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Evaluation of Oak Decline Areas In The South

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by

Dale A. Starkey, Pathologist, Pineville, LA
Steven W. Oak, Pathologist, Asheville, NC
George W. Ryan, Statistician, Atlanta, GA
Frank H. Tainter, Pathologist, Clemson University
Clair Redmond, Economist, Atlanta, GA
H. Daniel Brown, Pathologist, Atlanta, GA

USDA Forest Service
Southern Region
1720 Peachtree Road, NW
Atlanta, GA 30367-9102

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Summary

Widespread death of oaks in the Southeast during the 1980's has caused concern among forest managers, recreationists and the general public. This concern generated renewed interest in an old and recurrent problem–oak decline. Areas with declining oaks were evaluated to determine: (1) the amount and severity of decline; (2) species and size classes affected; (3) volume affected; and (4) site and stand characteristics of affected areas. Thirty-eight stands in 9 Southern and Central States were evaluated.

Oak decline is a complex problem characterized by progressive crown dieback and mortality. Other symptoms may include chlorosis, dwarfed or sparse foliage, premature autumn coloration, and epicormic branching. It is best explained as the interaction of long-term predisposing stress factors (drought, tree age, or droughty site factors), short-term inciting factors (spring frost or insect defoliation), and long-term contributing factors of biotic origin (root disease, bark beetles, and canker or decay fungi).

Only decline-damaged stands were surveyed. Most were sawtimber size. While age of affected stands ranged from 50 to 110 years, most were in the 60-80 year old age class. Overall, 80 percent of the dominant and codominant trees were dead or had some decline symptoms. Twenty percent were moderately or severely declined (≥1/3 crown dieback) and 17 percent were killed. Mortality in the red oak group was three times that in the white oak group. Individually, black and scarlet oaks sustained the highest mortality (34 and 23 percent, respectively). Stand basal area was unrelated to the amount of decline and mortality, but several site factors were related to the frequency of mortality. High mortality was associated with ridge topographic positions, slopes less than 20 percent, shallow or rocky soils, and site indices (base age 50) less than 65 feet. A rudimentary mortality risk-rating system was developed using these factors.

When plots were grouped into four geographic areas and reanalyzed, the relationships between some factors and mortality were altered, indicating that some factors may be more strongly related to damage in one area than another. Recently dead and severely declined trees had significantly lower radial growth rates than healthy trees for 20 to 40 years before the survey year. The present value of current mortality averaged $30 per acre and represented 15 percent of the timber value. A 10-year projection of stand growth and continued decline resulted in an average estimated loss of 18 percent of the present value of the timber.

Since 1900, oak declines in the East have been reported on several occasions. It is not known if the current situation is worse than previous ones. Recent droughts probably have played a significant role in the current situation. This survey provides a baseline against which continuing changes in forest health may be compared. Decline has potential impacts on species composition, rotation ages, regeneration methods, and wildlife habitat.

Introduction

Widespread mortality and crown dieback of oaks (*Quercus* species) in the Southeast during the 1980's has caused concern among forest managers, recreationists and the general public. This concern has generated renewed interest in an old and recurrent problem–oak decline.

Symptoms and Signs

Oak decline is characterized by a wide variety and progression of symptoms. The predominant symptom is progressive dieback of branches from the tips (figures 1, 2, and 3). Oak decline generally begins at the top and outside of the crown and proceeds downward and inward (figure 4). Other symptoms may accompany dieback:

- chlorotic, dwarfed, or sparse foliage (figure 5)
- epicormic sprouting from the main stem and larger branches
- premature autumn coloration
- foliage death

Reduced shoot growth may produce a tufting of remaining foliage, and diameter growth is reduced in severely affected trees. Symptomatic trees may progressively decline for several growing seasons before dying, while others recover, leaving a partly dead crown. Some trees decline very little before dying suddenly, but this is atypical. Wargo *et al.* (1983) described the etiology of oak decline in detail.

Figure 1.—Slight to moderate branch dieback with foliage browning

Figure 2.—Slight dieback

Distribution and History

From the early 1900's (Beal 1926) to the present, oak decline or mortality events have been reported in locations representing nearly the entire range of oak in the Eastern U.S. Documented cases have been reported in Arkansas (Bassett *et al.* 1982, Mistretta *et al.* 1981, Yeiser and Burnett 1982, Lewis 1981, Rhodes and Tainter 1980), Connecticut (Dunbar and Stephens 1975), Florida (Lewis 1981), Massachusetts (Feder *et al.* 1980), Minnesota (Chapman 1915, Walters and Munson 1980), Mississippi (Lewis 1981), New Jersey (Kegg 1971), New York (Long 1914), North Carolina (Tainter *et al.* 1984, Beal 1926), Pennsylvania (Fergus and Ibberson 1956, Nichols 1968, Wargo 1977, Staley 1965), South Carolina (Tainter *et al.* 1983), Tennessee (McGee 1984), Virginia (Skelly 1974, Beal 1926, Rauschenberger and Ciesla 1966), West Virginia (Gillespie 1956, Staley 1965) and Wisconsin (Haack and Benjamin 1982).

Figure 3.—Mortality in oak decline area

Figure 4.—Severe branch dieback with foliage browning

Concepts of Oak Decline

Many potential causal factors have been associated with oak decline. Among these are defoliating insects (Dunbar and Stephens 1975, Tryon and True 1958, Kegg 1971, Nichols 1968), drought (Lewis 1981, Mistretta *et al.* 1981, Rhodes and Tainter 1980, Balch 1927, Tryon and True 1958, Tainter *et al.* 1983, Tainter *et al.* 1984), late spring frost (Beal 1926, Staley 1965, Balch 1927, Nichols 1968), pathogenic fungi (Wargo 1977, Bassett *et al.* 1982, Lewis 1981, Fergus 1956, Filer and McCracken 1969, Toole 1960), and inner bark boring insects (Dunbar and Stephens 1975, Lewis 1981, Wargo 1977).

McCracken (1985a) recently summarized three concepts that have been used to explain oak decline: (1) single causal factors, (2) cohort senescence and (3) decline syndrome complex.

Single Causal Factors–Many tree diseases are known to be caused by a single disease-causing organism. The effects of these may be intensified or lessened by other factors, but the presence of a known biotic agent explains the majority of the host plant symptoms and damage. While many decline symptoms are known to result from individual organisms, declines have only occasionally been attributed totally to a single factor. Examples have been reported for such factors as frost (Beal 1926); drought (McIntyre and Schnur 1936, Tryon and True 1958, Gillespie 1956, Tainter and Benson 1982, Mistretta *et al.* 1981, Tainter *et al.* 1983, Bassett *et al.* 1982); defoliating insects such as the gypsy moth (*Porthetria dispar* L.; Baker 1941, Burgess 1922, Minott and Guild 1925, Kegg 1971, Knull 1932); inner bark boring insects such as the twolined chestnut borer (Chapman 1915); root disease fungi such as *Armillaria mellea* (Vahl. ex Fr.) Karst (Long 1914); *Clitocybe tabescens* (Scop. ex Fr.) Bres (Filer and McCracken 1969) and *Corticium galactinum* (Fr.) Bert. (Toole 1960); wilt fungi such as the oak wilt fungus *Ceratocystis fagacearum* (Bretz) Hunt (Lewis and Oliveria 1979); and possibly canker fungi such as *Hypoxylon atropunctatum* (Schw. ex Fr.) Cke. (Bassett *et al.* 1982, Tainter *et al.* 1983). More often, however, several factors are implicated together, with the effects of any single factor being difficult to assess.

Figure 5.—Severe chlorosis

Decline Syndrome Complex–This concept of disease is used by pathologists (Manion 1981) to explain the sequential interaction of two or more inciting factors in causing decline. The concept generally groups factors into three categories: (1) long-term predisposing factors such as adverse climatic trends, poor soil or site quality, tree age, tree genetics, or chronic air pollution; (2) short-term inciting factors like drought, frost, insect defoliation, or discrete air pollution events; and (3) long-term contributing factors such as root disease, bark beetles, canker, or decay fungi. Many reports have implicated multiple factors as contributors to oak decline (Staley 1965, Balch 1927, Nichols 1968, Dunbar and Stephens 1975, Wargo 1977, Lewis 1981, Haack and Benjamin 1982, Fergus 1956, Wargo 1977).

Cohort Senescence–This concept views decline phenomena from a plant community perspective, and was developed during the study of dieback and mortality of ohia (*Metrosideros polymorpha* Gaud.) forests in Hawaii (Mueller–Dumbois *et al.* 1983). It places primary emphasis on the life stage of the affected host, but is otherwise similar to the decline syndrome concept suggested by Manion (1981).

Particularly for earlier successional species, major environmental disturbances often create a large cohort of a single age class over a broad area. The cohort reaches a senescent life stage simultaneously and it becomes uniformly susceptible to a triggering stress (McCracken 1985b). Senescence is a condition associated not so much with chronological age as with a combination of age and environmental stress. Therefore, a tree on a poor quality site subject to frequent and prolonged stress becomes senescent at an earlier age than a tree of the same species on a good quality site.

Oak cohorts may have resulted in some places from the combined effects of exploitive logging early in the 20th century and the chestnut blight epidemic. Despite the differences between ohia forests in Hawaii (composed of early successional species with little overstory diversity developing after volcanic activity) and southern oak forests (later successional species with greater overstory diversity developing after less complete forest disturbance), this model adds to our understanding of decline, especially in areas of tree susceptibility to stress and the dynamics of plant communities.

Factors Associated With Oak Decline

Hosts–All oak species have exhibited decline but not to the same extent. Most reports indicate that the red oak group (*Erythrobalanus*) is more susceptible than the white oak group (*Leucobalanus*) (Rauschenberger and Ciesla 1966, Staley 1965, Tryon and True 1958, Tainter *et al.* 1983, Skelly 1974, Fergus and Ibberson 1956, Yeiser and Burnett 1982, Balch 1927). Among red oaks, scarlet oak (*Quercus coccinea* Muenchh.) is notably sensitive (Skelly 1974, Rauschenberger and Ciesla 1966, Tryon and True 1958, Gillespie 1956, Nichols 1968). However, depending on the most prevalent damaging agent, the white oak group may sometimes be affected more (Dunbar and Stephens 1975).

Weather–Weather factors can be major contributors to oak decline and drought has been most often associated. Because droughts can be long or short term and highly variable in severity over

Figure 6.—Leaf scorch; symptom of drought injury

large geographic areas, the effects are similarly variable and difficult to quantify in any particular stand. Leaf injuries may be attributed to oak decline, but could be entirely due to drought (figure 6). Drought may contribute to oak decline in several ways: (1) by killing trees directly during extreme drought; (2) by weakening trees, predisposing them to injury by other agents; and (3) by killing trees predisposed by other agents. As a predispositional factor, drought has been suggested as one cause of reduced radial growth prior to the development of crown symptoms (Fergus and Ibberson 1956, Nichols 1968, Rhodes and Tainter 1980). Mortality due to water stress alone has been suggested as the cause of mortality in several instances (McIntyre and Schnurr 1936, Mistretta *et al*. 1981, Yeiser and Burnett 1982, Tainter *et al*. 1983, Hursh and Haasis 1931, Bassett *et al*. 1982). Drought may also affect the tree by making it more vulnerable to mortality following defoliation (Young 1965), and more susceptible to attack by root disease fungi (Wargo 1977).

Late spring frosts have been linked to decline by several workers (Beal 1926, Hursh and Haasis 1931, Staley 1965, Nichols 1968, Balch 1927, Rauschenberger and Ciesla 1966) and should be considered a major decline-associated factor. In some cases, frost can selectively damage certain species if it occurs when tissues are at a highly susceptible stage (such as just after bud break (Beal 1926)) and is more severe when trees are dominant (i.e. exposed) and in hollows or frost pockets with poor air drainage (Beal 1926, Nichols 1968).

