency within the Laurentian Mixed Forest	Thomas Burk
NC-EM-03-02	2003	Soil Compaction Effects on Site Productivity and Organic Matter Storage in Aspen Stands of the Great Lakes States	Randy Kolka
NC-EM-03-04	2003	Evaluating the Distribution and Structure of Epidemic Populations of Sphaeropsis Sapinea	Glen Stanosz
NC-F-03-01	2003	Supporting the National Fire Plan with Maps and Digital Data Layers Derived from FIA and FHM Plot Observations	Ron McRoberts
NC-F-03-03	2003	Interactions of Prescribed Fire and Insect and Disease Pests in Red Pine	Linda Haugen
NE-EM-03-01	2003	Assessing the Impact of Hemlock Woolly Adelgid on the Health of Hemlock Stands	Dave Williams
NE-EM-03-02	2003	The Impact of Balsam Woolly Adelgid (<i>Adelges piceae</i>) on Balsam Fir (<i>Abies balsamea</i>) Stands in New England	Henry Trial
SO-EM-03-01	2003	Early-warning System for Hemlock Woolly Adelgid in the Southern Appalachians	Heather Cheshire and Hugh Devine
WC-EM-03-01	2003	An Assessment of Insects and Pathogens Associated with Declining Dry Forest Ecosystems in Hawaii	John Wenz
WC-F-03-01	2003	Port-Orford-Cedar Mapping within the Biscuit Fire Area	Frank Betlejewski
INT-EM-04-01	2004	Alder Dieback and Mortality in the Southern and Central Rocky Mountains: Extent, Severity, and Cause	James Worrall
INT-EM-04-02	2004	Monitoring the Status and Condition of Whitebark Pine in the Greater Yellowstone Ecosystem	Chuck Schwartz

Appendix B**Evaluation Monitoring Projects (1998-2007)**

Project Number	Year Initiated	Project Title	Principal Investigator
INT-EM-04-03	2004	Severity and Extent of Douglas-fir Beetle Infestations in Northern Wyoming	Kurt Allen
INT-EM-04-04	2004	Distribution, Species, and Ecology of Armillaria-fungi in Wyoming	James Blodgett
INT-EM-04-05	2004	Monitoring White Pine Blister Rust Spread and Establishment in the Central Rocky Mountains, Stage 2.	Kelly Sullivan
INT-EM-04-06	2004	Pine Wilt in the Central Great Plains: Differences in Pinewood Nematode Populations and Identification of Insect Vectors	Gary Hergenrader
INT-F-04-01	2004	Understanding the Effects of Fire Management Practices on Forest Health: Implications for Weeds and Vegetation Structure	Anne Black
INT-F-04-02	2004	Characterization of Fuels Complexes in Stands Affected by the Spruce Beetle	Michael Jenkins
NC-EM-04-01	2004	Forest Health Evaluation of Reported Yellow-poplar, Ash, and Bitternut Hickory Decline	Philip Marshall
NC-EM-04-02	2004	Developing a Damage Threshold for Dwarf Mistletoe Infested Spruce Stands	Fred Baker
NC-EM-04-05	2004	White Oak Decline in Eastern Iowa Woodlands: Exploration of Factors Involved	Steve Pennington
NC-F-04-01	2004	Interactions of Prescribed Fire and Insect and Disease Pests in Red Pine	Linda Haugen
NC-F-04-02	2004	Effects of Prescribed Burning on Indicators of Forest Health in Oak Savannas and Woodlands of Iowa: Implications for Ecological Monitoring and Restoration	Heidi Asbjornsen
NC-F-04-03	2004	Fire Season “Real Time” Estimation of Fuel Moisture Fluctuations in Regional Down Woody Material Inventories During a Fire Season	Joseph Charney and Christopher Woodall
NE-EM-04-01	2004	Development of a Challenge Protocol to Identify Young American Beech Trees that are Resistant to the Beech Scale insect	Jennifer Koch
NE-EM-04-02	2004	Historical and regional analysis of beech bark disease impacts	Andrew Liebhold
NE-EM-04-03	2004	Assessment of Forest Health and Forest Sensitivity to Nitrogen and Sulfur Deposition in New England	Linda Pardo
SO-EM-04-01	2004	Drought Impact on Forest Health in the Southeast—an Analysis Based on FHM/FIA data	G. Geoff Wang
SO-EM-04-02	2004	Assessing the Extent and Severity of Oak Decline in an Ozark Mountain Watershed	Eric Heitzman
SO-EM-04-03	2004	Development of Geospatial Techniques for Prediction and Assessment of Red Oak Decline Due to Red Oak Borer	Fred Stephen
SO-EM-04-04	2004	A Spatial Cluster of Poor Crown Conditions: Evaluating Results from Crown Indicators and Spatial Scan Statistics	Mike Schomaker
SO-F-04-01	2004	Duff and Litter Estimation for the SE US	David Chojnacky
WC-EM-04-01	2004	An Assessment of White Pine Blister Rust on High Elevation White Pines in California	John Kliejunas
WC-EM-04-02	2004	Status of 5-needle Pines in Washington and Northern Oregon (with Emphasis on High Elevation Stands with Whitebark Pine)	Dave Doede
WC-EM-04-04	2004	White Pine Blister Rust in Juvenile Western White Pine on State Lands in Washington	Daniel Omdal
WC-EM-04-05	2004	Detection and Monitoring of <i>Phytophthora Ramorum</i> in Oregon	Alan Kanaskie
WC-F-04-03	2004	Southern California Forest Health Assessment-analysis of Status and Trend, Post Drought-induced Bark Beetle Mortality Events of 2002-2003	Ralph Warbington

