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Proceedings of a Meeting

Held at

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University Park, PA

March 3-6, 1991

Edited by

Larry H. McCormick and Kurt W. Gottschalk

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FOREWORD

This conference is the eighth in a series of biennial meetings that began in 1976 at Southern Illinois University. Other conferences have been hosted by Purdue University, University of Missouri, University of Kentucky, University of Illinois, and University of Tennessee. The purpose of these conferences has remained the same: to provide a forum for the exchange of information concerning the central hardwoods and to engender coordination among forest scientists in the central hardwood region. This purpose is evidently well-served: the last several conferences have each attracted some 45 to 65 program contributions, and the audiences have been correspondingly large.

Previous organizers have refrained from drawing precise boundaries around the "central hardwood region." We prefer to continue that policy on the grounds that to do otherwise might preclude some very worthwhile participation. Thus, while the principal focus has remained on the oak resource for reasons that are obvious, the ecological scope has broadened from oak-hickory (in the early meetings) to Appalachian oak (Knoxville and State College) and mesophytic forests. With a few exceptions, the commercially significant species are similar for all these forest types, and advancements in knowledge are of general interest.

But the central hardwood region is not merely a collection of similar forest types. It also has historical, demographic, political, and economic characteristics that tend to distinguish it from other forest regions of the United States. For example, the population is heavily rural and agricultural, primary wood markets tend to be diffuse and unorganized, wilderness values and endangered species have generally not been overriding issues, and a relatively minor proportion of the forest land is controlled by public agencies or corporate ownerships. These and related conditions play critical roles in the practice of forestry in this region, and in the aggregate they emphasize its distinction from other regions; but no single one is necessarily unique to the central hardwoods. For these reasons, the characteristics of nonindustrial private forest land owners in Massachusetts might be just as relevant to the central hardwood region as regeneration methods for white oak in Indiana.

Since these proceedings are being published in advance, we have no way of judging the ultimate success of the upcoming Eighth Conference. Of course, our earnest hope is that this meeting shall sustain the excellent reputation of the series. We believe this hope is encouraged by the quality of the papers in these proceedings.

REVIEW PROCEDURES

Each manuscript published in these proceedings was critically reviewed by at least two scientists with expertise in disciplines closely aligned to the subject of the manuscript. Reviews were returned to the senior author, who revised the manuscript appropriately and resubmitted it in a diskette format suitable for printing by the Northeastern Forest Experiment Station, USDA Forest Service where they were edited to a uniform format and type style. Manuscript authors are responsible for the accuracy and style of their papers.

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SILVICULTURAL CUTTING OPPORTUNITIES IN OAK-HICKORY FORESTS OF WEST VIRGINIA

Stanford L. Arner, David A. Gansner, Martin E. Dale, and H. Clay Smith[1]

Abstract: Analysis of cutting opportunities for oak-hickory forests of West Virginia reveals a storehouse of economic opportunity. The potential cut from silviculturally sound thinning, regeneration, and harvest opportunities totals 100 million cords, or 60 times the current annual harvest of growing stock volume from the state. On the stump, the conversion value of this material totals $2.4 billion. Moreover, the good housekeeping associated with this silviculture would improve timber productivity and quality.

INTRODUCTION

During the early 1900's, West Virginia was a lumbering giant. In 1909, some 1,500 mills in the state produced 1.5 billion board feet of lumber to feed the needs of a growing industrial Nation. Unfortunately, "cut and move" was the rule in those days and little attempt was made to revegetate the landscape (Clarkson 1965). Wildfires followed the logging to complete the virtual destruction of the forest. Many believed the resource was ruined and never would return to the way it was.

But a recent inventory shows that West Virginia's woodlands are well on the road to recovery (Gansner et al. 1990). And the wood-using industry has taken notice. Log exporters and domestic mill operators are looking to West Virginia for more high-quality logs and bolts (Widmann 1990). Also, more of the small and low-grade material that has had limited markets in the past is finding its way into products such as pulpwood, pallets, and fuelwood. Concurrently, resource managers and policymakers, determined not to repeat the mistakes of a reckless past, are emphasizing cutting practices that are environmentally sound. The time is ripe to reevaluate cutting opportunities in the Mountain State.

This study looks at cutting opportunities for oak-hickory forests of West Virginia, a 9.2-million-acre resource that accounts for four-fifths of the state's timberland and is a major contributor to local and regional economies. Effects of timber prices, characteristics of ownership, woodland accessibility, traditional cutting practices, and other factors that influence the economic availability of timber were not considered in the analysis. An

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Crow, G. R., and R. R. Hicks, Jr. 1990. Predicting mortality following spring insect defoliation. For. Sci. 36: 831-841.

Ehrenfeld, J. G. 1980. Understory response to canopy gaps of varying size in a mature oak forest. Bull Torrey Bot. Club 107: 29-41.

Fosbroke, D. E., and R. R. Hicks, Jr. 1989. Tree mortality following gypsy moth defoliation in southwestern Pennsylvania. pp. 74-80 *In* Seventh Central Hardwood Forest Conf. Proc. *Edited by* G. Rink and C. A. Budelsky. Carbondale, Il. USDA For. Serv. Gen. Tech. Rep. NC-132.

Gansner, D. A. 1985. Ten years after gypsy moth and still no regeneration. Pennsylvania Forests 75: 6,12.

Hibben, C. R., and M. L. Daughtrey. 1988. Dogwood anthracnose in the northeastern United States. Plant Disease 72:199—203.

Lorimer, C. G. 1989. The oak regeneration problem: new evidence on causes and possible solutions. Dept. of For. Forest Resource Analysis No. 8. Univ. Wisconsin, Madison. 31 pp.

Sander, I. L., P. S. Johnson, and R. F. Watt. 1976. A guide for evaluating the adequacy of oak advance reproduction. USDA For. Serv. Gen. Tech. Rep. NC-23. 7 pp.

assessment of how these variables affect timber supplies would be extremely difficult and perhaps meaningless at a time when timber inventories and growth seem more than adequate to satisfy most current needs.

Instead, we have identified the acreage of timberland and yields of timber associated with recommended silvicultural cutting practices for the oak-hickory timber type. This same procedure could be used to determine cutting opportunities for all 118 million acres of the oak-hickory timber type in the Eastern United States. With modification, this approach could be used to analyze other forest types.

PROCEDURE

West Virginia's oak-hickory forest exhibits virtually every stage of stand condition and development. Our first task was to sort this highly variable resource into general yet well-defined cutting opportunities that are in keeping with the principles of sound silviculture (Roach and Gingrich 1968). A cutting decision guide that incorporates information about acceptable tree stocking, stand size, and recommended removals of timber was used (Fig. 1). The guide indicates, for example, that a well-stocked (B+) sawtimber-size stand with more than 50 percent of its sawtimber volume in trees 16 inches d.b.h. and larger should be harvested. B-level stocking is the lower limit of full stocking based on a stand's d.b.h., basal area, and number of trees per acre. Harvest opportunities with harvest volumes of more than 8,000 and less than 8,000 board feet/acre are identified as opportunities 1 and 2, respectively. A well-stocked sawtimber-size stand with less than 50 percent of its sawtimber volume in trees 16 inches d.b.h. and larger should be thinned to B-level stocking so that residual trees will make most efficient use of the site. Thinning opportunities in sawtimber stands where the recommended cuts amount to more than 5 cords and less than 5 cords/acre are recognized as opportunites 3 and 4, respectively. And so on. In all, 10 distinct cutting opportunities are identified by the guide.

The cutting decision guide was used to sort data from 1959 inventory plots from the latest forest survey of West Virginia (DiGiovanni 1990), representing 9.2 million acres of oak-hickory timberland. This separated the resource into cutting opportunities and provided information for estimating the acreage and stand characteristics for each opportunity (Table 1).

Information on tree d.b.h. and merchantable height was used to estimate total volume in cords and sawtimber volume in board feet (Scott 1979, 1981). Dollar values are based on tree-value conversion standards for tree species in the Northeastern United States.[2] These standards represent consistent regional measures of a standing tree's net value (marginal value

[2]DeBald, Paul S, and Martin E. Dale. Tree value conversion standards revisited. Research Paper, Northeastern Forest Experiment Station. [In preparation]

