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FOREST HEALTH EVALUATION OF OAK MORTALITY AND DECLINE ON THE OZARK NATIONAL FOREST, 1999

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INTRODUCTION

Widespread and locally severe mortality and decline of red oaks (northern red oak, *Quercus rubra*; black oak, *Q. nigra*; southern red oak, *Q. falcata*) and other species of trees occurred on the Ozark National Forest during the summer of 1999. Red oak borer (*Enaphalodes rufulus*) was an obvious pest associated with the damage and active timber sales were impacted due to the potential for product degrade from the borer tunnels.

The Forest Health Protection Field Office in Pineville, Louisiana was contacted for assistance in evaluating the problem and formulating options to minimize the impacts on forest health and management programs. An initial visit was made to the Pleasant Hill and Boston Mountain Ranger Districts by Alex Mangini on June 30, 1999 to investigate the red oak borer damage which was highly visible and seemed to be associated with unusual amounts of red oak mortality (USDA Forest Service 1999a). A similar visit was made August 31-September 1, 1999 to the Caddo and Mena Ranger Districts of the Ouachita National Forest by Dale Starkey and Forrest Oliveria since these districts were experiencing similar mortality, decline and red oak borer infestations (USDA Forest Service 1999b).

Further discussion with Ozark and Ouachita National Forest personnel at the September 22-24, 1999 Joint Leadership Team Meeting in Ft. Smith, Arkansas resulted in a plan to survey a portion of the affected area to gather information for a forest health evaluation. It was decided to limit the survey to the Pleasant Hill Ranger District north of Clarksville, Arkansas due to the concentration of damage in that area, the interest of the district staff, and the need to get field work done as soon as possible before fall color change and leaf drop.

METHODS

The Pleasant Hill Ranger District conducted an aerial sketch mapping survey September 30, 1999 and delineated areas with severe (estimated mortality/decline >75%; approximately 19,000 acres), moderate (50-75% mortality/decline; approximately 24,000 acres), and slight (<50% mortality/decline; the remainder of district acres) damage. Six sample stands were randomly selected for ground survey within each stratum with the caveats that they were immature or mature sawtimber-sized (since that is where decline and mortality were known to be occurring) and that road access had to be relatively good to minimize field survey time.

Sample stands were surveyed using 5, basal-area-factor (BAF) 10 prism plots arrayed on a transect through the main part of the stand at a minimum spacing of 150-200 feet. Plot-level data recorded at each plot included GPS (global positioning system) location as latitude and longitude (from hand-held units), topographic position, aspect and percent slope (Table 1). For sample trees >4 inches diameter at breast height (d.b.h.) data included species, d.b.h., crown class, crown condition, number of old red oak borer attacks, number of new red oak borer attacks, and number of old 2-lined chestnut borer attacks (Table 1). In addition, 3, 1/100-acre regeneration plots were placed at plot center, 25 feet north, and 25 feet south where advanced reproduction >1 foot tall and < 4 inches d.b.h. was tallied by species.

Table 1.--Plot and tree data collected from sample stands.

VARIABLE	*DESCRIPTION*
Plot-Level Data	
GPS LOCATION	Latitude/longitude as determined by hand-held global positioning unit.
TOPOGRAPHIC POSITION	1=wet bottomland 2=bottomland 3=flatland 4=lower slope 5=midslope bench 6=midslope 7=upper slope 8=ridgetop, narrow 9=ridgetop, broad, flat
ASPECT	Down-slope azimuth recorded to nearest degree
PERCENT SLOPE	Average percent slope measured over 50 feet across plot center
Tree-Level Data	
SPECIES	Appropriate species code
D.B.H.	Diameter at breast height to the nearest 0.1 inches
CROWN CLASS	4=dominant, 3=codominant, 2=intermediate, 1=suppressed
CROWN CONDITION	0=healthy, normal crown 1=slight dieback; <1/3 of crown 2=moderate dieback; 1/3-2/3 of crown 3=severe dieback; >2/3 of crown 4=dead; died this year; fine twigs present, brown leaves may be present, little or no bark sloughing 5=dead; died 2-4 years ago; no fine twigs present, bark sloughing 6=dead; died 4 or more year ago; stubby branches, bark sloughing
ROB-OLD	Red oak borer attacks from previous years; number of old attacks; 0=none, 1=1-10, 2=11-20, 3=21-30, etc.
ROB-NEW	Red oak borer attacks from current year; number of new attacks; 0=none, 1=1-10, 2=11-20, 3=21-30, etc.
2LCB-OLD	Two-lined chestnut borer attacks; number of old attacks; 0=none, 1=1-10, 2=11-20, 3=21-30, etc.

In all stands, plot 1 was marked with a large, red plastic stake and the GPS reading was made using the averaging mode (collecting at least 150 data points for greater accuracy). These plots will be relocated and measured next summer and perhaps for several more years to monitor the long-term progress of decline/mortality.

RESULTS

Eighteen stands were sampled in the 3 damage severity strata (Table 2). This yielded a total of 90 plots and 864 sample trees.

Table 2.--Sample stands (C=compartment number; S=stand number) by damage stratum.

SEVERE	*MODERATE*	*SLIGHT*
C-342, S-46	C-324, S-04	C-309, S-06
C-365, S-09	C-338, S-04	C-323, S-11
C-370, S-03	C-342, S-17	C-388, S-03
C-370, S-15	C-353, S-22	C-400, S-37
C-370, S-37	C-360, S-03	C-403, S-02
C-481, S-13	C-469, S-01	C-405, S-07

Average basal area per acre over all damage strata was 96 square feet; 46 percent was in red oaks (mostly northern red oak), 28 percent in white oaks (a majority were white oak), and the remaining 26 percent in other species (mostly hardwoods, but some pines; Table 3). Within damage strata average basal are per acre varied from 83.7 to 101.3 square feet (Table 3). Red oaks predominated in plots of all damage strata but were increasingly prevalent in the moderate and severe strata; conversely, white oaks were less prevalent in the moderate and severe strata.

Table 3.--Basal area within strata and proportion by species groups.

