GROUND TRUTH ASSESSMENTS OF FORESTS AFFECTED BY OAK DECLINE AND RED OAK BORER IN THE INTERIOR HIGHLANDS OF ARKANSAS, OKLAHOMA, AND MISSOURI: PRELIMINARY RESULTS FROM OVERSTORY ANALYSIS

James M. Guldin, Edward A. Poole, Eric Heitzman, John M. Kabrick, and Rose-Marie Muzika[1]

Abstract—Forests of the Interior Highlands of Arkansas, Oklahoma, and Missouri are being affected by oak decline and an unprecedented outbreak of a native beetle called the red oak borer. On average, Interior Highlands stands contained 236 trees per acre, of which 32 trees per acre (13.4 percent) were dead or dying. Stands averaged 97 square feet per acre of basal area, of which 14 square feet per acre (14.5 percent) was dead or dying. Red oak species had the greatest proportional damage. Red oak basal area in the region averaged 27.2 square feet per acre, of which 8.2 square feet per acre (30 percent) was affected. White oak basal area averaged 36.0 square feet per acre, of which 3.4 square feet per acre (9.4 percent) was dead or dying. White oak species showed evidence of decline in both the small and large diameter classes, whereas red oaks had some proportion of unhealthy trees across all diameter classes.

INTRODUCTION

Forests of the Interior Highlands of Arkansas, Oklahoma, and Missouri are now being affected by oak decline and an unprecedented outbreak of a native cerambycid beetle, the red oak borer [*Enaphalodes rufulus* (Haldeman)] (Crook and others 2003, Heitzman 2003, Muzika and Guyette 2004, Starkey and others 2004). Data from the Ozark-Ouachita Highlands Assessment (Guldin and others 1999) show that the region has a total land area of 37.287 million acres of which 22.894 million acres, or 61 percent, is classified as timberland. One-third of this timberland area is composed of stands dominated by oaks (*Quercus* spp.) that are ≥ 70 years old and are potentially at risk. Roughly 13.8 billion board feet, or one-quarter of the total timber volume, is in the red oak group, (subgenus *Erythrobalanus)*. Although the distribution of unhealthy forests on all public and private lands across the region is not yet known, if one-third of that red oak volume is lost, the potential loss exceeds $1.1 billion. Our goal was to quantify the distribution, severity, and extent of oak decline and the red oak borer epidemic in the Interior Highlands.

STUDY DESIGN

We used a risk-based sampling polygon approach that was developed to quantify regional trends in forest health (U.S. Department of Agriculture, Forest Service 2000). Polygons equal to the number of plots were identified on a map of the Interior Highlands which had been created using a geographic information system (GIS) (Heitzman and Guldin 2004).

We then applied an expert systems approach to classify sampling polygons based on risk, using published and unpublished literature and discussions with professional resource managers knowledgeable about oak decline. The system resulted in a classification of polygon plots into four categories based on site and red oak basal area factors:

1. High risk: stands with low site indices, e.g., ridgetop, south- or southwest-facing slopes having > 30 square feet per acre of red oak species; or high red oak basal area (> 60 square feet per acre) on high site indices;
2. Moderate risk: stands with > 60 square feet per acre in red oak basal area but located on sites other than those specified in the high risk category;
3. Low risk: stands with moderate to high basal area (10 to 30 square feet per acre) in red oak species; and
4. No risk: stands with low basal area in red oak species (< 10 square feet per acre)

Plot Location Protocols

Within the geographic area represented by each sample polygon, a random point was identified as the location of the sample plot. During the summers of 2002 and 2003, 225 field plots were established in Arkansas, Missouri, and Oklahoma. Plots were excluded from this analysis if there were no oak species present in the overstory, if the plot fell in an agricultural area, if permission for access could not be obtained from the landowner, or if the plot had improper or questionable data records present. Thus, of the initial 225 plots, 181 plots contained some type of oak species within the overstory, and these were retained for data analysis.

Field Procedure

Field crews used portable geographic positioning system (GPS) units to locate the center of each sample plot. At predetermined coordinates, crew members visually assessed stand homogeneity and, if necessary, adjusted the location of the plot center within the immediate vicinity to ensure homogeneous stand conditions. This avoided situations where a sample plot fell adjacent to a road or in a stand transition area such as the border between forest and pasture. Plot attributes were recorded using the plot center as the

[1] Supervisory Ecologist/Project Leader, USDA Forest Service, Southern Research Station, Hot Springs AR 71902; Graduate Research Assistant and Assistant Professor, respectively, School of Forest Resources, Arkansas Forestry Resources Center, University of Arkansas at Monticello, Monticello AR 71656; Research Forester, USDA Forest Service, North Central Research Station, Columbia MO 65211; and Associate Professor, School of Natural Resources, University of Missouri-Columbia, Columbia MO 65211.

