# OAK DECLINE AND RED OAK BORER IN THE INTERIOR HIGHLANDS OF ARKANSAS AND MISSOURI: NATURAL PHENOMENA, SEVERE OCCURRENCES

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**Abstract**—Oak decline is a complex disease resulting in dieback and mortality of oaks. A number of factors are involved and can be classified as predisposing, inciting, or contributing, according to their roles. Decline events have been noted repeatedly during the past century in the eastern U.S. A severe episode of oak decline is occurring in the Interior Highlands region of Arkansas and Missouri. It includes an unprecedented epidemic of red oak borer (*Enaphalodes rufulus* Haldeman). Mortality and dieback of northern red, (*Quercus rubra* L.), black, (*Q. velutina* Lam.), scarlet (*Q. coccinea* Muenchh.) and southern red (*Q. falcate* Michx.) oaks on thousands of acres of Interior Highland forest became evident in 1999 following 2 years of severe regional drought. A third year of drought in 2000 greatly exacerbated the problem and mortality and dieback have continued through 2002. Aerial sketch-map surveys of portions of the Ozark National Forest in Arkansas estimated that up to 300,000 acres are severely affected. Data from ground evaluations during 1999-2000 on the Ozark and Mark Twain National Forests (Missouri) showed an average of 15-28 percent of red oak basal area per acre is dead in affected stands. An additional 2-14 percent had severe dieback. Data from 2000 and 2002 plot re-measurements on the Ozark National Forest showed that mortality and dieback continued, especially in red oaks where an additional 16-20 percent of basal area per acre died over three years. However, many stands with high basal areas of red oaks have experienced nearly 100 percent mortality. Red oak borer attacks were noted only on red oak species. Greater than 10 old and new red oak borer attacks on the lower bole were noted on over 18 and 23 percent, respectively, of red oak basal area per acre in damaged stands on the Ozark National Forest in 1999. On the Mark Twain National Forest in 2000, 54 percent of the red oak basal area per acre had greater than 10 attacks.

## INTRODUCTION

Oak decline is a complex disease with no single cause (Manion 1981, Wargo and others 1983). It is characterized primarily by progressive branch dieback and mortality of oaks growing in the overstory. Dieback and mortality are generally slow and can occur over several years. However, sudden mortality and rapid dieback can occur as well. A number of interacting factors contribute to decline—stand, site, abiotic and biotic factors (fig. 1). Oak decline is best conceptualized, according to Manion (1991), by categorizing factors into predisposing, inciting and contributing groups (fig. 2). Stands are predisposed to decline by such factors as relatively advanced physiologic age (Hyink and Zedaker 1987, Oak and others 1996), shallow, rocky soils, ridgetop and upper slope locations, dense oak stocking, and previous climate (e.g., severe regional droughts during the 1950's, 1980's (Tainter and others 1990)). Decline is incited by factors such as short-term, acute drought or insect defoliation. Secondary insects and pathogens are contributing factors that further stress trees and ultimately lead to mortality. Some contributing factors are: armillaria root rot (*Armillaria* [Fr.:Fr.] spp.), two-lined chestnut borer (*Agrilus*

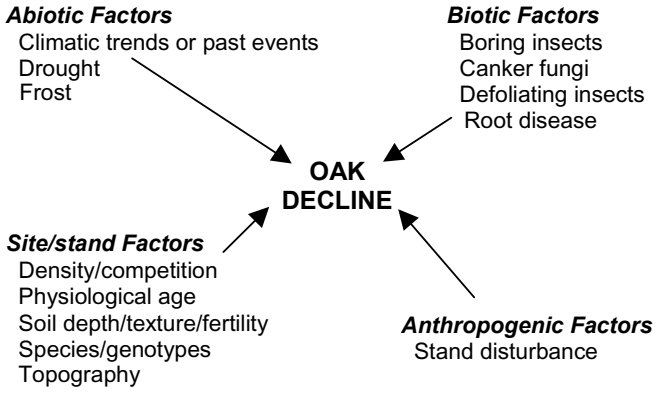


Figure 1—Causal factors of oak decline organized by type.

