Changes in Forest Structure Associated with Oak Decline in Severely Impacted Areas of Northern Arkansas

Eric Heitzman, Adrian Grell, Martin Spetich, and Dale Starkey

ABSTRACT

Four mature northern red oak (*Quercus rubra* L.)–white oak (*Quercus alba* L.) stands in the Boston Mountains of northern Arkansas were studied to describe the vegetation dynamics of forests heavily impacted by oak decline. Northern red oak was the species most susceptible to decline. Across the four stands, 51–75% of red oak density (trees/ha) was dead or dying, as was 40–70% of the red oak basal area. Red oak damage occurred across a range of tree sizes. Healthy red oak had low populations of red oak borer (*Enaphalodes rufulus* Haldeman), and dead/dying red oak supported large numbers of borers. Impacts on white oak were less severe and generally limited to smaller trees. Decline had changed what once were red oak-dominated stands to more mixed forests of white oak, hickory (*Carya* spp.), red oak, blackgum (*Nyssa sylvatica* Marsh.), and red maple (*Acer rubrum* L.). Understory trees and seedlings were predominantly blackgum, red maple, hickory, black cherry (*Prunus serotina* Ehrh), flowering dogwood (*Cornus florida* L.), and sassafras (*Sassafras albidum* [Nutt.] Nees). However, well-developed red and white oak advance regeneration was present in all stands. It is unclear if the death of overstory trees will favor the regeneration of nonoaks, or whether oak regeneration will successfully recruit within canopy gaps created by this disturbance.

Keywords: Arkansas, Boston Mountains, oak decline, *Quercus* spp., red oak borer

Oak decline is a disease complex that involves the interaction of multiple biotic and abiotic factors, with impacts that range from partial crown dieback to tree death (Johnson et al. 2002). The effects of decline on oak forests in the eastern United States have been well documented for the past 100 years (Long 1914, Balch 1927, Nichols 1968, Law and Gott 1987, Jenkins and Pallardy 1995). These and numerous other major oak mortality events since 1900 (Millers et al. 1989) make oak decline one of the most serious forest disease problems in the southern and eastern United States (Oak 2002). Causes implicated in these events include drought, advanced tree age, insects (e.g., gypsy moth [*Lymantria dispar* L.] and the two-lined chestnut borer [*Agrilus bilineatus* Weber]), and fungi (e.g., *Armillaria* spp. and *Hypoxylon* spp.).

Beginning in 1999, forests in the Ozark Mountains of northern Arkansas and southern Missouri and the Ouachita Mountains of western Arkansas and eastern Oklahoma experienced a dramatic increase in oak mortality (Spencer 2001, Lawrence et al. 2002). The causes of decline are best conceptualized, according to Manion (1991), as predisposing, inciting, and contributing factors. In this decline, predisposing factors included advanced tree age, shallow and rocky soils, and high proportions of red oaks (Starkey et al. 2004). Species in the red oak group are much more susceptible to oak decline than those in the white oak group (Starkey and Oak 1989, Stringer et al. 1989). The inciting factor in the current event was a regional drought from 1998 to 2000. Contributing factors may include the red oak borer (*Enaphalodes rufulus* Haldeman), *Armillaria* spp., and the two-lined chestnut borer (Starkey et al. 2004).

Before 1999, the red oak borer had not been implicated as a factor in oak decline. This native wood-boring beetle normally maintains relatively low populations. Hay (1974) found the mean number of attacks on the basal 1.8 m of individual red oaks in Kentucky ranged from 2.8 to 3.7, and 71 was the greatest number of attacks on one tree. Donley and Rast (1984) reported that borer attacks on whole trees averaged 2.0 per tree in Pennsylvania and 3.6 per tree in Indiana. However, red oak borer populations are much higher in the current decline than those previously reported (Stephen et al. 2001). Indeed, Fierke et al. (2005a) sampled red oaks in a severely impacted forest in northern Arkansas and determined the mean number of active attack holes per tree was 30.1 on the basal 1.5 m and 599 for whole trees, with a maximum on one tree of 1,244 active attacks.

