# Oak Decline Alters Habitat in Southern Upland Forests

**Steven W. Oak,** *U.S. Department of Agriculture Forest Service, Southern Region, Forest Pest Management, P. O. Box 2680, Asheville, NC 28802*

**Dale A. Starkey,** *U.S. Department of Agriculture Forest Service, Southern Region, Forest Pest Management, 2500 Shreveport Highway, Pineville, LA 71360*

**Joseph M. Dabney,** *U.S. Department of Agriculture Forest Service, Cherokee National Forest, P.O. Box 2010, Cleveland, TN 37311*

---

*Abstract:* Oak decline is a complex disease involving interactions between initiating environmental or biological stresses and subsequent attack by normally secondary pests. It causes crown dieback, reduced radial growth and tree mortality, which in turn, influences wildlife habitat. In upland hardwood stands, oaks (*Quercus* spp.) are affected most while other species infrequently show crown symptoms or mortality. Recent surveys of declining stands in the southeastern United States show that 80% of the dominant and codominant trees are affected. Species in the red oak group are damaged more than those in the white oak group, with black (*Q. velutina*) and scarlet (*Q. coccinea*) oaks most prone to mortality. The annual increase in newly symptomatic trees is estimated at 6.5%. Potential wildlife habitat impacts include reduced mast yield and quality, reduced oak regeneration capacity, and altered species composition in subsequent stands. Estimates of current and 5-year projected mast yield in an affected stand show a 41% current reduction and a 58% projected reduction when compared to potential mast yield without decline. The consistent association of damage with specific stand and site conditions indicate that risk rating systems can be developed to guide management decisions. Habitat managers should consider oak decline in inventory procedures and resource management planning.

Proc. Annu. Conf. Southeast. Assoc. Fish and Wildl. Agencies 42:491–501

---

Oaks (*Quercus spp.*) are the most important group of upland hardwood tree species in the southern United States in terms of wide distribution, high timber value, and contribution to wildlife habitat. Nearly 173 million ha of southern commercial forest land (30% of the total) are upland hardwoods in which oak species predominate (U.S. Dep. Agric. For. Ser. 1987). Hard mast produced by oaks is the most important habitat component for many wildlife species. Decline is the most widespread of disease problems in oaks, causing dieback and mortality. Until recently, distribution and losses were unknown.

Periodic episodes of oak decline and mortality have been reported from virtually the entire range of eastern oaks since the early 1900s (Long 1914, Balch 1927). In the southern United States, documented cases have been reported in Arkansas (Rhodes and Tainter 1980), Mississippi and Florida (Lewis 1981), South Carolina (Tainter et al. 1983), Tennessee (McGee 1984), North Carolina (Tainter et al. 1984), Virginia (Rauschenberger and Ciesla 1966, Skelly 1974), and West Virginia (Gillespie 1956).

Oak decline is best described as a disease complex resulting from the interaction of predisposing stress and disease and insect pests of secondary action, so called because of their ability to successfully attack trees weakened by other agents. Disease progression is generally slow, occurring over several years.

The inciting factor in the decline complex is environmental or biological stress, such as prolonged drought or spring defoliation by frost or leaf-feeding insects. Starch stored in the roots is converted to sugars to support metabolism during stress periods. Under these conditions, *Armillaria mellea,* which is the causal agent of armillaria root rot and is ordinarily saprophytic, attacks and kills portions of the tree's root system. This may exacerbate drought stress. Twigs and limbs die back to accommodate a reduced root system. The two-lined chestnut borer, *Agrilus bilineatus,* usually follows. Preferentially attacking weakened trees, the adult oviposits in bark crevices. The larvae bore in the inner bark, creating meandering galleries that eventually girdle and kill the tree. Armillaria root rot may spread to adjacent oaks subject to the same inciting stress factor, such as droughty site conditions, resulting in groups of dead and declining trees. Because of differences in the dynamics of internal water and stored food budgets (Kramer and Kozlowski 1960), physiologically mature trees continue to decline, even if good growing conditions return, while other physiologically less mature trees recover and rebuild their crowns.

