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

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Abstract—Forests of the Interior Highlands of Arkansas, Oklahoma, and Missouri are 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 red oak borer epidemic in the Interior Highlands.

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 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.

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). Plots were excluded from this analysis if there were no oak species present in the overstory, if the plot fell in an agricultural area, or if permission for access could not be obtained from the landowner, or if the plot had incomplete 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.

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, or 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

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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 percent-
age units using a clinometer.

Two plot sizes were used based on tree size. Trees with diam-
eter 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 vege-
tation on the plots. In addition, they estimated crown condi-
tion 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 die-
back. 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 abso-
lute 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, lobilly 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. cordi-
formis* (Wangenh.) K. Koch), shagbark hickory (*C. ovata* (Mill.)
K. Koch), and pignut hickory (*C. glabra* Mill.). Other hard-
woods 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 inci-
dence 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 High-
lands. 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 concen-
trated in McCurtain, LeFlore, and Latimer counties in the
southeastern corner of that State.

The map created using IDW analysis shows the largest per-
centage of unhealthy oak basal area in a crescent encompass-
ing 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 per-
cent 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 per-
cent 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 clas-
sified 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.
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 disproportionately 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

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

<table>
<thead>
<tr>
<th>Species group</th>
<th>Healthy Stem density</th>
<th>Dead or dying Stem density</th>
<th>Healthy Basal area</th>
<th>Dead or dying Basal area</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>- - - trees/ac - - -</td>
<td>percent</td>
<td>- - - ft²/ac - - -</td>
<td>percent</td>
</tr>
<tr>
<td>Red oak</td>
<td>33.65</td>
<td>16.44</td>
<td>32.82</td>
<td>19.05</td>
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<tr>
<td>White oak</td>
<td>72.15</td>
<td>9.14</td>
<td>11.25</td>
<td>32.64</td>
</tr>
<tr>
<td>Hickory</td>
<td>34.20</td>
<td>0.44</td>
<td>1.28</td>
<td>9.49</td>
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<tr>
<td>Miscellaneous hardwoods</td>
<td>33.51</td>
<td>2.29</td>
<td>6.40</td>
<td>8.70</td>
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<tr>
<td>Conifers</td>
<td>29.25</td>
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<td>6.61</td>
<td>13.00</td>
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<tr>
<td>Unknown</td>
<td>1.60</td>
<td>1.19</td>
<td>42.57</td>
<td>0.56</td>
</tr>
</tbody>
</table>

Total 204.36 31.57 13.38 83.43 14.11 14.47

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![Figure 3](image-url)

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

ACKNOWLEDGMENTS
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LITERATURE CITED