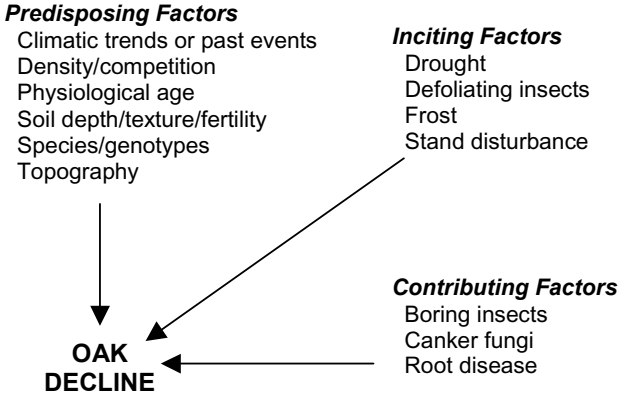


Figure 2—Causal factors of oak decline organized by their function in the decline syndrome.

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*bilineatus* Weber), red oak borer (ROB, *Enaphalodes rufulus* Haldeman) and hypoxylon canker (*Hypoxylon atropunctatum* [Schwein.:Fr.] Cooke). Species in the red oak group (northern red oak, *Quercus rubra* L.; black oak, *Q. velutina* Lam.; scarlet oak, *Q. coccinea* Muenchh.; and southern red oak, *Q. falcate* Michx.) are affected more quickly and severely than those in the white oak group (white oak, *Q. alba* L.; post oak, *Q. stellata* Wangenh.; chestnut oak, *Q. prinus* L.; Starkey and others 1989). Other species are affected as well, to varying degrees, but generally much less severely than oaks.

Oak decline or similar events have been described in most eastern states since the mid-1800's (Ammon and others 1989, Hopkins 1902, Millers and others 1988). Events have been documented in the Ozark Highlands of Arkansas and Missouri in the early and mid-1980's (Bassett and others 1982, Lewis 1981, Mistretta and others 1981, Rhodes and Tainter 1980, Starkey and others 1989, Yeiser and Burnett 1982). The Highlands area has an abundance of older oak-hickory forest types on sites of low to moderate productivity that are susceptible to decline. Stands with these characteristics seem particularly prevalent on national forests. In 1999, mortality and dieback of red oaks became abundant on the Ozark and Ouachita National Forests in Arkansas, and the Mark Twain National Forest in Missouri. Decline and mortality were accompanied by unusually heavy attacks by the ROB.

ROB's have generally been considered to cause degrade in red oaks due to the galleries they excavate in the wood (Donley and Acciavatti 1980, Solomon 1995) rather than causing tree mortality. They have a two-year life cycle with adult emergence mostly synchronous in odd-numbered years. Emergence peaks in mid-summer and adults lay eggs on red oak bark, particularly under lichens. After the eggs hatch, young larvae bore through the bark and begin to feed in the inner bark and eventually excavate a small area, killing the cambium layer in an area usually not exceeding about 4 square inches. During the second season, larvae begin to bore into the wood of the tree and turn upward until the larvae reach mature size (about 0.5 inches in diameter). Frass and sawdust are ejected from the galleries as they are excavated and continually enlarged to accommodate the growing larvae. Borers pupate within the gallery and adults exit the same entrance hole they created, leaving an oval emergence hole. Casual tree examinations and dissections on the Ozark National Forest have documented high borer populations and adult emergence in 1999 and 2001. Most foresters, entomologists and pest management specialists who have viewed the problem indicate they have never before seen an outbreak of such magnitude. Preliminary, detailed tree dissections have documented hundreds of old and new attacks on individual red oaks (Personal communication. Dr. Fred Stephen. 2001. Professor, University of Arkansas, 317 Agriculture Bldg., Fayetteville, AR 72701), whereas the highest previously published rates are about 71 attacks per tree (Hay 1974).

Aerial sketch-map surveys were conducted to estimate the extent and severity of the problem, and to guide field survey work. Ground evaluations were conducted in Arkansas (Starkey and others 2000) and Missouri (Mielke and others 2000) to determine the extent, severity and cause of the recent dieback/mortality and to document its association with ROB attacks. Revisits to surveyed stands on the Ozark National Forest were made in 2000 and 2002 in order to monitor progress of the decline event.