Project Number	Year Initiated	Project Title	Principal Investigator
INT-EM-05-01	2005	Piñon and Juniper Mortality—Extent, Severity, and Causal Agents	Brytten Steed
INT-EM-05-04	2005	Monitoring Host Selection Behavior and Progression of Infestation by the Mountain Pine Beetle, in Mixed Stands of Limber and Lodgepole Pine	Alexandre Latchininsky
INT-F-05-02	2005	Evaluation and Monitoring of Whitebark Pine Regeneration After Fire in the Frank Church River of No Return Wilderness	Lauren Fins
NC-EM-05-02	2005	Evaluating Black Ash (<i>Fraxinus nigra</i>) Decline in the Upper Midwest	Brian Palik
NC-EM-05-04	2005	A Multi-Scale Remote Sensing Approach for Quantifying Regional Impacts of Insect Defoliators	Brian R. Sturtevant
NC-F-05-01	2005	Effects of Prescribed Fire on Oak Pests and Invasive Plant Species	Rose-Marie Muzika
NC-F-05-03	2005	Multi-Scale Modeling and Mapping Coarse Woody Debris	Stephen Shifley and Zhaofei Fan
NC-F-05-04	2005	The Distribution of Mercury in a Forest Floor Transect	Charles Perry
NE-EM-05-01	2005	Evaluating Environmental and Disturbance Conditions Associated with Invasive Plants Using the Allegheny National Forest Intensive Plot Data	Cynthia Huebner
SO-EM-05-01	2005	Validation of FIA/FHM Data for Predicting Dogwood Occurrence in Conjunction with a Dogwood Anthracnose Hazard Risk Rating System	William Jones
SO-F-05-01	2005	Models for Using FIA Data to Assess Impacts of Fire and Fuel Loading on Water Quality	David Chojnacky
SO-F-05-04	2005	Locate, Map and Establish Long-term Monitoring of Exotic Invasive Plant Species in the Sou. Appalachian Mts.	Jack Ranney
WC-EM-05-02	2005	Effects of Western Spruce Budworm Defoliation on the Northern Spotted Owl and its Habitat in South Central Washington	Beth Willhite
WC-EM-05-03	2005	Intensified Ozone Monitoring and Assessment of Ozone Impacts on Conifers in Southern California	Michael Arbaugh and Andrzej Bytnerowicz
WC-F-05-02	2005	Ecological Impacts of Invasive Species after Fire	Leigh Dawson
WC-F-05-04	2005	Determination of the Incidence and Impacts of Phytophthora Ramorum in Coastal Forests of California	David Rizzo
WC-F-05-05	2005	Pre- and Post-fire Fuel Loads: Empirical vs Simulated Results for Mixed-Conifer Forests of the Cascade Range	Susan Hummel
WC-F-05-06	2005	Port-Orford-cedar Mapping within the Biscuit Fire Area—Part 2	Frank Betlejewski
INT-EM-06-01	2006	The Influence of Wolves on Decline in Aspen Communities in Northern AZ	Tom DeGomez
INT-EM-06-03	2006	Monitoring Limber Pine Health in the Rocky Mountains	Kelly Burns
INT-F-06-01	2006	Monitoring the Condition of Aspen in the Northern and Intermountain Regions	John Guyon, Jim Hoffman and Marcus Jackson
INT-F-06-02	2006	Potential Fire Hazard Following Bark Beetle Outbreak in Pinon-juniper Woodlands	Jerome Jenkins
INT-F-06-03	2006	Mountain Pine Beetle in Lodgepole Pine: Mortality and Fire Implications	Sheryl Costello
INT-F-06-04	2006	Monitoring Tree Deterioration Following Stand-destroying Wildfires	Roy Mask
NC-EM-06-01	2006	Assessment of Decline and Contributing Diseases in White Ash Stands in Michigan	Gerard Adams
NC-F-06-02	2006	Effects of Prescribed Fire on Upland Oak Forest Ecosystems in Missouri Ozarks	Daniel Dey and Zhaofei Fan