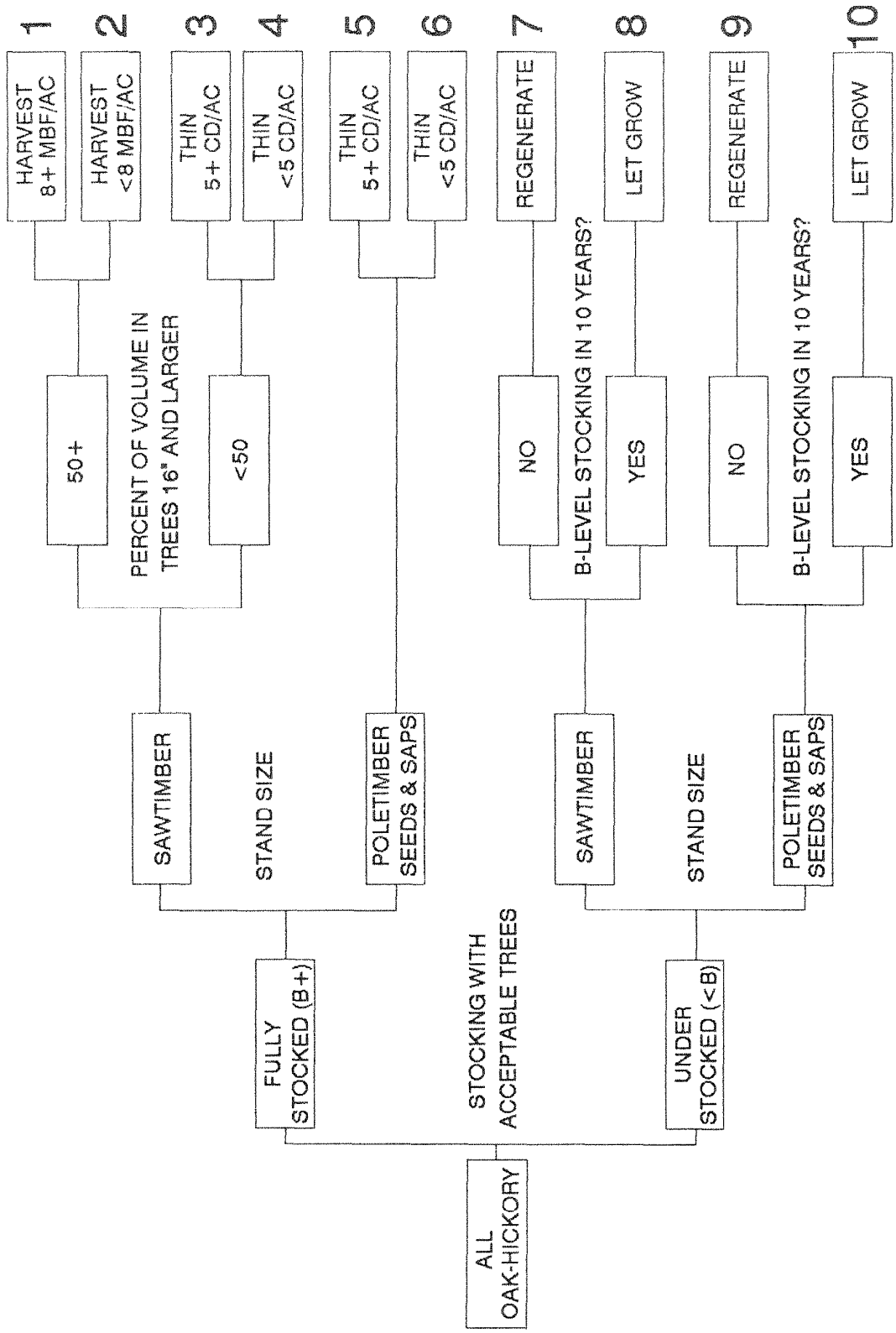

Figure 1. Guide for sorting oak-hickory forest into cutting opportunities.

Table 1.--Acreage and stand characteristics of cutting opportunities in oak-hickory forests of West Virginia

Cutting Opportunity	Area	Average d.b.h.	Basal area per acre	Stand volume per acre		Stand value per acre
				Total	Sawtimber	
	Thousand acres	Inches	Ft^2	Cords	Mbf	Dollars
1. Harvest fully stocked mature satwimber stand (removals 8+ Mbf/acre)	1,065	10.5	139	34.7	10.9	1,139
2. Harvest fully stocked mature sawtimber stand (removals <8 Mbf/acre)	1,078	8.4	122	23.4	5.9	582
3. Thin fully stocked immature sawtimber stand (removals 5+ cords/acre)	1,773	8.9	137	30.5	7.1	564
4. Thin fully stocked immature sawtimber stand (removals <5 cords/acre)	743	8.7	109	22.9	5.4	375
5. Thin fully stocked poletimber, sapling, or seedling stand (removals 5+ cords/acre)	513	7.3	129	24.7	3.4	312
6. Thin fully stocked poletimber, sapling, or seedling stand (removals <5 cords/acre)	1,088	6.8	106	17.2	2.3	188
7. Regenerate understocked sawtimber stand that will not reach full stocking in 10 years	1,030	10.9	67	13.7	3.7	267
8. Let grow understocked sawtimber stand that will reach full stocking in 10 years	1,297	9.7	94	20.4	5.3	419
9. Regenerate understocked poletimber, sapling, or seedling stand that will not reach full stocking in 10 years.	980	6.5	50	7.3	1.0	74
10. Let grow understocked poletimber, sapling, or seedling stand that will reach full stocking in 10 years	609	7.4	84	15.3	2.1	149
All acres	9,176	[illegible]	102	20.8	4.9	425

or shadow price) in the production of 4/4 (1-inch) lumber, allowing for the cost of conversion. They account for a tree's species, diameter, merchantable height, and tree grade (based on butt-log grade measures). For example, a 16-inch-diameter northern red oak (*Quercus rubra* L.) with a grade 2 butt log and merchantable height of 2 logs was valued at $29. For trees other than hardwood sawtimber, merchantable height, d.b.h., and cull estimates were converted to net volumes and assigned value based on recent local stumpage price information. For example, pulpwood stumpage averages about $5 per cord.

PLENTY OF CHANCES FOR CUTTING

Some 3.1 million acres, about one-third of West Virginia's oak-hickory timberland, could use some thinning (opportunities 3 through 6). Another 2.1 million acres are in mature sawtimber stands that are ready for harvest (opportunities 1 and 2). More than 40 percent of the resource is inadequately stocked with acceptable growing stock, that is, trees of commercial species that are not rough or rotten. More than half of this understocked forest is not expected to reach an acceptable level of stocking in 10 years and should be regenerated (opportunities 7 and 9). Nearly 2 million acres of understocked forest that are projected to reach an acceptable stocking level during the next decade can be left to grow (opportunities 8 and 10). Stands representing every cutting opportunity are fairly well distributed in all regions of the state (Fig. 2).

As expected, stand conditions vary greatly for the 10 cutting opportunities. Per-acre statistics for opportunity 1 are most impressive: nearly 35 cords of total volume, including 11,000 board feet of sawtimber, with a total worth of more than $1,100. At the other extreme is opportunity 9: averaging only 7 cords of total volume, including 1,000 board feet of sawtimber, worth less than $75 per acre.

Species composition is no surprise. The oaks combined account for the largest share of the resource but other commercial species are abundant (Fig. 3). Yellow-poplar (*Liriodendron tulipifera* L.) and other high-value hardwoods (sugar maple--*Acer saccharum* Marsh., black cherry--*Prunus serotina* Ehrh., white ash--*Fraxinus americana* L., and walnut--*Juglans nigra* L.) combined make up one-fourth of the inventory. Hickory (*Carya* spp.), red maple (*Acer rubrum* L.), beech (*Fagus grandifolia* Ehrh.), and basswood (*Tilia americana* L.) also are well represented.

TOTAL CUT AMOUNTS TO 100 MILLION CORDS

The cut associated with all of the silvicultural opportunities totals 99.6 million cords (Table 2). That is a lot of wood, amounting to 60 times the current annual harvest of growing stock volume from the state. Included in this harvest is 25 billion board feet of sawtimber. On the stump, the conversion value of these removals amounts to $2.4 billion.

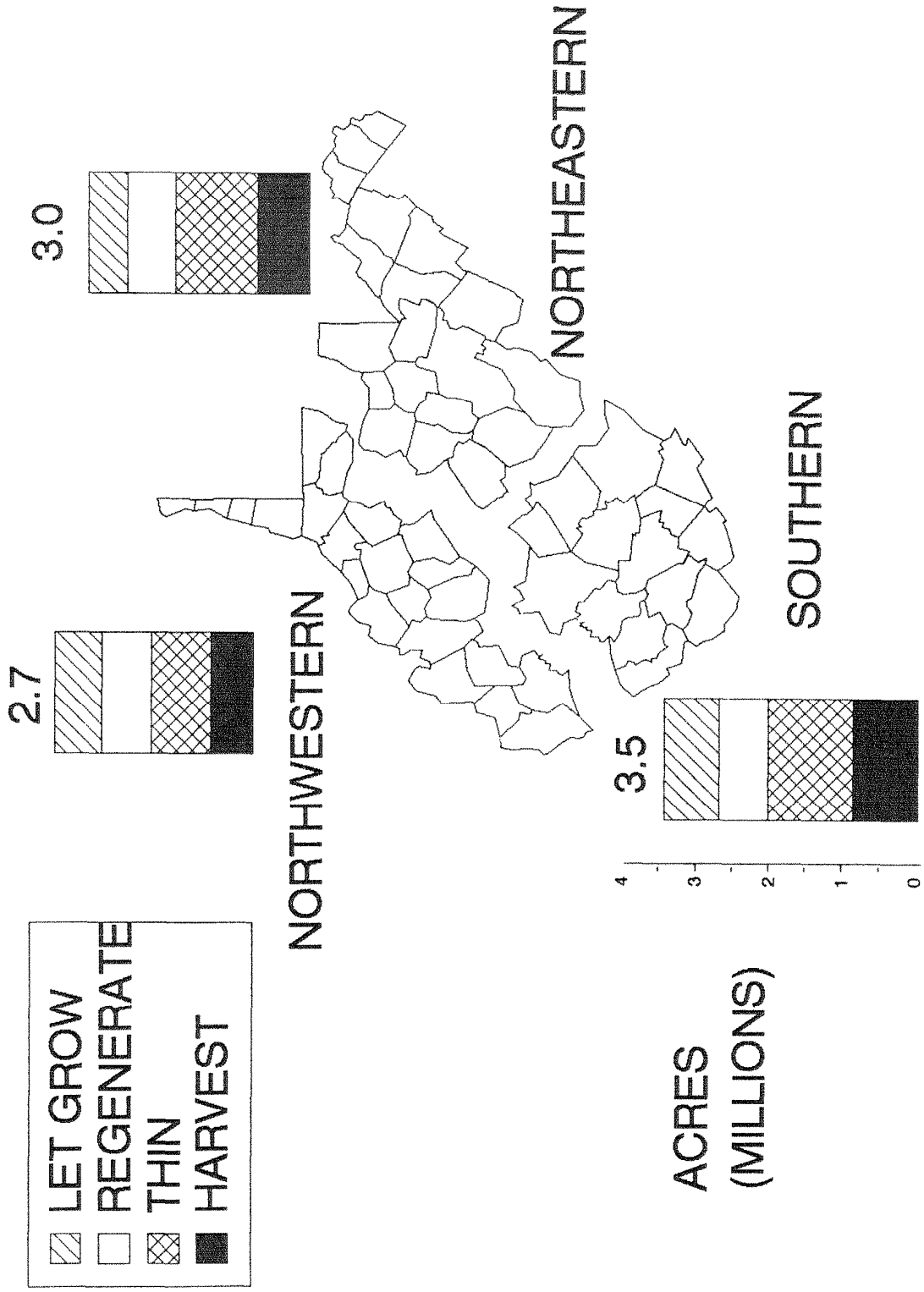

Figure 2. Geographic distribution of cutting opportunities in oak-hickory forests of West Virginia.