## METHODS/ACTIVITIES

An evaluation was conducted in late summer, 1999 on the Pleasant Hill Ranger District of the Ozark National Forest north of Clarksville, Arkansas (Starkey and others 2000). Ranger District personnel conducted an aerial sketch-map survey and delineated large areas of forest that fell into 3 strata of damage: severe (hardwood stands within the gross

**Table 1—Data collected on trees in sample stands, Ozark and Mark Twain National Forests, 1999–2002**

| Variable | Description |
|---|---|
| Species | Appropriate species code |
| D.b.h. | Diameter at breast height to the nearest 0.1 inches |
| Crown class | 4 = dominant, 3 = codominant, 2 = intermediate, 1 = suppressed |
| Crown condition | 0 = healthy, normal crown<br>1 = slight dieback: <1/3 of crown<br>2 = moderate dieback: 1/3-2/3 of crown<br>3 = severe dieback: >2/3 of crown<br>4 = dead, died this year: fine twigs present, brown leaves may be present, little or no bark sloughing<br>5 = dead, died 2–4 years ago: no fine twigs present, bark sloughing, sapwood rot obvious<br>6 = dead, died 4 or more year ago: stubby branches, extensive bark sloughing, extensive sapwood rot |
| ROB-OLD | Red oak borer attacks from previous years; number of old attacks on the lower 8 feet of bole: 0 = none, 1 = 1–10, 2 = 11–20, 3 = 21–30, etc. |
| ROB-NEW | Red oak borer attacks from current year; number of new attacks on the lower 8 feet of bole: 0 = none, 1 = 1–10, 2 = 11–20, 3 = 21–30, etc. |

ROB = red oak borer.

forest area with a visual estimate of 75+ percent of crown cover affected [mortality, dieback or dead foliage]), moderate (50-75 percent of crown cover affected) and slight (<50 percent crown cover affected). Six sawtimber-sized oak-hickory stands with reasonably good road access were selected at random in each of the damage strata for ground survey. Sample stands were surveyed using 5 basal-area-factor 10 prism plots arrayed on a transect through the main part of the stand at a minimum spacing of 150-200 feet. For sample trees >4 inches in diameter at breast height (d.b.h.), data included species, d.b.h., crown class, crown condition, number of old ROB attacks and number of new ROB attacks (table 1). In each stand, plot 1 was marked and a GPS (global positioning system) reading taken. These plots were relocated and re-measured in 2000 and 2002 to monitor the long-term progress of decline/mortality.

A similar ground survey was done on the Potosi and Salem Ranger Districts of the Mark Twain National Forest in Missouri in 2000 (Mielke 2000). Five affected stands were sampled on the Potosi Ranger District and 6 on the Salem. Stands were sampled in the manner described above except that old and new ROB attacks were not differentiated.

A more extensive aerial sketchmapping survey was performed in 2001 over the entire main division of the Ozark National Forest (Boston Mountain, Pleasant Hill, Bayou, and Buffalo Ranger Districts) by Forest personnel. Areas with light, moderate, and severe activity were delineated as in 1999.

## RESULTS

Aerial sketchmapping of the Pleasant Hill Ranger District in 1999 delineated approximately 19,000 acres (16 percent) as severely affected, 24,000 (20 percent) as moderately affected and 75,000 acres (64 percent) as slightly affected. Ground sampling of the 54 plots yielded a sample tree population of 864 trees. Red oaks comprised 46 percent of the basal area, white oaks 28 percent, and other species 26 percent. Ground sampling confirmed the relative damage classification during aerial sketchmapping. Mortality and dieback of all species were most prevalent in the severe stratum where 24 percent of the basal area per acre had moderate to severe dieback or was dead fig. 3). Damage was less in the moderate (12 percent) and light (8 percent) strata. Comparing species groups, red oaks were more severely affected across all strata than white oaks or other species—22 percent of basal area per acre with moderate to severe dieback or dead compared to 8 and 7 percent, respectively (fig. 4). Red oaks in the severe stratum had the most damage—35 percent of basal area per acre with moderate to severe dieback or dead and less in the moderate (19 percent) and light (9 percent) strata (fig. 5).