Stratum	*Square Ft. Per acre*	*% Reds*	*% Whites*	*% Others*	*% All*
Light	101.3	41	37	22	100
Moderate	103.0	42	29	29	100
Severe	83.7	55	17	28	100
Overall	96.0	46	28	26	100

The majority of the basal area per acre was in the dominant and co-dominant crown classes (Figure 1), accounting together for 71 percent. This is as expected since sampling was limited to pole- and sawtimber-sized stands with sample trees selected by a 10 BAF prism.

The d.b.h. of the tree of average basal area was 10.2 square feet overall (Table 4). Among damage strata, the d.b.h. was progressively greater with the damage estimated. This was mostly true within species groups as well. Red oaks were slightly larger than white oaks which were larger than other species.

Overall, most trees were healthy (65 percent of basal are per acre with no or slight dieback; Figure 2). Dead trees accounted for almost 10 percent and declining (moderate or severe dieback) trees over 4 percent of basal area per acre.

Figure 1.--Percent of basal area by crown class.

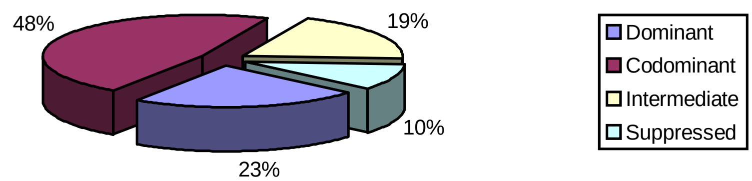
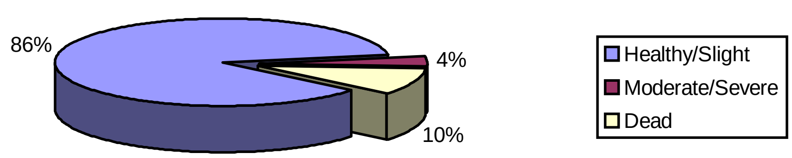


Table 4.--Diameter at breast height of trees of average basal area by stratum and species groups.

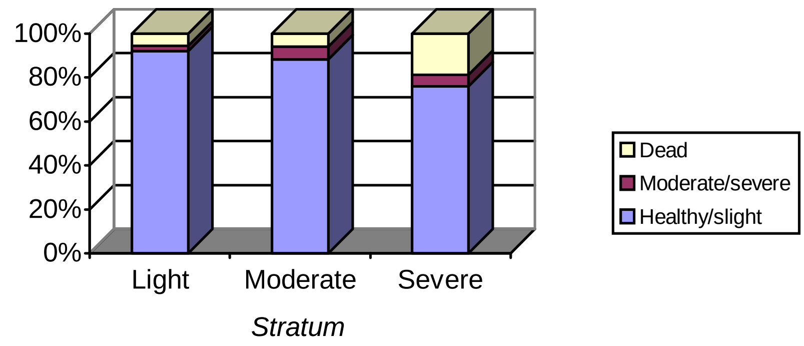
STRATUM	*REDS*	*WHITES*	*OTHERS*	*ALL*
LIGHT	9.8	9.3	7.9	9.1
MODERATE	13.9	9.7	9.0	10.7
SEVERE	13.0	11.5	9.2	11.3
ALL	11.9	9.7	8.7	10.2

Figure 2.--Percent of basal area per acre by crown condition.



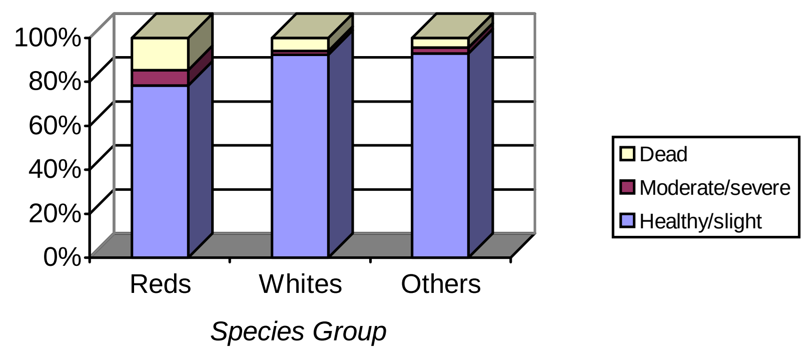
Damage severity on the ground generally followed the damage strata estimated from the air (Figure 3.) Over 92 percent of the basal area in the light stratum was healthy while in the severe stratum only 76 percent was healthy and over 18 percent was dead. The proportion of basal area with moderate to severe dieback was small in all strata.

Figure 3.--Percent of basal area by stratum and crown condition.



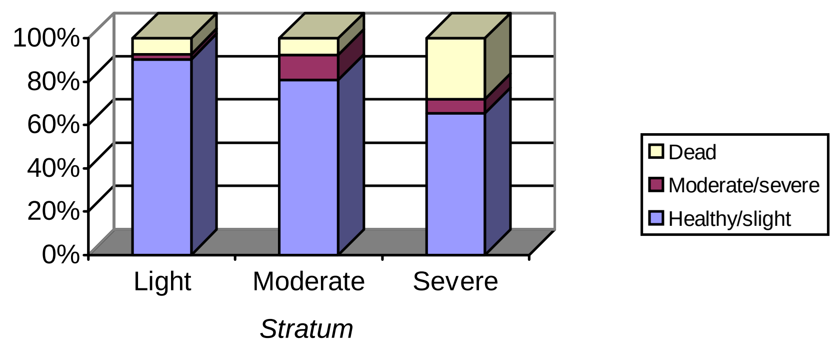
Among species, reds oaks were more affected than white oaks or other tree species (Figure 4). Only 78 percent of red oak basal area was healthy compared to over 92 percent for white oaks and other species. The red oaks sustained the greatest decline (almost 7 percent of basal area with moderate/severe dieback) and mortality (almost 15 percent of basal area).

Figure 4.--Percent of basal area by species group and crown condition.