The most common symptom of decline-affected trees is a progressive dying back from the ends of the branches, generally beginning at the top and outside of the crown and proceeding downward and inward. Other accompanying symptoms may include chlorotic, dwarfed, or sparse foliage; development of epicormic sprouts on the main bole and larger branches; premature autumn coloration; marginal leaf scorch; foliage wilt; and foliage death. Reduced shoot and diameter growth occurs in severely affected trees. While some dead trees show little prior evidence of decline, most have declined for 2 to 5 years or more before succumbing. Patterns of decline and mortality may be easy or difficult to discern in forest stands, depending on the inciting stress factors, site conditions, and species affected.

In the early 1980s, it appeared that the southern United States sustained a substantial increase in oak mortality and decline. In response, extensive ground and aerial surveys were conducted of southeastern upland oak forests to determine distribution, severity, and impact. Inquiries of Federal land managers and state foresters were made in late 1984 concerning the current status of oak decline in their areas of jurisdiction. Oak decline was reported from Virginia to Arkansas, with concentrations in the Appalachian and Ozark Mountains (Starkey and Brown 1986). Responses to these inquiries provided the 1985 survey population of damaged stands. Oak decline is not limited to southern upland hardwood forests where these surveys were conducted. Bottomland oak species have been damaged and killed in ornamental and forest settings in Piedmont and Coastal Plain areas across the region (Lewis 1981, Tainter et al. 1983). We confined our surveys to areas where oaks were predominant and on easily accessed public land. This paper presents oak decline biology, summarizes stand and site conditions consistently associated with a high incidence of damage in upland forests, and discusses the implications for wildlife habitat managers.

## Methods

Thirty-eight sites were chosen for survey from the population of damaged stands. Criteria for selection included the absence of recent site disturbances (e.g., fire, logging, road construction), predominance of oak, and an area uniform enough to be considered a stand-sized management unit (35–100 ha). We attempted to achieve a dispersion of stands across the region where decline was reported. Surveyed stand location and number were: Virginia (11), North Carolina (4), South Carolina (3), Georgia (2), Tennessee (5), Alabama (2), Illinois (2), Missouri (2), and Arkansas (7).

Survey methods are detailed in Starkey and Brown (1986). Briefly, each stand was sampled with 12 basal area factor 10 prism plots. Stand data included elevation, slope, aspect, topographic position, soil depth and texture to 60 cm, timber size class, and site index. Trees $\geq$12.7 cm were tallied and classified according to crown position, crown decline condition class (estimated percent crown dieback), and decline duration. The percentages of dominant and codominant trees in the various crown decline condition classes were compared for individual species and species groups, decline duration, and various site factors using analysis of variance, Duncan's Multiple Range Test, and occasionally chi-square analysis. The sampling method used (probability of tree selection proportional to size) resulted in differences between the number of trees observed and the actual trees per hectare they represent. Therefore, data were transformed to reflect trees per hectare rather than basal area per hectare. Crown decline condition classes were combined for some analyses. Suppressed and intermediate crown classes were omitted from analyses because dieback and mortality caused by decline could not be separated from that caused by overstory competition in these crown classes.

The present and future effects of oak decline on mast yield also were illustrated by interpreting decline conditions in a surveyed stand. We first estimated the maximum potential mast yield for the stand by assuming all oaks were healthy and applying the values found in the U.S. Department of Agriculture Forest Service Wildlife Habitat Management Handbook (1980: Table II, p. 203.12—3). An estimate of current mast yield was derived by reducing these values proportionally to the level of crown decline for each diameter class within a species. Future yields are difficult to predict because the dynamics of decline intensification and spread are not well known. However, inferences can be made. These inferences were based on the distribution of trees in the entire survey among the various crown decline condition classes for each species. Species with a relatively high proportion of trees in the dead and advanced decline classes were presumed to decline at a more rapid rate than others. The decline condition of oaks in the subject stand was presumed to worsen over the projection period (5 years) according to our assumptions and an estimate of future mast yield derived by reducing the maximum potential yield in the same proportions.

## Results and Discussion

Evaluated stands were mainly sawtimber-size with ages ranging from 50 to 110 years, with most (31 of 38 stands) in the 60- to 80-year-old age class. A few poletimber-sized stands of advanced age were encountered.