Enumeration and characterization of ROB attack sites on the lower 8 feet of bole represent just a rough (and probably very conservative) estimate of infestation levels since they are difficult to tally accurately and quickly. Nonetheless, they provide a useful picture of the relative extent and nature of borer attacks. ROB attacks (both old and new) were noted only on red oak species—54 percent of basal area per acre had 1 or more old attacks and 45 percent had 1 or more new attacks (fig. 6). Both old and new ROB attacks on red oaks were most prevalent in the severe stratum, followed by the moderate and slight strata (figs. 7 and 8). Old ROB attacks on red oaks were most prevalent on dead trees (fig. 9). New ROB attacks, however, were most prevalent on moderate/severe red oaks followed by dead, then healthy/slight red oaks (fig. 10).

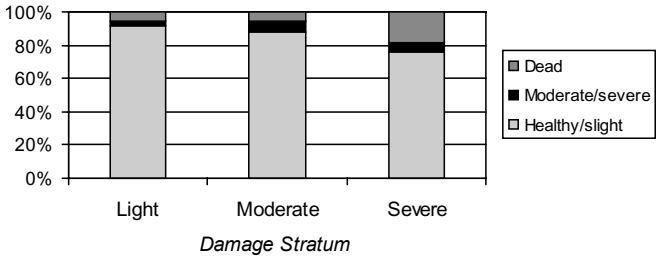


Figure 3—Percentage of basal area per acre by stratum and crown condition, Ozark National Forest, 1999.

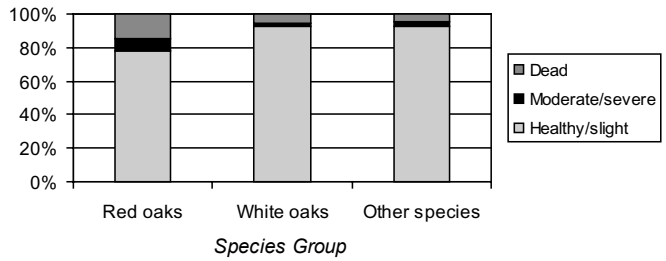


Figure 4—Percentage of basal area per acre by species group and crown condition, Ozark National Forest, 1999.

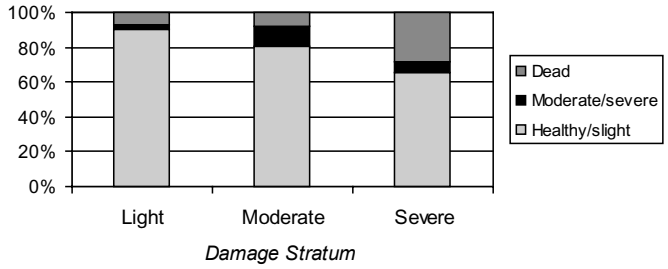


Figure 5—Percentage of basal area per acre of red oaks by stratum and crown condition, Ozark National Forest, 1999.

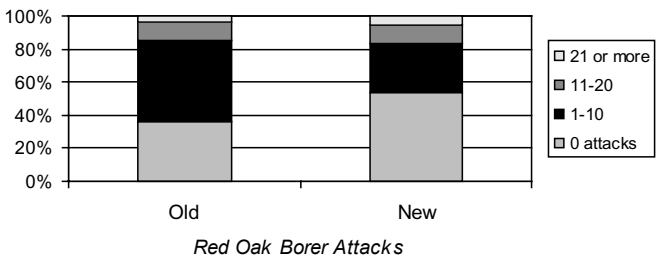


Figure 6—Percentage of red oak basal area per acre with old and new red oak borer attacks, Ozark National Forest, 1999.

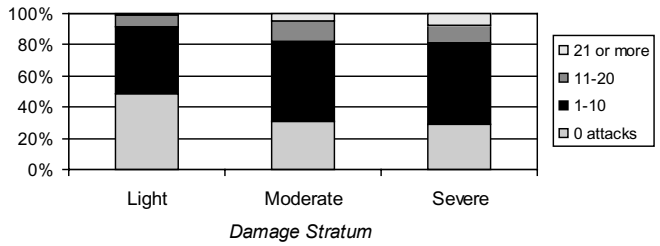


Figure 7—Percentage of red oak basal area per acre with old red oak borer attacks by stratum, Ozark National Forest, 1999.