Site–Site factors also contribute to decline. Some workers have noted an apparent association of decline with south-facing aspects (Gillespie 1956), which are usually driest. The degree of slope may be related due to its effect on air drainage and the resultant probability of frost damage as well as effects on such factors as moisture availability (Gillespie 1956). Topographic position may also be related. Increased occurrence of decline has been noted on ridges and upper slopes (True and Tryon 1956). Soils there are often coarse, rocky or shallow, exacerbating moisture stress (Hursh and Haasis 1931, Tainter *et al*. 1983, Staley 1965, True and Tryon 1956). Other soil factors such as low fertility or restricted rooting or drainage may also play a part (Kegg 1973, Tryon and True 1958, Staley 1965, Gillespie 1956). Flooding has also been implicated in decline (Francis 1983, Schlaegel 1984, Bell and Johnson 1974, Broadfoot and Williston 1973), but such occurrences are limited to greentree reservoirs, water impoundments and floodplains inundated for extended periods.

Insects–Several insects have been associated with decline. Spring defoliating insects such as the gypsy moth, leaf rollers, loopers and spanworms (Kegg 1971, Burgess 1922, Nichols 1968, Tryon and True 1958, Knull 1932), and the twolined chestnut borer *Agrilus bilineatus* (Weber) (Dunbar and Stephens 1975, Lewis 1981, Balch 1927; figure 7) are most often mentioned. Defoliation can at times be responsible for decline and mortality, especially if repeated in successive years (Minot and Guild 1925, Nichols 1968, Staley 1965). However, defoliators are most often believed to function as an initiating stress factor, reducing growth (Baker 1941) and lowering carbohydrate reserves of the tree (Stephens *et al.* 1972, Staley 1965, Dunbar and Stephens 1975, Parker and Patton 1975). When a tree is weakened in this manner, drought and normally nonaggressive insects or disease organisms can have greater impacts. Some place the twolined chestnut borer in this category of secondary pests that attack trees weakened by other factors (Haack and Benjamin 1982); others consider it a primary pest (Dunbar and Stephens 1975, Chapman 1915, Nichols 1968). Twolined chestnut borers burrow in the inner bark, in a generally horizontal pattern girdling the attacked tree (figure 7).

Figure 7.—Galleries of twolined chestnut borer

Disease–Root rot caused by *Armillaria* spp. (shoestring root rot) is often associated with dead and declining oaks (figure 8). Like the twolined chestnut borer, this soilborne fungus is considered a secondary pest that successfully attacks only weakened trees (Balch 1927, Staley 1965, Wargo and Houston 1974, Wargo 1977, 1972). Weakening agents include defoliation, drought, flooding, and perhaps other injuries (Wargo 1972, Parker and Patton 1975, Wargo and Montgomery 1983). As *Armillaria* spp. invade a tree's root system, roots are damaged or killed and the tree is weakened further. Tree death may occur before the root collar is colonized (Wargo 1977). Other root pathogens sometimes associated with declincd trees in addition to those cited as single cause factors are *Ganoderma (Polyporus) lucidum* (Ley.) Karst. (Lewis 1981) and *Polyporus dryadeus* Pers. ex Fries (Fergus 1956). A canker disease caused by *Hypoxylon atropunctatum* is occasionally mentioned as a possible factor in oak decline. Although branches die back after the fungus invades the cambium and sapwood, most workers believe only trees severely weakened by other agents are successfully colonized (Bassett *et al.* 1982, Lewis 1981, Tainter *et al.* 1983, Mistretta *et al.* 1981).

Figure 8.—Mushroom of* Armillaria *species; causal agent of shoestring root rot

Objectives

A survey of southern forest managers and other cooperators made in late 1984 (Starkey 1985) indicated that oak decline was widespread in the South and often severe. Underlying public concern plus the recent interest in forest declines prompted this evaluation. Four specific objectives were established:

1. A regional characterization of oak decline sites, including species and size classes affected, amount and severity of decline and mortality, volume affected, and site/stand characteristics of affected areas.
2. An assessment of the radial growth history of affected and healthy trees in decline areas.
3. Gathering of sufficient data to prioritize the oak decline problem in comparison to other forest problems.
4. Obtaining enough information to answer professional and public concerns.

Methods

Survey

State and national forest land managers in nine Southern and Central States provided the locations of forested areas known to be exhibiting symptoms characteristic of oak decline. From these, 38 sites were chosen for survey (figure 9). The criteria for selection included the absence of recent site disturbance (e.g., fire, logging, and road construction), predominantly oak species composition, and an area uniform enough to be considered a management unit (stand) of between 15 and 40 acres. We attempted to disperse sample stands throughout the region. The most concentrated were three sites within 6 miles of each other in South Carolina.

A topographic or other map of the area was obtained, and the sample stand was divided into three subunits of approximately equal area. Each subunit was sampled by placing a cluster of four basal area factor (BAF) 10 prism plots on the map in the approximate center of the subunit. The prism plots were about 2 chains (132 feet) apart and were arranged to maintain a minimum buffer of two chains from adjacent stands. The configuration of plots usually was square, but it occasionally was linear. Therefore, each stand was sampled with 12 BAF 10 prism plots (three clusters of four plots each).

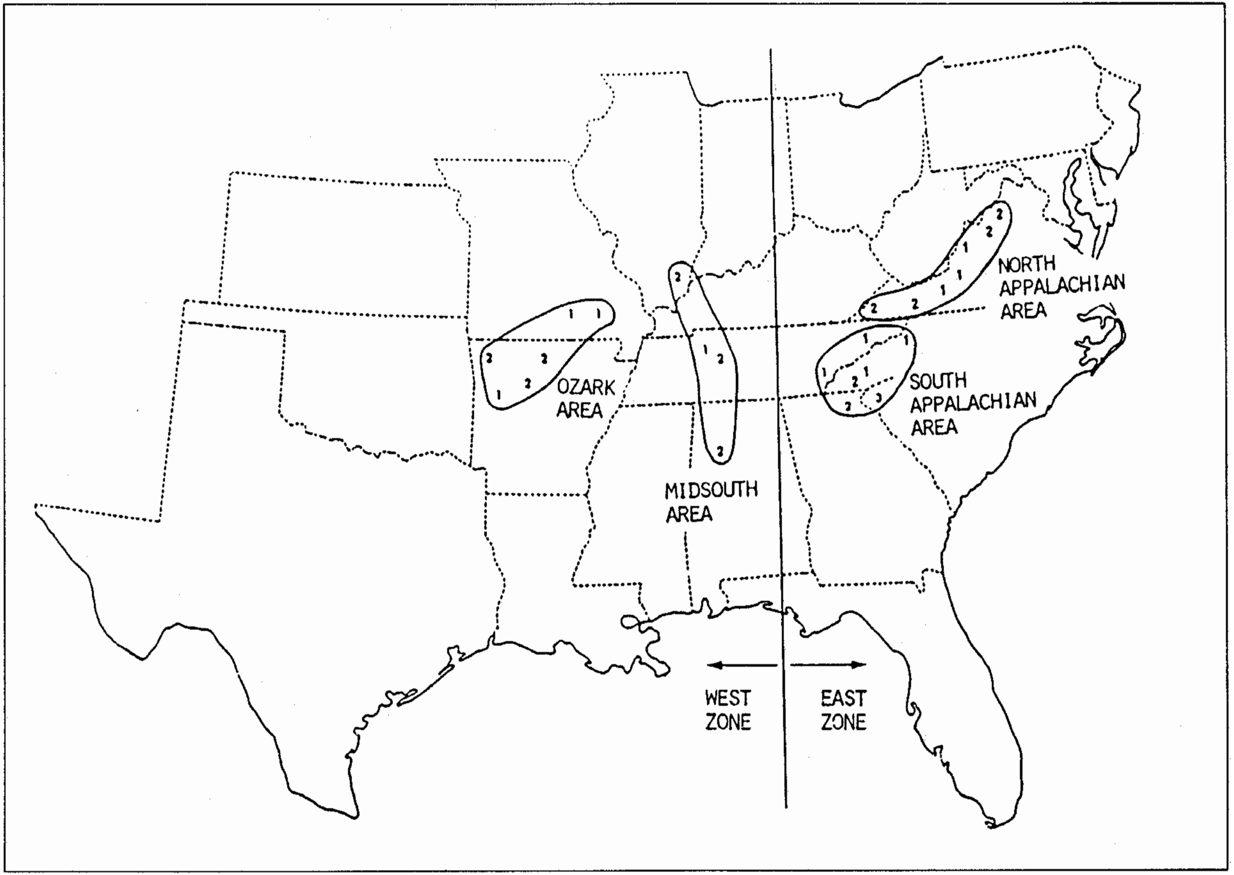
The location, ownership, compartment, and stand number were recorded for each site. Site index was determined for each cluster of prism plots from one dominant or codominant tree in the red oak group (three site index estimates per stand). Each prism plot was further characterized with respect to the factors summarized in table 1. Table 2 lists the characteristics that were measured or observed for each sample tree >5 inches d.b.h.

The statistical significance of differences in the crown condition of dominant and codominant trees for oak species, species group, decline duration, basal area class, and various site factors were estimated using analysis of variance (ANOVA) with Duncan's Multiple Range Test (DMRT) and by chi-square analysis (χ^2). Survey stands were partitioned among four broad geographic areas and two zones (figure 9) that share common climatic patterns (e.g. rainfall amounts and seasonal distribution, seasonal temperatures) and physiography. Data were then reanalyzed to detect differences in decline condition among the areas and trends with respect to the various site factors.

Table 1.—Site factors used to characterize sample plots; oak decline evaluation, Southern Region, 1985.

Site Factor	Measure
Elevation	Feet above sea level
Slope	Percent
Aspect	Cardinal compass points plus the intervening point in each quadrant
Topographic position	Ridge Slope Bottom (flood plain of water course) Terrace (relatively flat area immediately above a bottom) Bench (relatively flat upland area below a ridge)
Soil depth (to rock)	6-inch classes from 0 to 24 inches and >24 inches
Surface soil texture	Sand, loam, and clay with intergradations; presence of gravel, cobbles, or stones (termed stony or gravelly)

Figure 9.—Location of stands evaluated for oak decline; geographic areas and zones, 1985.



Growth Histories

Five stands in 3 states distributed across the region were chosen to characterize the radial growth histories of trees in decline areas. The three areas were widely separated (middle Tennessee, 2 stands; western North Carolina, 2 stands; northwestern Arkansas, 2 stands) and generally represented 3 of the 4 geographic areas used in decline analyses. Recently dead (during the survey year with bark intact) or severely declined trees in the red oak group were selected and paired with the nearest healthy tree of the same species and diameter class. All trees were from the dominant or codominant crown classes.

Increment cores to the pith were removed at breast height from the north and south sides of each tree and stored in grooved wooden blocks until processed. The number of trees cored in each stand was:

Area & Stand	# Healthy Cored	# Dead or Declined Cored
Arkansas - 1	12	12
Arkansas - 2	12	12
Tennessee -1	12	12
Tennessee -2	12	12
North Carolina - 1	16	16
North Carolina - 2	13	13

Table 2.—Sample tree data collected (all trees>5" d.b.h.); oak decline evaluation, Southern Region, 1985.