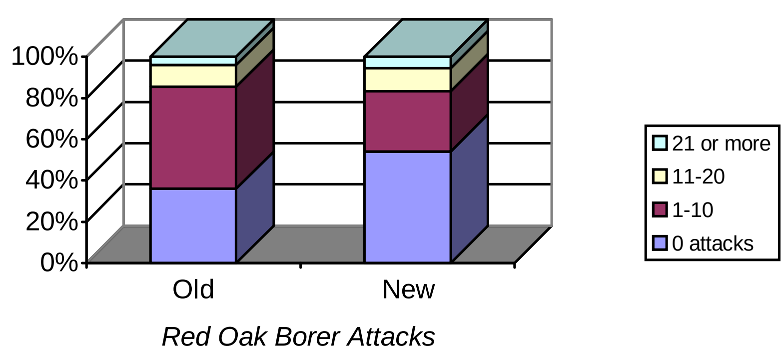
The crown condition of red oaks was generally correlated with damage strata (Figure 5). Mortality was lowest in the light stratum (over 7 percent of basal area) and highest in the severe stratum (28 percent of basal area). The moderate stratum had the greatest proportion of moderate/severe dieback at over 11 percent of basal area.

Figure 5.--Percent of basal area of red oaks by stratum and crown condition.



Only red oaks were attacked by the red oak borer and overall, attacks were not that prevalent. Only 4.1 percent of the basal area had 21 or more old attacks and only 5.6 percent had new attacks (Figure 6). A fairly high proportion had 1-10 old or new attacks (49.2 and 29.2, respectively), but this is a rather small number of attacks for individual trees. When combined with un-attacked trees, over 80 percent of the basal area had 10 or fewer old or new attacks.

Figure 6.--Percent of red oak basal area with old and new red oak borer attacks.



Both old and new borer attacks were more prevalent in the moderate and severe damage strata, so attacks were somewhat correlated with overall damage (Figures 7 and 8). However, the basal area sustaining greater than 21 old or new attacks was still rather low, even in the severe stratum—7.9 percent and 5.8 percent respectively.

Figure 7.--Percent of red oak basal area with old red oak borer attacks by stratum.

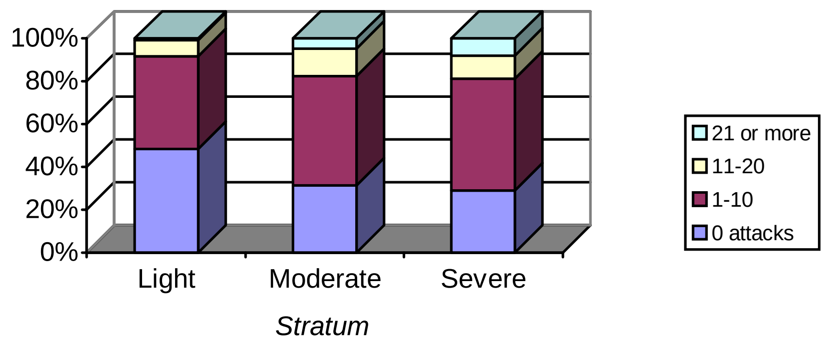
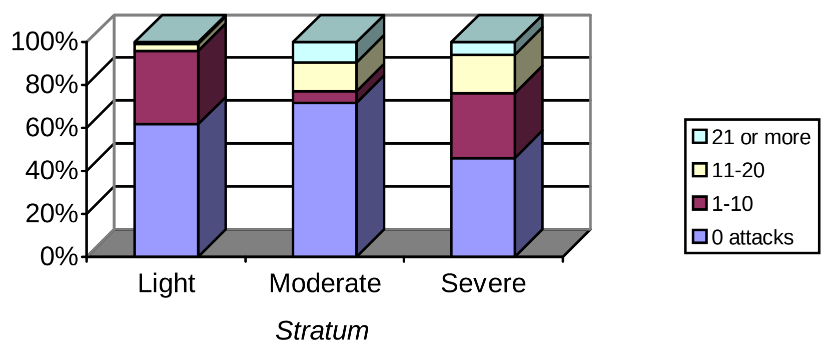


Figure 8.--Percent of red oak basal area with new red oak borer attacks by stratum.



The number of old and new borer attacks was also generally correlated to the crown condition of red oaks (Figures 9 and 10). Trees with moderate/severe dieback or dead trees had more borer attacks (both old and new). It is interesting to note that old borer attacks were most prevalent on dead trees while new borer attacks were most prevalent on trees with moderate/severe dieback. This makes sense in that the borers are attacking declining trees and vacating trees as they die. As mentioned previously, though, the proportion of basal area with high numbers of borer attacks, even declining and dead trees, is not that high, and few trees had more than 20 attacks—not a high number for red oak borers.

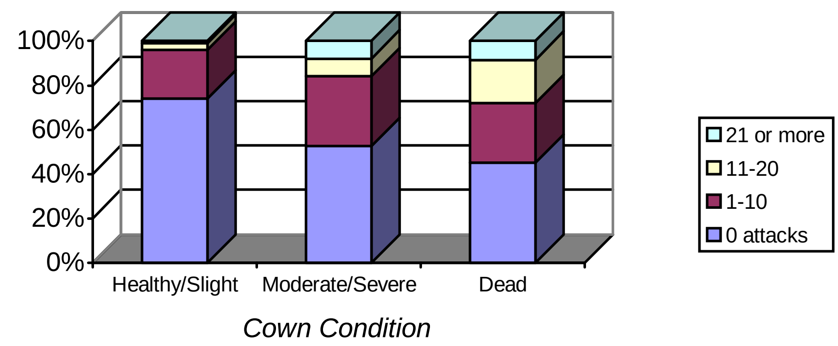


Figure 9.--Percent of red oak basal area with old red oak borer attacks by crown condition.

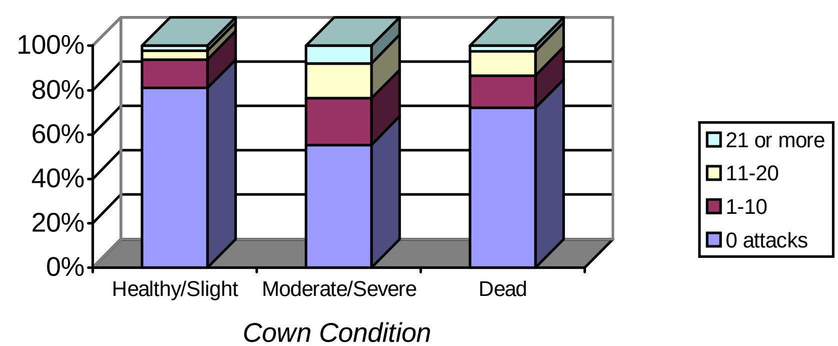


Figure 10.--Percent of red oak basal area with new red oak borer attacks by crown condition.