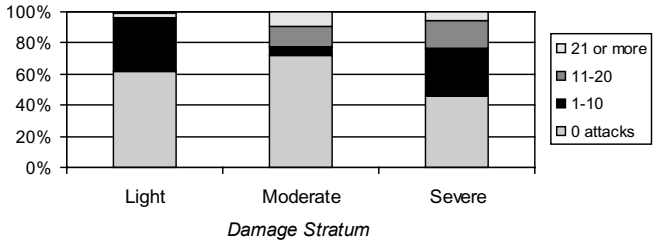


Figure 8—Percentage of red oak basal area per acre with new red oak borer attacks by stratum, Ozark National Forest, 1999.

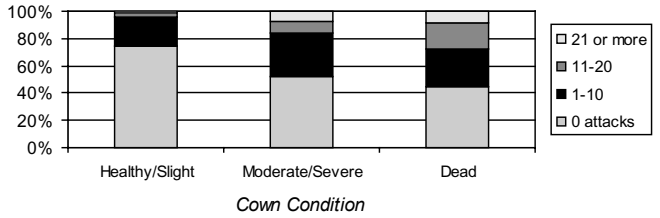


Figure 9—Percentage of red oak basal area per acre with old red oak borer attacks by crown condition, Ozark National Forest, 1999.

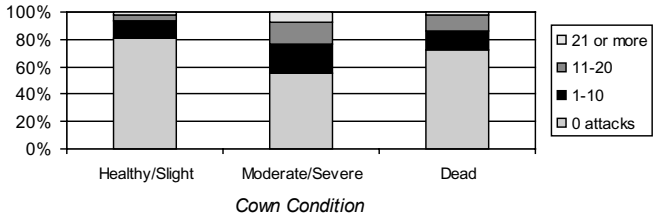


Figure 10—Percentage of red oak basal area per acre with new red oak borer attacks by crown condition, Ozark National Forest, 1999.

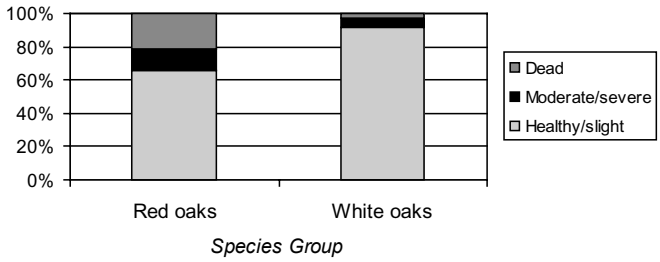


Figure 11—Percentage of basal area per acre by species group and crown condition for the Mark Twain National Forest.

Sampling on the Mark Twain National Forest in 2000 produced similar results with about 20 percent of scarlet and black oak basal area per acre dead, and 11 percent with moderate to severe decline (fig. 11). As on the Ozark National Forest, white oaks were much less affected. In addition, ROB attacks were present on most red oaks—almost 45 percent of basal area per acre had over 10 attacks (fig. 12).

Data from the re-measured plots on the Ozark National Forest showed that dieback and mortality continued in 2000 and 2002. In 2000, newly killed basal area accrued mostly in red oaks across all strata—an increase of 5-6 percent (table 2). Moderate/severe dieback increased most in white oaks in the light stratum (3.6 percent), but also increased in both white and red oaks in the light and moderate strata. In 2002 red oak mortality increased 11-14 percent in the moderate and severe strata (table 3). Thus, over the 3-year period, red oak mortality increased 7-20 percent while white oak and other species increases were only 2-7 percent and 2-8 percent (table 4).