Because our sampling did not include a wide range of ages, no firm conclusion could be drawn regarding age and decline. However, we limited our sampling to known areas of decline and therefore assumed that damage was probably more common and severe in these older age and larger size classes. We received no reports of young poletimber-sized stands being affected.

A total of 3,623 trees were tallied in the 456 plots in 38 stands affected by oak decline. Of these, 2,810 were dominant or codominant and consisted of 86% oak, 6% hickory (*Carya* spp.), and 8% other species. The predominant species in the other category were maple (*Acer* spp.), yellow-poplar (*Liriodendron tulipifera*), black locust (*Robinia pseudoacacia*), and blackgum (*Nyssa sylvatica*).

Scarlet oak accounted for >20% of all trees on decline sites, followed by black oak, white oak (*Q. alba*), and chestnut oak (*Q. prinus*). Hickories accounted for 7% of the trees (Table 1). The small difference in numbers of black and white oaks actually tallied was somewhat magnified by converting to trees/ha because black oaks were larger in diameter.

Eighty percent of all trees in oak decline areas showed decline or mortality. About one-fifth of these were moderately or severely declined (>⅓ crown dieback) and 17% of the trees were killed. We combined moderate and severely declined trees into an advanced decline condition class for subsequent analyses because of the relative infrequency of severely declined trees and because tree growth and vigor were known to be significantly reduced when decline reached these levels. Healthy and slight crown decline condition classes also were combined for some analyses.

Species in the red oak group were much more likely to be damaged by decline than those in the white oak group. The percentage of healthy red oaks was one-third that of white oaks, while the percentage of dead red oaks was 3 times that of white oaks. These differences were highly significant ($P = 0.01$). Slight and advanced decline differed only slightly between the oak groups.

Not all species were affected equally (Table 2). Black and scarlet oaks sus-

**Table 1.** Distribution of tallied dominant and codominant trees by species in oak decline evaluations, southern region, 1985.

| Species | Trees tallied *N* | Trees tallied % | Calculated Trees/ha | Calculated % |
|---|---|---|---|---|
| Scarlet oak (*Quercus coccinea*) | 654 | 23 | 6.31 | 21 |
| Black oak (*Q. velutina*) | 432 | 15 | 3.84 | 12 |
| White oak (*Q. alba*) | 431 | 15 | 5.10 | 17 |
| Chestnut oak (*Q. prinus*) | 352 | 13 | 3.56 | 12 |
| Northern red oak (*Q. rubra*) | 261 | 9 | 2.75 | 9 |
| Hickory (*Carya* spp.) | 157 | 6 | 2.23 | 7 |
| Red oak[a] (*Quercus* spp.) | 88 | 3 | 1.42 | 5 |
| Post oak (*Q. stellata*) | 56 | 2 | .65 | 2 |
| Southern red oak (*Q. falcata*) | 49 | 2 | .65 | 2 |
| Blackjack oak (*Q. marilandica*) | 22 | 1 | .32 | 1 |
| Oak[a] (*Quercus* spp.) | 11 | 3 | .16 | 1 |
| Other | 297 | 8 | 3.52 | 11 |
| Total | 2,810 | 100 | 30.51 | 100 |

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

tained the highest mortality levels (34% and 23%, respectively), followed by white oak (12%), northern red oak (10%), and chestnut oak (5%). Among non-oak species, hickories were most severely affected (12% mortality). Advanced decline was worst in scarlet, northern red, and chestnut oaks.