Estimates vary regarding the extent and severity of the present decline. Starkey et al. (2004) reported that in 2001 over 242,000 ha in northern Arkansas had moderate to severe damage, with 121,000 ha of that in the severe category. Also, in 2001, more than 40,000 ha were seriously affected by oak decline on US Forest Service land in southern Missouri (Lawrence et al. 2002). Oak et al. (2004) analyzed Forest Inventory and Analysis data collected in 1995—4 years before the earliest reports of the current episode—and concluded

Received September 1, 2006; accepted October 20, 2006.

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that 286,000 ha in Arkansas were affected by the oak decline. In 2002 and 2003, Guldin et al. (2006) established 181 field plots in Arkansas, Missouri, and Oklahoma and estimated that 33% of red oak density (trees/ha) and 30% of red oak basal area in the region were dead or dying. Kabrick et al. (2004) studied nine forested sites in southern Missouri ranging in size from 312 to 514 ha. They reported that 20.8% of red oaks and 5.5% of white oaks died between 1992 and 2002, although not all mortality was associated with decline.

The magnitude and spatial distribution of mortality indicate this decline is a landscape phenomenon. Based on previous oak decline events in the Ozark Mountains (Law and Gott 1987, Starkey and Oak 1989, Jenkins and Pallardy 1995), it is likely that oaks will remain an important forest component at the regional scale. Over time, however, it is unclear how various levels of oak decline will affect forest structure, species composition, and regeneration dynamics at the local scale, particularly in areas exhibiting high levels of mortality.

Our objectives in this study were to examine four northern red oak (*Quercus rubra* L.)–white oak (*Quercus alba* L.) stands in northern Arkansas that were severely impacted by oak decline to (1) describe the decline-associated changes in forest structure and species composition and (2) examine the regeneration status of red and white oak within these heavily disturbed stands.

Methods

Study Areas

The four stands selected for study—Rotary Ann (59 ha), Chinquapin Knob (39 ha), Pilot Knob (46 ha), and Sand Gap (40 ha)—are located in the Boston Mountains of Arkansas, a heavily forested region in the southwestern portion of the Ozark Plateau. The Boston Mountains are characterized by a sharply dissected landscape and rugged terrain, which forms a band 48–64 km wide and 320 km long from north central Arkansas westward into eastern Oklahoma. Stands are in Pope and Johnson Counties at latitude 35°35′ to 35°43′ N and longitude 92° 55′ to 93°15′ W. All stands are located on the Bayou Ranger District of the Ozark National Forest. Stands were chosen because they were (1) mature oak stands, (2) very badly damaged by oak decline (according to local Forest Service personnel), and (3) located on south- to west-facing upper slopes and ridgetops. Similarity in aspect and topographic position was an important criterion because the stands also are replicates in a long-term prescribed burning project. However, no burning took place before this study. The distance between stands ranged from 6 to 30 km. Elevations varied from 488 to 610 m with slopes of 20–40%. Soils were well drained, gravelly, or stony fine sandy loams in the Nella, Enders, Mountainburg, and Linker series (Garner et al. 1977, Vodrazka et al. 1981).

Sampling Design

From May to August 2003, 30 field plots were established at Rotary Ann, 18 at Chinquapin Knob, 18 at Pilot Knob, and 21 at Sand Gap. Depending on stand shape, parallel transects were spaced at 80- to 380-m intervals, and plots were located along these transects every 55–240 m. In each plot, using a 2.3 m^2/ha basal area prism, we tallied living trees more than 14 cm dbh and dead trees more than 14 cm dbh that were judged to have died in the past 3 years. Each tree was recorded by species, dbh, and crown condition. For crown condition, tree crowns were assessed visually from the ground and placed into one of the following categories: less than 25% dieback, 25–50% dieback, more than 50% dieback but still alive, and dead. We define "healthy" trees as trees with 50% or less dieback and "dying" trees as living trees with more than 50% dieback.

Understory trees and seedlings were also tallied in each stand. Three 0.002-ha understory plots and three 0.0004-ha seedling plots were nested within each prism plot at plot center and 8 m east and west of plot center. Understory trees 1.5–14.0 cm dbh were tallied by species and dbh. Seedlings less than 1.5 cm dbh and more than 60 cm tall were tallied by species and height class (61–90 cm, 91–120 cm, 121–150 cm, and more than 150 cm).