Statistical test results for the above data have been omitted from this section for the sake of readability. Results for tests suited to the data we collected are presented in Appendix I.

CONCLUSIONS

It is clear that large numbers of red oaks are dying over thousands of acres on the Pleasant Hill and adjacent ranger districts. However, the average percent of basal area affected—for red oaks, the most affected species—is not too high at 15 percent dead and 7 percent with moderate/severe dieback. But, in the severe stratum, red oak basal area is dead at a much higher level of 28 percent with 11 percent with moderate/severe dieback. Thus, mortality and decline seem concentrated in areas where site and stand conditions are conducive to damage. Many areas are probably only lightly affected and will recover with little serious damage.

The red oak borer infestation, while not alarmingly high overall, is loosely correlated with the amount of damage. However, its effect is probably greater on the grade or price of timber than on the actual health and survival of individual trees. Even among dead trees, nearly half had no evidence of old borer attacks and over 70 percent had no new borer attacks. Clearly, borers alone are not responsible for this episode of mortality and decline. We believe they are acting as a secondary, contributing factor—albeit a noticeable one—in the oak decline syndrome.

We believe that oak decline as a concept best explains the current episode. Decline is a syndrome caused by predisposing, initiating and contributing factors which together result in decline and mortality of oaks, particularly red oaks. This phenomenon has been studied and described in the past in many upland hardwood areas of the eastern U.S. (Starkey et al. 1989, Wargo et al. 1983). It is a natural and recurring phenomenon involving a complex set of circumstances, none of which can be addressed alone and mitigate decline to any great extent. In the current episode, we believe the last several years of drought to be the inciting (and primary) factor responsible for the problem. Predisposing factors such as high proportions of red oak in stands, advanced age, ridge and upper slope topographic positions, shallow, rocky soils and other factors have set the stage for decline. Contributing factors are the red oak borer and probably other organisms like *Armillaria* root rot (we only saw one instance of its presence, but it is hard to detect without a targeted effort and known to be common and widespread in oak forests).

RECOMMENDATIONS

Since no direct treatments are available for the remediation of decline, silvicultural and other management activities must be used to mitigate effects over relatively long periods of time. A discussion of silvicultural systems and oak decline is in draft form (Starkey et al., in preparation) and appended to this evaluation (see Appendix II).

Depending on the management objectives for areas or stands, several short- and long-term treatment or management options can be identified. In this discussion, we assume generally that an oak-hickory or mixed oak-hardwood forest type is the desired condition for most stands.

Short-Term Options

Areas with concentrated mortality and decline can be identified from the ground, aerial sketch-map surveys, or from hazard rating efforts (Oak and Croll 1995, Oak et al. 1996) and are candidates for short-term actions. Depending on the amount and distribution of mortality/decline in the stand, any of the following actions, alone or in combination may be useful:

1. *Salvage cutting of dead/declining red oaks, then other oaks, including removal of red oak borer brood trees* -- to capture usable, high-value oak volume, reduce red

oak borer populations (Donley and Acciavatti 1980), and eliminate hazards to the public along well-travelled roads, trails or in recreation areas,

2. *Mid-story removal of less desirable, more shade-tolerant species* -- to encourage development of oak advanced reproduction,
3. *Group selection regeneration* -- to capture oak regeneration potential which may exist in areas of heavy mortality/decline,
4. *Patch or stand clearcut regeneration* – to capture oak regeneration potential which may exist in larger areas of heavy mortality/decline.
5. *Prescribed burning* – to encourage development of oak advanced reproduction and reduce stocking of less desirable, more shade-tolerant species.

Long-Term Options

For areas with less severe mortality/decline, and areas which may be vulnerable to decline, the following options may be useful.

1. *Hazard-rating systems* (Oak and Croll 1995, Oak et al. 1996) may be useful in identifying stands vulnerable to decline, that would be candidates for silvicultural treatments to reduce their vulnerability,
2. *Silvicultural treatments* such as mid-story removal, light thinnings (from below), or even prescribed burning could be used to develop oak advanced reproduction, reduce stocking of less desirable, more shade-tolerant species, reduce the stocking of more susceptible species (like red oaks) in favor of quality stems of other less susceptible, but acceptable species like white oaks, hickory, etc.,
3. *Regenerate vulnerable stands* with acceptable oak advanced reproduction using group selection, patch or stand clearcutting with the aim of reducing the inventory of highly-susceptible stands somewhat (we suspect, but don't have the data, that upland hardwood acres on the Ozark NF are heavily weighted in the older age classes)

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APPENDIX I

STATISTICAL SUMMARY

INTRODUCTION

Survey data were analyzed using SAS (SAS Institute 1988) routines. Data categories, with the exception of diameter at breast height (DBH), are categorical measurements (e.g. 0 = none, 1 = 1 to 10 attacks, and so on). Categorical data seldom are normally distributed and must be transformed to ranked data. Once ranked, the standard statistical tests can be done (Brownie and Boos 1994, Conover and Iman 1981, Stokes et al. 1995). Where appropriate, rank transformations were performed on the survey data.

FREQUENCY ANALYSIS

Percentages displayed in Figures 3 through 10 were calculated using the frequency analysis routine (PROC FREQ) in SAS. This procedure automatically calculates the chi-square test for equal proportions (i.e. that the differences in frequencies are real and not due to chance). All frequencies illustrated in the tables were significant at P = 0.001 or better (i.e. there is only one chance in 1000 that the results are due to chance only).

CORRELATION ANALYSIS

Correlations were calculated using the correlation analysis procedure (PROC CORR) of SAS. For the red oak group, there were significant but small correlations among the variables Crown Class, Crown Condition, Red Oak Borer New Attacks, and Red Oak Borer Old Attacks. This indicates, not unexpectedly, that there are factors other than Crown Class and Crown Condition influencing the red oak borer populations.