Factor	Measure
Species	Species
Diameter breast height	Inches
Product size	(1) Pulpwood 5-9 inches d.b.h.; (2) sawtimber≥10 inches d.b.h.
Volume	(1) Pulpwood, estimated number of 5-foot sticks to a 4-inch top o.b.; (2) sawtimber, number of 16-foot logs to a 9-inch top o.b.
Form (sawtimber only)	(1) Good, first log grade 1 or 2[1]; (2) fair, first log grade 3; (3) pulpwood; lower quality than grade 3
Crown position	(1) Dominant; (2) codominant; (3) intermediate; (4) suppressed
Crown condition	(1) Healthy-no distinct symptoms; (2) slight-< 1/3 of crown dead or generalized chlorosis; (3) moderate-1/3-2/3 of crown dead; (4) severe- > 2/3 of crown dead; (5) dead
Oldest previous decline	(1) Decline absent–no evidence of past decline; (2) 1 year prior to survey–fine twigs only remain without foliage, buds visible, bark intact; (3) 2 to 3 years prior to survey–fine twigs gone, blunt twigs to stubby limbs, bark beginning to loosen or loose, cambium softening to mushy; (4) 4 or more years prior to survey–stubs instead of limbs, bark sloughing or gone, sapwood sloughing
Decline duration	(1) Absent–no evidence of past or current decline; (2) current year only–no evidence of past decline, current symptoms only (foliage chlorotic or dead and adhering, current years twigs affected only); (3) previous years only–evidence of past decline (as above) but no current symptoms; (4) current and previous years–both 2 and 3

[1]Hanks 1971

In the laboratory, cores were glued onto wooden blocks and a flat surface was sanded on each to prepare a transverse face suitable for measuring annual ring widths. Rings were measured to the nearest 0.01mm with a Bannister incremental measuring device. The growth histories of healthy and severely declined or recently dead trees were compared by analysis of variance to detect growth differences that were potentially useful in predicting decline and its economic impact.

Economic Analyses

An economic analysis was performed on each stand utilizing the sawtimber volumes of dominant and codominant trees. Pulpwood volume was excluded due to its low value.

Volume and present value (PV) were calculated for current (1985) and projected (1995) conditions, with and without decline. Losses were calculated as the difference between scenarios (with and without decline) in board feet and dollars per acre and as a percentage of PV without decline.

The key assumptions used in the economic analysis included: (1) a 4 percent discount rate, (2) no real increase in stumpage prices in future years, (3) mortality in evaluated stands at the time of survey (1985) had accumulated in equal amounts from 1980-1985. (4) mortality would continue to accrue from 1985 through 1988 at the same rate but, only in trees with advanced decline in 1985, and (5) growth loss would continue to accrue from 1985 through 1995 in trees with advanced decline which were not expected to die by 1988. A more detailed explanation of the assumptions, methods, and calculations for the analysis and its individual components is found in the appendix.

Results and Discussion

Evaluated stands were mainly of sawtimber size. Stand age ranged up to 110 years, but most stands were 50 to 80 years old (figure 10). A few poletimber-sized stands of advanced age were encountered. Because our sampling did not include a wide range of ages, no firm conclusion can be drawn about the relation between age and decline. However, our sampling was limited to known areas of decline and we infer that damage is probably more common and severe in stands over age 50 than in younger stands. We received no reports of decline in younger poletimber-sized stands.

Declined stands occurred over a range of site qualities, but most were on site index 70, average for upland hardwood sites (figure 11). Only 18 percent of evaluated sites were on site indices below 70.

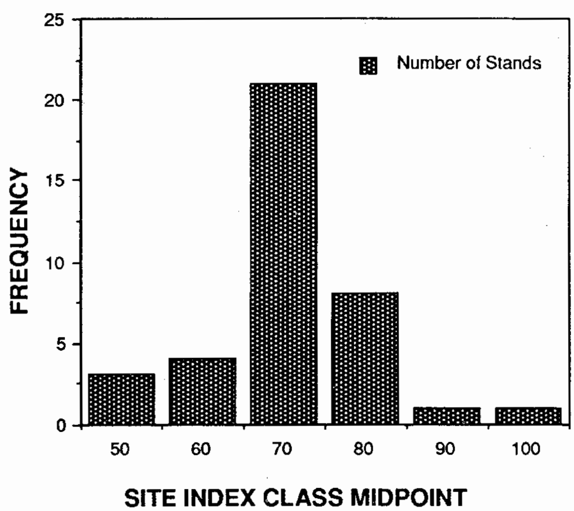
In all, 3,623 trees were tallied on the 456 plots in 38 stands affected by oak decline. Of these, 2,810 trees were dominant or codominant and consisted of 84 percent oaks, 6 percent hickories (*Carya* species) and 10 percent other species (table 3). The predominant species in the "other" category were red maple (*Acer rubum* L.) yellow-poplar (*Lirodendron tulipifera* L.), black locust (*Robinia pseudoacacia* L.), and blackgum (*Nyssa sylvatica* Marsh.). Scarlet oak was the species most often tallied on decline sites followed by black (*Q. velutina* Lam.), white (*Q. alba* L.), and chestnut oaks (*Q. prinus* L.) Scarlet oak accounted for over 20 percent of such trees. Hickories accounted for 6 percent.

Due to the point sampling method used, differences exist in the actual number of trees observed on the number of trees per acre they represent (table 3). This is demonstrated in a comparison of white and black oaks. The small difference in the numbers of trees tallied was inflated in the caluations of trees per acre because black oaks as a group were somewhat larger in diameter than white oaks.

Since stands were evaluated over a fairly wide time span, the presence of individual insects or diseases could not be accurately recorded. However, evidence of shoestring root rot, twolined chestnut borer and *Hypoxylon* canker was very common. All three were often noted on the same tree. Some evidence of defoliating insects was occasionally noted, although none of the stands were in areas defoliated by gypsy moth.

Figure 10.—Age class distribution for stands evaluated for oak decline, Southern Region, 1985.

Figure 11.—Site index distribution for stands evaluated for oak decline, Southern Region, 1985.



Crown Condition

Eighty percent of the trees in areas of oak decline had decline symptoms or were dead (figure 12). Twenty percent had ≥1/3 crown dieback and 17 percent were killed. We combined moderately and severely declined trees into an advanced decline condition class for subsequent analyses because of the low numbers of severely declined trees. The healthy and slight decline condition classes were also combined for some analyses.

Oak Groups—The proportional distribution of oaks in the white oak group (AWO; white oak, chestnut oak, post oak (*Q. stellata* Wangenh.)) and red oak group (ARO; black oak, scarlet oak, southern red oak (*Q. falcata* Michx.), northern red oak (*Q. rubra* L.), and blackjack oak (*Q. marilandica* Muenchh.) differed in the healthy and dead condition classes (figure 13). The healthy proportion of AWO was three times that of ARO. Conversely, percent of dead ARO (24) exceeded that of AWO by about the same factor. Both differences were highly significant. The levels of slight and advanced decline differed only slightly between the two oak groups. However, nearly half of the stocking of both groups was in the slight decline condition class.

Figure 12.—Percentage of dominant and codominant trees per acre, by crown condition.

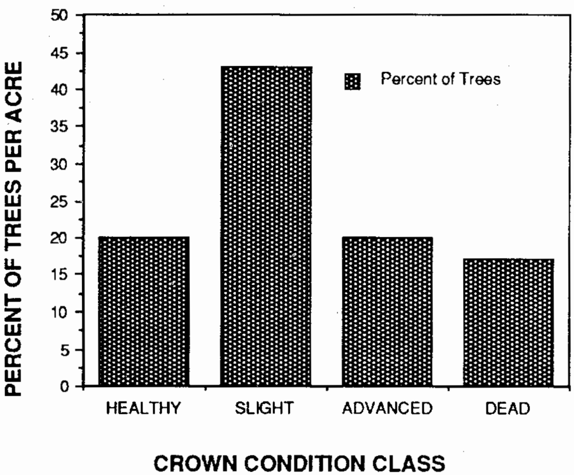


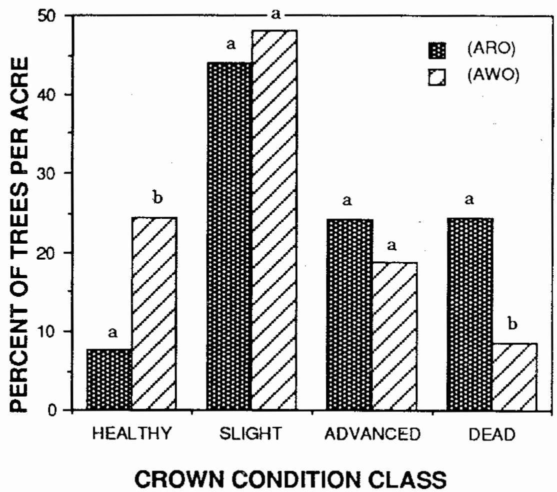
Table 3.—Distribution of tallied trees (dominant and codominant) by species; oak decline evaluation, Southern Region, 1985.

Species	Trees Tallied		Calculated	
	Actual	Percent	Trees/Ac.	Percent
Scarlet oak	654	23	15.6	21
Black oak	432	15	9.5	12
White oak	431	15	12.6	17
Chestnut oak	352	13	8.8	12
Northern red oak	261	9	6.8	9
Hickory	157	6	5.5	7
Red oak[1]	88	3	3.5	5
Post oak	56	2	1.6	2
Southern red oak	49	2	1.6	2
Blackjack oak	22	1	0.8	1
Oak	11	3	0.4	1
Other	297	8	8.7	11
Total	2,810	100	75.4	100

[1]Trees not identified to species; many were dead, without identifiable features.

Individual Species–Not all species were equally affected. Black oak and scarlet oak sustained the highest levels of mortality (34 and 23 percent, respectively; table 4) followed by white

Figure 13.—Percentage of trees by acre, by oak group and crown condition.



Values of paired bars labelled with different lowercase letters are significantly different at the p<0.01 level according to Duncan's multiple range test.

oak (12 percent), northern red oak (10 percent), hickory (12 percent) and chestnut oak (5 percent). Advanced decline was greatest in scarlet and northern red oak (30 and 29 percent, respectively) followed by chestnut oak, white oak, hickory and black oak.

Most oak species had around 10 percent of their stocking in the healthy condition class. White oak was a notable exception with nearly one-third healthy stocking. The percentage of healthy hickories was somewhat less (23 percent).

Duration of Decline

Current decline symptoms were present on many trees and the evidence of previous damage indicated that decline had been present in many areas for 4 or more years. Over half of all trees had symptoms of both current and previous decline (table 5). One estimate of the rate of annual increase in decline is the percentage of trees with current decline only (i.e. no previous decline). In the survey year, 6.5 percent of the trees were in this class. This estimate varied among species groups and was higher for ARO (8.2 percent) than for AWO (5.6 percent). For non-oak species the annual increase was about half the overall rate, but none of the differences were significant. Previous damage only was significantly higher for ARO than either AWO or other species. These results are supported by the relative distribution of trees among the various crown condition classes for individual species (table 4) and imply earlier initiation and/or more rapid intensification of symptoms in the red oak group, especially in black and scarlet oaks.

Table 5.—Percentage of trees per acre, by decline, duration class and species group, oak decline evaluation, Southern Region, 1985.

	Species Groups			All
Duration of decline	ARO[1]	AWO	Other	Species
Healthy	8a[2]	25b	48c	21
Previous only	25a	10b	8b	18
Current only	8a	6a	4a	6
Previous plus current	59a	59a	40b	55
Total	100	100	100	100

[1]ARO=black scarlet, southern red, northern red and blackjack oaks; AWO=white, chestnut and post oaks.
[2]Values within crown condition classes followed by different letters are significantly different at the $p<0.01$ level according to Duncan's multiple range test.

Basal Area

Basal area per acre (all crown positions) of evaluated stands averaged 87 square feet, and stand averages ranged from about 70 to 110 square

Table 4.—Percentage of stocking of dominant and codominant trees by species and crown condition; oak decline evaluation; Southern Region, 1985.