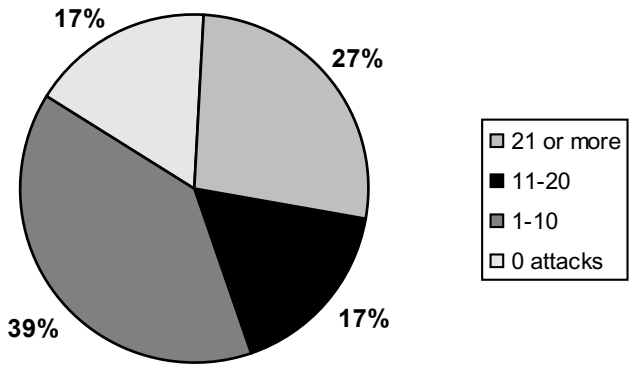


Figure 12—Percentage of red oak basal area per acre with red oak borer attacks on the Mark Twain National Forest.

**Table 2—Estimated change (1999–2000) in percent of basal area per acre (trees >4 inches d.b.h.) by crown condition, species group, and damage strata on the Ozark National Forest**

| | Stratum | | |
|---|---|---|---|
| Crown condition | Light | Moderate | Severe |
| Red oaks | | | |
| Healthy and slight | -7.3 | -7.9 | -5.4 |
| Moderate and severe | +1.8 | +1.5 | 0 |
| Dead | +5.5 | +6.3 | +5.4 |
| White oaks | | | |
| Healthy and slight | -5.4 | -1.6 | 0 |
| Moderate and severe | +3.6 | +1.6 | 0 |
| Dead | +1.8 | 0 | 0 |
| Other species | | | |
| Healthy and slight | -1.8 | 0 | 0 |
| Moderate and severe | +1.8 | 0 | 0 |
| Dead | 0 | 0 | +1.8 |

**Table 3—Estimated change (2000–2002) in percent of basal area per acre (trees >4 inches d.b.h.) by crown condition, species group, and damage strata on the Ozark National Forest**

| | Stratum | | |
|---|---|---|---|
| Crown condition | Light | Moderate | Severe |
| Red oaks | | | |
| Healthy and slight | -1.8 | -10.9 | -8.9 |
| Moderate and severe | 0 | -3.1 | +0.5 |
| Dead | +1.8 | +14.0 | +11.5 |
| White oaks | | | |
| Healthy and slight | -1.8 | -3.0 | -0.5 |
| Moderate and severe | -3.6 | +1.5 | 0 |
| Dead | +5.5 | +1.5 | +0.2 |
| Other species | | | |
| Healthy and slight | 0 | 0 | -9.2 |
| Moderate and severe | -1.8 | 0 | 0 |
| Dead | -1.8 | 0 | +6.4 |

**Table 4—Estimated change (1999–2002) in percent of basal area per acre (trees >4 inches d.b.h.) by crown condition, species group, and damage strata on the Ozark National Forest**

| | Stratum | | |
|---|---|---|---|
| Crown condition | Light | Moderate | Severe |
| Red oaks | | | |
| Healthy and slight | -9.1 | -18.8 | -14.3 |
| Moderate and severe | +1.8 | -1.6 | +0.5 |
| Dead | +7.3 | +20.3 | +16.9 |
| White oaks | | | |
| Healthy and slight | -7.2 | -4.6 | -0.5 |
| Moderate and severe | 0 | +3.1 | 0 |
| Dead | +7.3 | +1.5 | +0.2 |
| Other species | | | |
| Healthy and slight | -1.8 | 0 | -11.0 |
| Moderate and severe | 0 | 0 | 0 |
| Dead | +1.8 | 0 | +8.2 |

The most recent (2001) aerial sketchmapping over the entire main division of the Ozark National Forest estimated that over 600,000 gross acres had moderate to severe damage from oak decline, with 300,000 of that in the severe category.

## DISCUSSION

Clearly, the current oak decline episode in Arkansas and Missouri is severe and unique in relation to its association with such extremely high populations of ROB. The decline episode will run its course, probably abating with the return of more normal rainfall patterns. However, forest composition and structure will be severely impacted for years to come. Oaks generally, and the red oak group particularly, will be a smaller component of the new forest taking shape, and given the prevailing low-disturbance/fire suppression regime, will most likely be replaced by shade-tolerant hardwood trees. The course of the ROB epidemic is uncertain. The reduction in host material will probably result in a return to a more historically normal population. The effects of these phenomena are currently being felt by the wood-using industry in the Ozark Highlands. Effects on wildlife, recreation, or other resources are no doubt occurring as well. These remain to be well documented.

