IMPACTS OF OAK DECLINE ON FOREST STRUCTURE IN ARKANSAS AND OKLAHOMA: PRELIMINARY RESULTS

Eric Heitzman and James M. Guldin[1]

Abstract—We established field plots in the Ouachita and Ozark Mountains of Arkansas and Oklahoma to quantify the impacts of oak decline on forest structure. Plots were identified as either high risk (red oak basal area $\geq$ 20 square feet per acre) or low risk (red oak basal area < 20 square feet per acre). Red oak had the highest importance values on high-risk plots whereas shortleaf pine was the most important species on low-risk plots. Fifty percent of red oak density and 53 percent of red oak basal area were dead or dying on high-risk plots. In contrast, 20 percent of red oak density and 20 percent of red oak basal area were dead or dying on low-risk plots. Red oaks on all plots were killed regardless of tree d.b.h. Sapling and seedling regeneration on high-risk plots was dominated by nonoak, shade-tolerant species. In severely impacted areas, oak decline appeared to be accelerating a change in long-term species composition away from oak-dominated forests.

INTRODUCTION

Since 1999, widespread and locally severe mortality of red oaks has been observed in the Ozark Mountains of Arkansas and Missouri and the Ouachita Mountains of Arkansas and eastern Oklahoma. Mortality has been attributed to oak decline, a disease complex caused by predisposing, inciting, and contributing factors that interact and result in mortality, particularly for red oaks (Starkey and others 1989). Oak decline is a natural and recurring phenomenon in the Southern United States. However, the level of mortality associated with the current decline is unprecedented in the Ozark and Ouachita Mountains. At least 300,000 acres in Arkansas and more than 100,000 acres in Missouri have been severely damaged (Lawrence and others 2002, Spencer 2001).

In the current episode, Mielke (2001) and Starkey and others (2000) have suggested the predisposing factors include high proportions of red oak in stands, advanced tree age, and shallow, rocky soils. The inciting factor was probably a pronounced regional drought from 1998 to 2000. Contributing factors are the red oak borer [*Enaphalodes rufulus* (Haldeman) (Coleoptera: Cerambycidae)] and, more speculatively, other organisms such as *Armillaria* spp. root rot, *Hypoxylon* spp. stem canker, and two-lined chestnut borer [*Agrilus bilineatus* (Weber)]. The role of red oak borer in this decline is particularly remarkable. The insect is native to the Eastern and Southern United States. It feeds in the phloem and xylem of living oak trees, with preferred upland hosts being northern red oak (*Quercus rubra* L.), black oak (*Q. velutina* Lam.), and scarlet oak (*Q. coccinea* Muenchh.) (Donley and Acciavatti 1980, Solomon 1995). Species in the white oak group [including white oak (*Q. alba* L.) and post oak (*Q. stellata* Wangenh.)] are less commonly attacked. Normally, red oak borer populations are too low to kill trees. However, recent dissections of dead and declining trees in Arkansas indicated that borer populations were at unprecedentedly high levels (Stephen and others 2002).

Despite the magnitude of the disturbance, no formal studies have examined the impacts of oak decline on the forest structure of the region. In 2002, field plots were established in Arkansas and Oklahoma to quantify the distribution and severity of oak decline. This fieldwork initiated a larger project that will include additional plots in Arkansas, Oklahoma, and Missouri. For this paper, we used preliminary field plot data to describe (1) the structural characteristics of stands having high and low mortality levels, and (2) the regeneration status of high-mortality stands.

METHODS

In July and August 2002, 44 field plots were established throughout the Ozark Mountains of northern Arkansas and the Ouachita Mountains of western Arkansas and eastern Oklahoma. Most plots were located on the Ozark-Saint Francis National Forest and the Ouachita National Forest. Elevations ranged from 490 to 2,200 feet. Plots were located on a variety of topographic positions and aspects. Site index was generally 50 to 60 feet for upland oak at base age 50 years. Most slopes were 10 to 40 percent, although slopes exceeding 55 percent were recorded.