The degree of deterioration of declined crowns (retention of progressively coarser twig and branch material) provided an estimate of the duration of decline. Symptoms indicated that decline had been present in most stands ≥4 years. More than half of all trees had both current and previous decline symptoms (Table 3). One estimate of the rate of annual increase in decline was the percentage of trees with current decline and no previous decline. In the survey year (1985), 6.5% of the trees were in this class. Though this estimate varied among species groups

**Table 2.** Percent of dominant and codominant trees in various crown decline conditions classes by species in oak decline evaluations, southern region, 1985.[a]

| Crown decline condition | Species[b] BLO | SCO | NRO | WHO | CHO | H | Other | All species |
|---|---|---|---|---|---|---|---|---|
| Healthy | 9.5 | 8.0 | 8.5 | 31.4 | 13.5 | 23.4 | 63.5 | 20.4 |
| Slight | 40.5 | 39.4 | 52.5 | 38.6 | 60.6 | 47.6 | 22.9 | 42.8 |
| Advanced | 16.5A[c] | 29.7B | 28.6B | 18.5A | 21.3AB | 17.0A | 10.0 | 20.2 |
| Dead | 33.5A | 22.9A | 10.4B | 11.5B | 4.6B | 12.0B | 3.6 | 16.6 |
| Total | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |

[a]Species with >100 observations (>5% of total trees).
[b]BLO = *Q. velutina*, SCO = *Q. coccinea*, NRO = *Q. rubra*, WHO = *Q. alba*, CHO = *Q. prinus*, *H* = *Carya* spp.
[c]Values followed by different letters within the same row are significantly different. Values for the advanced decline class are significant at $P = 0.05$ and for the dead class at $P = 0.01$. Where no letters appear, $F$ statistics were not significant or no analysis was performed.

**Table 3.** Percent of dominant and codominant trees by decline duration and species group in oak decline evaluations, southern region, 1985.

| Decline duration | All red oak | All white oak | Other | All species |
|---|---|---|---|---|
| Healthy | 7.6A[a] | 25.2B | 48.2C | 20.5 |
| Previous only | 25.2A | 10.4B | 8.3B | 17.7 |
| Current only | 8.2A | 5.6A | 3.6A | 6.5 |
| Previous plus current | 59.0A | 58.8A | 39.9B | 55.3 |
| Total | 100 | 100 | 100 | 100 |

[a]Values followed by different letters within the same row are significantly different at $P = 0.0.1$

(white oak = 5.6%, red oak = 8.2%), the differences were not statistically signifiant.

Associations were explored between damage and topographic position, slope class, aspect, soil texture, soil depth, and site index (Table 4). It should be noted, however, that the strength of associations varied when data were partitioned according to physiographic subregion.

Decline and mortality were present on all topographic position categories (ridge, slope, bench, terrace, and bottom), but there were adequate numbers of observations on only slope and ridge positions. Statistically significant differences occurred for mortality with ridges exceeding slopes (20% vs. 16%; $P = 0.05$).

The effects of slope class were examined only for plots with a slope topographic position (65% of all plots). Overall, the percentage of trees in healthy plus slight crown decline condition classes increased with increasing slope, while there was a concomitant decrease in mortality. Significant differences existed only for the percent mortality ($P = 0.05$).

Associations of damage with aspect also were examined only for plots with a slope topographic position. While no statistically significant differences existed, overall damage (advanced decline plus dead) was greatest in west-to-north aspects, least on northeast and east aspects, and intermediate in southeast-to-southwest aspects.

Two broad soil texture categories were established because of the small number of observations in many individual classes. Stony or gravelly soils had greater mortality than other soil textures (26 vs. 12%; $P = 0.01$). The converse was true for advanced decline (9% for stony or gravelly soils, 25% for other textures). Healthy plus slight crown decline condition classes were approximately equal.

Soil depth classes also were combined, and results were similar to those for soil texture. Shallow soils (<45 cm deep) had higher mortality levels than deeper soils (25% vs. 8%). The converse was true for advanced decline (27% vs. 14%). Both of these relationships were highly significant ($P = 0.01$).