	Species							
Crown Condition	BLO[1]	SCO	NRO	WHO	CHO	H	Other	All Species
Healthy	9	8	8	31	13	23	63	20
Slight	41	39	53	39	61	48	23	43
Advanced	16 a*[2]	30 b	29 b	18 a	21 ab	17 a	10	20
Dead	34 a**	23 a	10 b	12 b	5 b	12 b	4	17
Total	100	100	100	100	100	100	100	100

[1]Species with >100 observations (>5 percent of the stocking); BLO=black oak, SCO=scarlet oak, NRO=northern red oak, WHO=white oak, CHO=chestnut oak, and H=hickory spp.
[2]Significance applies among species within crown condition classes. Values followed by different letters are significant at the 0.01 level (**) or 0.05 level (*) according to Duncan's multiple range test. Where no letters appear, F statistics were not significant and no Duncan's was preformed.

feet. Several statistical analyses were performed on plot basal areas versus advanced decline and mortality, but no significant relationship was detected. A representative portion of these data is presented in table 6.

Site Factors

The sample of surveyed stands was incomplete for the purposes of measuring the effects of site factors on decline because only decline-damaged stands were included. Until data are collected from sites with a wider range of site factors and damage, these observations can be used to classify site factors according to the most severe damage potential (ie. mortality).

Topographic Position—Decline and mortality occurred on all topographic positions sampled. However, there were too few observations in many categories to be compared. Most stands observed were on ridges and slopes. While differences in the levels of advanced decline on these positions were not statistically significant (figure 14), mortality was slightly but significantly higher on ridges (20 percent) than slopes (16 percent).

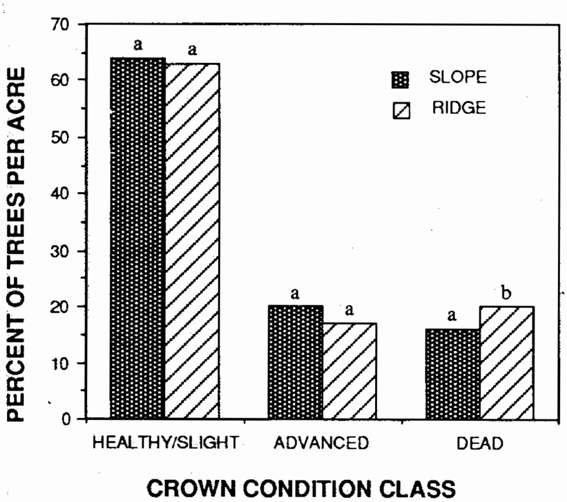
Table 6.—Average percentage of trees in various crown condition classes and basal area categories.

Basal area (Sq. Ft. per Acre)	Advanced	Dead
<70	17[1]	17
70-80	17	17
90-100	13	21
>120	18	19

[1]Values in columns are not significantly different.

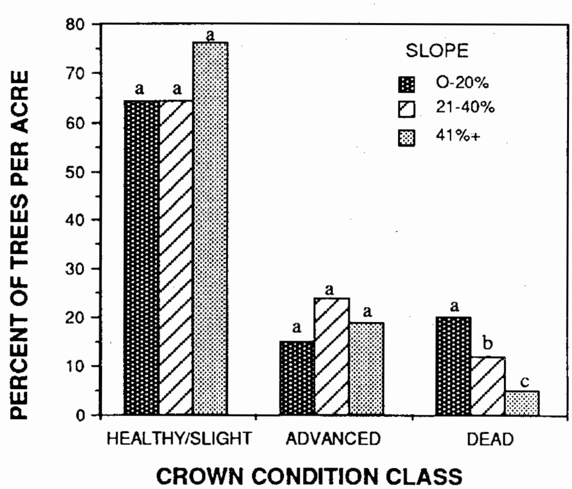
Slope—Effects of slope class were examined only for plots with a slope topographic position (65 percent of all plots). No significant differences were found among slope classes for advanced decline. There were more healthy and slightly declined trees and fewer dead trees on steep slopes (figure 15), but the differences among slope classes were significant only for mortality. This result may be due to some gently sloping ridges being classified as slopes.

Figure 14.—Percentage of trees per acre, by topographic position and crown condition.



Values of paired bars labelled with different lowercase letters are significantly different at the p<0.01 level according to Duncan's multiple range test.

Figure 15.—Percentage of trees per acre, by slope steepness and crown condition.



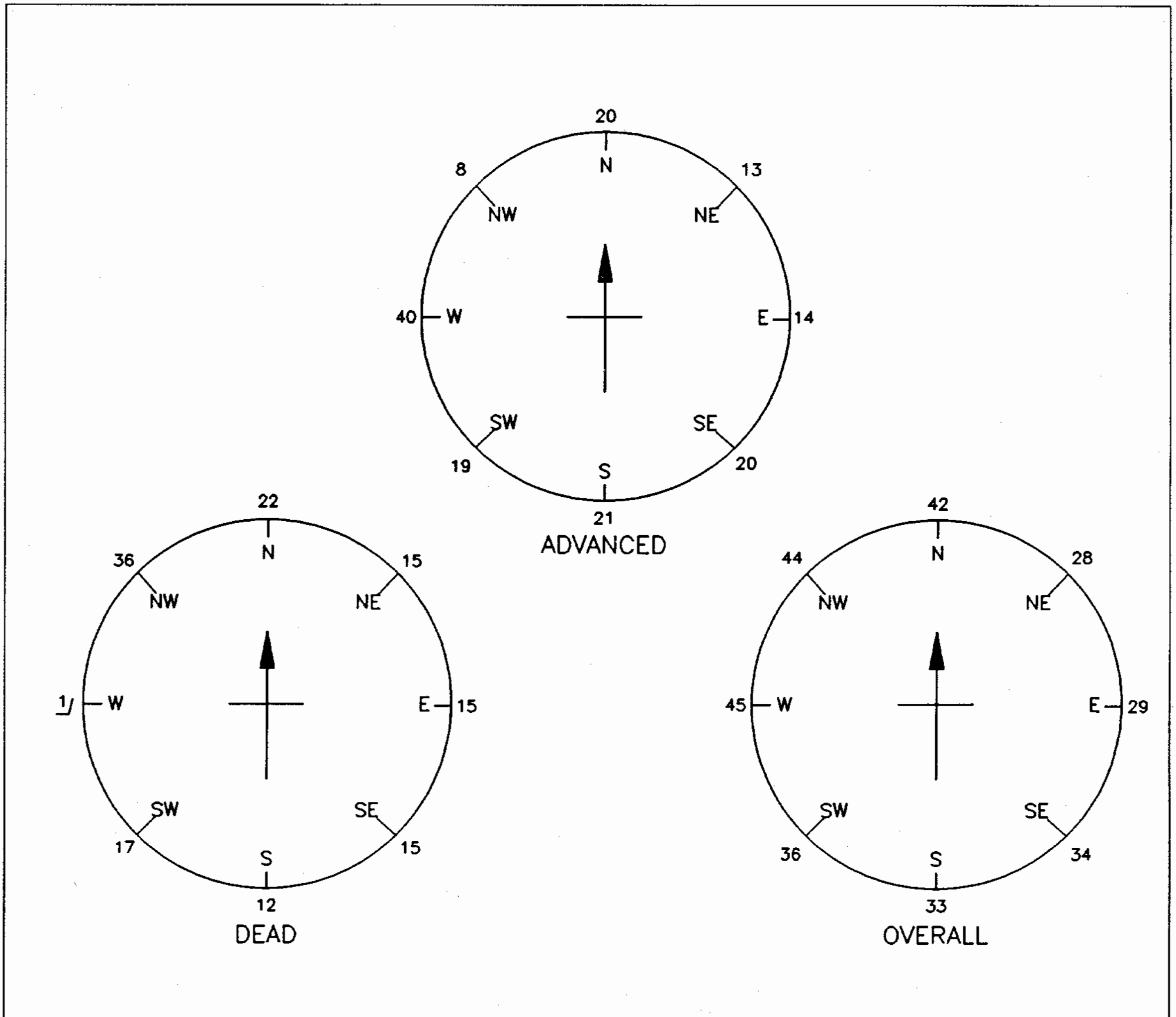
Values of paired bars labelled with different lowercase letters are significantly different at the p<0.01 level according to Duncan's multiple range test.

Aspect—The association of aspect with decline was also examined only for plots with a slope topographic position. Although there were no significant relationships between aspect and advanced decline plus mortality, W to N aspects were apparently most damaged, NE and E the least, and southerly aspects intermediate (figure 16). Damage in ARO was consistently greater than in AWO on all aspects.

Soils

Texture—Broad soil texture categories were established because many individual classes contained few observations. Mortality was significantly greater for trees growing on stony or gravelly soils (26 vs. 12 percent; figure 17) while significantly more advanced decline trees occurred on other soil textures. Healthy and slightly damaged condition classes combined were approximately equal on both soil texture groups.

Figure 16.—Percentage of trees per acre, by aspect and damage category.



[1]Too few observations for a meaningful result.

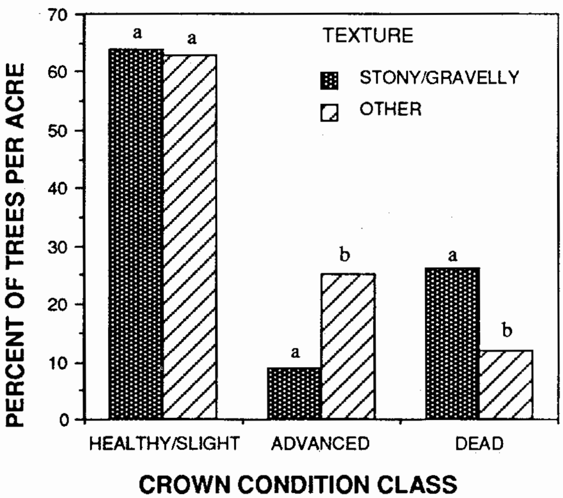
Depth—Soil depth classes were also combined. Shallow soils (< 18" deep) had higher mortality levels than deeper soils (≥18"; 25 vs 8 percent; figure 18). As with earlier observations on soil texture, advanced decline was more prevalent on the deeper soils than shallow soils (27 vs 14 percent). Both of these were highly significant relationships.

Site Index–Combinations of site factors may be more important than individual site factors in determining decline severity. Site index integrates many individual site factors into a single measure of site productivity. Mortality was 22 percent of stocking on poor sites (indices < 65 ft) and only 10 percent on the best sites (indices > 75 ft; figure 19). Conversely, advanced decline was higher on the best sites (27 vs 13 percent on poor sites; figure 19) resulting in nearly identical levels of overall damage on all site index classes.

Site Factor Summary

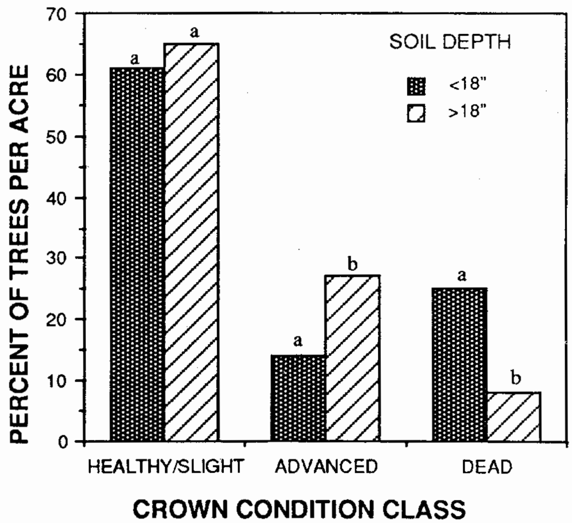
Overall damage (advanced decline plus mortality) was nearly equal for most categories within individual site factors, reflecting the character of the survey population (damaged stands). Differences were apparent, however. in how this damage was allocated. Generally, mortality was more frequent where site conditions were more harsh. These results suggest that decline may occur on all types of sites but that mortality may occur first or more frequently on less productive sites associated with ridges, gentle slopes, and shallow and/or rocky soils. However, high mortality may also occur on more productive sites if other stand conditions are conducive to decline (e.g., older stands that are predominantly stocked with black and/or scarlet oaks) and especially if stresses are severe or persist for long periods.

Figure 17.—Percentage of trees per acre, by soil texture and crown condition.