The field methods for site selection have been developed for similar forest health issues of oak, specifically, gypsy moth, ozone, and, most recently, sudden oak death syndrome (Smith 1995). The basic approach is to generate 500 units of area, called polygons, where each polygon is stratified by the proportion of stands it contains at high or low risk using available Forest Service data within each polygon. In this study, the sample design had a large expansion factor; the inventory was designed to sample approximately 500 plots, or roughly 1 plot for every 50,000 acres of forest land in the Ozark and Ouachita Mountains. An expert systems approach was used to identify variables of importance in quantifying risk strata for oak decline, based on red oak basal area, aspect, and site index. The sample was then stratified in such a manner as to visit more polygons in the higher risk categories and fewer in

[1]Assistant Professor, School of Forest Resources, University of Arkansas, Monticello, Arkansas 71656; and Project Leader and Research Forest Ecologist, Southern Research Station, Hot Springs, Arkansas 71902, respectively.

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the lower risk categories. But, because a 50,000-acre polygon contains a variety of stands, often the stand actually visited did not match the classifying parameters. Thus, final stratification of plots was based on data actually collected in the field rather than through *a priori* assignment.

Plots consisted of one 0.2-acre overstory plot in which all living, dying, and dead trees ≥ 9.6 inches in d.b.h. were tallied by species, tree condition, and d.b.h. Tree condition was recorded as: alive and healthy, alive but dying, or dead within the past 3 years. Trees that died more than 3 years ago were not recorded. A series of smaller plots were nested within each 0.2-acre plot. These included: one 0.1-acre midstory plot in which all living, dying, and dead trees 3.6 to 9.5 inches in d.b.h. were tallied by species, tree condition, and d.b.h,; two 0.01-acre sapling plots in which we recorded living trees 1.6 to 3.5 inches in d.b.h. by species and d.b.h.; and eight 0.001-acre regeneration plots in which tree seedlings less than 1.6 inches in d.b.h. and taller than 1.5 feet were tallied by species and 1-foot height class.

Plots were established in stands having varying proportions of red oak. Some plots were dominated by red oak, whereas others contained no red oak at all. Because red oak is more susceptible than white oak to oak decline, we assumed that plots with a high proportion of red oak were at greater risk than plots with relatively few red oak. Therefore, we defined high-risk plots as having at least 20 square feet per acre of red oak basal area (including living and dead or dying trees) and low-risk plots as having less than 20 square feet per acre of red oak basal area. Of the 44 plots established, 18 were classified as high risk and 26 as low risk.

For trees ≥ 3.6 inches in d.b.h. on high- and low-risk plots, importance values (IV) for each species or species group were calculated using the equation IV=(relative density + relative basal area)/2. For all 44 plots, we used simple linear regression to explore the relationship between the total (i.e., living plus dead or dying) red oak basal area in a given plot and the dead or dying red oak basal area in the same plot. Significance was accepted at $P \leq 0.05$.

RESULTS AND DISCUSSION

Species importance values differed between high-risk and low-risk plots (table 1). Red oak had the highest species importance values on the high-risk plots, whereas shortleaf pine (*Pinus echinata* L.) was the most important species on the low-risk plots. On the high-risk plots, the order of species importance was red oak > other species > white oak > shortleaf pine. On the low-risk plots, the order of species importance was shortleaf pine > other species > white oak > red oak. Other species on high- and low-risk plots included hickory (*Carya* spp.), red maple (*Acer rubrum* L.), blackgum (*Nyssa sylvatica* Marsh.), and numerous associated species (table 1).

Red oak mortality was dramatic on the high-risk plots (table 2). For trees ≥ 3.6 inches in d.b.h., 53 percent of red oak density and 50 percent of red oak basal area were dead or dying. In contrast, 13 percent of white oak density and 7 percent of white oak basal area were dead or dying. Shortleaf pine and other species appeared to be relatively healthy. Including all species, 57 trees per acre and 25 square feet per acre were dead or dying on the high-risk plots. Red oak mortality was less pronounced on the low-risk plots (table 3). For trees ≥ 3.6 inches in d.b.h., 20 percent of red oak density and 20 percent of red oak basal area were dead or dying. Interestingly, white oak mortality as expressed in density (11 percent) and basal area (16 percent) was similar to or exceeded the white oak mortality recorded on high-risk plots. Shortleaf pine and other species on the low-risk plots were generally in good condition. Overall, only 16 trees per acre and 6 square feet per acre were dead or dying on the low-risk plots.