Data on red oak borer abundance were gathered from living and dead/dying red oak that were more than 14 cm dbh in four, eight, five, and four randomly chosen prism plots at Rotary Ann, Chinquapin Knob, Pilot Knob, and Sand Gap, respectively. Sampling intensity varied across stands because of availability of field personnel. Red oaks in these plots were examined carefully for red oak borer emergence holes created in 2001 and/or 2003. A total of 27 healthy and 41 dead/dying red oaks were examined. For each tree, the number of borer holes was counted on the lower 2 m of the bole. Emergence hole data were tallied in four classes: 0 holes/tree, 1–5 holes/tree, 6–20 holes/tree, or more than 20 holes/tree (Fierke et al. 2005b).

Data Analysis

Plot data in each stand were summarized to describe the health of trees more than 14 cm dbh and the density of understory trees and seedlings. We also wanted to determine whether small-diameter trees were more or less likely to be impacted by decline than large-diameter trees. For red oaks and white oaks within each stand, the proportion of dead/dying trees 15–25 cm dbh was compared with the proportion of dead/dying trees more than 25 cm dbh. Comparisons were made using two-sample tests of proportion. In addition, a chi-square test was used to examine differences between the number of red oak borer emergence holes in healthy and dead/dying red oak. For all tests, significance was accepted at the $P \leq 0.05$ level.

Results

Dead/dying trees more than 14 cm dbh in the four stands ranged from 26 to 38% of total density and from 23 to 42% of total basal area (Table 1). Red oaks (predominantly northern red oak with scattered black oak [*Quercus velutina* Lam.]) were particularly impacted. There were 79 dead/dying red oak trees/ha at Rotary Ann, 86 trees/ha at Chinquapin Knob, 54 trees/ha at Pilot Knob, and 103 trees/ha at Sand Gap. This represents 51–75% of red oak density in each stand and 40–70% of red oak basal area. Red oak damage exceeded white oak damage in every stand. Impacts on white oak were most pronounced at Rotary Ann and Sand Gap, where 15–27 white oak trees/ha, 25–26% of density, and 13–14% of basal area were affected, respectively. About 10% of hickory (*Carya* spp.) stems were dead/dying in two stands, but no hickory damage was observed in the other two stands (Table 1).

Decline resulted in a shift in species importance. Before decline, red oak density and basal area were greater than any other species in all stands (Table 1). However, we measured more healthy white oak trees than red oak in three stands, and more healthy white oak basal area than red oak in two stands. At Rotary Ann, which was the stand having the greatest proportion of dead/dying red oak, healthy red

Table 1. Density and basal area of healthy and dead/dying trees more than 14 cm dbh at four upland oak stands in Arkansas.

Site/species	Density (trees/ha)			Basal area (m^2/ha)		
	Healthy	Dead/dying	Dead/dying (%)	Healthy	Dead/dying	Dead/dying (%)
Rotary Ann						
Red oak[a]	26	79	75	3	7	70
White oak	45	15	25	4	<1	13
Hickory	12	0	0	<1	0	0
Blackgum	52	0	0	2	0	0
Black cherry	6	0	0	<1	0	0
Red maple	28	4	13	<1	<1	8
Others[b]	2	<1	33	<1	<1	50
Totals	171	99	37	11	8	42
Chinquapin Knob						
Red oak[a]	66	86	57	5	4	44
White oak	44	1	3	3	<1	4
Hickory	29	3	10	2	<1	8
Blackgum	7	0	0	<1	0	0
Black cherry	0	0	0	0	0	0
Red maple	16	0	0	<1	0	0
Others[b]	0	0	0	0	0	0
Totals	162	90	36	11	5	31
Pilot Knob						
Red oak[a]	52	54	51	3	2	40
White oak	88	6	6	5	<1	8
Hickory	59	6	9	2	<1	12
Blackgum	<1	0	0	<1	0	0
Black cherry	3	0	0	<1	0	0
Red maple	0	0	0	0	0	0
Others[b]	3	7	70	<1	<1	31
Totals	205	73	26	10	3	23
Sand Gap						
Red oak[a]	67	103	61	6	6	50
White oak	75	27	26	5	<1	14
Hickory	8	0	0	<1	0	0
Blackgum	23	0	0	1	0	0
Black cherry	9	0	0	<1	0	0
Red maple	31	0	0	<1	0	0
Others[b]	3	0	0	<1	0	0
Totals	216	130	38	14	6	30