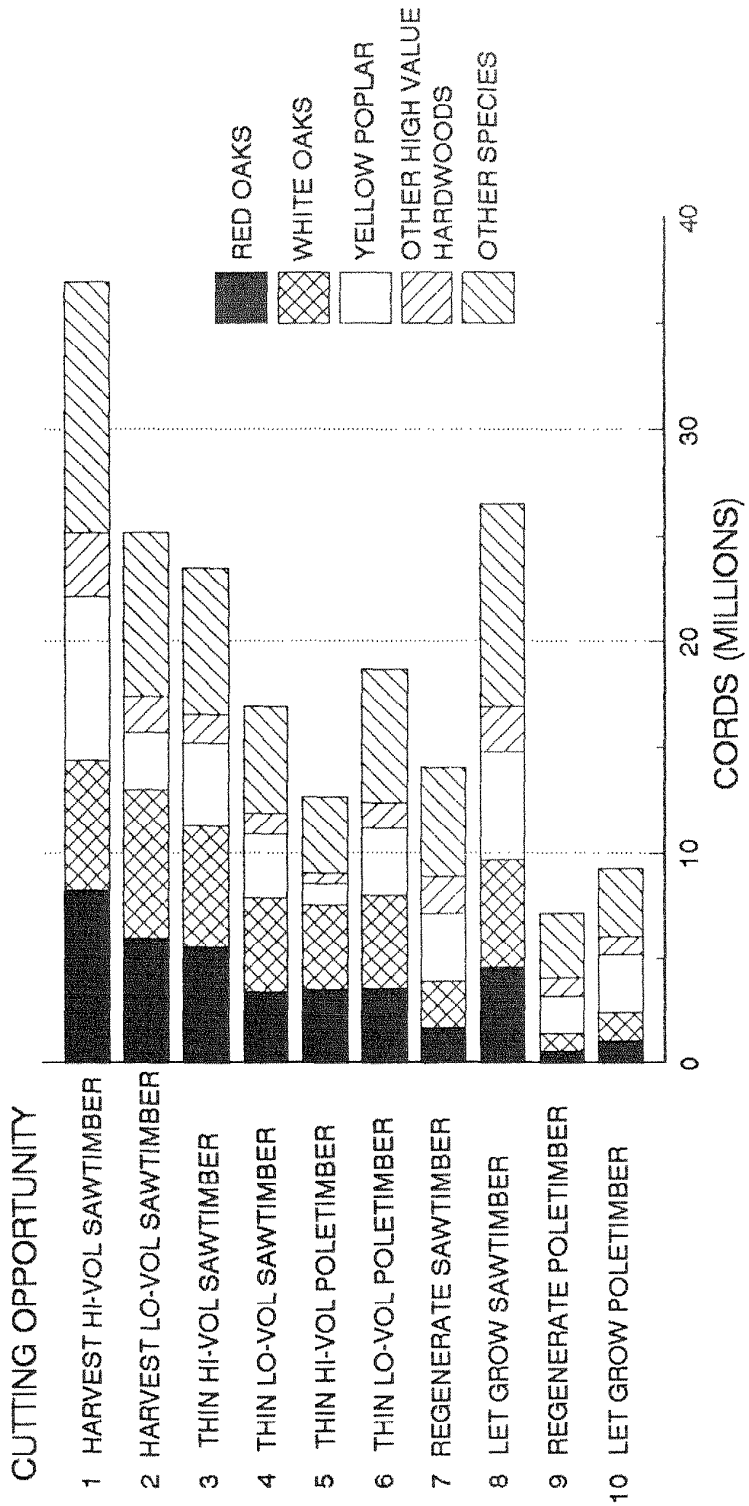

Figure 3. Distribution of inventory volume, by cutting opportunity and species group, oak-hickory forests of West Virginia.

Table 2.--Potential cut by opportunity in oak-hickory forests of West Virginia

Cutting opportunity	Per acre			All acres		
	Total volume	Sawtimber	Value	Total volume	Sawtimber	Value
	Cords	Mbf	Dollars	Million cords	Mmbf	Million dollars
1. Harvest fully stocked mature sawtimber stand (removals 8+ Mbf/acre)	34.7	10.9	1,139	36.9	11,651	1,214
2. Harvest fully stocked mature sawtimber stand (removals <8 Mbf/acre)	23.4	5.9	582	25.2	6,380	627
3. Thin fully stocked immature sawtimber stand (removals 5+ cords/acre)	9.3	1.9	115	7.2	1,479	89
4. Thin fully stocked immature sawtimber stand (removals <5 cords/acre)	2.5	0.6	35	1.9	390	26
5. Thin fully stocked poletimber, sapling, or seedling stand (removals 5+ cords/acre)	9.0	1.2	85	4.6	593	44
6. Thin fully stocked poletimber, sapling, or seedling stand. (removals <5 cords/acre)	2.4	0.3	22	2.5	345	24
7. Regenerate understocked sawtimber stand that will not reach full stocking in 10 years	13.7	3.7	267	14.1	3,774	275
9. Regenerate understocked poletimber, sapling, or seedling stand that will not reach full stocking in 10 years	7.3	1.0	74	7.2	1,005	73
All acres	10.9	2.9	258	99.6	25,617	2,372

From the standpoint of operability, the most lucrative options are harvesting opportunities 1 and 2 with cuts per acre exceeding 20 cords of total volume, including more than 5,000 board feet of sawtimber. The value of removals associated with the 2.1 million acres in opportunities 1 and 2 totals $1.8 billion. Other opportunities are reasonably attractive. For example, the regeneration of understocked sawtimber stands, opportunity 7, yields an average of nearly 14 cords per acre, including 3,700 board feet of sawtimber. By contrast, thinning opportunities 4 and 6 have per-acre cuts averaging fewer than 3 cords. While these thinning chances would be snubbed by most professional loggers, they might be of interest to the occasional fuelwood cutter with a chain saw and pick-up truck.

Oaks account for about 40 percent of the total volume (38 million cords) and 70 percent of the total value ($1.6 billion) included in the cutting prescriptions (Figs. 4-5). Northern red oak alone accounts for 25 percent of the value. Two-fifths of the sawtimber harvest is in trees with butt logs of grade 2 or better (Fig. 6). The quality of material taken in harvesting and regeneration operations is much better than that removed in thinnings where improvement cutting tends to leave the better trees in the woods.

CUTTING WOULD ENHANCE TIMBER PRODUCTIVITY

Dramatic improvements in timber productivity and quality would result from sound cutting practices. An individual-tree growth simulator was used to project gains in yield that might be expected over the next two decades from thinnings of similar forest stands in Pennsylvania (Gansner et al. 1987). Gains in timber yield (over no treatment) averaged nearly 4 percent. Poletimber, seedling, and sapling stands would net bigger gains in volume than sawtimber stands. But much more impressive than the gains in timber volume would be improvements in quality and value. Assuming prices remain constant, projected increases in timber value attributed to thinning averaged nearly 12 percent over 20 years. If these stands were left unthinned, their compound annual rates of value growth will average nearly 3 percent . If they were thinned, value growth rates on the residual stands would average more than 4 percent.

ROOM FOR INDUSTRIAL EXPANSION

The bottom line is that West Virginia's 9.2 million acres of oak-hickory forest represent a storehouse of economic opportunity. The potential cut from silvicultural thinning, regeneration, and harvest operations amounts to 100 million cords. Moreover, the good housekeeping associated with this environmentally sound cutting would result in significant improvements in timber productivity and quality. Obviously all of the cutting couldn't be done at once. The amount that might be undertaken remains a big question. At least one major flooring firm has taken advantage of the timber supply situation by establishing a new mill in the state. Further developments will require some tough decisions based on the interaction of a multitude of complex socioeconomic factors such as:

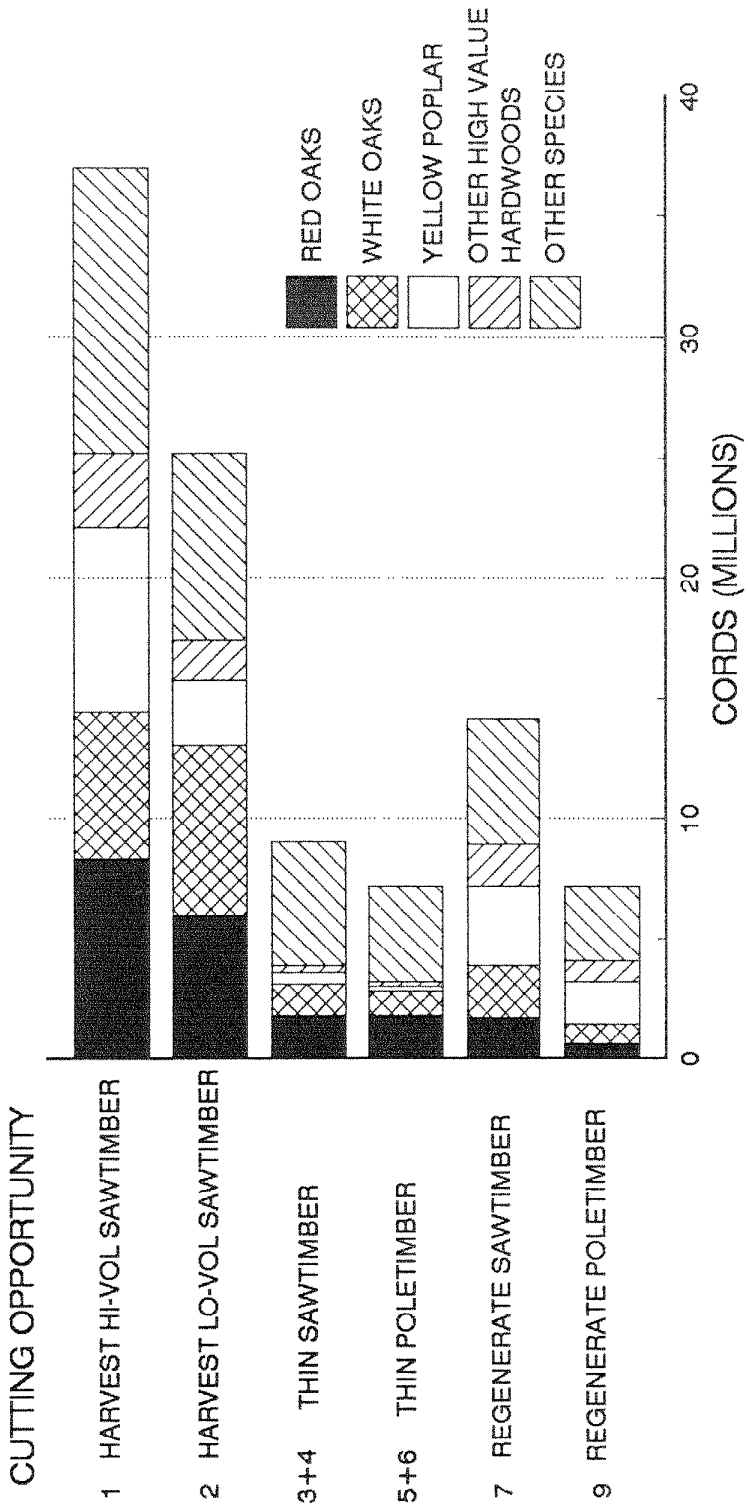

Figure 4. Potential cut of timber volume, by cutting opportunity and species group, oak-hickory forests of West Virginia.

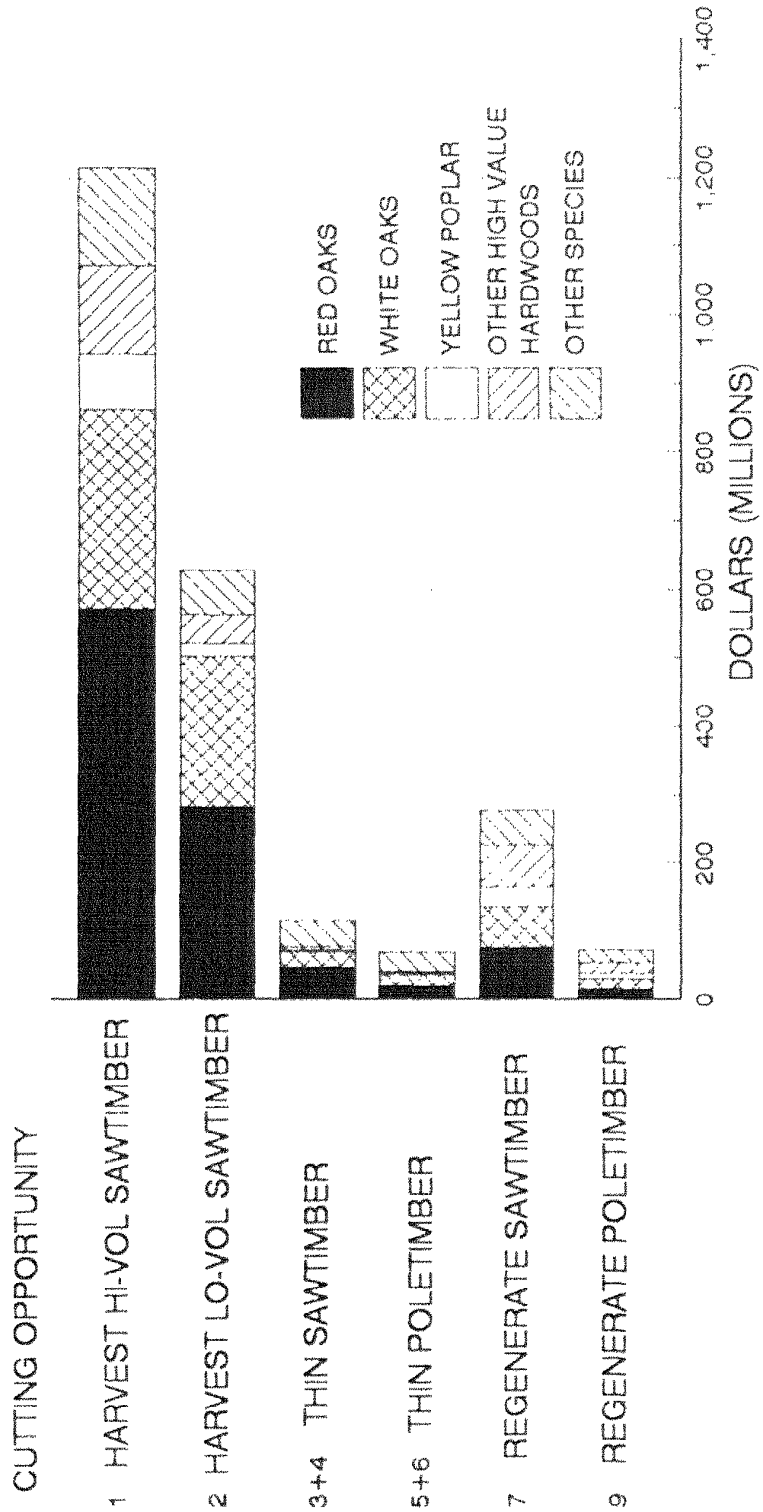

Figure 5. Conversion value of potential cut, by cutting opportunity and species group, oak-hickory forests of West Virginia.

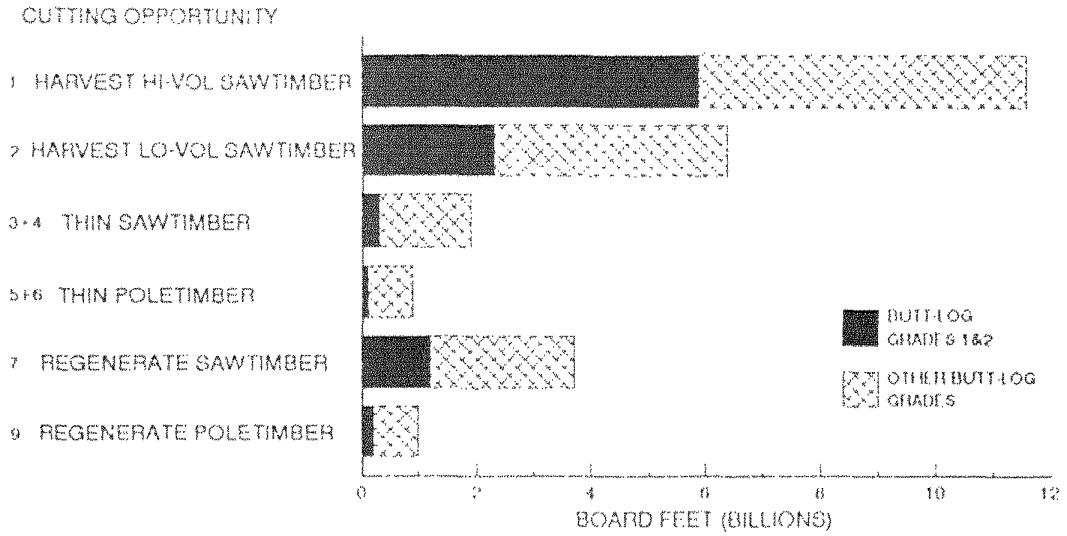

Figure 6. Potential cut of sawtimber volume, by cutting opportunity and tree grade, oak-hickory forests of West Virginia.

* Changes in timber demand, utilization, and operability.

* Attractiveness of local business climates to an expanding timber industry.

* Attitudes of woodland owners and other citizenry toward increased timber cutting.

* Desires to maintain a balanced distribution of age classes and sustainable flow of quality timber.

* Continued use of traditional cutting practices such as diameter-limit cutting and clearcutting of immature stands in place of recommended silviculture.

* Inadequate regeneration, especially where deer populations are high.

Given today's conditions, major increases in silvicultural cutting would have to be spread over the next several years. Only time will tell how this works out. At any rate, there is no denying that physical supplies of timber reveal a potential opportunity for significant expansion in wood use.

LITERATURE CITED

Clarkson, R. B. 1965. Tumult on the mountains. McClain Printing Co., Parsons, WV. 410 p.

DiGiovanni, D. M. 1990. Forest statistics for West Virginia. USDA For. Serv. Resour. Bull. NE-114. 172 p.

Gansner, D. A., M. E. Dale, O. W. Herrick., D. R. Dickson, and D. E. Lutz. 1987. Silvicultural cutting opportunities in oak-hickory forests. North. J. Appl. For. 4:59-63.

Gansner, D. A., R. H. Widmann, and D. M. DiGiovanni. 1990. New West Virginia inventory reveals storehouse of economic potential. Natl. Woodlands (July/August).

Roach, B. A., and S. A. Gingrich. 1968. Evenaged silviculture for upland central hardwoods. U.S. Dep. Agric., Agric. Handb. 355. 39 p.

Scott, C. T. 1979. Northeastern forest survey board-foot volume equations. USDA For. Serv. Res. Note NE-271. 3 p.

Scott, C. T. 1981. Northeastern forest survey revised cubic-foot volume equations. USDA For. Serv. Res. Note NE-304. 3 p.

Widmann, R. H. 1990. West Virginia timber products output--1987. USDA For. Serv. Resour. Bull. NE-115. 20 p.