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Project Number	Year Initiated	Project Title	Principal Investigator
NE-EM-06-03	2006	Assessment of Butternut Canker on Public and Private Lands in the Eastern United States.	Scott Schlarbaum
SO-EM-06-01	2006	Red Bay Mortality Survey in the Coastal Region of Georgia	James Johnson
SO-EM-06-02	2006	Red Bay Mortality Survey in the Southeastern Coastal Region of South Carolina	Laurie Reid
SO-EM-06-03	2006	Modeling Drought Effects on Forest Health in the Southeast—Annual Analysis at the Sub-regional and Regional Level	Bill Bauerle
SO-EM-06-04	2006	Regional Oak Decline-Related and Regular Oak Mortality Predictions of Extent and Severity	Martin Spetich
SO-F-06-01	2006	Fuel Characteristics in the Southern Appalachian Mts.—a Test of FIA's Down Woody Material Indicator for Regional Fuel Estimation	Geoff Wang
WC-EM-06-01	2006	Effects of Western Spruce Budworm Defoliation on the Northern Spotted Owl and its Habitat in South Central Washington	Beth Willhite
WC-EM-06-03	2006	Ecological Impacts of Drought Stress in AK Birch Stands	Robert Ott
WC-F-06-05	2006	Estimating Snag Densities and Down Wood with Aerial Survey Data	Keith Sprengel
WC-F-06-06	2006	Ecological Impacts of Invasive Species After Fire	Leigh Dawson
INT-EM-07-01	2007	Recent, Rapid, Severe Aspen Mortality in the Rocky Mountain Region	James Worrall
INT-EM-07-02	2007	Ground Based Distribution Surveys for Exotic Balsam Woolly Agedgid (<i>Adelges piceae</i>) in Idaho	Lee Pederson
INT-EM-07-04	2007	The Effects of Silvicultural Manipulations on Spruce Beetle Populations	Tom Eager and Roy Mask
INT-F-07-01	2007	Contribution of Landscape Level Bark Beetle Outbreaks to Fuel Loading and Fire Behavior in Pine Forests of the Southwest	Joel McMillin
INT-F-07-02	2007	Bugs & Burns: Effects of Fire on Ponderosa Pine Bark Beetle	Tom Degomez
INT-F-07-03	2007	Monitoring Bark Beetle-caused Mortality and Relation to Fire Occurrence	Sheryll Costello
INT-F-07-05	2007	Modeling Fire Spread and Intensity Across Bark Beetle-affected Landscapes	Michael Jenkins
NC-EM-07-01	2007	Assessment and Etiology of Hickory (<i>Carya</i> spp.) Decline in the Midwest and Northeastern Regions	Jennifer Juzwik
NC-EM-07-02	2007	Relating Black Ash (<i>Fraxinus nigra</i>) Decline and Regeneration to Tree Age and Site Hydrology	Brian Palik
NE-EM-07-01	2007	Evaluating Elevated Levels of Crown Dieback Among Northern White-Cedar (<i>Thuja occidentalis</i>) Trees in Maine and Michigan	KaDonna Randolph
WC-EM-07-01	2007	Yellow-cedar Decline: Evaluating Key Landscape Features of a Climate-Induced Forest Decline	Paul Hennon and Dustin Wittwer
WC-EM-07-02	2007	Assessment of Aspen Leaf Miner Distribution in Alaska Using Satellite Imagery.	John Lundquist and James Kruse
WC-EM-07-05	2007	Improving the Interpretation of Lichen Biomonitoring for Nitric Acid and Ozone Air Pollution in the Detection Monitoring Program	Pamela Padgett

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A synthesis of evaluation monitoring projects by the forest health monitoring program (1998-2007). Gen. Tech. Rep. SRS-159. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 140 p.

The national Forest Health Monitoring Program of the Forest Service, U.S. Department of Agriculture, has funded over 200 Evaluation Monitoring projects. Evaluation Monitoring is designed to verify and define the extent of deterioration in forest ecosystems where potential problems have been identified. This report is a synthesis of results from over 150 Evaluation Monitoring projects initiated between 1998 and 2007. The purpose of this synthesis is to document results, provide material for a planned online database, and establish priorities for future Evaluation Monitoring projects.

Keywords: Down woody material, evaluation monitoring, fire, forest health, insects and disease, lichens, ozone, soils.



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