[a] Mostly northern red oak with scattered black oak
[b] Includes shortleaf pine (*Pinus echinata* Mill.), white ash (*Fraxinus americana* L.), black locust (*Robinia pseudoacacia* L.), and sweetgum (*Liquidambar styraciflua* L.).

oak density decreased from first to fourth in magnitude. Nevertheless, red oak remained an important species in all stands, comprising 15–41% of total density and 27–43% of total basal area (Table 1).

In general, the relationship between tree size and health differed between red and white oak. For red oak, there was a high frequency of dead/dying stems across a wide range of diameters (Figure 1). In two stands (Chinquapin Knob and Sand Gap), there was a significantly higher proportion ($P = 0.03$) of dead/dying small dbh (15–25 cm) red oak than large dbh (more than 25 cm) red oak. However, 41 and 47% of large dbh red oak in these stands were dead or dying. Thus, both small and large red oaks were severely impacted in all stands. In contrast, dead/dying white oak trees more than 25 cm dbh were uncommon (Figure 1). At Rotary Ann and Sand Gap, 37–41% of small dbh white oak were dead/dying, but only 4–7% of large dbh trees. Averaging all stands, the proportion of damaged small white oak was three times greater than the proportion of damaged large white oak, although this difference was not significant ($P = 0.26$).

There was a significant difference ($P < 0.001$) in the number of red oak borer emergence holes on the boles of healthy and dead/dying red oak (Figure 2). Healthy trees had fewer holes than dead/dying trees. In fact, 78% of the sampled healthy red oak had five or less borer holes, and no healthy tree had more than 20 holes. For dead/dying red oak, 76% of the sampled trees had six or more exit holes, and only three trees had no holes at all.

There was a well-developed stratum of understory trees in the study areas (Table 2). The number of trees 1.5–14 cm dbh ranged from 810 to 1,316 stems/ha. There were 37 times more nonoaks than oaks in the understory at Rotary Ann, 6 times more at Chinquapin Knob, and 52 times more at Sand Gap. Important competitors included blackgum (*Nyssa sylvatica* Marsh.), red maple (*Acer rubrum* L.), hickory, black cherry (*Prunus serotina* Ehrh), and flowering dogwood (*Cornus florida* L.). Only at Pilot Knob was oak density (319 stems/ha) nearly equal to nonoak density (446 stems/ha). Including all stands, density of understory red oak averaged 38 stems/ha, and understory white oak averaged 87 stems/ha. White oak was more numerous than red oak in three stands.

There also was a high number of seedlings at each site, with densities of 5,039–10,018 stems/ha (Table 3). As in the overstory, common competitors to oaks included blackgum, red maple, hickory, black cherry, and flowering dogwood, along with sassafras (*Sassafras albidum* [Nutt.] Nees). These and other nonoak species made up 64–94% of the total seedlings and 73–98% of seedlings taller than 150 cm. Among taller seedlings (more than 150 cm) at the four stands, red and white oak density averaged 116 and 63 stems/ha, respectively. Density of tall red oak seedlings equaled or exceeded that of tall white oak in three stands.