The factors discussed previously influence site productivity, which was measured as site index. Most individual factors associated with low site indices (i.e., shallow, stony soils on ridges) had the highest levels of mortality. This also was the

**Table 4.** Percent of dominant and codominant trees in various crown decline condition classes for various site factors in oak decline evaluations, southern region, 1985.

| | Healthy and slight | Advanced | Dead | Advanced and dead |
|---|---|---|---|---|
| Topographic position | | | | |
| Ridge | 63A[a] | 17A | 20A | |
| Slope | 64A | 20A | 16B | |
| Slope | | | | |
| 0–20% | 63A | 16A | 21A | |
| 21–40% | 65A | 23A | 12B | |
| 41 + % | 76A | 19A | 5C | |
| Aspect | | | | |
| N | | | | 42A |
| NE | | | | 28A |
| E | | | | 29A |
| SE | | | | 34A |
| S | | | | 33A |
| SW | | | | 36A |
| W | | | | 45A |
| NW | | | | 44A |
| Soil texture | | | | |
| Stony or gravelly | 65A | 9A | 26A | |
| Other textures | 63A | 25B | 12B | |
| Soil depth | | | | |
| ≤45 cm | 61A | 14A | 25A | |
| >45 cm | 65A | 27B | 8B | |
| Site index | | | | |
| <20 m | 65A | 13A | 22A | |
| 20–22.7 m | 63A | 21AB | 16AB | |
| >22.7 m | 63A | 27A | 10B | |

[a]Values followed by different letters are significantly different within columns for individual site factors only. Topographic position and site index values are significant at $P = 0.05$; all other differences significant at $P = 0.0.1$.

case when site index was analyzed. Twenty-two percent of the trees on low site indices (<20 m at age 50) were dead, while only 10% were dead on the highest site indices (>22.7 m at age 50). Advanced decline was higher on productive sites (27%) than on the least productive (13%). Both of these relationships were highly significant ($P = 0.01$).

These results suggested that severe decline may occur on all types of sites, but that decline more commonly resulted in high mortality levels on sites of lower productivity. However, more productive sites exhibited high mortality if stand conditions indicated a high mortality risk (e.g., older stands with a predominance of black or scarlet oaks) and if environmental stress persisted for longer periods.

## Management Implications

Wildlife habitat changes resulting from oak decline vary with the severity of the decline, amount of mortality, species composition and age strucuture of the declined stand, and the duration of decline before stress is eased and recovery begins.

Some changes may be viewed as positive, such as: the creation of small openings, reduced canopy density, short-term stimulation of understory species, increased diversity of cover types, and more denning and cavity-nesting sites. Seed sources or advanced reproduction of pines (*Pinus* spp.) would quickly fill voids. This shift in species composition may be significant enough to result in a change of forest type from predominantly oak to mixed pine-oak type or even pine type. This may be desirable when pine is an insignificant component of a large management unit.

Other changes may be interpreted as negative. Once decline is initiated, susceptible species such as black and scarlet oaks are prone to more severe decline and death. The result is reduced diversity of oak species, which is important for ensuring a continual supply of mast in years when production may be low for some species but not others. Living, but declining, oaks produce less mast because of a reduced crown, and the mast that is produced may be of lower quality due to reduced tree vigor. Gysel (1957) showed that while total numbers of black oak acorns on medium- and poor-quality sites were approximately equal, only a small portion of the acorns on the poor-quality site were sound. Further, black oak acorns on poor sites had lower percentage composition of many constituents (including protein and phosphorus) than those on medium-quality sites. While the decline status of trees on various site qualities were not described, we can infer that low site quality black oak were not vigorous by virtue of their small crowns, poor stem form, and decay.

Besides affecting food supply, the capacity of stands to be regenerated to oak species is altered once decline begins. Fewer acorns leads to fewer opportunities for seedling reproduction, and the stump sprouting capability of declined trees is compromised because of impaired root systems. Changes in species composition and forest type cited under potentially beneficial habitat effects are undesirable in other circumstances. Replacement of oak species by pines and other non-mast producing hardwoods in areas where mast is already in short supply can be detrimental and not easily reversed, whether this replacement occurs in an existing stand or in the subsequent regenerated stand. This is especially true in southern Piedmont and Coastal Plain forests where oaks are less plentiful and frequently occur in mixtures with pines. Red oaks, such as willow (*Q. phellos*), water (*Q. nigra*), laurel (*Q. laurifolia*), and southern red (*Q. falcata*), are vulnerable to decline (Lewis 1981, Tainter et al. 1983) and a vital habitat component in such circumstances.