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locus of measurements. Geographic position was recorded using the portable GPS device to quantify latitude, longitude, and elevation, collected in UTM zone 15 and the NAD83 datum. Aspect was measured using a compass (declination set to 7° E.), and slope steepness was measured in percentage units using a clinometer.

Two plot sizes were used based on tree size. Trees with diameter at breast height (d.b.h.) ≥ 3.6 inches but ≤ 9.5 inches were sampled using a 0.1-acre fixed radius plot (r = 37.24 feet). Trees with d.b.h. ≥ 9.6 inches were sampled using a 0.2-acre fixed radius plot (r = 52.66 feet). Field crews determined the size, species composition, and condition of the woody vegetation on the plots. In addition, they estimated crown condition for each tree using an ordinal crown dieback rating from 0 to 3 as follows: 0 = no dieback, 1 = 1 to 33 percent dieback, 2 = 34 to 66 percent dieback, and 3 = 67 to 100 percent dieback.

DATA ANALYSIS

We assumed tree health to be inversely related to crown dieback. Overstory trees with a dieback rating of 2 or 3 were classified as unhealthy—dead, dying, or strongly affected. Trees with a dieback rating of 0 or 1 were classified as healthy. Assessment of plot health was made by calculating the absolute value and the percent of healthy vs. unhealthy oak basal area and stem density. Calculations of healthy and unhealthy oak basal area, and respective oak basal area percentages, were made for each plot by species group. Dominant species in the white oak species group, *Leucobalanus*, were white oak (*Quercus alba* L.) and post oak (*Q. stellata* Wagenh.). Minor white oaks included bur oak (*Q. macrocarpa* Michx.), chinkapin oak (*Q. muehlenbergii* Engelm.), and chestnut oak (*Q. prinus* L.). The red oak species group primarily consisted of northern red oak (*Q. rubra* L.), black oak (*Q. velutina* Lam.), scarlet oak (*Q. coccinea* Muenchh.), southern red oak (*Q. falcata* Michx. var. *falcata*), and blackjack oak (*Q. marilandica* Muenchh.). Minor and varying species included pin oak (*Q. palustris* Muenchh.), scrub oak (*Q. ilicifolia* Wagenh.), water oak (*Q. nigra* L.), willow oak (*Q. phellos* L.), and Shumard oak (*Q. shumardii* Buckl.). Conifers were primarily shortleaf pine (*Pinus echinata* Mill.), eastern redcedar (*Juniperus virginiana* L.), and rarely, loblolly pine (*P. taeda* L.). Hickories included all members of the *Carya* genus, and those most frequently recorded were mockernut hickory [*C. tomentosa* (Poir.) Nutt.], black hickory (*C. texana* Buckley), bitternut hickory [*C. cordiformis* (Wangenh.) K. Koch], shagbark hickory [*C. ovata* (Mill.) K. Koch], and pignut hickory (*C. glabra* Mill.). Other hardwoods included all other hardwoods not included in the oak or hickory groups.

We used inverse distance weighting (IDW) to map the extent of oak mortality in the Interior Highlands (Johnston and others 2001) and to evaluate the geographic pattern of incidence and severity. The estimate of oak decline at a given plot was calculated using a weighted distance score for oak decline at the nearest five plots to the given plot. We then used these coordinates and IDW calculations for each plot to generate a map representing the percentage of basal area affected by oak decline across the region.

RESULTS

Oak Decline Mapping

Across the Interior Highlands, 22 plots (12 percent of 181 plots) had unhealthy oak basal area > 29 square feet per acre (fig. 1). The highest absolute levels of unhealthy oak basal area were in Missouri forests, along a crescent of counties from the south-central to central part of the State, including Howell, Shannon, Reynolds, Jefferson, Crawford, and Pulaski counties, the heart of the southeastern Missouri Ozark Highlands. Arkansas also had several plots with high levels of unhealthy oak basal area. Those plots were distributed in counties diagonally across the State: Randolph, Sharp, Marion, and Searcy counties in the north to Montgomery and Polk counties in the southwest. Oklahoma's damage was concentrated in McCurtain, LeFlore, and Latimer counties in the southeastern corner of that State.

The map created using IDW analysis shows the largest percentage of unhealthy oak basal area in a crescent encompassing Latimer and LeFlore Counties, OK, and Polk County, AR. Smaller hotspots appear in Marion County, AR, and Reynolds and Pulaski Counties, MO (fig. 2).