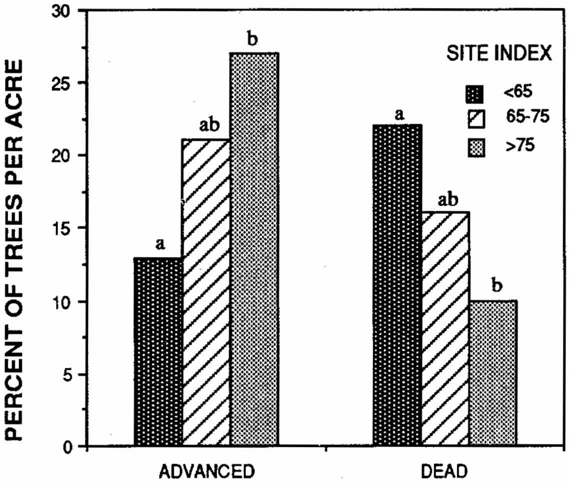
Values of paired bars labelled with different lowercase letters are significantly different at the p<0.01 level according to Duncan's multiple range test.

Figure 18.—Percentage of trees per acre, by soil depth and crown condition.



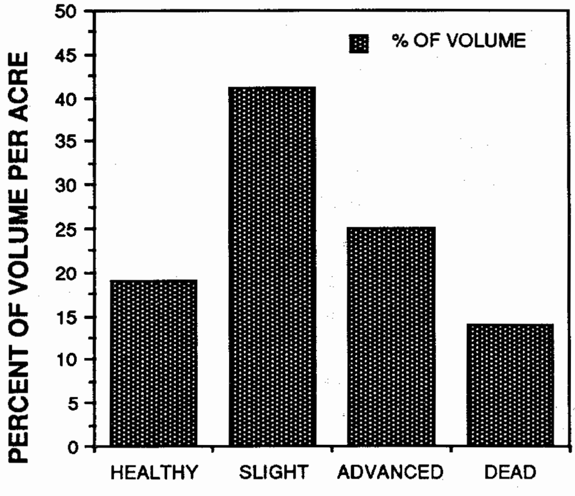
Values of paired bars labelled with different lowercase letters are significantly different at the p<0.01 level according to Duncan's multiple range test.

Figure 19.—Percentage of trees per acre, by site index and crown condition.



Values of paired bars labelled with different lowercase letters are significantly different at the p<0.01 level according to Duncan's multiple range test.

Figure 20.—Percentage saw timber volume per acre, by condition class.



These results can be used to define a rudimentary classification of mortality potential or a simple risk-rating system (table 7). Factors are arranged in what we judge to be a descending order of importance based on the strength of their association with mortality. As for any risk-rating system, there many sites with high-risk features that do not have decline. Where decline has occurred, these relationships exist. Further analyses are required to confirm our judgements about the importance of individual factors and to modify them by geographic area. Additional data from sites representing a broader range of damage are required to fully evaluate the effects of site factors on decline.

Table 7.—Conditions conducive to low or high risk of mortality from oak decline.

Low Mortality Risk	High Mortality Risk
Adequate growing-season moisture	Acute summer drought (2-3 yrs. prior)
No recent spring defoliation	Recent spring defoliation
Physiologically immature (pole-size, <50 yrs. old)	Physiologically mature (sawtimber, >50 yrs. old)
Composition predominately white oak group	Composition predominantly red oak group
High site index (>70)	Low site index (≤70)
Mesic site conditions:	Xeric site conditions:
Loamy soils, few rocks	Rocky soils
Deep (>18 inch) soils	Shallow (<18 inch) soils
Coves, terraces, bottoms, lower slopes	Ridges or upper slopes
North and east aspects	South and west aspects

Volume

Average estimated sawtimber volume (dominants and codominants only) was 4,638 bf/ac (table 8), of which only 19 percent was in healthy trees. Twenty-five percent of the volume was in the advanced decline condition class while 14 percent was dead (figure 20). These percentages agree closely with those based on the number of trees (table 4).

Pulpwood volume in the dominant and codominant crown positions was necessarily low (averaging < 1 cord per acre) because sampled stands were predominately of sawtimber size. A larger percentage of pulpwood volume was healthy (36 vs 19 percent) or dead (24 vs 14 percent) in comparison with sawtimber volume, while advanced decline was much lower (3 vs 25 percent).

Form–Chi-Square analysis detected significant differences in the distribution of percent volume among form classes for ARO and AWO but not for other species or for all species combined (table 9). Form 1 trees of both oak groups were less likely to show advanced decline than form 2 trees. but form class did not influence mortality. Form 1 oaks were more likely to be healthy than form 2 oaks, with the difference most pronounced in AWO.

Table 8.—Board feet volume (International 1/4") per acre of dominant or codominant trees by species group and condition class; oak decline evaluation, Southern Region, 1985.

Condition	Species				Total
	ARO[1]	AWO	H	Other[2]	
Healthy	168	334	48	349	899
Slight	1,157	566	77	116	1,916
Advanced	767	313	45	30	1,155
Dead	574	51	26	17	668
Total	2,666	1,264	196	512	4,638

[1]ARO=black oak, scarlet oak, southern red oak, northern red oak, and blackjack oak; AWO=white oak, chestnut oak and post oak; H=hickory species.
[2]Includes 6 board feet per acre overall of unidentified oaks, mostly dead.

Geographic Areas

Differences in the dominant land forms, climate, species composition, soils, and site

Table 9— Percentage of sawtimber volume by species group, form class and crown condition; oak decline evaluation, Southern Region, 1985.

Condition	ARO[1]		AWO		Other		Total	
	1	2	1	2	1	2	1	2
Healthy	7[2]	4	41[3]	14	61[4]	51	23[4]	15
Slight	49	34	38	50	26	30	43	39
Advanced	23	39	17	32	7	15	19	33
Dead	21	23	4	4	6	4	15	13
Total	100	100	100	100	100	100	100	100

[1]ARO=black oak, scarlet oak, southern red oak, northern red oak and blackjack oak: AWO =white oak, chestnut oak, and post oak.
[2]Distribution of volume between form 1 and 2 significantly different at the p=0.05 level [χ^2=8.25*(p<.05)].
[3]Distribution of volume between form 1 and 2 significantly different at the p=0.01 level [χ^2=19.32**(p<.01)].
[4]Distribution of volume between form 1 and 2 not significantly different [χ^2=4.960 (p>.05) for Other, χ^2=5.79 (p>.05) for Total].

quality existed among the 4 geographic areas (figure 9). Overall damage also varied among areas, reflecting the influence of these factors. There remained considerable variation within a geographic area with respect to some site factors, but overall, conditions on decline sites were similar. In the discussion that follows, the features of individual geographic areas are detailed and comparisons are made among areas for decline condition, decline duration, and the various site factors.

North–The 11 stands comprising the North Appalachian Area (N) occur in a region characterized by relatively moderate summers, cold winters and relatively high moisture levels evenly distributed throughout the year. Soil and landform are variable but tend toward shallow, stony soils and broad, parallel ridges. Slopes generally face southeast and northwest. ARO comprise about 50 percent of stocking and AWO 33 percent.

South–The 11 stands comprising the South Appalachian Area (S) occur in a region with a climate similar to N. Site characteristics are highly variable, but site quality tends to be better than in N. Ridges are usually narrow and slopes steep with no single prevailing aspect. Species composition is more diverse than in N, with oaks comprising 64 percent of the stocking (40 percent ARO and 24 percent AWO).

Midsouth–The seven stands in the Midsouth Area (M) occur in a region characterized by hot, often dry, summers and cold winters. Topography varies from gently rolling to steeply rolling (but elevation differences are not extreme) and soils range from sandy to silty. Oaks predominate (81 percent of stocking) and hickories are common (12 percent of stocking). AWO are more plentiful in M than in other areas but are still exceeded by ARO (AWO= 35 percent of stocking; ARO= 46 percent).

Ozark–The Ozark Geographic Area (O) consisted of nine stands in Arkansas and southern Missouri. Climate here is characterized by hot, dry summers and cold winters. Topography varies from gently rolling to steep and mountainous. Soils are often shallow and rocky, and dry site

Table 10. —Percentage of dominant and codominant trees in various crown condition classes for four geographic areas; oak decline evaluation, Southern Region, 1985.

	Ozark		Mid-South		South		North	
Decline duration								
Current decline only	18a[1]		4b		3b		2b	
Crown condition								
all species								
Healthy & slight	70a		64a		62a		58a	
Advanced	4a		10a		32b		27c	
Dead	26a		26a		6b		15c	
Oak groups	ARO[2]	AWO	ARO	AWO	ARO	AWO	ARO	AWO
Advanced	5a[3]	1a	14a	5a	39a	40a	34a	23a
Dead	29a	22a	45a	8b	8a	3a	23a	4b
Overall	34a	23b	59a	13b	47a	43a	57a	27b

[1]Within rows, values followed by the same letter do not differ significantly at the p<0.05 according to Duncan's multiple range test or analysis of variance.

[2]ARO=black oak, scarlet oak, southern red oak, northern red oak and blackjack; AWO=white oak, chestnut oak and post oak.

[3]Within geographic areas, values for ARO and AWO followed by the letter are not significantly different at the 0.05 level according to analysis of variance.

species predominate (black, blackjack, post oaks). Species composition is about 44 percent ARO, 22 percent AWO and 4 percent hickory.

Comparisons Among Geographic Areas

Condition–All geographic areas had similar percentages of healthy and slightly declined trees, with a range of 58 percent (N) to 70 percent (O; table 10). However, there were marked differences in the percentages of dead and advanced decline trees in the O and M areas and the S and N. Mortality was more common than advanced-decline in the O and M areas but less in the S and N areas. In all areas, ARO had a higher percentage of overall damage than AWO. The difference was greatest for the M area (59 vs. 13 percent) and smallest in the S area, where the 2 oak groups were nearly equally affected.

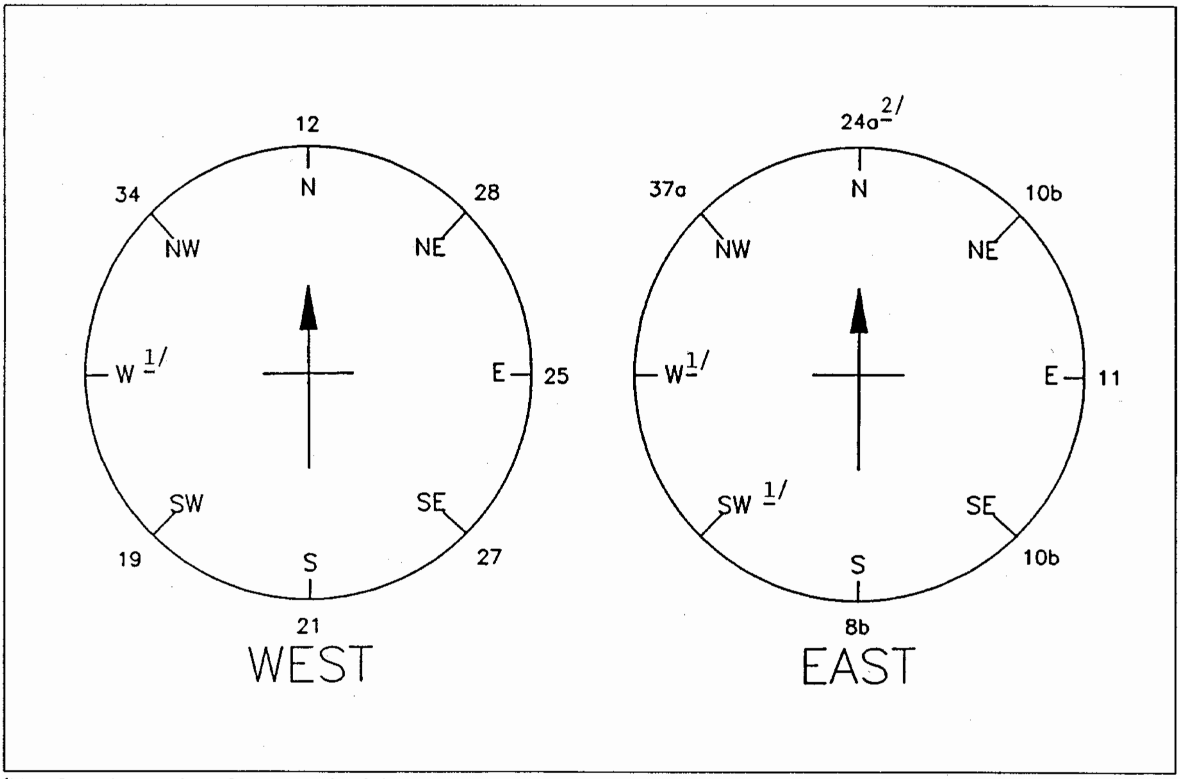
Duration–The O area had a significantly higher rate of new symptoms on previously unaffected trees (18 percent overall; table 10). This difference

Table 11.—Percentage of trees per acre with current decline only by species group and geographic area; oak decline evaluation, Southern Region, 1985

Region	ARO	AWO	Other
North	3	3	2
South	1	3	6
Midsouth	3	8	1
Ozark	23	11	3

Analysis of variance revealed no significant differences among species groups with geographic regions.