These results may be used to guide resource management decision-making for asymptomatic stands on decline-prone sites, as well as stands already exhibiting symptoms. While further analyses of this and other data sets are required before risk-rating systems are developed and validated, stands may be evaluated along a decline damage risk continuum by combining these results with general knowledge of decline biology (Fig. 1). Stands with higher decline risk but without current symptoms may be given higher priority for thinning to forestall competitive stress. Changes in rotation age and future desired forest type may be indicated in some stands, depending on risk and current symptoms.

The present and future effects of decline on mast yield may be estimated as well. These were determined from crown decline condition data for the various spe-

| LOW DAMAGE POTENTIAL (MORTALITY RISK LOW) | | HIGH DAMAGE POTENTIAL (MORTALITY RISK HIGH) |
|---|---|---|
| ADEQUATE GROWING SEASON MOISTURE | < ---- > | ACUTE SUMMER DROUGHT (2–3 YRS. PRIOR) |
| NO RECENT SPRING DEFOLIATION | < ---- > | RECENT SPRING DEFOLIATION |
| PHYSIOLOGICALLY IMMATURE | < ---- > | PHYSIOLOGICALLY MATURE |
| COMPOSITION PREDOMINANTLY WHITE OAK GROUP | < ---- > | COMPOSITION PREDOMINANTLY RED OAK GROUP |
| HIGH SITE INDEX (>20M) | < ---- > | LOW SITE INDEX (<20M) |
| MESIC SITE CONDITIONS<br>Loamy soils, few rocks<br>Deep (>45cm) soils<br>Coves, terraces, bottoms, lower slopes<br>North and east aspects | < ---- > | XERIC SITE CONDITIONS<br>Rocky soils<br>Shallow (<45cm) soils<br>Ridges or upper slopes<br>South and west aspects |

**Figure 1.** Continuum of oak decline damage potential.

cies (Table 2). These data suggest that decline intensifies more rapidly over time for black and scarlet oaks than for all other species. Over half of the black and scarlet oaks were dead or had advanced decline. In contrast, only about one-fourth of the white and chestnut oaks were in that condition. Mast yield losses are inferred from these data (Table 5). For example, black and scarlet oaks with presently slight decline can be expected to decline more rapidly (and show greater projected acorn yield losses) than other species. On the other hand, chestnut oaks had the lowest mortality rate of all oak species (Table 2). Therefore, chestnut oaks with presently

**Table 5.** Present (1985) and 5-year projected (1990) decline condition with estimated acorn yield reduction (%) by oak species.

| Crown decline class | Species[a] | | | | |
|---|---|---|---|---|---|
| | NRO | BLO | SCO | WHO | CHO |
| Healthy | | | | | |
| Present | 0 | 0 | 0 | 0 | 0 |
| Projected | 0 | 0 | 0 | 0 | 0 |
| < ⅓ Dieback | | | | | |
| Present | 25 | 25 | 25 | 25 | 25 |
| Projected | 33 | 66 | 66 | 33 | 33 |
| ⅓–⅔ Dieback | | | | | |
| Present | 50 | 50 | 50 | 50 | 50 |
| Projected | 66 | 100 | 75 | 66 | 66 |
| > ⅔ Dieback | | | | | |
| Present | 66 | 66 | 66 | 66 | 66 |
| Projected | 100 | 100 | 100 | 100 | 75 |
| Dead | | | | | |
| Present | 100 | 100 | 100 | 100 | 100 |
| Projected | 100 | 100 | 100 | 100 | 100 |

[a]NRO = *Quercus rubra*, BLO = *Q. velutina*, SCO = *Q. coccinea*, WHO = *Q. alba*, CHO = *Q. prinus*.