INCIDENCE OF TWOLINED CHESTNUT BORER AND *HYPOXYLON ATROPUNCTATUM* ON DEAD OAKS ALONG AN ACIDIC DEPOSITION GRADIENT FROM ARKANSAS TO OHIO

Robert A. Haack and Richard W. Blank[1]

Abstract: The incidence of twolined chestnut borer (TLCB), *Agrilus bilineatus* (Weber), and the canker fungus *Hypoxylon atropunctatum* (Schw. ex Fr.) Cke. was recorded on dead oak (*Quercus*) trees ≥7 cm diameter at breast height (DBH) along an acidic deposition gradient from Arkansas to Ohio in 1989 and 1990. Approximately, one to three hectares of oak-hickory forests were inspected at each of seven study sites: one site in Arkansas, two in Illinois, two in Indiana, and two in Ohio. All sites were broadly analogous with respect to geology, soil, slope, aspect, and forest cover type. Proportionally, more trees in the red oak group had died than trees in the white oak group at the Illinois, Indiana, and Ohio sites. Mean DBH of dead red oaks was greater than that of dead white oaks at all sites. Evidence of TLCB and *H. atropunctatum* attack was observed at all sites on several red oak species (scarlet, blackjack, northern red, and black oak) and white oak species (white, chestnut, and post oak). TLCB attack was generally more common than *H. atropunctatum* on both red oaks and white oaks. Moreover, incidence of both pests tended to be (a) higher on red oaks than on white oaks, and (b) higher in Illinois, Indiana, and Ohio than in Arkansas.

INTRODUCTION

The Ohio Corridor Study is focused on the possible effects of acidic deposition on oak-hickory forests in the lower midwestern United States (LeBlanc et al. 1988, Loucks et al. 1991). This geographic gradient study was one of several forestry-related studies funded in the 1980's as part of the Forest Response Program of the National Acid Precipitation Assessment Program; see Schroeder and Kiester (1989) for program details. The Ohio Corridor Study was originally designed to test the hypothesis that, for analogous stand conditions and soil types, differences in growth responses of oak and hickory along the gradient could be explained by differences in pollutant dose. Seven study sites were selected within or near four national

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Table 1.--Site location data, median stand age of dominant and co-dominant trees, percent of basal area consisting of *Quercus* and *Carya* species (trees ≥10 cm DBH), mean annual precipitation at or near the site (1955-1986), and estimated annual total (wet + dry) sulfate deposition for two time spans (details in Loucks et al. 1991).

	Sites						
Parameter	ARK	DIX	TON	CSF	HNF	EOA	WNF
State	Arkansas	Illinois	Illinois	Indiana	Indiana	Ohio	Ohio
County	Franklin	Pope	Jackson	Scott	Jackson	Adams	Perry
Latitude	35°45′	37°25′	37°38′	38°30′	39°03′	38°40′	39°35′
Longitude	93°47′	88°40′	89°11′	85°50′	86°12′	83°27′	82°03′
Elevation (m)	685	87	121	97	86	101	123
Age (yr)	61	74	105	93	88	99	121
% *Quercus*	98	88	77	86	98	96	87
% *Carya*	1	9	20	6	>1	1	10
% *Q* + *C*	99	97	97	92	99	97	98
Precip (cm)	120.4	118.1	120.3	108.5	112.6	106.2	104.8
Estimated total annual sulfate deposition ($g/m^2/yr$)							
1900-1985	5.51	8.64	7.66	8.68	8.80	9.99	9.89
1955-1986	3.85	6.73	5.97	6.14	6.23	7.16	7.08

forests along a gradient from northwest Arkansas through southern Illinois and Indiana to south central Ohio. Within the United States, the Ohio River Valley has consistently been a region of high sulfur oxide emissions during the 1900's (Gschwandtner et al. 1986). Estimates of total sulfate deposition (wet + dry) during the 1900's show nearly a two-fold increase from Arkansas to Ohio (Table 1; Loucks et al. 1991), with sulfate concentrations decreasing in more recent years. In addition, the Ohio River Valley is recognized as an area of high ozone concentrations within the United States (Lefohn and Pinkerton 1988); however, no major ozone gradient was detected in the present study (Loucks et al. 1991). All study sites were selected to be south of the maximum glacial advance and north of areas where soils have high sulfate absorption capacities. Soils were primarily of the sandy loam types, with low cation capacity (Guillemette 1989, Loucks et al. 1991).

Although the Ohio Corridor Study sites were selected to be highly analogous, subsequent detailed soil and stand-structure studies indicated that the Arkansas site, and some of the Illinois and Ohio plots would have to be withdrawn from analyses when considering only the most narrowly analogous sites (Loucks et al. 1991). Nevertheless, in the present study, we present results from all seven sites.

Aspects of oak decline and mortality were investigated by several researchers in the Ohio Corridor Study (Loucks et al. 1991). Two pests that were commonly associated with dead oaks along the gradient were the twolined chestnut borer (TLCB), *Agrilus bilineatus* (Weber) (Coleoptera: Buprestidae), and the canker fungus *Hypoxylon atropunctatum* (Schw. ex Fr) Cke. These two pests are commonly associated with stressed oaks, especially drought-stressed oaks (Bassett and Fenn 1984, Haack and Benjamin 1982, Lewis 1981, Mistretta et al. 1981, Tainter et al. 1983). The TLCB is recognized as the principal insect mortality agent of stressed oaks in the eastern United States (Haack and Acciavatti 1991). The virulence of *H. atropunctatum* is less well documented; it is recognized as a saprophyte,

but it may be a weak parasite on severely stressed trees. No other above-ground pests were commonly found on recently dead and dying oaks across the gradient.

The objective of the present study was to categorize the dead oaks at each of the seven Ohio Corridor Study sites with regard to tree species or sub-genus, DBH (diameter at breast height), trunk condition and orientation, and incidence of TLCB and *H. atropunctatum* attack.

METHODS

Study Sites

Detailed information on study site selection and baseline information for all permanent plots is found in Guillemette (1989), LeBlanc et al. (1988) and Loucks et al. (1991). Briefly, seven study sites were selected that had similar vegetation, soils, and geology. These oak-hickory sites were selected to have broadly analogous environments, except for the acidic dose. Sites and their abbreviations are Ozark National Forest in Arkansas (ARK), Dixon Springs (DIX) and Touch of Nature (TON) in Illinois, Clark State Forest (CSF) and Hoosier National Forest (HNF) in Indiana, and Wayne National Forest (WNF) and Edge of Appalachia (EOA) in Ohio; administratively, HNF and WNF have been combined and are now known as the Wayne-Hoosier National Forest. Additional location and site data are presented in Table 1. At each site, approved sampling areas (sample elements) were located on upper slopes with southerly aspects in mature oak-hickory stands that showed no evidence of recent fire damage or logging. Eight 0.04-ha permanent plots were established at each site at randomly chosen points within the sample elements. Across the gradient, tree species composition was complex; about 30 different species were encountered on the 56 permanent plots (LeBlanc et al. 1988). The oak and hickory components of each site are presented in Table 2.

During summer 1989, we inspected all dead oaks for TLCB and *H. atropunctatum* on each permanent plot. That procedure, however, provided fewer than 10 suitable dead oaks per site at four of seven sites. To increase the sample size of dead oaks, we revisited all sites in spring 1990 and marked off large sections of practically all approved sample elements at each site for further inspection; approximately 1-3 ha per site.

Tree Measurements

We first determined whether individual dead trees were oaks by using characters such as bark, branching pattern, buds, wilted foliage, distinctive genus-specific beetle galleries, and wood grain. Then, if possible, oaks were assigned to a species or sub-genus group, i.e., the red oak group (ROG) *Erythrobalanus* or the white oak group (WOG) *Lepidobalanus*. Such assignments were usually not done with oaks that had lost all bark and/or were in advanced

Table 2.--Mean basal area (m^2/ha) of hickory (*Carya*) and oak (*Quercus*) species by site for trees ≥10 cm DBH, based on eight 0.04-ha plots per site (LeBlanc et al. 1988).

	Basal area						
Tree species	ARK	DIX	TON	CSF	HNF	WNF	EOA
Hickory species							
Bitternut, *C. cordiformis*	-	-	-	0.49	-	-	-
Pignut, *C. glabra*	-	0.67	1.97	1.15	0.11	-	3.57
Red, *C. ovalis*	0.22	0.46	1.49	-	-	-	0.31
Shagbark, *C. ovata*	-	0.76	0.11	-	-	0.25	0.17
Mockernut, *C. tomentosa*	-	-	-	-	-	0.08	-
Oak species							
White, *Q. alba* L *	7.23	5.24	2.85	2.20	0.83	10.11	0.95
Scarlet, *Q. coccinea* L	-	-	-	0.55	4.77	0.83	-
Southern red, *Q. falcata* E	-	0.50	-	-	-	-	-
Blackjack, *Q. marilandica* E	-	0.06	0.06	-	-	-	-
Chestnut, *Q. prinus* L	-	-	-	19.21	18.71	8.96	19.16
Northern red, *Q. rubra* E	9.97	1.07	1.05	-	-	0.79	1.81
Post, *Q. stellata* L	-	6.18	6.21	-	-	0.32	0.51
Black, *Q. velutina* E	0.26	4.70	2.71	0.68	0.98	5.33	4.08
Red oak group	10.23	6.33	3.82	1.23	5.75	6.95	5.89
White oak group	7.23	11.42	9.06	21.41	19.54	19.39	20.86
All oaks	17.46	17.75	12.88	22.64	25.29	26.34	26.75
All hickories	0.22	1.89	3.57	1.64	0.11	0.33	4.05
All other species	0.18	0.54	0.42	2.05	0.33	0.62	1.11
All species combined	17.86	20.18	16.87	26.33	25.73	27.55	31.67

* L = white oak group *Lepidobalanus* of genus *Quercus*, E = the red oak group *Erythrobalanus*.

stages of decay. Bark was the principal character used for species or sug-genus designation among dead oaks.