ANALYSIS OF VARIANCE

Ranked data for the red oak group were subjected to the general linear model (PROC GLM) routine to test for differences among the strata (Light, Moderate, Severe). As expected, there was no significant difference (F = 1.66, P>F = 0.1909) among strata for the variable Crown Class. For the variable Crown Condition there was also no significant difference (F = 1.48, P>F = 0.2299) among the strata. For Red Oak Borer Old Attacks results were not significant (F = 1.54, P>F = 0.2151) as were data for Red Oak Borer New (F = 1.56, P>F =0.2105).

Because of the large numbers of zero counts in the data; we suspected that the analysis of ranked data may be invalid (Stokes et al. 1995). The red oak data was subjected to a nonparametric analysis of variance (PROC NPAR1WAY). Comparisons among strata were as follows: Crown Condition, significant (CHISQ = 16.414, P>CHISQ = 0.0003); Crown Class, not significant (CHISQ = 1.6819, P>CHISQ = 0.4313), Red Oak Borer New Attacks, significant (CHISQ = 8.3259, P>CHISQ = 0.0156), Red Oak Borer Old Attacks, significant (CHISQ = 15.602, P>CHISQ = 0.0004). These results are more consistent with our expectations. Crown Class should not vary greatly among the different strata given that the stands are similar. However, as observed from the aerial and field evaluations, Crown Condition should be expected to be different among the strata as should Red Oak Borer attacks.

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APPENDIX II

SILVICULTURAL OPTIONS AND OAK DECLINE IN UPLAND HARDWOOD FORESTS

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SILVICULTURAL OPTIONS AND OAK DECLINE IN UPLAND HARDWOOD FORESTS

Oak decline is a generally slow-acting, complex problem characterized by progressive crown dieback and mortality. Decline has the potential for causing long-term adverse effects on wildlife, recreation, and timber resources. The practice of silvicuture aims to shape forest composition and structure in a direction compatible with many diverse management objectives. Silvicultural practices in oak forests can help to mitigate oak decline effects or can exacerbate or even initiate decline, compromising some objectives and limiting silvicultural options. Controlled experiments on the effects of various silvicultural treatments on the mitigation, initiation, or intensification of decline have not been performed. However, the knowledge bases for upland hardwood silviculture and oak decline are extensive and allow some reasoned judgements to be made concerning appropriate actions. Because oak decline is most often associated with mature or overmature stands, regeneration decisions are most often affected (Starkey and Oak 1989). The purpose of this paper is to interpret the interactions of oak decline and various regeneration methods.

OAK DECLINE

A variety of causal factors are involved in oak decline including the unique physiology of mature oaks, environmental stress, insects and diseases. Manion (1981) describes the decline phenomenon as a sequential interaction of two or more factors grouped generally into (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) contributing factors such as root disease, bark beetles, canker or decay fungi (figure 1). On upland sites in the South, oaks in the red oak group are the most severely affected, although white oaks and hickories are also vulnerable. Mature and overmature stands, especially on lower site indices (55-70), are most frequently affected. A more detailed description of oak decline can be found in Starkey et al. (1989) and Wargo et al. (1983).

Throughout this discussion we will refer to decline-affected and decline-vulnerable stands. Affected stands generally have some of the characteristics mentioned above including mature/over-mature, low to moderate site indices, shallow, rocky or gravelly soil, etc. Oaks in affected stands, particularly in the red oak group may be exhibit varying amounts of dieback and/or mortality. Decline severity can be quite variable, from just a few trees with a little dieback to a high percentage of trees dead or with severe dieback. Vulnerable stands are similar in most respects to affected stands, but without decline symptoms. These stands may develop symptoms whenever an inciting factor is imposed.

Hazard rating systems for decline offer the potential to identify areas of high risk for preventive or remedial treatments. A simple subjective model for determining risk for oak decline has been developed (Starkey et al. 1989) where factors associated with high and low risk situations are enumerated (figure 2). Another model incorporating these factors has been developed for use on southern national forests which accesses stand inventory data to assess risk. It has been applied with satisfactory results (Oak and Croll 1995). More quantitative risk rating models have also been developed for several regions which can be of use on any ownership (Oak et al. 1996). These systems should be utilized whenever possible to assess the risk to oak decline in subject areas before silvicultural methods are selected of regenerating oak forests.

In the following discussion of oak decline and silvicultural options, we assume that one goal of silvicultural treatments is to sustain a viable diverse oak component in forest ecosystems for its high value for wildlife habitat, recreation, and timber. Therefore, an understanding of oak regeneration ecology is essential. Oak decline is of little consequence in situations where sustaining this component is too costly or otherwise conflicts with management objectives and where the resulting composition and structure of the affected stands is acceptable.

OAK REGENERATION ECOLOGY

Oaks occur in diverse ecosystems ranging from dry to wet (Braun 1967) and there is a general relation between site quality and regeneration success; the better the site the more difficult it is to regenerate oaks (Arend and Scholz 1969; Loftis 1990b; Lorimer 1989; Trimble 1973). In dry ecosystems, oak reproduction tends to accumulate beneath the parent stand over time. Accumulation may occur over several decades, resulting in oak reproduction originating from several acorn crops (Johnson 1992). Oak reproduction grows little in height in the typically low light conditions of the understory (Hanson et al. 1987; Johnson 1941) and recurrent shoot dieback of seedlings occurs. But oak reproduction survives dieback by resprouting from dormant buds near the root collar eventually producing seedling sprouts with root systems several to many years older than shoots (Johnston 1941; Merz and Boyce 1956; Tryon et al. 1980) and large root:shoot ratios. This investment in root biomass ultimately facilitates rapid shoot growth following a future stand disturbance (Dickson 1991; Johnson 1979). In more mesic ecosystems oak reproduction can accumulate as well, but is much less successful because oak propagules must compete against faster-growing, more shade-tolerant species, particularly in the absence of recurrent disturbance. Disturbance, such as a ground fire, would be of benefit to young oak reproduction by causing mortality of competing species, setting back the growth of competing species, allowing oaks to sprout and grow more freely and further develop a large, vigorous root system (Barnes and Van Lear 1998).