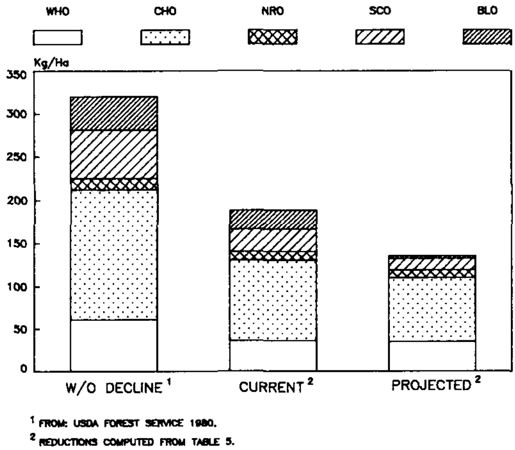


**Figure 2.** Estimated mast yield with and without oak decline for stand 712–11, Deerfield Ranger District, George Washington National Forest, Virginia; 1985 and projected to 1990.

severe decline (>⅔ crown dieback) are presumed to worsen only slightly but remain alive (acorn yield reduction from 66% currently to 75% projected), while all other species with presently severe decline are presumed to die. The decline condition of all healthy and dead trees is not presumed to change, regardless of species. A 5-year projection period was used. Though it may take many years of accumulated stress for decline symptoms to be expressed, symptoms will probably reach their maximum expression during that period.

The impact of oak decline on mast yield can be estimated by applying the reductions in Table 5 to standard forest inventory data supplemented by an evaluation of crown condition (Fig. 2). In the subject stand, estimated maximum potential mast yield was reduced by decline and mortality nearly 41% in 1985. Most of this occurred in the red oak group. If decline continues at projected rates among the various species, mast yield will be reduced by 58% of the estimated maximum potential by 1990.

These results indicate a need for research in several areas: decline risk-rating models; rates of decline initiation, intensification, and spread on different sites; the regeneration consequences of declines; and detailed studies of habitat impacts. Habitat managers should consider the positive and negative effects mentioned previously when evaluating habitat capability and writing stand prescriptions or long-term resource management plans.

## Literature Cited

Balch, R. E. 1927. Dying oaks in the southern Appalachians. For. Worker. 3:13.

Gillespie, W. H. 1956. Recent extensive mortality of scarlet oak in West Virginia. Plant Disease Rep. 40:1121–1123.

Gysel, L. W. 1957. Acorn production on good, medium, and poor oak sites in southern Michigan. J. For. 55:570–574.

Kramer, P. J. and T. T. Kozlowski. 1960. Physiology of trees. McGraw-Hill Book Co., New York. 642pp.

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

Long, W. H. 1914. The death of chestnuts and oaks due to *Armillaria mellea.* U.S. Dep. Agric., Bur. Plant Industries Bul. 89, Washington, D.C. 9pp.

McGee, C. E. 1984. Heavy mortality and succession in a virgin mixed mesophytic forest. U.S. Dep. Agric., For. Serv., South. For. Exp. Sta. Res. Pap. 50–209, New Orleans, La. 9pp.

Rauschenberger, J. L. and W. M. Ciesla. 1966. Evaluation of oak mortality on the George Washington and Jefferson National Forests, Virginia. U.S. Dep. Agric., For. Serv., South. Reg., State and Private For., Rep. No. 66-1-31, Asheville, N.C. 13pp.

Rhodes, J. D. and F. H. Tainter. 1980. Precipitation extremes and tree growth. Ark. Farm Res. 29:12.

Skelly, J. M. 1974. Growth loss of scarlet oak due to oak decline in Virginia. Plant Disease Rep. 58:396–399.

Starkey, D. A. and H. D. Brown. 1986. Oak decline and mortality in the Southeast: an assessment. Pages 103–114 *in* Anon. (eds.) Proceedings of the 14th Annu. Hardwood Symposium, Hardwood Res. Counc., Cashiers, N.C.

Tainter, F. H., T. M. Williams, and J. B. Cody. 1983. Drought as a cause of oak decline and death on the South Carolina coast. Plant Disease 67:195–197.

———, S. W. Fraedrich, and J. D. Benson. 1984. The effect of climate on growth, decline, and death of northern red oaks in the western North Carolina Nantahala Mountains. Castanea 49:127–137.

USDA Forest Service. 1980. Wildlife Habitat Management Handbook. U.S. Dep. Agric., For. Serv., South. Reg., For. Serv. Handb. 2609.23R, Atlanta, Ga.

———. 1988. The South's fourth forest: alternatives for the future. For. Resource Rep. 24. U.S. Dep. Agric., For. Serv., Washington, D.C. 512pp.