Several parameters were recorded for all dead oaks ≥7 cm DBH, using methods modified from McCune et al. (1988). DBH was recorded to the nearest 1 cm with no correction made for bark loss. At times, DBH had to be estimated, especially for stumps and decadent trees. Precision, as indicated by remeasurement of DBH, was within 0-3% of the original values.

Broad categories of tree condition were recorded to allow inference about the timing of death. Dead oaks that could be identified to species or sub-genus were assigned to one of five categories as given in McCune et al. (1988): 1 = small twigs intact, 2 = main trunk solid, small branches gone, 3 = main trunk soft but shape mostly intact, 4 = main trunk deeply rotted, collapsed, and 5 = main trunk gone, only fragments of tree base remaining. Dead oaks that could not be identified to species or sub-genus because of lack of bark or being in an advanced stage of decay were assigned to category 6.

We estimated percent of bark lost from the main trunk using 10% intervals, with remeasurements never exceeding ±1 interval. In addition, we recorded orientation of the main trunk as either standing, leaning but not touching the ground, fallen on the ground, or only remains of the stump existed.

Definitive signs of TLCB and *H. atropunctatum* were used to designate a dead oak as having been definitely attacked. For TLCB, the distinctive meandering larval galleries on the sapwood surface or D-shaped adult exit holes on the bark surface were used as positive evidence of TLCB attack (Haack 1989, Haack and Acciavatti 1991). In trees that had died the previous growing season (1989), TLCB larvae and pupae were often found because the 1990 surveys took place before adults emerged.

We designated trees as having *H. atropunctatum* infection if we observed one or more stromata on the main trunk as illustrated in Fenn and Holland (1984), Thompson (1963), and Van Arsdel (1972). We recognize that this method underestimates the actual level of *H. atropunctatum* because some infections may not yet have developed stromata, and others may never develop stromata.

On standing trees, the lower 2 m of trunk were always inspected for both pests; upper portions of the main trunk were examined from the ground for *H. atropunctatum* stromata. On leaning trees and those on the ground, nearly the entire trunk was inspected. Typically, incidence of TLCB and *H. atropunctatum* on oaks assigned to trunk conditions 4-6 could not be assessed with high accuracy due to lack of bark and to advanced stages of decay. Although standing trees had the smallest percentage of their trunk area inspected at close range, we consider the TLCB data reliable because this beetle attacks to ground level in the year of tree death (Haack and Benjamin 1982).

RESULTS

Characteristics of Dead Oak Trees

We inspected a total of 1384 dead oaks (≥7 cm DBH) on the seven sites (Table 3). Of the eight oak species found on the study plots, dead individuals of seven species were found: white (*Q. alba* L.), scarlet (*Q. coccinea* Muenchh.), blackjack (*Q. marilandica* Muenchh.), chestnut (*Q. prinus* L.), northern red (*Q. rubra* L.), post (*Q. stellata* Wangenh.), and black oak (*Q. velutina* Lam.) (Table 2). No dead southern red oak (*Q. falcata* Michx.) were found; however, this species was recorded at only one site (DIX; Table 2).

DBH of dead oaks ranged from 7 to 75 cm; mean DBH for red oaks exceeding that of white oaks at all sites (Fig. 1). The 10- to 19-cm DBH class was the most heavily represented at each site. Mean DBH for all dead oaks combined was smallest in ARK and greatest in EOA; mean DBH was positively correlated with median stand age (r^2=0.61, P<0.038, N=7 sites).

In general, dead oaks in trunk-condition categories 3 and 6 were the most frequently assigned (Table 3). Trunk condition patterns were broadly similar between red oaks and white oaks (data not shown). Based on examination by others of dead oaks ≥20 cm DBH on these same sites, oaks in trunk-condition categories 1 and 2 had died in the past 10 years, and those in categories 3 to 5 had died more than 10 years ago (Loucks et al. 1991).

Table 3.--Number or percent of dead oak trees ≥7 cm DBH in various categories by site.

	Site							
Category *	All	ARK	DIX	TON	CSF	HNF	WNF	EOA
Number of dead oaks in all trunk orientation categories (N=1384 trees total)								
All, conditions 1-6	1384	235	309	176	123	285	130	128
All, conditions 1-3	698	139	207	110	51	100	33	58
ROG, conditions 1-3	268	63	61	45	17	33	19	30
WOG, conditions 1-3	430	76	146	65	34	67	14	28
Number of standing or leaning dead oaks (N=647 trees total)								
All, conditions 1-6	647	156	183	63	52	115	33	45
All, conditions 1-3	493	113	157	56	40	75	15	37
ROG, conditions 1-3	189	50	55	23	14	21	9	17
WOG, conditions 1-3	304	63	102	33	26	54	6	20
Percent of all dead oaks (N=1384) by trunk condition (%)								
Condition 1	4	9	4	5	4	4	2	3
Condition 2	10	14	9	4	6	10	3	19
Condition 3	37	36	54	53	32	23	21	23
Condition 4	15	32	10	6	25	12	17	9
Condition 5	4	7	1	2	4	5	9	2
Condition 6	30	2	22	30	30	50	49	44
Percent of all dead oaks (N=1384) by percent bark lost (%)								
0 - 5 %	23	33	37	28	14	14	3	17
10 - 20 %	15	23	21	19	11	8	6	10
30 - 70 %	15	20	10	13	15	16	14	13
80 - 90 %	13	19	8	8	23	10	19	12
95 -100 %	34	5	24	32	37	52	58	47
Percent of all dead oaks (N=1384) by trunk orientation (%)								
Standing	43	62	56	33	43	37	20	30
Leaning	3	4	3	3	0	4	5	5
Fallen on the ground	51	34	41	64	56	57	61	53
Stump only	3	0	0	0	1	2	14	12

* ALL = all red oaks, white oaks, and oaks of unknown species combined; ROG = red oak group; WOG = white oak group.

Percent of bark lost from the main trunk of dead oaks is given in Table 3. Overall, most dead oaks in Arkansas and Illinois had lost relatively little bark (0-20%), while most dead oaks in Indiana and Ohio had lost most of their bark (80-100%). Patterns of percent bark lost were generally similar between red oaks and white oaks (data not shown). There was a positive correlation between percent bark lost and trunk condition category (r^2=0.66, P<0.001, N=1384 trees).

Percent of dead oaks in each trunk-orientation category is presented in Table 3. The ARK and DIX sites had the highest percentage of dead oaks in the standing position, whereas most were on the ground at the other five sites. Trees in the leaning category accounted for 0-5% of the dead oaks at any one site. Decayed stumps (with no obvious associated trunk) were found only at the Indiana and Ohio sites, suggesting some prior logging.

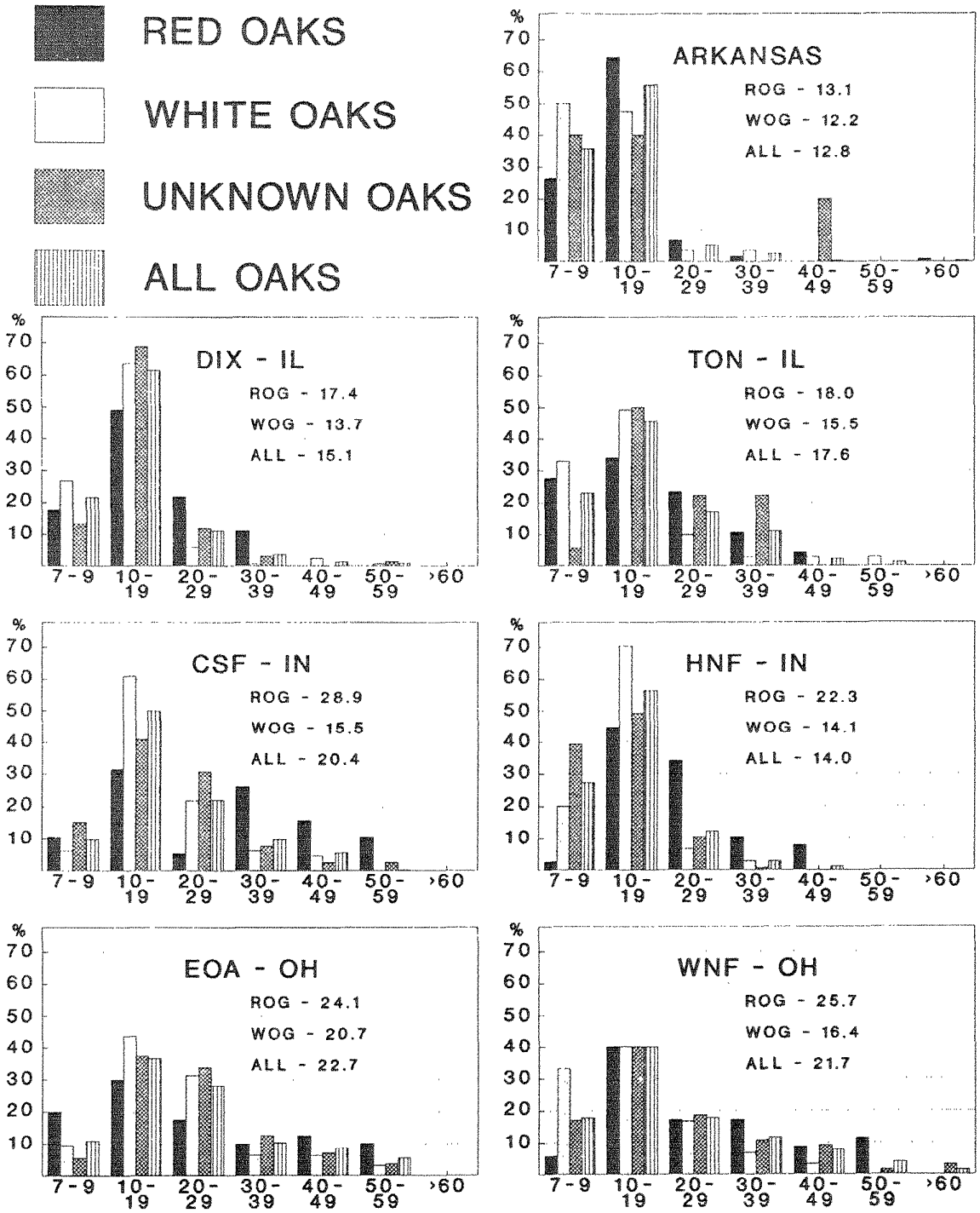

Figure 1. Percent of dead oaks for each site in various groupings by DBH (cm); N values given in Table 3. Unknown oaks are those in trunk-condition category 6 for which species determination was not made. Numbers within each box represent the mean DBH for all dead red oaks (ROG), all dead white oaks (WOG), and all dead oaks combined including those in trunk condition category 6 (ALL).