General Trends in Overstory Health

Mean stem density for all sample plots across the Interior Highlands was 236 trees per acre, of which 32 trees per acre, or 13.4 percent, were unhealthy (table 1). Mean total basal area for all plots was 97.5 square feet per acre, of which slightly > 14 square feet per acre (14.5 percent) was unhealthy.

The red oak group had the largest number of unhealthy trees of any species group: 33 percent of stem density and 30 percent of basal area. Of all trees classified as unhealthy, the red oaks constituted 52 percent of stem density and 59 percent of basal area.

The white oak group had the next highest number of unhealthy trees, but the percentage was only about one-third that of the red oaks. The only other group with a high percentage of dead or dying trees was the unknown group, and this is partially attributable to the difficulty in identifying species of dead and deteriorating stems.

Hickory, miscellaneous hardwoods, and conifers groups all had much lower absolute and relative levels of unhealthy trees. Collectively, these three groups accounted for roughly 43 percent of the total stem density but only 15 percent of unhealthy stems. Similarly, these species groups total 34 percent of the total basal area but only 15 percent of unhealthy basal area across the region.

Diameter Distributions

We compared the diameter distributions for both healthy and unhealthy red oak and white oak species groups in the region (fig. 3). These data support anecdotal observations that the current outbreak has less severely affected white oaks, although they are more numerous. Unhealthy white oaks tended to be within the smaller size classes, although some larger trees also showed decline symptoms. In the 4-inch to the 8-inch d.b.h. classes, at least one tree per acre was classified as unhealthy. While the absolute number of white oaks per acre declined with increasing size, the percentage of

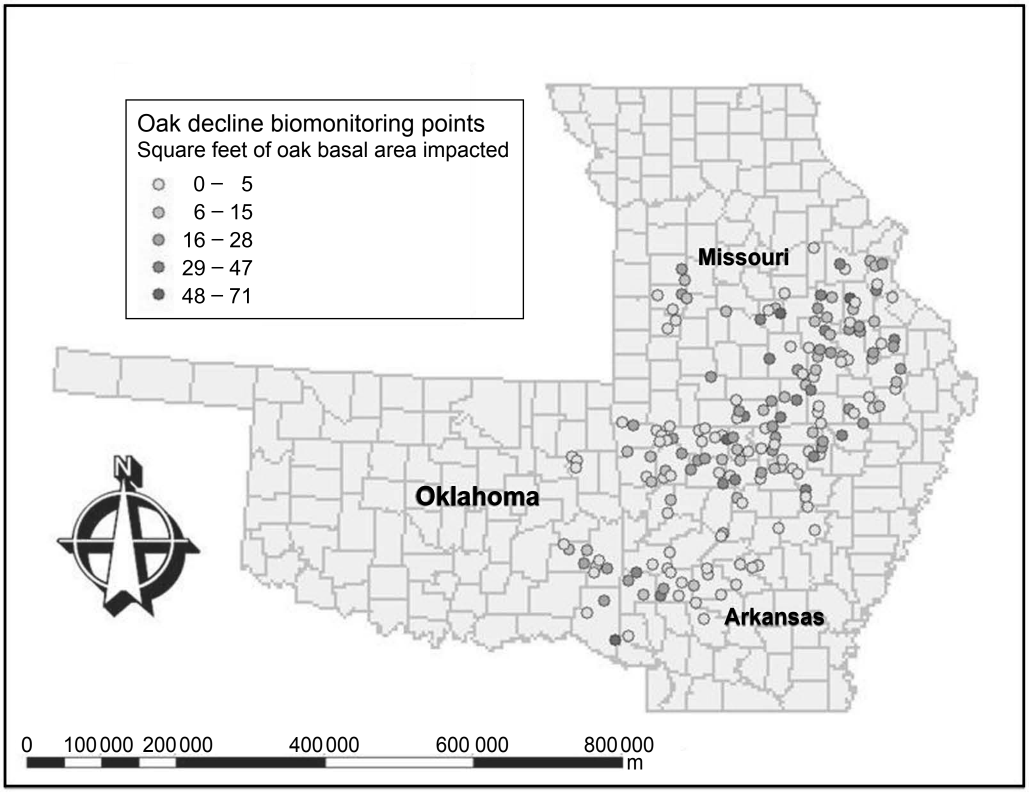

Figure 1—Absolute impacts on oak basal area (square feet per acre) by the oak decline/red oak borer event.