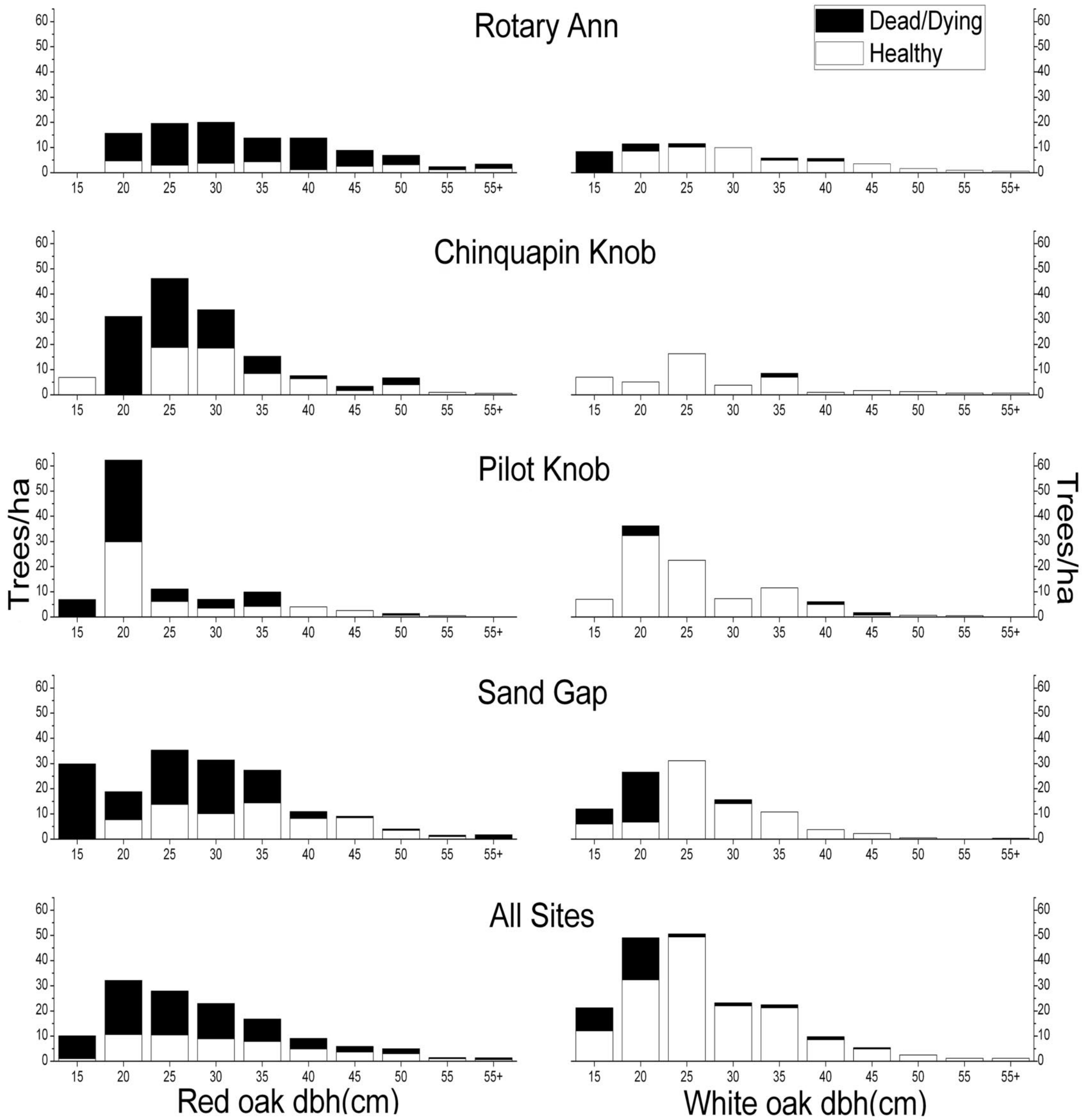

Figure 1. Diameter distributions of healthy and dead/dying red and white oak at four upland oak stands in Arkansas.

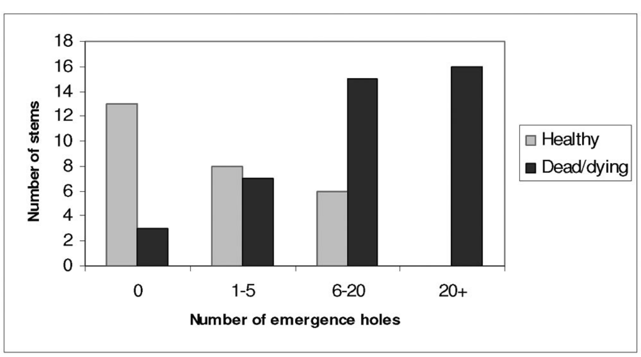

Figure 2. Number of red oak borer emergence holes in 27 healthy and 41 dead/dying red oaks at four upland oak stands in Arkansas.