Including data from all 44 plots, there was a statistically significant linear relationship ($P \leq 0.05$) between the total red oak basal area in a given plot and the dead or dying red oak basal area in the same plot (fig. 1). Not surprisingly, the highest basal area of dead or dying red oak was generally found in plots dominated by red oak. However, red oak-dominated plots differed in the extent to which they had been affected by oak decline. For example, almost all of the red oak basal area on plots 12 and 16 was dead or dying. On plots 34 and 40, however, a relatively low proportion of red oak basal area was dead or dying, even though total red oak basal area was 45 and 60 square feet per acre, respectively. This suggests that other factors such as topographic position, aspect, tree age, and proximity to red oak borer populations may also influence tree susceptibility to decline (Oak and others 1996, Starkey and Oak 1989).

Table 1—Species importance values for trees ≥ 3.6 inches d.b.h. on high risk plots (red oak basal area ≥ 20 square feet per acre) and low risk plots (red oak basal area < 20 square feet per acre) in Arkansas and Oklahoma

	Importance values	
Species	High risk plots	Low risk plots
	percent	
Red oak[a]	35	7
White oak[b]	24	22
Shortleaf pine	11	37
Other species[c]	30	34

[a] Includes northern red oak, southern red oak, black oak, and blackjack oak (*Quercus marilandica* Muenchh.).
[b] Includes white oak and post oak.
[c] Includes hickory, red maple, blackgum, flowering dogwood (*Cornus florida* L.), winged elm (*Ulmus alata* Michx.), black cherry (*Prunus serotina* Ehrh.), white ash (*Fraxinus americana* L.), eastern hophornbeam (*Ostrya virginiana* (Mill.) K.Koch), eastern redcedar (*Juniperus virginiana* L.), sweetgum (*Liquidambar styraciflua* L.), black walnut (*Juglans nigra* L.), sugar maple (*Acer saccharum* Marsh.), American beech (*Fagus grandifolia* Ehrh.), and sassafras [*Sassafras albidum* (Nutt.) Nees].

Table 2—Stand characteristics for healthy and dead or dying trees ≥ 3.6 inches d.b.h. on high risk plots (red oak basal area ≥ 20 square feet per acre) in Arkansas and Oklahoma

	Density		Basal area	
Species	Healthy	Dead/dying	Healthy	Dead/dying
	trees per acre		*square feet per acre*	
Red oak[a]	38	42	21	21
White oak[b]	47	7	26	2
Shortleaf pine	22	1	15	< 1
Other species[c]	83	7	25	2
Total	190	57	87	25

[a] Includes northern red oak, southern red oak, black oak, and blackjack oak.
[b] Includes white oak and post oak.
[c] Includes hickory, red maple, blackgum, flowering dogwood, winged elm, black cherry, white ash,eastern hophornbeam, eastern redcedar, sweetgum, black walnut, sugar maple, American beech, and sassafras.

Table 3—Stand characteristics for healthy and dead or dying trees ≥ 3.6 inches d.b.h. on low risk plots (red oak basal area < 20 square feet per acre) in Arkansas and Oklahoma

	Density		Basal area	
Species	Healthy	Dead/dying	Healthy	Dead/dying
	trees per acre		*square feet per acre*	
Red oak[a]	12	3	5	1
White oak[b]	39	5	16	3
Shortleaf pine	59	7	35	2
Other species[c]	78	1	26	< 1
Total	188	16	82	6

[a] Includes northern red oak, southern red oak, black oak, and blackjack oak.
[b] Includes white oak and post oak.
[c] Includes hickory, red maple, blackgum, flowering dogwood, winged elm, black cherry, white ash,eastern hophornbeam, eastern redcedar, sweetgum, black walnut, sugar maple, American beech, and sassafras.