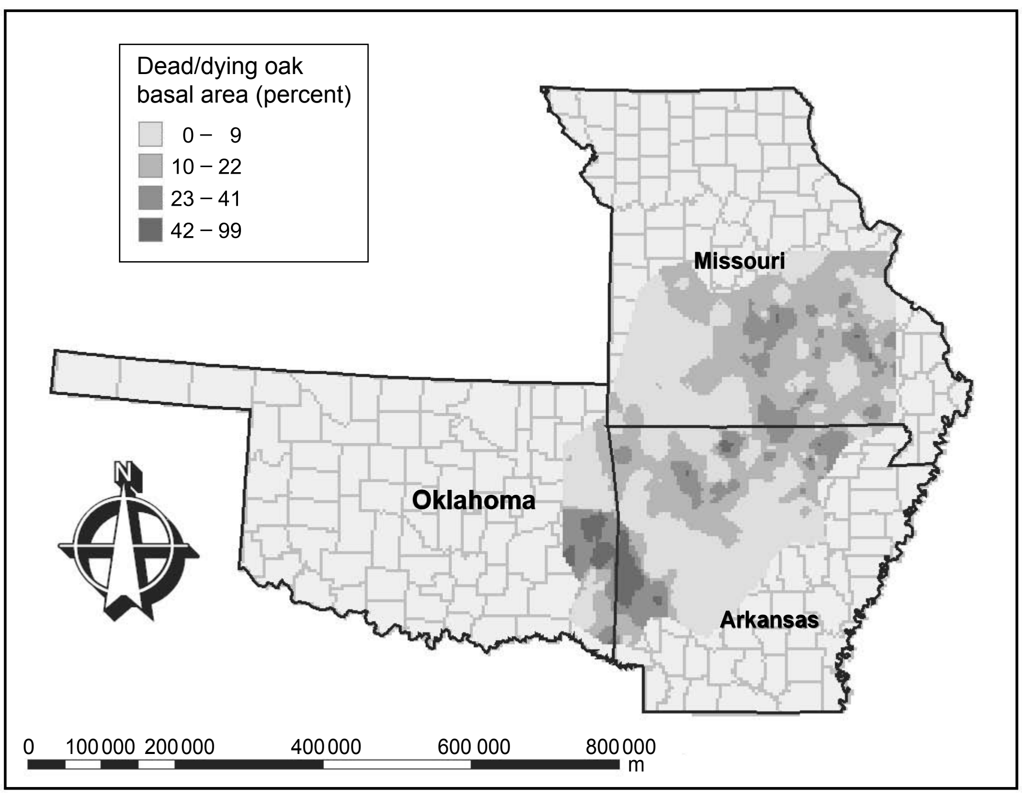

Figure 2—Predicted impact of the oak decline/red oak borer event in terms of percent of basal area of oak affected, using inverse distance weighting methodology.

Table 1—Stem density and basal area of healthy and dead or dying trees by species group across all plots in the Interior Highlands

Species group[a]	Stem density			Basal area		
	Healthy	Dead or dying		Healthy	Dead or dying	
	- - - - trees/ac - - - -		*percent*	*- - - - ft²/ac - - - -*		*percent*
Red oak	33.65	16.44	32.82	19.05	8.17	30.02
White oak	72.15	9.14	11.25	32.64	3.37	9.35
Hickory	34.20	0.44	1.28	9.49	0.65	6.37
Miscellaneous hardwoods	33.51	2.29	6.40	8.70	0.80	8.44
Conifers	29.25	2.07	6.61	13.00	0.77	5.57
Unknown	1.60	1.19	42.57	0.56	0.36	38.86
Total	204.36	31.57	13.38	83.43	14.11	14.47

[a] Red oak group: northern red oak (*Quercus rubra* L.), black oak (*Q. velutina* Lam.), scarlet oak (*Q. coccinea* Muenchh.), southern red oak (*Q. falcata* Michx.), and blackjack oak (*Q. marilandica* Muenchh.); minor and varying species reported included pin oak (*Q. palustris* Muenchh.), scrub oak (*Q. ilicifolia* Wagenh.), water oak (*Q. nigra* L.), willow oak (*Q. phellos* L.), and Shumard oak (*Q. shumardii* Buckl.). White oak group: white oak (*Q. alba* L.) and post oak (*Q. stellata* Wagenh.); minor white oaks reported included bur oak (*Q. macrocarpa* Michx.), chinkapin oak (*Q. muehlenbergii* Engelm.), and chestnut oak (*Q. prinus* L.). Hickories: all species in the genus *Carya*. Miscellaneous hardwoods: identifiable hardwoods not in the oak or hickory groups. Conifers: shortleaf pine (*Pinus echinata* Mill.) and eastern redcedar (*Juniperus virginiana* L.), and also loblolly pine (*P. taeda* L.). Unknown: species that could not be identified in the field.