Discussion

In the severely impacted stands we examined, red oak was more affected than white oak. Other studies of this decline and previous declines also reported a greater susceptibility by red oak to decline (Starkey and Oak 1989, Stringer et al. 1989, Kabrick et al. 2004). The reduction in red oak has shifted these formerly red oak-dominated stands toward a more mixed assemblage of white oak, hickory, red oak, blackgum, and red maple.

Dead/dying red oak occurred over a wide range of tree dbh, but dead/dying white oak was most conspicuous among trees 15–25 cm dbh. A similar pattern in the current decline was observed in Arkansas, Missouri, and Oklahoma (Heitzman 2003, Heitzman and Guldin 2004, Guldin et al. 2006). Although no age data were collected, it is likely that many small red and white oak trees in the four stands were about the same age as the larger dbh oaks. Many mature oak forests in northern Arkansas originated after timber harvests and/or wildfires in the early 1900s (Sutton 2001). In the resulting even-aged stands, both red and white oak can persist for extended periods as small trees in lower canopy positions (Soucy et al. 2004, 2005). In this study, such suppressed and presumably older stems were particularly vulnerable to oak decline. Stressed, low vigor oaks are especially susceptible to attack by a variety of organisms (Dunn et al. 1986, Bruhn et al. 2000). That larger red oak also were severely impacted may be due, in part, to the physiological maturity of this cohort. Northern red oak is shorter-lived than white oak (Burns and Honkala 1990).

Table 2. Density of understory trees 1.5–14 cm dbh at four upland oak stands in Arkansas.

	Density (trees/ha)																			
	Rotary Ann Dbh class (cm)					Chinquapin Knob Dbh class (cm)					Pilot Knob Dbh class (cm)					Sand Gap Dbh class (cm)				
Species	2.5	5.0	7.5	10.0	12.5	2.5	5.0	7.5	10.0	12.5	2.5	5.0	7.5	10.0	12.5	2.5	5.0	7.5	10.0	12.5
Red oak[a]	33	0	0	0	0	0	0	0	9	9	9	27	27	9	27	0	0	0	0	0
White oak	0	5	0	0	0	27	18	37	9	9	37	91	37	37	18	8	0	0	16	0
Hickory	126	22	17	5	5	55	27	9	18	9	64	73	55	18	18	71	16	16	8	0
Blackgum	115	99	82	27	22	27	37	9	9	0	46	0	9	0	0	157	149	63	16	8
Black cherry	66	60	17	5	0	18	0	18	0	0	27	37	0	0	0	110	23	16	0	0
Red maple	154	66	33	39	0	101	27	18	18	9	18	0	0	0	0	133	63	39	23	0
Dogwood	22	27	22	11	0	46	46	9	9	9	9	0	0	9	0	39	47	8	0	0
Others[b]	165	49	11	11	0	137	27	0	0	0	18	9	0	27	18	102	102	47	0	0
Totals	681	328	182	98	27	411	182	100	72	45	228	237	128	91	81	620	400	189	63	8

[a] Mostly northern red oak with scattered black oak.
[b] Includes white ash, black locust, shortleaf pine, elm (*Ulmus* sp.), Carolina buckthorn (*Frangula caroliniana* [Walter] A. Gray), sassafras, pawpaw (*Asimina triloba* [L.] Dunal), downy serviceberry (*Amelanchier arborea* [Michx.f.] Fern.), and red buckeye (*Aesculus pavia* L.)

Table 3. Density of seedlings more than 60 cm tall and less than 1.5 cm dbh at four upland oak stands in Arkansas.

	Density (trees/ha)															
	Rotary Ann Height class (cm)				Chinquapin Knob Height class (cm)				Pilot Knob Height class (cm)				Sand Gap Height class (cm)			
Species	61–90	91–120	121–150	150+	61–90	91–120	121–150	150+	61–90	91–120	121–150	150+	61–90	91–120	121–150	150+
Red oak	412	138	109	193	91	138	138	46	321	138	91	183	314	79	40	40
White oak	138	82	0	27	640	274	91	183	778	230	91	0	78	0	40	40
Hickory	412	356	247	329	595	321	46	46	230	230	46	0	314	432	195	472
Blackgum	356	329	138	274	595	183	412	91	274	183	138	91	393	746	274	746
Black cherry	301	385	220	440	46	46	46	91	91	46	46	91	158	40	158	314
Red maple	576	850	603	961	1647	961	321	412	138	91	46	46	785	1,215	393	1,020
Dogwood	301	220	54	82	230	0	91	0	138	0	0	0	235	119	0	79
Sassafras	0	0	0	0	320	183	138	274	183	138	46	91	0	79	0	40
Others[b]	274	326	163	356	0	46	0	0	457	138	46	183	79	274	237	590
Totals	2,770	2,686	1,534	2,662	4,164	2,152	1,283	1,143	2,610	1,194	550	685	2,356	2,984	1,337	3,341