The accumulation of oak reproduction under the parent stand is one of the most important aspects of the regeneration ecology of oaks. Oak silviculturists call this “advance reproduction” because, in the even-aged management of oaks, it is present in advance of final harvest. It also largely determines the composition of the next stand. Oaks benefit from this accumulation process because it facilitates their quick capture of growing space when the overstory is removed or destroyed. Advance reproduction generally consists of (1) seedlings, (2) seedling sprouts, and (3) stump sprouts (Johnson 1992). True seedlings and small seedling sprouts usually have root systems that are too small to support rapid shoot growth (Sander 1971). Potential shoot growth of oak reproduction generally increases with stem basal diameter (and thus root size) peaking at about 6-8 inches depending on species (Loftis 1990a; Sander 1977). Sprouts from larger stumps, like seedling sprouts, originate from dormant buds at or near the bases of stumps of harvested overstory trees or trees with tops killed by a fire or broken by wind. The frequency of sprouting from larger stumps decreases with increasing tree diameter, age, and decreasing site quality (Johnson 1977). Thus, stump sprouts may be a major form of reproduction when stands with large numbers of trees with good sprouting characteristics are harvested or destroyed by fires. But stump sprouts from overstory trees, by themselves, are usually not numerous enough to capture all of the available growing space (Sander et al. 1984). Stump sprouting may be reduced in trees weaken by gypsy moth defoliation and oak decline (Gottschalk 1988). Other factors such as season of cutting and shading also may affect stump sprouting.

Thus, all living oaks, from seedlings to mature trees, have some potential to contribute to the regenerative capacity of a stand. It is the number, size, and spatial distribution of all three classes of reproduction — seedlings, seedling sprouts, and stump sprouts — that collectively express the total oak “regeneration potential” of a stand (Sander et al. 1984). Sustaining oak-dominated forests depends on perpetuating pre-established propagules from one generation to the next.

Obtaining the accumulation of oak reproduction necessary for successful regeneration on more productive sites usually requires recurrent disturbance. Historically, fire may have created the necessary conditions (Abrams 1992, Barnes and Van Leer 1989, McGee 1979). Thus, one potential solution to sustaining oaks on productive sites is prescribed burning. Fire, if correctly employed, has the potential to accomplish that objective in many oak-dominated ecosystems (Barnes and Van Leer 1989, Van Lear and Waldrop 1988). Another alternative is intermediate stand treatments such as the first “cut” of the modified shelterwood method proposed by Loftis (1990b) for mesic sites. Such sites are usually extremely difficult to prescribe burn.

Obtaining sufficient advance reproduction before harvest may well be the most difficult job of the silviculturist. Guidelines and predictive models are available for assessing the regeneration potential of hardwood stands in several regions including the southern Appalachians (Loftis 1990a), the Allegheny region (Marquis et al. 1984), the Cumberland Plateau (Waldrop et al. 1986), the Missouri Ozarks (Sander et al. 1984), and stands threatened by the gypsy moth (Gottschalk 1993). For a more complete discussion of the silvicultural implications of oak regeneration ecology see Johnson (1993).

REGENERATION METHODS

Since a number of regeneration methods are useful in regenerating oak stands, the effect of each on the decline status of stands will be discussed. The various regeneration methods available are:

<u>Even-aged methods</u>:
- Clearcutting

Seed-tree
Shelterwood

Two-Aged Methods:
Clearcutting with reserves
Seed-tree with reserves
Shelterwood with reserves

Uneven-age methods:
Group selection
Single-tree selection

Even-aged methods are used to establish a new stand by natural or artificial means where the resulting stand of trees consists of a single age class and will usually produce a normal distribution of tree diameters (figure 3). Even-aged regeneration methods generally remove trees of all ages and sizes from the stand in a single operation in order to establish a new stand in a short period of time resulting, essentially, in a single age class. Even-aged methods are most useful for tree species which are intolerant of shade, and regenerate, grow, and develop best in full or nearly-full exposure to sunlight.

Two-aged regeneration methods, like even-aged methods, are mostly used to regenerate shade-intolerant species. But here, some trees from the existing stand are retained — reserve trees — as part of the newly regenerated stand, resulting in a stand which has at least 2 distinct age classes. The goal of retaining these trees are usually unrelated to regeneration; that is, they are not necessary to successful regeneration of the stand but serve other purposes, such as benefits to wildlife, aesthetics, or other purposes.

Uneven-aged methods are used to establish regeneration at various times and locations in a stand such that the stand consists of trees of various ages and diameters which produce a reverse-J diameter distribution; smaller diameters predominate, but all age classes are continuously represented in the stand (figure 4). Regeneration cuts in uneven-aged stands generally remove trees from many diameter classes at each entry so that the reverse-J diameter distribution is maintained, but regeneration of desired species is accomplished. Uneven-aged methods are usually applied where desired tree species are tolerant of shade or where partial exposure to sunlight is sufficient for adequate regeneration, growth and development.

EVEN-AGED METHODS AND EFFECTS ON OAK DECLINE

Clearcutting Method

The clearcutting method has often been applied to the regeneration of forest stands where an even-aged population of shade-intolerant species is the management objective. The entire stand is removed in a single operation and reproduction develops in fully sunlit environmental conditions creating an even-aged stand. Clearcutting is successful in regenerating oaks and other hardwoods when regeneration potential is adequate to meet management objectives prior to harvesting (Sander et al. 1983). As previously described, oak regeneration potential accrues from several sources but most usually comes from large advance reproduction with large root systems.

If sufficient reproduction potential exists, decline-affected stands can be regenerated by the clearcutting method. Since clearcutting removes the entire overstory in one operation, decline and mortality in affected stands is immediately alleviated. Volume of recent mortality and the declining trees which might be lost without action is captured. Vulnerability of the stand is immediately reduced since young oak trees developing from advance regeneration do not share the physiology that predisposes mature trees to decline (Oak and Starkey 1991, Starkey et al. 1989). However, trees remaining at the edges of clearcuts may suffer the onset or exacerbation of decline due to site changes resulting from abrupt exposure and possibly root damage from harvesting machinery when ground skidding is used to remove trees (Mason et al. 1989, Wargo and Harrington 1991). Of some concern in decline-affected stands is the contribution of stump sprouts to total stand regeneration potential. As overstory oaks decline, their capacity to produce sprouts is reduced or eliminated. Therefore, it is important that regeneration potential be comprised mainly of seedling sprout advance reproduction. On the other hand, if decline is not too severe, stand conditions may develop which permit very small advanced reproduction to attain a larger size if clearcutting is delayed. This may also provide an opportunity for a shelterwood or preharvest stand treatment to develop advance reproduction (see shelterwood discussion below).