Figure 21.— Mortality percentage (in trees per acre), by aspect and geographic zone.



[1]Too few observations for a meaningful result.
[2]Values within a geographic zone followed by different lowercase letters are significantly different at the $p<0.05$ level according to Duncan's multiple range test.

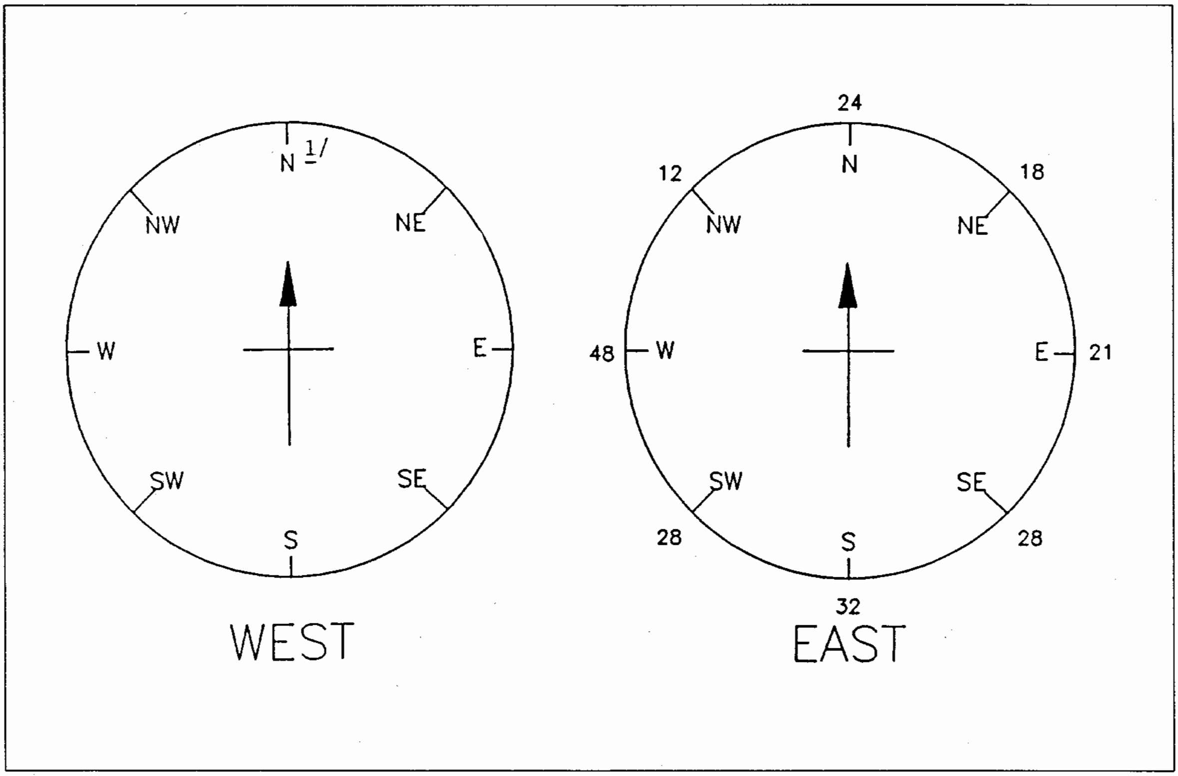
was due mainly to a very high rate of new symptom appearance on ARO (23 percent; table 11), but new symptoms on AWO also occurred more often in the O area than in all others. New decline symptoms in non-oak species were less than in oaks in every area except S, where it exceeded the rate for both oak groups.

Topographic position—Significant differences in overall damage were detected for the O and M areas only (table 12). In both areas, damage on ridges exceeded damage on slopes. This relationship was due to significant differences in both mortality and advanced decline in the O area and in mortality alone in M area. In other areas, significant differences existed only for mortality in N.

Slope—Damage was not significantly associated with slope class in any geographic area. However, in all areas except S, more mortality occurred on the 0-20 percent slopes than on steeper slopes (table 12). Interpretation of the regional influence of slope was complicated by the lack of samples in the steepest slope classes in most areas. Only the S area had an adequate number of observations.

Aspect—Trends in damage for individual geographic areas were unclear. Some weak relationships emerged when N and S areas were combined into an east zone (E) and O and M areas into a west zone (W; figures 21, 22 and 23). In the E zone, mortality was higher on northwest and north aspects than east and south aspects (figure 23). It was somewhat surprising that the more mesic sites had more mortality than the xeric sites. Perhaps this was related to a greater impact of acute drought events on trees growing on ordinarily moist sites compared with the impact on trees

Figure 22:— Percentage of trees per acre with advanced decline, by aspect and geographic zone.



[1]Too few observations on individual aspects for a meaningful result; other values not significantly different according to analysis of variance.

Table 12—Percent of dominant or codominant trees by crown condition class and site factors for geographic areas; oak decline, Southern Region, 1985.

Topographic Position	Ozark		Mid-South		West Zone	South		North		East Zone
	Ridge	Slope	Ridge	Slope		Ridge	Slope	Ridge	Slope	
Advanced	6a	1b	13a	5b	-	24a	33a	33a	29a	-
Dead	31a	21b	25a	27b	-	33a	6a	6a	19b	-
Overall	38a	22b	39a	32b	-	29a	39a	39a	41a	-

Slope	Ozark			Mid-South			West Zone	South			North			East Zone
	0-20	21-40	41+	0-20	21-40	41+		0-20	21-40	41+	0-20	21-40	41+	
Advanced	1a	2a	-	9a	3a	-	-	30a	36a	19a	22a	20a	32a	-
Dead	23a	15a	-	30a	25a	14a	-	3a	7a	5a	23	14	-	-
Overall	24a	16a	-	40a	27a	14a		33a	43a	24a	45a	34ab	32b	-

Soil texture	Ozark	Mid-South	West Zone		South	North	East Zone	
			Stony	Other			Stony	Other
Advanced	-	-	4a	11b	-	-	32a	29a
Dead	-	-	31a	18b	-	-	11a	11a
Overall	-	-	35a	29a	-	-	43a	40a

Soil depth	Ozark		Mid-South		West Zone	South		North		East Zone
	<18	>18	<18	>18		<18	>18	<18	>18	
Advanced	4a	-	5a	15b	-	37a	31a	27a	28a	-
Dead	26a	30a	43a	7b	-	4a	6a	19a	11a	-
Overall	29a	30a	48a	22b	-	41a	37a	46a	39a	-

Site index	Ozark			Mid-South			West Zone	South			North			East Zone
	<65	65-75	>75	<65	65-75	>75		<65	65-75	>75	<65	65-75	>75	
Advanced	4a	1a	1a	1a	12a	7a	-	31a	24a	36a	19a	28a	32a	-
Dead	29a	13a	23a	43a	24a	24a	-	3a	13b	3a	20a	14a	12a	-
Overall	34a	14a	24a	44a	36a	31a	-	34a	37a	39a	39a	43a	44a	-
							-							-

[1] Significance applies to values compared within geographic areas and zones. Values followed by a different letter are significantly different at the p<0.05 level according to analysis or Duncan's multiple range test.

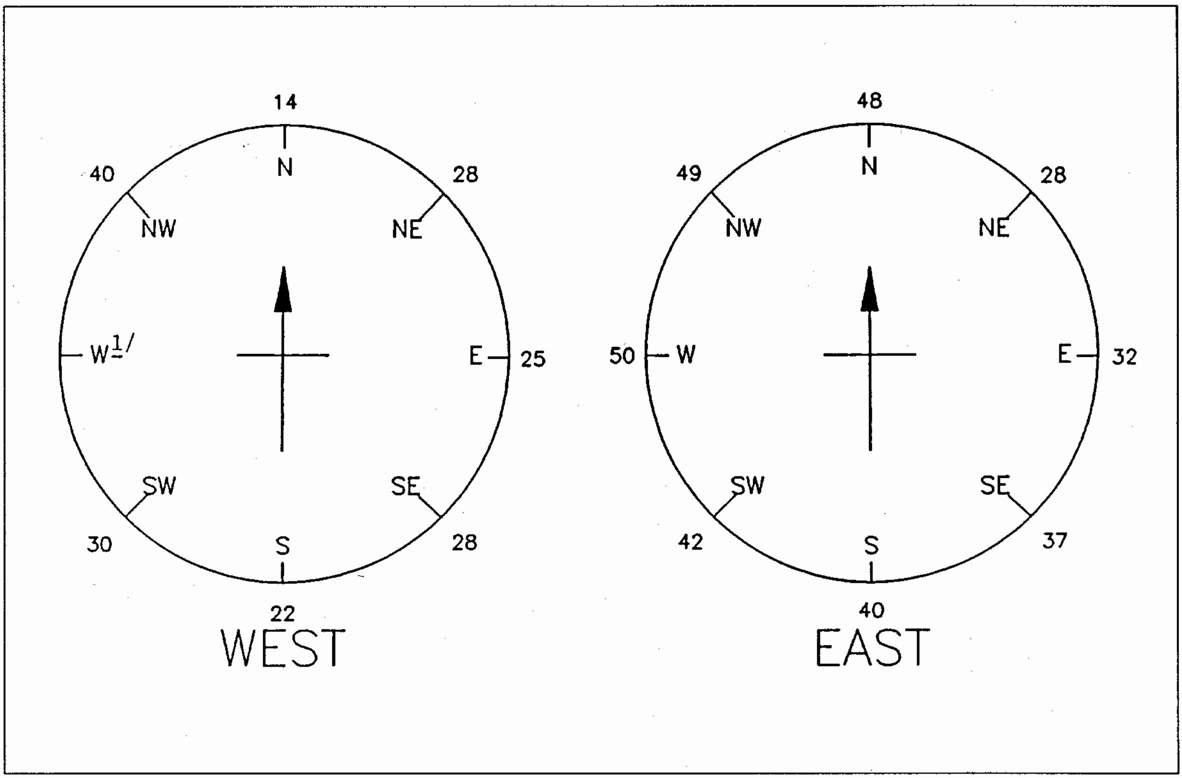
growing on sites that are usually dry. Southwest and west aspects did not have enough observations to provide a meaningful result. Although analysis of overall damage did not detect any statistically significant differences among aspect classes, damage appeared to be greatest on west, northwest, and north aspects, least on northeast and east aspects, and intermediate elsewhere. In the W zone, no consistent trends existed for mortality, advanced decline, or for overall damage. Many aspects had too few observations to make meaningful comparisons.