[a] Mostly northern red oak with scattered black oak.
[b] Includes white ash, black locust, elm, Carolina buckthorn, pawpaw, downy serviceberry, red buckeye, plum (*Prunus* sp.), and witch-hazel (*Hamamelis virginiana* L.).

Dead/dying red oaks were associated with high populations of the red oak borer. Individual trees with low borer populations generally were healthy, but trees supporting higher numbers of borers usually were dead or dying. The unprecedented insect densities in the phloem and sapwood probably weakened already stressed red oak and contributed to tree death. Because borer holes were examined only on red oak, the influence of the red oak borer on the health of white oak is unknown. White oak has been reported as a host for the borer, albeit an uncommon one (Galford 1983, Fierke et al. 2005a). Furthermore, we did not examine borer-infested red oak for the presence of other possible contributing factors such as *Armillaria* root rot or the two-lined chestnut borer. It is possible that one or both of these interact with the red oak borer to cause tree death.

The canopy gaps created by the death of overstory trees will increase the availability of resources for the abundant understory trees and seedlings at the four stands. It remains unclear whether oaks will compete successfully for these resources and eventually replace dead oaks in upper canopy positions. On the one hand, smaller oaks were greatly outnumbered by faster-growing species such as blackgum, red maple, and black cherry. Field observations indicated that overstory mortality, although widespread, generally was patchy in distribution and rarely included groups of more than several large, dead trees. Because oaks are intermediate in shade tolerance, the size of the openings may be too small for oak recruitment. For successfully regenerating oaks using the group selection method, an average opening diameter of at least twice the height of the surrounding overstory trees is favored by most authorities (Trimble 1973, Miller et al. 1995). Thus, a circular opening among 23-m tall trees should be at least 0.17 ha in size. It appeared that most canopy gaps at the four stands were smaller than this, suggesting that additional disturbances may be needed for successful oak recruitment into larger size classes.

On the other hand, oak saplings and seedlings may be well positioned to regenerate these damaged stands. With the exception of Sand Gap, there were over 250 oaks/ha taller than 150 cm (including understory trees) at the study areas. Sander (1972) suggested that oak advance regeneration at least 150 cm tall is likely to compete successfully after a harvest cutting. Furthermore, the four stands are located on south- to west-facing upper slopes and ridgetops. Such relatively xeric sites favor oak regeneration over nonoak species (Sander et al. 1984). These findings of abundant oak advance regeneration in decline-impacted areas contrast with other regional studies (Heitzman 2003, Heitzman and Guldin 2004). Those studies, which were not limited to xeric sites, indicated that oak decline was accelerating a change in species importance to nonoak species.

The extent to which site factors such as topography and aspect influence oak decline severity is poorly understood. A number of investigators in the southern United States have reported that ridgetops and/or dry aspects had the greatest amount of oak decline (Starkey and Oak 1989, Stringer et al. 1989, Oak et al. 1996). However, more recent work from Arkansas and Missouri suggests that factors other than (or perhaps in addition to) topography and aspect, such as species composition, tree age, and crown position, are important determinants of oak decline that confound the influences of site (Kabrick et al. 2004, Poole et al. 2006). Although decline is most severe on xeric sites such as those we studied, not all xeric sites in the Boston Mountains display the high levels of damage we have reported.

Conclusion

In the heavily impacted stands we examined, red oak was no longer the dominant species it was before the decline event. However, red oak was not eliminated from upper canopy positions and remained a common overstory tree at all four sites. Given the complex species composition and densities of understory trees and seedlings and the relatively short period of 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.

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