In decline-vulnerable stands where decline and mortality are currently not ongoing, the need to regenerate is less urgent. Such stands can be regenerated by clearcutting if regeneration potential is adequate and management objectives are satisfied. Where regeneration potential is inadequate, time may be available for shelterwood or preharvest treatments to encourage the development of advance reproduction (see shelterwood discussion below). In landscapes dominated by even-aged stands of older age classes vulnerable to decline, clearcutting reduces oak decline vulnerability over a region by introducing greater age class diversity.

Seed-Tree Method

The seed tree method involves the removal of all trees from an area except for a small number of seed-bearing trees left to provide seed for the establishment of new reproduction. Even-aged stands are produced, usually of intolerant species. Seed tree cutting has little, if any utility for regeneration of oak and other hardwood stands (Sander et al. 1983), particularly since acorns are heavy and do not disperse significant distances from a seed tree. Oaks also have highly variable flower and seed crops (Cecich 1991) and though heavy stands of seedlings are occasionally established (Johnson 1975, McQuilken 1983, Sander 1979), wildlife predation and environmental conditions usually decimate seed crops before long (Sander et al. 1983). Regeneration of oaks from this method of cutting, as with clearcutting, results from advance reproduction, not seed, so in the strict sense, a seed-tree cut would be more correctly categorized as a clearcut with reserves (see later). The implications for decline would be as stated above.

Shelterwood Method

A shelterwood regeneration method is one in which the existing stand is removed in two or more cuts and provides for the establishment of reproduction under the shade and protection of the residual trees. Reproduction can be from artificial or natural sources, although it was primarily designed for use in naturally-regenerating forest trees with cuts occurring near the end of the rotation. Shelterwood trees are left for varying lengths of time in order to provide seed and shelter reproduction, but they can also provide wildlife food and habitat, protect water quality, improve biological diversity and/or enhance visual quality. The choice of leave trees is a function of management objectives. Shelterwood cuts are designed to produce even-aged stands, although the shelterwood method with reserves may also be adapted to the creation and continuous maintenance of a two-aged stand (Beck 1991, Smith 1986). This may have utility where management objectives require a continuous forest cover.

Shelterwoods can be used to promote the development of oak advanced reproduction before the final reproduction cut is made (Sander et al. 1983), although on more xeric sites, where advance reproduction tends to accumulate shelterwoods may not be necessary (Sander and Clark 1971). The system may be particularly useful on higher-quality mesic sites (Loftis 1990b). A modified application of the method has been particularly useful in oak stands growing on high-quality mesic sites (Loftis 1990b) where advanced reproduction is already present but needs further development before a final harvest cut. The steps usually include an initial shelterwood cut that reduces stand stocking from below by 20 to 40 percent. This can be a commercial removal or a mid-story “removal” from below using herbicides. Such cuts remove most of the subcanopy of tolerant non-oak hardwoods and leaves most of the main canopy intact. Under the shelterwood, advance oak reproduction is allowed to develop for about 10 years until a final cut is made. Where advance reproduction is insufficient in size or density, two or more decades may be required for advance reproduction to develop to an adequate size.

In decline-affected stands, many oaks in the dominant and codominant crown classes are already damaged (Starkey et al. 1989). Unfortunately, these are the trees needed to meet the management objectives of many shelterwoods. The risks of employing shelterwood systems in decline-damaged stands involve three factors: (1) the vigor of the trees to be retained, (2) the level of exposure and damage they receive (a function of the level of basal area reduction), and (3) the time span that they are to be retained. The highest risks occur when mature, predisposed oaks (especially red oaks) are exposed or damaged after heavy reductions in basal area, and are to be retained for extended periods (10-20 years). In these high-risk situations, it is unlikely that the residual trees will survive long enough to provide the benefits for which they were intended (Mason et al. 1989, Wargo and Harrington 1991), whether for sustained mast production, a second commercial harvest cut, visual screening, or other values. Some dead or declining trees might be salvaged in the initial cuts but a sufficient number of healthy, well-distributed trees must be available. Given the approximately even-age structure of many upland hardwood stands it is unlikely that there would be many healthy, vigorous, decline-resistant overstory trees. The risk would be least where the first “cut” of the shelterwood is a non-commerical thinning from below (removing mid-story competitors) using herbicides (Loftis 1990b). Where decline is not too severe, development of advance regeneration may be enhanced by thinning and dying of dominant crown class trees, particularly on xeric sites. On mesic sites, this would probably not occur without at least a mid-story removal of more tolerant species to enhance growth of oak advance reproduction.

In vulnerable stands, the shelterwood system can be used as long as trees in the shelterwood are expected to have high survival rates for 10-20 years. It is unknown if the brief release of growing space from the shelterwood cut would provide any protection from decline to the shelterwood by improving their general vigor. The trade-off between the release of growing space with the effects of disturbance on residual oaks has not been quantified.

TWO-AGED METHODS AND EFFECTS ON OAK DECLINE

Clearcutting with Reserves

Clearcutting with reserves is a variation of clearcutting where a high proportion of the stand basal area is removed to facilitate regeneration, but a small basal area (usually about 10-20 square feet) of mid- and/or overstory trees are retained for purposes other than regeneration, eg., wildlife habitat, aethetics. As with clearcutting, regeneration success is largely dependent on the regeneration potential of the stand before cutting. Similarly, the effects of decline are mostly alleviated since the majority of the overstory is removed in the harvest operation.

In decline-affected stands, the pool of healthy, vigorous trees available for reserves may be limited, or may be more vulnerable to decline than in unaffected stands. Reserve trees may also be subjected to stresses that exacerbate or initate decline because of the severe change in environmental conditions created by abrupt exposure, and root damage from harvesting machinery.

In decline-vulnerable stands, the pool of potential reserve trees would be in better health, but would be subject to the same stresses after cutting. As with clearcutting, vulnerability to decline would be immediately reduced.