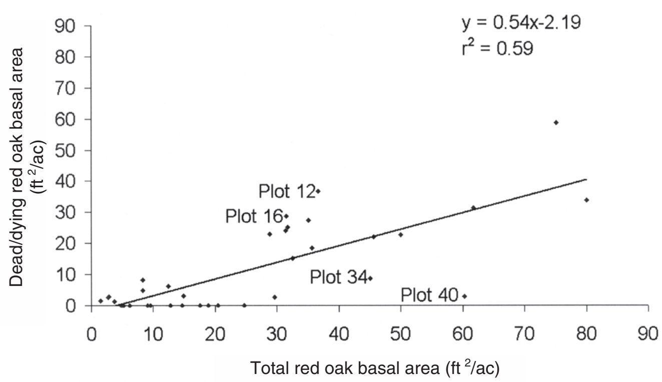
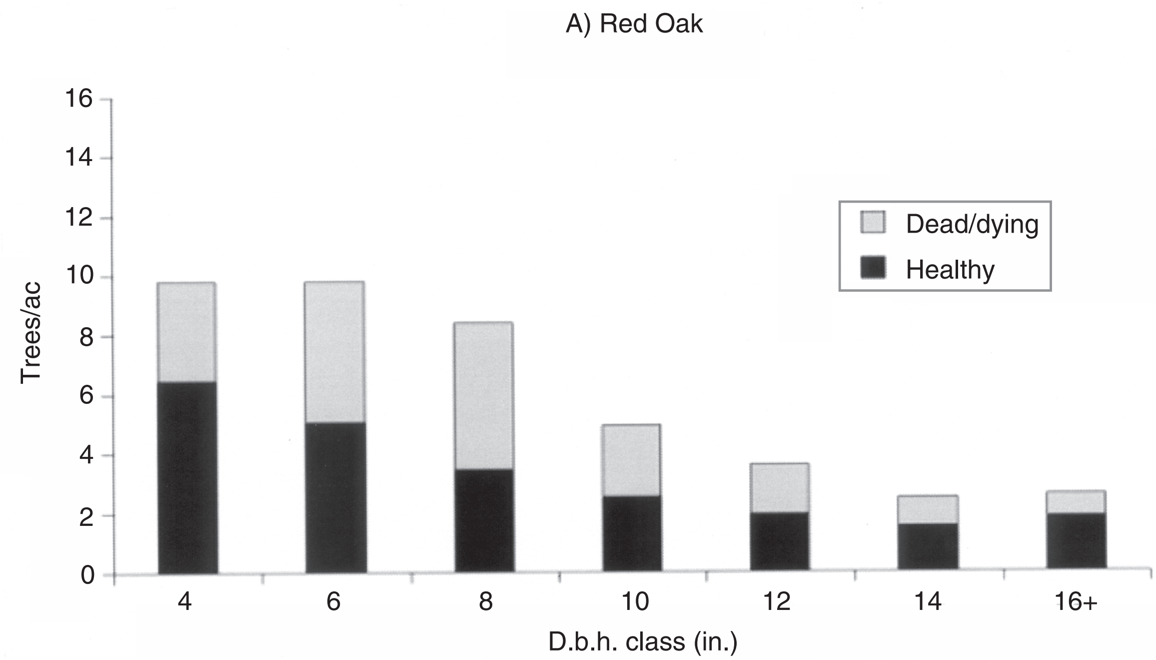


Figure 1—Relationship between total red oak basal area and dead or dying red oak basal area for trees ≥ 3.6 inches d.b.h. on high risk plots (red oak basal area ≥ 20 square feet per acre) and low risk plots (red oak basal area < 20 square feet per acre) in Arkansas and Oklahoma.

The diameter distribution of dead/dying red oak from all 44 plots was different from the diameter distribution of all dead or dying white oak (figs. 2a and 2b). Red oak mortality was observed across a range of diameters; high proportions of small, mid-sized, and large d.b.h. red oak trees were dead or dying (fig. 2a). In contrast, white oak mortality was greatest in small diameter trees (particularly the 4-inch d.b.h. class) and decreased with increasing diameter (fig. 2b). Such a pattern may indicate that red oak borers – which prefer red oak over white oak - can effectively kill trees of any size, whereas the factors responsible for the death of white oak generally kill small and presumably suppressed stems. Small-diameter white oaks are not necessarily young trees; although considered intermediate in shade tolerance, white oaks can persist in shaded understory conditions for decades (Rogers 1990).