The above parameters were reanalyzed after restricting the data set to only oaks ≥10 cm DBH and again for oaks ≥20 cm DBH. In general, similar distributions were observed in trunk condition categories, percent bark lost, and trunk orientation (data not shown).

Proportions, on a basal-area basis, were calculated for living oaks in the red oak and white oak groups, using data presented in Table 2. Similarly, using DBH measurements of the dead oaks from the present study (trunk condition categories 1-3 only), basal area of red oaks and white oaks were determined for eact site and the proportions calculated. Comparisons of these two sets of proportions (Fig. 2), indicated slightly increased white oak mortality in ARK, slightly increased red oak mortality at DIX in Illinois, and greatly increased red oak mortality at the remaining five sites, especially CSF in Indiana.

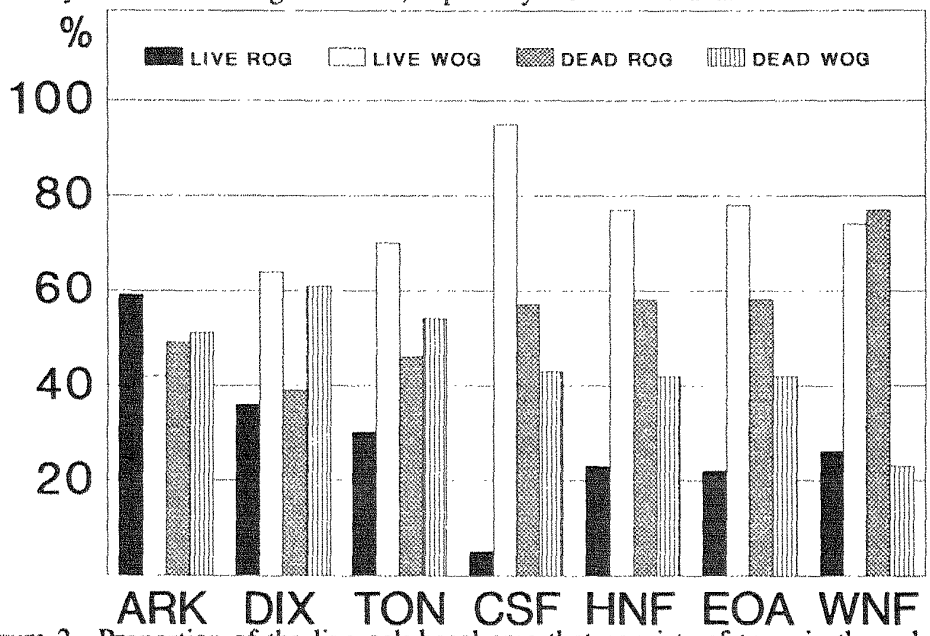

Figure 2. Proportion of the live oak basal area that consists of trees in the red oak group (ROG) compared with those in the white oak group (WOG) (as given in Table 2), and similarly for the proportion of dead oak basal area (from the present study).

Borer and *H. atropunctatum* Infestation Patterns

Both TLCB and *H. atropunctatum* were commonly associated with the dead oaks at all sites. Signs of both pest organisms were noted on individual white, scarlet, blackjack, chestnut, northern red, post, and black oaks at each site where those trees were found as listed in Table 2. For oaks ≥7 cm DBH in trunk- condition categories 1-3, for which signs of attack were most reliable, incidence of TLCB and *H. atropunctatum* attack was lowest in ARK and generally higher in Illinois, Indiana, and Ohio (Fig. 3). In general, more dead red oaks had been attacked by TLCB and *H. atropunctatum* compared with white oaks (Fig. 3). Evidence of attack by both TLCB and *H. atropunctatum* was found on several individual trees, especially red oaks (Fig. 3). The number of dead oaks lacking evidence of attack by either pest declined from west to east (Fig 3).

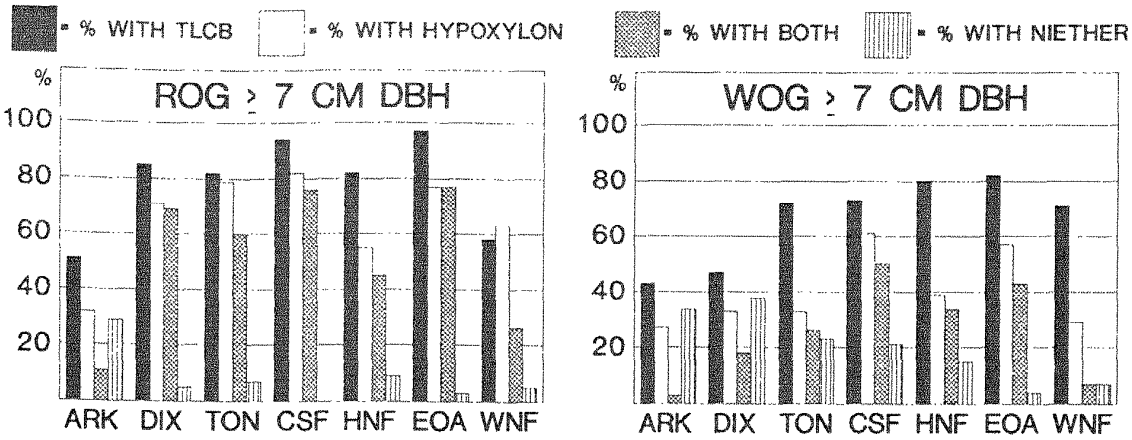

Figure 3. For each site, percent of dead oaks with evidence of TLCB and *H. atropunctatum* attack; based on oaks in trunk-condition categories 1-3 and all trunk orientations (N values given in Table 3).

DISCUSSION

Results of this study indicate that (a) oak mortality occurred at all study sites, (b) that red oaks suffered proportionally greater losses than white oaks at six of the seven sites, and (c) that TLCB and *H. atropunctatum* were commonly associated with dead oaks. Many others have reported episodes of oak decline in the 1980's, especially after drought (Law and Gott 1987, Mistretta et al. 1981, Stringer et al. 1989, Tainter et al. 1983). In the Ohio Corridor Study, historical weather data (1900-1987) indicated similar growing season climate at all sites (including incidence and duration of droughts), although much year-to-year variation did occur (Loucks et al. 1991).

Other Recent Reports of Oak Decline

Several local and regional reports of oak decline have appeared in recent years, and the occurrence of TLCB and *H. atropunctatum* has been mentioned in most; see Kessler (1989) and Millers et al. (1989) for more detailed reviews. For example, in Arkansas, Mistretta et al. (1981) reported widespread oak mortality following the 1980 drought. Both red oaks and white oaks were affected. Of 215 dead oaks examined, *H. atropunctatum* was evident on 49% of the red oaks and 32% of the white oaks: TLCB was not specifically recorded. Of 215 living oaks examined, only 3 had obvious *H. atropunctatum* stromata.

In Missouri, severe oak mortality was recorded by Law and Gott (1987) after the droughts of 1980 and 1983. Red oaks suffered the greatest mortality, especially scarlet and black oaks. TLCB and *H. atropunctatum* were commonly observed on the dead oaks but not quantified.

In addition, Pallardy et al. (1988) have reported increased red oak mortality in central Missouri during the period 1968-1982.

In Kentucky, Stringer et al. (1989) reported widespread oak mortality associated with droughts. Again, red oaks suffered the greatest mortality, mostly scarlet and black oak. Mortality was greatest on xeric sites, on mid- and upper slopes. TLCB was found on 100% of the dead and dying oaks inspected; *H. atropunctatum* was not recorded.

Tainter et al. (1983) reported increased oak mortality in South Carolina after the 1978 and 1980 droughts. Red oaks were the most commonly affected. *Hypoxylon atropunctatum* was evident on practically all dead oaks and on several declining but still living oaks as well.

In a southwide study by Starkey and Oak (1989), oak mortality was associated with sites characterized by shallow rocky soils, upper slopes, and a predominance of red oak species, especially black and scarlet oak. Red oaks suffered more mortality than white oaks; TLCB and *H. atropunctatum* were commonly observed on dead oaks but not quantified.

Incidence of TLCB and *H. atropunctatum*

TLCB and *H. atropunctatum* were commonly associated with dead oaks in our study. TLCB has been documented as a principal mortality agent of stressed oaks, especially those affected by drought and defoliation (Cote and Allen 1980, Dunbar and Stephens 1976, Dunn et al. 1986, Haack and Benjamin 1982). In contrast, the role of *H. atropunctatum* is less clear. Although *H. atropunctatum* fruiting bodies (stromata) are commonly found on recently dead oaks (Karasevicz et al. 1984, Lewis 1981, Thompson 1963, Van Arsdel 1972), they are rare on healthy-appearing or declining oaks. Except for Thompson (1963), most pathologists consider *H. atropunctatum* only a weak parasite, and primarily a secondary invader (Bassett and Fenn 1984).

Detailed work on the ecology of *H. atropunctatum* was conducted in Arkansas by Bassett and Fenn (1984). They isolated *H. atropunctatum* from branches of 57% and trunks of 11% of 300 healthy-appearing oaks, indicating that this fungus is well- positioned to colonize quickly. Moreover, isolation frequencies were similar between healthy-appearing red oaks and white oaks. After girdling of 196 healthy oaks, *H. atropunctatum* developed within 5 months on 77% of the red oaks and 70% of the white oaks.