Soil Texture—As for aspect, areas were combined into E and W zones. Differences in damage for soil texture classes were not statistically significant in either zone (table 12). despite the higher mortality frequency on stony soils in the W zone. High mortality in the W zone resulted in few trees remaining in the advanced decline class and produced a statistically significant, but perhaps not biologically significant, difference.

Soil Depth—Overall damage was greatest on shallow soils in three of the four geographic areas (table 12). Only in M was the difference statistically significant. This difference was due primarily to very high mortality rates on shallow soils. The large difference in mortality between shallow and deep soils in this area may have been responsible for the significant difference detected for all sites combined.

Site Index—The significant differences detected for mortality and advanced decline on various site index classes were largely lost when data were partitioned into geographic areas. Nevertheless, mortality levels on poor sites were higher in three of the four areas (table 12). As stated earlier in the site index analysis for all sites combined, it is obvious that overall damage can be severe on all

Figure 23.— Percentage of trees per acre with damage (dead plus advanced decline), by aspect and geographic zone.



[1]Too few observations for a meaningful result; other values not significantly different according to analysis of variance.

Figure 24.—Mean radial growth of oak trees, Area 1, Western Tennessee, 1985.

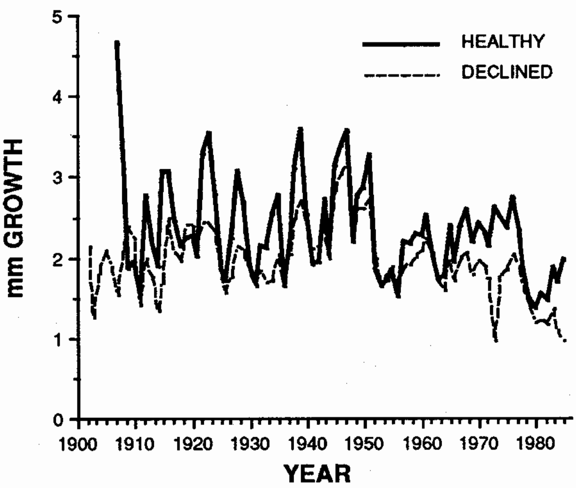


Figure 25.—Mean radial growth of oak trees, Area 2, Western Tennessee, 1985.

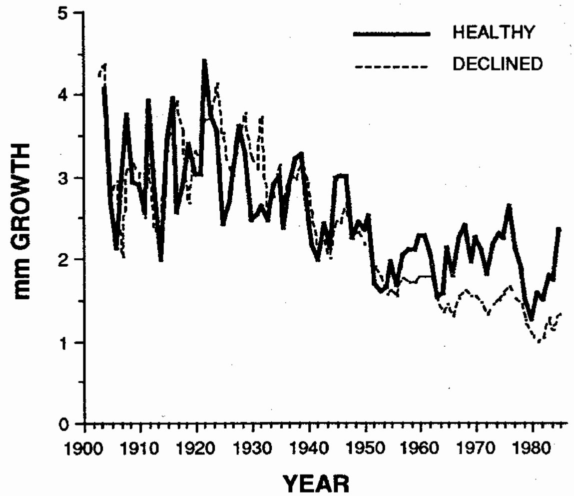


Figure 26.—Mean radial growth of oak trees, Area 1, Northwest Arkansas, 1985.

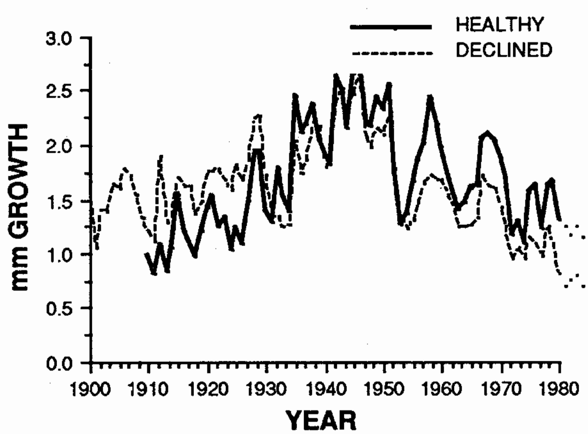
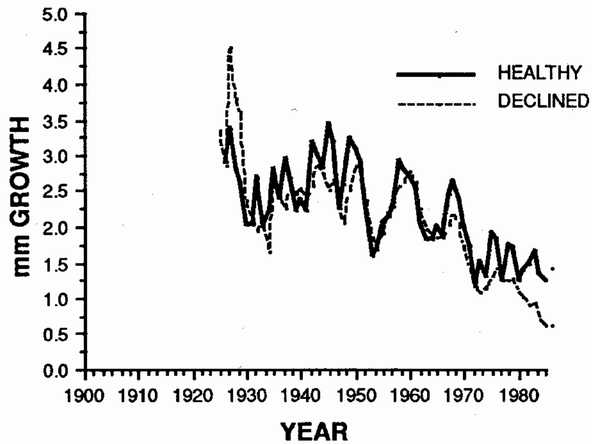


Figure 27.—Mean radial growth of oak trees, Area 2, Northwest Arkansas, 1985.



site qualities in all geographic areas under some conditions.

Growth History Analysis

Radial increment histories for healthy and declined trees were similar in all six stands, especially before 1940. However, in the latter portion of each history, the mean annual growth increment of declined trees became significantly less than for healthy trees. This was evident after 1965 and dramatically so in the 1980's (figures 24 to 29). The amount of growth reduction and the timing of its inception varies by stand, but the patterns are similar.

Healthy trees were tested against declined trees (using Student's t-test, Method 1) for differences in average radial growth increment occurring after 1940 and again after 1965 (table 13). While annual growth of declined trees averaged 17 percent less for the period after 1940, these differences were not statistically significant. Five of six stands yielded significance probabilities of less then 0.05 for the after-1965 chronology, indi-

Figure 28.—Mean radial growth of oak trees, Area 1, Western North Carolina, 1986.

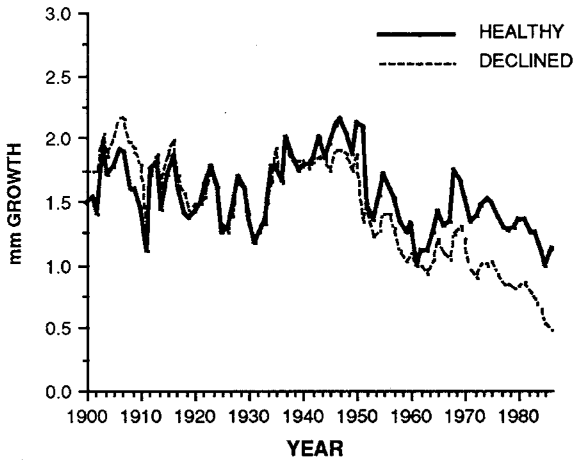


Figure 29.—Mean radial growth of oak trees, Area 2, Western North Carolina, 1986.

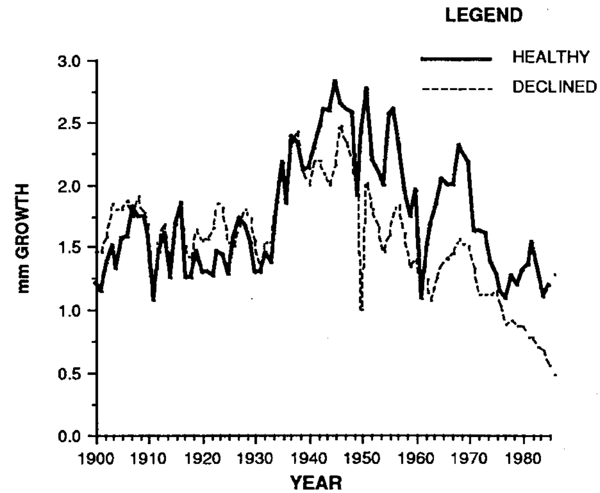


Table 13.—Mean annual increment and percent growth reduction for declined or recently dead oak trees compared to similar, healthy trees by area for two time periods.

Area and Tree Condition	After 1940 Mean annual Increment (mm)	After 1940 Growth Reduction (%)	After 1965 Mean annual Increment (mm)	After 1965 Growth Reduction (%)
Arkansas 1-healthy	1.78a[1]	-----	1.57a	-
Arkansas 1-declined	1.48a	17	1.13b	28
Arkansas 2-healthy	2.13a	-----	1.78a	-
Arkansas 2-declined	1.88a	12	1.38b	22
North Carolina 1-healthy	1.50a	-	1.42a	-
North Carolina 1-declined	1.20a	20	0.97b	32
North Carolina 2-healthy	1.89a	-	1.61b	-
North Carolina 2-declined	1.44a	24	1.11b	31
Tennessee 1-healthy	2.21a	-	2.09a	-
Tennessee 1-declined	1.94a	12	1.64b	22
Tennessee 2-healthy	2.06a	-	1.96a	-
Tennessee 2-declined	1.70a	17	1.37b	30
Overall mean-healthy	1.93	-	1.74	-
Overall mean-declined	1.61	17	1.27	27

[1]Within columns, means followed by a common letter do not differ significantly at the 0.05 level according to Student's t-test. Significance applies to the healthy and declined values within individual sites.

Table 14—Mean annual increment and percent growth reduction for declined or recently dead oak trees compared to similar, healthy trees by state for two time periods.

Area and Condition	After 1940 Mean annual Increment (mm)	After 1940 Growth Reduction (%)	After 1965 Mean annual Increment (mm)	After 1965 Growth Reduction (%)
Arkansas-healthy	1.96a[1]	----------	1.68a	-
Arkansas-declined	1.68b	14	1.26b	25
North Carolina-healthy	1.70a	-	1.52a	-
North Carolina-declined	1.32b	22	1.04b	32
Tennessee-healthy	2.14a	-	2.03a	-
Tennessee-declined	1.82b	15	1.51b	26
Overall mean-healthy	1.93	-	1.74	-
Overall mean-declined	1.61	17	1.27	27

[1]Means not followed by a common letter are significantly different ($p<0.05$) according to Student's t-test and analysis of variance techniques. Significance applies to the healthy and declined values within States.

cating statistically significant growth differences for that period. The remaining stand, (area two in Arkansas) had a significance probability of 0.0641.

Annual growth of declined trees averaged 27 percent less than that of healthy trees after 1965 (table 13). Growth differences occurring before 1940 and before 1965 were tested in a similar manner, but none indicated any statistically significant differences between healthy and declined trees.

The data were analyzed again, grouping the data by states. Growth differences were tested using the same dividing years and techniques as for individual stands, but adding an analysis of variance that first eliminated variation due to area and then tested growth differences between healthy and declined trees. Both methods of testing strongly supported the hypothesis of growth differences at least as far back as 1965 (statistically significant at $p<0.05$; table 14). The analysis of variance provided slightly stronger statistical support to the hypothesis of differences between healthy and declined trees.

Growth loss in declined trees in Arkansas may have been somewhat greater than shown in figures 26 and 27 (assuming the trend of decreasing growth rate continued). Many of the cored decline trees were infected by *H. atropunctatum*. and the last-formed annual increments were impossible to measure or cross-date accurately because of ad-

Table 15—Current (1985) and projected (1995) volume of evaluated timber stands with and without oak decline, Southern Region, 1985.

Scenario and Loss	1985 Volume (bd. ft/ac) Ave.	1985 Volume (bd. ft/ac) Range	1995 Volume (bd. ft/ac) Ave.	1995 Volume (bd. ft/ac) Range
Without oak decline	4638	783-10194	4903	973-10681
With oak decline	3860	295-9836	3985	361-10076
Volume loss	678	0-5099	918	4-5744
Percent loss	15	0-65	19	0-65

Table 16.—Present value (1985) of current (1985) and projected (1995) volumes of evaluated timber stands with and without oak decline, Southern Region, 1985.