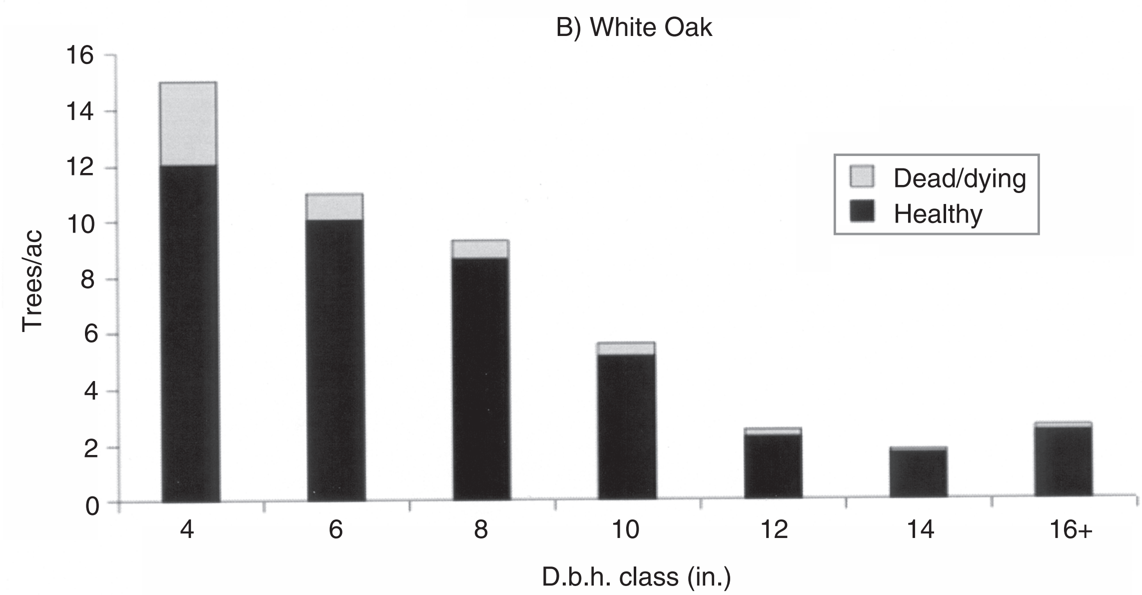


Figure 2—Diameter distribution of healthy and dead or dying (A) red oak and (B) white oak ≥ 3.6 inches d.b.h. on high risk plots (red oak basal area ≥ 20 square feet per acre) and low risk plots (red oak basal area < 20 square feet per acre) in Arkansas and Oklahoma.

On many of the high-risk plots, field observations indicated that oak mortality had triggered a regeneration response. On the high-risk plots, data indicate that the vast majority of sapling and seedlings in all d.b.h. and height classes were nonoak species (table 4). Indeed, only 16 percent of saplings and 18 percent of seedlings were oaks. Regenerating stems were predominantly shade-tolerant red maple, blackgum, and flowering dogwood (*Cornus florida* L.). Most red and white oak seedlings were in the 2- and 3-foot height classes. Previous research in the Missouri Ozarks suggested that such short oak seedlings have a low probability of survival (Sander 1972, Sander and others 1984).

Many mature oak forests in the Southern and Eastern United States are characterized by understories of shade tolerant, nonoak species (e.g., Abrams 1998, Lorimer and others 1994). In severely impacted forests in the Ozark and Ouachita Mountains of Arkansas and Oklahoma, it seems likely that oak decline is accelerating a long-term change in species composition toward fewer oaks. Data will

Table 4—Density of saplings (1.6–3.5 inches d.b.h.) and seedlings (< 1.6 inches d.b.h. and >1.5 feet tall) on high risk plots (red oak basal area ≥ 20 square feet per acre) in Arkansas and Oklahoma

	D.b.h. class (*inches*)			Height class (*feet*)			
Species	1	2	3	2	3	4	≥ 5
	Saplings per acre			*Seedlings per acre*			
Red oak[a]	3	13	8	181	28	28	0
White oak[b]	0	6	6	42	14	7	0
Other species[c]	49	81	60	729	306	146	167
Total	52	100	74	952	348	181	167

[a] Includes northern red oak, southern red oak, black oak, and blackjack oak.
[b] Includes white oak and post oak.
[c] Includes hickory, red maple, blackgum, flowering dogwood, winged elm, black cherry, white ash, eastern hophornbeam, eastern redcedar, sweetgum, American beech, sassafras, shortleaf pine, black locust (*Robinia pseudoacadia* L.), hawthorn (*Crataegus* spp.), downy serviceberry (*Amelanchier arborea* (Michx.f.) Fern.), and American hornbeam (*Carpinus caroliniana* Walt.).

be collected in 2003 from many additional field plots in Arkansas, Oklahoma, and Missouri to more completely describe the changes in forest structure occurring throughout the region.

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