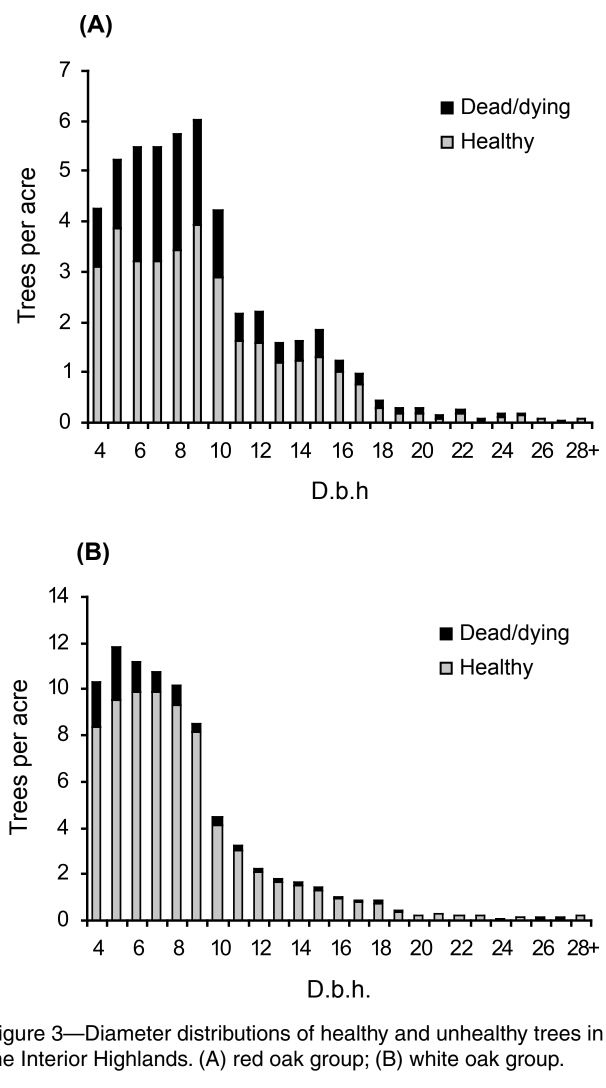

Figure 3—Diameter distributions of healthy and unhealthy trees in the Interior Highlands. (A) red oak group; (B) white oak group.

unhealthy trees remained relatively small until the largest size classes, which show a higher percentage of unhealthy trees.

Compared to white oak, red oak species in the region comprised more stems per acre and also had a higher percentage of unhealthy trees. Where white oak exhibited a larger percentage of unhealthy trees in small and large d.b.h. classes, red oak had a relatively constant percentage of unhealthy trees among all size classes. In red oaks in the 4- to 15-inch d.b.h. classes, an average of two trees per acre were classified as unhealthy, and nearly one-half of the trees in the 6- to 8-inch d.b.h. classes were unhealthy.

DISCUSSION

The current oak decline/red oak borer event is widespread and appears to be distributed relatively uniformly across 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. Unhealthy white oaks constitute 8 to 13 percent of white oak stem density and 7 to 19 percent of white oak basal area. GIS-based IDW 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.

In addition to the roughly threefold difference in damage between the red oak and white oak groups, there appear to be differences in impacts on different size classes. Unhealthy white oaks occurred disproportionally in the smaller diameter classes (the 4- to 9-inch classes) or in trees with d.b.h. ≥ 18 inches. Conversely, unhealthy red oaks were relatively uniformly distributed in roughly equal proportions across the diameter distribution. This might be explained by differences in vigor and senescence as related to size of red oaks vs. white oaks. For example, one might hypothesize that the unhealthy small oaks of either species group are adversely affected because of a lack of vigor. But in the white oak group, a lack of vigor and resulting increase in susceptibility to decline and borer attack might not be seen until the trees are quite advanced in age and size. Both of the two major white oaks in the study, white oak and post oak, reach advanced age (300 years and older) and are capable of growing to large size. Conversely, some of the red oak species, such as scarlet oak, often reach maturity and senescence in about 100 years and in relatively unremarkable sizes. Thus, in the red oak group, the presence of unhealthy trees across the diameter distribution might be related to the particular species of red oak in the group, which collectively reach maturity at different age and size across the region. While a hypothesis developed along these lines might explain the observed differences in tree health between the species groups across the diameter distribution, other hypotheses do as well. Additional research is needed on this or other datasets to develop an acceptable hypothesis that explains the observations.

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