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.

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 different 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.

- Ground truth assessments show that unhealthy white oaks occurred disproportionally 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 (PCRRFLP), 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.

- 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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