## ACKNOWLEDGMENTS

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## LITERATURE CITED

Ammon, V.; Nebeker, T.E.; Filer, T.H. [and others]. 1989. Oak decline. Tech. Bull. 161. Mississippi State, MS: Mississippi Agricultural & Forestry Experiment Station. 15 p.

Bassett, E.N.; Fenn, P.; Mead, M.A. 1982. Drought-related oak mortality and incidence of *Hypoxylon* canker. Arkansas Farm Research 31(1): 8.

Donley, D.E.; Acciavatti, R.E. 1980. Red oak borer. Forest Insect and Disease Leaflet 163. Washington, D.C.: U. S. Department of Agriculture, Forest Service. 7 p.

Hay, C.J. 1974. Survival and mortality of red oak borer larvae on black, scarlet, and northern red oak in eastern Kentucky. Annals of the Entomological Society of America 67: 981-986.

Hopkins, A.D. 1902. On the study of forest entomology in America. U.S. Department of Agriculture, Division of Entomology bull. 37: 5-28.

Hyink, D.M.; Zedaker, S.M. 1987. Stand dynamics and the evaluation of forest decline. Tree Physiology 3: 17-26.

Lewis, R., Jr. 1981. *Hypoxylon* spp., *Ganoderma lucidum* and *Agrilus bilineatus* in association with drought related oak mortality in the South. (Abstr.) Phytopathology 71(8): 890.

Manion, P.D. 1981. Tree disease concepts. Prentice Hall, Inc. Englewood Cliffs, NJ. 399 p.

Mielke, M. 2000. Forest health evaluation of oak mortality and decline on the Mark Twain National Forest, 2000. St. Paul, MN: U.S. Department of Agriculture, Forest Service, Northeastern Area, State & Private Forestry, Forest Health Protection, St. Paul Field Office. 10 p.

Millers, I.; Shriner, D.S.; Rizzo, D. 1988. History of hardwood decline in the Eastern United States. Gen. Tech. Rep. NE-126. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 75 p.

Mistretta, P.A.; Affeltranger, C.E.; Starkey, D.A. [and others]. 1981. Evaluation of oak mortality on the Ozark National Forest, Arkansas, 1981. Rep. No. 81-2-26. Alexandria, LA: U.S. Department of Agriculture, Forest Service, Southeastern Area. 15 p.

Oak, S.; Tainter, F.; Williams, J.; Starkey, D. 1996. Oak decline risk rating for the Southeastern United States. Ann. Sci. For. 53: 721-730.

Rhodes, J.D.; Tainter, F.H. 1980. Precipitation extremes and tree growth. Arkansas Farm Research. 29(6): 12.

Solomon, J.D. 1995. Guide to insect borers in North American broadleaf trees and shrubs. Ag. Hdbk. AH-06. Washington, D.C.: U.S. Department of Agriculture, Forest Service. 735 p.

Starkey, D.A.; Oak, S.W.; Ryan, G.W. [and others]. 1989. Evaluation of oak decline areas in the South. Prot. Rep. R8-PR17. Atlanta, GA: U.S. Department of Agriculture, Forest Service, Southern Region. 36 p.

Starkey, D.A., Mangini, A.; Oliveria, F.L. [and others]. 2000. Forest health evaluation of oak mortality and decline on the Ozark National Forest, 1999. Rep. No. 2000-02-02. Alexandria, LA: USDA Forest Service, Southern Region, State & Private Forestry, Forest Health Protection. 31 p.

Tainter, F.H.; Retzlaff, W.A.; Starkey, D.A.; Oak, S.W. 1990. Decline of radial growth in red oaks is associated with short-term changes in climate. European Journal of Forest Pathology 20: 95-102.

Wargo, P.M.; Houston, D.R.; LaMadeleine, L.A. 1983. Oak decline. Forest Insect and Disease Leaflet 165. Washington, D.C.; U.S. Department of Agriculture, Forest Service. 8 p.

Yeiser, J.L.; Burnett, F. 1982. Fate of forest trees stressed by heat and drought in southeastern Arkansas. Southern Journal of Applied Forestry. 6(4): 194-195.