Scenario and loss	Present value of 1985 volume (dollars/ac) Ave.	Present value of 1985 volume (dollars/ac) Range	Present value of 1955 volume (dollars/ac) Ave.	Present value of 1955 volume (dollars/ac) Range
Without oak decline	205	27-518	147	43-368
With oak decline	175	10-501	120	8-248
Volume loss	30	0-253	27	0-188
Percent loss	15	0-65	18	0-66

vanced soft-rot in the sapwood. These cores were deleted, resulting in loss of single cores from most decline trees and loss of both cores from one declined tree.

The overall results of these analyses support the contention that the dramatic crown dieback evident during the early 1980's involved trees that had radial growth reductions at least as far back as 1965 and perhaps as early as 1940. These were the years when statistically significant differences in radial growth were detected. The inception of reduced radial increment may have occurred even earlier, requiring several years to accumulate a difference that became statistically significant. Whether this reduction in radial growth was manifested in crown dieback at that time is unknown. These trees may have been predisposed to decline in some way, but the data provide no evidence as to specific causes of the early growth reduction or the more dramatic growth losses in the 1980's and the associated crown decline and/or death. The abundance of *H. atropunctatum* on many declined trees may be the result of decline rather than a cause (Bassett *et al.* 1982, Lewis 1981, Mistretta *et al.* 1981, Tainter *et al.* 1983).

Economic Analysis

Oak decline losses were highly variable in the surveyed stands. Total volume in both live and dead trees in 1985 ranged from 783 to 10,194 board feet per acre, but averaged 4,638 (table 15). Dead trees accounted for an average of 15 percent of this volume; this proportion varied between 0 and 65 percent of total volume.

The present value (PV) of stand volumes in declined stands in 1985 averaged 15 percent less than the estimated average PV of the same stands had decline been absent, or $30 less per acre (table 16). Annualized for the 5-year period of accumulating mortality (1980-1985), this figure was $6.74 per acre per year, but reached as high as $56.83 per acre per year.

The average PV of projected stand volumes without decline dropped from $205 per acre to $147 per acre over the 10-year projection period (table 16). This reflected the very slow growth rate characteristic of stands in the age classes represented in the survey, and the combined effects of discounting at 4 percent without any real increases in stumpage prices. The present value of decline losses also dropped over the period from $30 per acre to $27 per acre for these same reasons, but actually rose when expressed as a percentage of the no-decline PV (15 to 18 percent). Annualized for the entire 15-year decline period (1980–1995), this figure was $2.42 per acre per year with a maximum of $16.91 per acre per year in the most severely damaged stand.

Conclusions

These data are consistent with the decline syndrome complex concept of oak decline, rather than the single-causal factor or cohort senescence concepts. The key predisposing factor in the South may be the interaction of site quality and stand age. Seasonal drought is presently the most widespread short-term inciting factor but spring defoliation is having an increasingly important role as gypsy moths become more widely distributed in the region.

Although oak decline has been a recurring condition with a long history in the East, it is not known if the current situation represents an increase in damage occurrence or severity. However, the severe droughts of the early 1980's have probably contributed substantially to the current episode of oak decline.

Results of this survey should serve as a baseline for monitoring continuing changes in the hardwood resource due to oak decline. Past cutting practices, fire, woods grazing, and the chestnut blight have had enormous impacts on the condition and species composition of southeastern forests. The void remaining on dry sites after chestnut blight losses may have been filled by oaks that are less well adapted to the prevailing conditions, especially under the management regimes currently being applied (i.e., extensive management in sawtimber rotations). Shorter rotations would most likely result in lower decline-associated losses in timber, wildlife, and recreation resources, but might not be compatible with other objectives.

Numbers of newly symptomatic trees (not previously affected) increased by 6.5 percent in the survey year where oak decline was already occurring. This represents an estimate of the rate of decline spread, but is based on observations made at only one point in time. Repeated sampling would provide more reliable estimates of the increases.

Resource Impacts

Oak potentially affects most major forest resources including timber, wildlife, and recreation. Impact is most easily quantified for the timber resource. Our population of declined stands had lost about 15 percent of their value in 1985 and projected loss through 1995 was estimated at 18 percent. Other resource impacts are more difficult to quantify but include a reduction of hard mast production for wildlife, other changes in wildlife habitat due to alterations in overstory density and stand structure (detrimental to some species; a potential benefit to others), increases in hazardous trees along trails or in recreation areas, a temporarily less aesthetically pleasing landscape due to dead and dying trees, and potential long-term changes in forest species composition that may be viewed as detrimental to all resources.

Management Implications

The implications of these data for the management of hardwood forests are several. While not an accurate predictive tool, the simple risk rating system presented here should be useful to managers in identifying stands and sites prone to decline and in assigning regeneration, preventive, or remedial treatments. However, more information is needed to help make better informed management decisions. For instance, data are needed to build and verify risk rating systems that account for defoliation episodes by insects such as the gypsy moth. Because they tend to feed more intensely on certain tree species (Herrick and Gansner 1987), gypsy moth may cause decline patterns varying from those reported here. Further, the influence of species, site, age and present decline condition on decline intensification and mortality requires investigation.

The species composition of declining stands is likely to shift away from the generally faster-growing red oaks to the less-affected and slower growing white oaks. This change may not be a problem if a larger white oak component is desired and adequate stocking of white oaks is present. Where white oaks are less abundant, other species that are less desirable will probably increase, contributing to a reduction in timber and wildlife value.

Severe decline and mortality makes the decision to carry or regenerate such stands a difficult one. If regeneration is delayed too long, affected stands may not have the capacity to develop the advanced oak reproduction necessary for successful regeneration and undesirable understory species may outcompete the oak reproduction that does exist for newly available space. This may be the result even with immediate harvest if decline is well advanced. Under this circumstance, the land manager must decide whether or not to control the composition of the future stand, perhaps supplementing natural reproduction of desirable hardwoods by planting pine. On some sites, pine management may be the most appropriate choice.

In stands where decline is present but not severe, some form of remedial treatment might be considered. Unfortunately, there are many instances where partial cuttings appear to have contributed to more severe decline and mortality. These observations may be explained by the creation of additional food sources for *Armillaria* spp. (stump root systems and root injuries on residual trees), and changes in the soil moisture regime due to compaction and heating of the forest floor. There may be situations where partial cuttings in affected stands are appropriate, but research is needed to identify these situations. Partial cutting in young stands before decline begins may be useful in preventing future losses by maintaining or increasing stand vigor and controlling species composition. Such cutting may also begin the process of developing uneven-aged stands from even-aged ones resulting in conditions where decline impacts may be less severe. However, all sites and stands may not be appropriate for uneven-aged management. Where even-aged management is practiced, the association of decline with older, slow-growing stands may indicate the need for fundamental changes in the prevailing rotation age of hardwoods (100-200 years) in the survey area. On some sites, hardwoods may be successfully managed without decline losses in shorter rotations (60-80 years).

Decline will probably be a recurring problem in southern upland hardwood forests. Future droughts are unpredictable but a virtual certainty, and gypsy moth populations are increasing in the northern parts of the region and spreading southward. More poorly understood are the effects of regional air pollutants such as ozone and acidic precipitation and possible climatic changes resulting from global warming.

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Appendix

Economic Analysis—Methods and Assumptions

I. General

A. Only dominant and codominant sawtimber tree volumes were considered. All are expressed on a per acre basis.

B. Log volumes are International 1/4-inch rule (Forbes 1955).

C. Sawtimber prices (table 17) are state averages for the period 1980–1985 as reported in *Timber Mart South* except in Illinois, Missouri and West Virginia (prices for these states were obtained from National Forest timber sale data). *Timber Mart South* prices were converted from Doyle scale to International 1/4 inch using a factor based on the log volumes of an average 14 inch d.b.h. tree with 1.3 logs ($Doyle/1.65= $Int. 1/4). A price differential was established between good quality trees (form 1) and fair quality trees (form 2). Form 1 volume was valued at the state average price for the species group (oak sawtimber or mixed hardwood). Form 2 volume was valued at the minimum price quoted for the species group.

D. The analysis was made with a 4 percent discount rate and a 1985 stumpage value that was not adjusted for inflation in future years. All future values were discounted back to 1985 and are expressed on a per acre basis.

E. The analysis covered a period of 15 years including the 5 years prior to the survey and the 10 subsequent years (1980–1995). The analysis consisted of 4 components:

1. Current volume and value in 1985 with oak decline
2. Current volume and value in 1985 without oak decline
3. Projected volume and present value in 1995 with oak decline
4. Projected volume and present value in 1995 without oak decline

II. Current Volumes and Values with and without Oak Decline

A. 1985 stumpage prices were applied to the volume of standing live timber to obtain a current value for each stand with oak decline if harvested in 1985.

Table 17.—Prices for sawtimber by species group and form class, by state, used in economic analyses of oak decline and mortality, 1985 [1].

	Oak		Other Species	
State	Form 1	Form2	Form 1	Form 2
	----------	$/mbf	----------	----------
Arkansas	65	49	56	39
North Carolina	62	47	49	34
South Carolina	144	108	144	101
Georgia	53	40	45	32
Virginia	62	47	38	27
Tennessee	100	75	68	48
Illinois	88	66	37	26
Missouri	59	44	51	36
Alabama	152	114	132	92

[1]*Prices are from* **Timber Mart** *South (June 1985), except for Illinois and Missouri, where prices were derived from USDA Forest Service timber sale data.*

B. The same procedure was used for live and standing dead volume to obtain a current value without oak decline.

III. Projected Volumes and Values with Oak Decline

A. Existing dead volume in 1985 was assumed to be the result of oak decline that had accumulated in equal amounts over the previous 5 years. Therefore, annual mortality (for 1980–1985) was calculated by dividing the current dead volume by 5.

B. Stumpage prices for each year between 1980–1985 were inflated to 1985 prices using known inflation rates and multiplied by the volume calculated for each year to give a 1985 present value. Total mortality loss over the period was simply the sum of the calculated present values for each of the 5 years.

C. Decline-associated mortality was assumed to occur for an additional 3 years following the survey year. No further mortality was assumed. Average annual percent mortality (for each year of the period 1986–1988) was calculated by dividing the annual mortality volume (from A above) by the total stand volume (for the appropriate year). Projected mortality for each year (1986–1988) was subtracted from the volume in the advanced decline condition class until it was exhausted or until the 3 year period ended.

D. Trees in the advanced decline class were assumed to grow at a growth rate 27 percent less than trees in the healthy and slight classes (described in E below). This differential was determined from data obtained in the radial growth analysis portion of the survey. Volume increases in the advance decline class come from growth of trees already present in the class; no new trees are added. Any volume remaining in this class after 3 years of mortality was grown at the reduced rate for the remainder of the analysis period (1989–1995).

E. Volumes of trees in the healthy and slight classes were assumed to increase at a rate obtained from volume calculations found in USDA Forest Service, *The South's Fourth Forest–Alternatives for the Future* (Review Draft).

F. No positive growth response was assumed for remaining trees due to reduced stocking resulting from mortality.

G. Appropriate stumpage prices were applied to volumes in 1995 and discounted back to 1985. Present values were summed to obtain a present value for the stand with oak decline.

IV. Projected Volumes and Values without Oak Decline

A. Trees that were dead in 1985 were assumed to have never died. But since they were probably in advanced decline prior to death, the volume was discounted by the reduced growth rate for the appropriate number of years (from III. A. above) back to 1980. Then the normal growth rate was applied for the period 1980–1995.

B. Volume of the healthy and slight classes was increased by the normal growth rate for the period 1985–1995.

C. Appropriate stumpage prices were assigned to the above volumes and discounted to 1985. Present values were summed to obtain a present value for the stand without oak decline.

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The Southern Region

- Represents the National Forest System and the State and Private Forestry branches of the Forest Service in Alabama, Arkansas, Florida, Georgia, Kentucky, Louisiana, Mississippi, North Carolina, Oklahoma, Puerto Rico, South Carolina, Tennessee, Texas, Virginia, and U.S. Virgin Islands.