Seed Tree with Reserves

Seed tree with reserves is a variation of seed tree method where the seed trees and, perhaps, other trees are retained for other purposes resulting in a stand with 2 distinct age classes. In decline-affected or decline-vulnerable stands, the success of this method may be affected over time since the retained trees are the part of the stand most susceptible to decline. If this age class of the stand is severely affected by decline it may result in management objectives being unfulfilled.

Shelterwood with Reserves

A shelterwood with reserves is similar to the shelterwood method but, again, trees in the shelterwood are retained as part of the regenerated stand resulting in 2 distinct age classes. As mentioned for seed tree with reserves, in decline-affected or decline-vulnerable stands, the success of this method may also be affected over time since the retained trees are the part of the stand most susceptible to decline. If this age class of the stand is severely affected by decline it may result in management objectives being unfulfilled. However, in the shelterwood with reserves, a larger proportion of the stand is left in this age class, so management objectives may not be at as much risk from decline as with a clearcut or seed tree with reserves.

UNEVEN-AGED METHODS AND EFFECTS ON OAK DECLINE

Group Selection

The group selection method usually involves harvesting small groups of trees across a stand to create openings that are at least 1.5 to 2 times the mature-tree height of the adjacent stand. The intent is to produce and maintain an uneven-age structure in the stand. The resulting mosaic of small openings facilitates regeneration of single-age class groups. The method is readily adaptable to a wide range of conditions because the ecological requirements of many species can be met by the method (Smith 1986). In oak forests, the group selection method can be used successfully if there is sufficient advance reproduction in the groups selected for cutting and they are large enough to allow full sunlight to reach most of the forest floor within groups (Sander et al. 1983).

The effects of decline are not likely to be mitigated by group selection harvesting for several reasons. First most hardwood stands are even-aged or nearly so and to convert them to uneven-aged stands using group selection will require several cutting cycles. Since only a very small portion of the stand is regenerated in the early cycles, large areas must be carried well past physiological maturity thereby increasing the risk to decline (Oak and Starkey 1991). In affected areas, decline would continue and vulnerability would increase as the stand ages (Johnson and Law 1989, McGee 1986, Oak et al. 1990) although a shelterwood or pre-harvest treatment remaining stand may be use to enhance advance reproduction. Future regeneration potential may also be reduced due to the reduced sprouting capability of stumps and smaller, lower-quality acorn crops (Oak et al. 1988). Second, decline may be initiated or intensified on many trees on group edges due to exposure and root disturbance. With group selection, edge exposure is proportionally greater per unit area cut than with clearcutting. Third, there may also be an initiation and increase in decline in the intervening, uncut area due to the increased traffic necessary to disperse groups over the stand with repeated stand entries.

In decline-vulnerable stands, group selection cutting could be used, but decline might be initiated on perimeter trees and in intervening areas of the stand. Because several cutting cycles would be required to cut over an entire stand, unregenerated areas would continue to age and increase in vulnerability to decline. Of course, on more xeric sites where oak reproduction tends to accumulate, regeneration potential may actually increase if decline is not too severe.

Single-Tree Selection

Single-tree selection is used primarily to create and manage uneven-aged stands where the species of interest are able to regenerate under deep shade (Smith 1986). Single-tree selection may not be well suited to regenerating oaks on many sites because environmental conditions necessary for successful oak regeneration are not provided (Della-Bianca and Beck 1985, Sander et al. 1983). Oaks are intermediate in shade tolerance and even when advance oak reproduction is present, openings created by the removal of single trees may be insufficient for reproduction to grow into the overstory. This system has the greatest potential to initiate and increase decline in upland forest types because a large component of the stand is left to increase in age and decline vulnerability. This is especially true where essentially even-aged stands are being converted uneven-aged stands through the single-tree selection method. In decline-affected stands, decline will continue and may accelerate due to exposure and traffic-related root damage dispersed over large areas of the stand. There is little opportunity to capture decline mortality. In decline-vulnerable stands, some decline may be initiated by disturbance, few high-risk trees could be removed and a large component of the stand would be left to age and increase in decline vulnerability over many cutting cycles. In xeric environments where oak advance reproduction readily accumulates, decline, coupled with a single-tree method may allow for development and regeneration of oaks if overstory decliners are harvested along with other trees and openings created were somewhat larger than created by strictly single-tree removals. Such a method would be more like a group selection than a true single-tree.

NO CUTTING AND EFFECTS ON OAK DECLINE

In some situations, where oak productivity is very low, site conditions are extreme or management objectives preclude active management for timber products, stands may never receive regeneration cuts of any kind. The effect of oak decline on the regeneration potential of such stands is largely unpredictable. Where no silvicultural measures are taken, the outcome may be positive or negative, depending on the initial state of the oak advance reproduction, the rate and severity of decline, competition, current acorn production, site quality, and other factors. For example, in an ecosystem where oak reproduction has accumulated over several decades, dieback and decline of the overstory may accelerate the development of existing oak reproduction and thus facilitate its capture of the canopy gaps may not be adequate for regenerating oaks when advanced reproduction typically does not accumulate, rapid dieback and decline may accelerate the succession from oak to non-oak forest by stimulating the development of an understory of sugar maple, beech, yellow-poplar, and other non-oaks (Loftis 1990b). In any case, severe oak decline will significantly reduce acorn production (Oak et al. 1988) and thus the establishment of new oak seedlings.

Vulnerability to decline increases as stands age, even though additional decline risk factors are not introduced by harvest activities (exposure, root damage). Future environmental stress from drought and/or insect defoliation is a certainty, but the timing of these events is unpredictable. Decline in affected stands will likely continue (Johnson and Law 1989, McGee 1986, Oak et al. 1990).

SUMMARY

A variety of regeneration methods are available to the silviculturist working with upland oak forest types. Several have the potential to mitigate the effects of oak decline as well as successfully regenerate oak species. The challenge for silviculturists is to correctly evaluate both oak regeneration potential and risk to oak decline and utilize the best silvicultural technology available to meet the management objectives on the areas under their management. The diversity of oak-dominated ecosystems in the U.S. makes this an exciting and challenging task.

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FIGURES

1—Decline spiral from Manion 1981
2—High/low risk factor list from Starkey et al. 1989
3—Normal (even-aged) diameter distribution
4—Reverse-J (uneven-aged) diameter distribution