In our study, several dead oaks had no obvious signs of TLCB or *H. atropunctatum* attack, especially many white oaks (Fig. 3). Some dead oaks were wind-blown, and a few others had been struck by lightning; such oaks would not be attractive to TLCB adults unless the trees were damaged close to or during the adult flight season. We did not examine root systems of the dead oaks, so we do not know the extent of colonization by *Armillaria* spp., another important complex of weak parasites that attack stressed trees. *Armillaria* often attacks root systems concurrently with TLCB (Wargo 1977). Moreover, we do not know what portion of

the observed mortality was the result of suppression or competition. For example, the high numbers of small-diameter dead oaks in Arkansas (Fig. 1), may reflect the lower median age of that site (Table 1), and that active "self-thinning" was occurring.

Greater Susceptibility of Red Oaks

Higher mortality rates of red oaks versus white oaks can be partially explained in terms of differences in xylem translocation. That is, conduction in the red oak group occurs primarily in the outermost annual ring, while conduction in white oaks occurs in the outer two to three annual rings (Kozlowski and Winget 1963, Kramer and Kozlowski 1979). As a result, red oaks are more susceptible to the girdling action of feeding borer larvae, because only the outer growth ring needs to be severed to effectively girdle and kill a branch or the entire tree. Repeated annual attacks may be necessary to kill part or all of a white oak.

Loucks et al. (1991) presented another theory to explain the greater mortality of red oaks, which is based on the apparent greater sensitivity of red oaks vs. white oaks to ozone (Reich et al. 1986, Loucks et al. 1991). Given the high ozone levels in the Ohio River Valley (Lefohn and Pinkerton 1988), this theory suggests that during periods of drought stress, it is the ozone- sensitive red oaks that succomb first to pest attack.

Pollutant Effects on Plant-Pest Interactions

Air pollution stress is known to induce a diverse array of biochemical, morphological, and physiological changes in trees (Kozlowski and Constantinidou 1986). The possibility that these changes could alter plant-pest interactions has been a topic of several reviews (Alstad et al. 1982, Baltensweiler 1985, Fuhrer 1985, Hain 1987, Heagle 1973, Hughes and Laurence 1984, Huttunen 1984, Lechowicz 1987, Mattson and Witter 1990). Moreover, several studies have shown increased insect populations with increased dose of various aerial pollutants (Bolsinger and Fluckiger 1987, Cobb et al. 1968, Dohmen 1988, Hughes and Voland 1988, Neuvonen and Lindgren 1987, Spencer et al. 1988, Stinner et al. 1988, Trumble et al. 1987).

Although TLCB is a common mortality agent of oaks stressed by drought and defoliation, there are no published reports of it attacking oaks stressed by pollutants or acidic deposition. Similarly, there are no reports linking *H. atropunctatum* attack to pollution stress. Our study, with only seven sites, was not robust enough to link pest attack to acidic deposition, or to any other pollutant. However, it is plausible that pollutants could stress oaks sufficiently to increase tree susceptibility to TLCB attack, especially during periods of drought.

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LITERATURE CITED

Alstad, D. N., G. F. Edmunds Jr., and L. H. Weinstein. 1982. Effects of air pollution on insect populations. Annu. Rev. Entomol. 27:369-384.

Baltensweiler, W. 1985. "Waldsterben": forest pests and air pollution. Z. Ang. Entomol. 99:77-85.

Bassett, E. N., and P. Fenn. 1984. Latent colonization and pathogenicity of *Hypoxylon atropunctatum* on oaks. Plant Dis. 68:317-319.

Bolsinger, M., and W. Fluckiger. 1987. Enhanced aphid infestation at motorways: the role of ambient air pollution. Entomol. Exp. Appl. 45:237-243.

Cobb, F. W., Jr., D. L. Wood, R. W. Stark, and J. R. Parmeter, Jr. 1968. IV. Theory on the relationships between oxidant injury and bark beetle infestation. Hilgardia 39:141-152.

Cote, W. A., III, and D. C. Allen. 1980. Biology of two-lined chestnut borer, *Agrilus bilineatus*, in Pennsylvania and New York. Ann. Entomol. Soc. Am. 73:409-413.

Dohmen, G. P. 1988. Indirect effects of air pollutants: changes in plant-parasite interactions. Environ. Pollut. 53:197-207.

Dunbar, D. M., and G. R. Stephens. 1976. The bionomics of the two-lined chestnut borer. In J. F. Anderson and H. K. Kaya (eds.) Perspectives in Forest Entomology, p. 73-83. New York: Academic Press.

Dunn, J. P., T. W. Kimmerer, and G. L. Nordin. 1986. The role of host tree condition in attack of white oaks by the twolined chestnut borer, *Agrilus bilineatus* (Weber) (Coleoptera: Buprestidae). Oecologia 70:596-600.

Fenn, P., and R. T. Holland. 1984. Changes in wood properties of upland oaks invaded by *Hypoxylon atropunctatum*. Ark. Agric. Exp. Sta. Rep. 286. 9p.

Fuhrer, E. 1985. Air pollution and the incidence of forest insect problems. Z. Ang. Entomol. 99:371-377.

Gschwandtner, G., K. Gschwandtner, K. Eldridge, C. Mann, and D. Mobley. 1986. Historic emissions of sulfur and nitrogen oxides in the United States from 1900 to 1980. J. Air Pollut. Control Assoc. (JAPCA) 36:139-149.

Guillemette, R. N. 1989. Reconnaissance survey of geological substrates at the study sites, Ohio Corridor Project. Holcomb Research Institute, Butler University, Indianapolis, Indiana. HRI Rep. 133. 43p.

Haack, R. A. 1989. The twolined chestnut borer. USDA For. Serv., North Central For. Exp. Sta., Northern Hardwoods Note 7.08. 2p.

Haack, R. A., and R. E. Acciavatti. 1991. Twolined chestnut borer. USDA For. Serv., Forest Insect & Disease Leaflet No. 168 (in press)

Haack, R. A., and D. M. Benjamin. 1982. The biology and ecology of the twolined chestnut borer, *Agrilus bilineatus* (Coleoptera: Buprestidae), on oaks, *Quercus* spp., in Wisconsin. Can. Entomol. 114:385-396.

Hain, F. P. 1987. Interactions of insects, trees and air pollutants. Tree Physiol. 3:83-102.

Heagle, A. S. 1973. Interactions between air pollutants and plant parasites. Annu. Rev. Phytopath. 2:365-388.

Hughes, P. R., and J. A. Laurence. 1984. Relationship of biochemical effects of air pollutants on plants to environmental problems: Insect and microbial interactions. In M. J. Koziol and F. R. Whatley (eds.) Gaseous Air Pollutants and Plant Metabolism, p. 361-377. London: Butterworths.

Hughes, P. R., and M. L. Voland. 1988. Increase in feeding stimulants as the primary mechanism by which SO2 enhances performance of Mexican bean beetle on soybean. Entomol. Exp. Appl. 48:257-262.

Huttunen, S. 1984. Interactions of disease and other stress factors with atmospheric pollution. In M. Treshow (ed.) Air Pollution and Plant Life, p. 321-356. New York: Wiley.

Karasevicz, D., W. Merrill, and B. Towers. 1984. Biodeterioration of oak trees dead following gypsy moth defoliation. Phytopathology. 74:871. (Abstract)

Kessler, K. J., Jr. 1989. Some perspectives on oak decline in the 80's. In Proc. 7th Central Hardwood Forest Conference, Carbondale, IL, March 5-8, 1989. USDA For. Serv. Gen. Tech. Rept. NC-132, p. 25-29.

Kozlowski, T. T., and H. A. Constantinidou. 1986. Responses of woody plants to environmental pollution. For. Abst. 47:5-51.

Kozlowski, T. T., and C. H. Winget. 1963. Patterns of water movement in forest trees. Bot. Gaz. 124:301-311.

Kramer,P. J., and T. T. Kozlowski. 1979. Physiology of Woody Plants. New York: Academic Press.

Law, J. R., and J. D. Gott. 1987. Oak mortality in the Missouri Ozarks. In: Proc. 6th Central Hardwood Forest Conference, Knoxville, TN, February 24-26, 1987. p. 525-526.

LeBlanc, D. C., P. W. Somers, T. V. Armentano, and C. C. Myers. 1988. Permanent plot establishment and tree baseline data: the Ohio corridor study. Holcomb Research Institute, Butler University, Indianapolis, Indiana. Rep. 143. 108p.

Lechowicz, M. J. 1987. Resource allocation by plants under air pollution stress: implications for plant-pest-pathogen interactions. Bot. Rev. 53:281-300.

Lefohn, A. S., and J. E. Pinkerton. 1988. High resolution characterization of ozone data for sites located in forested areas of the United States. J. Air Pollut. Control Assoc. (JAPCA) 38:1504-1511.

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

Loucks, O. L., T. V. Armentano, J. Foster, J. Fralish, R. Haack, R. Kuperman, D. LeBlanc, B. McCune, B. Pedersen, and P. Somers. 1991. Pattern of air pollutants and response of oak- hickory ecosystems in the Ohio corridor. In The Eastern Hardwoods Research Cooperative: A Summary of Project Results. USDA Forest Service Gen. Tech. Rept. NE- . (in press)

Mattson, W. J., and R. A. Haack. 1987. The role of drought stress in outbreaks of plant-eating insects. BioScience 37:110-118.

Mattson, W. J., and J. A. Witter. 1990. Pollution induced changes in forest-insect relationships. In Proc. 19th IUFRO World Congress, Section 2, Montreal, Canada, August 5-11, 1990. p. 152-163.

McCune, B., C. L. Cloonan, and T. V. Armentano. 1988. Tree mortality and vegetation dynamics in Hemmer Woods, Indiana. Amer. Midl. Natr. 120:416-431.

Millers, I., D. S. Shriner, and D. Rizzo. 1989. History of hardwood decline in the eastern United States. USDA For. Serv. Gen. Tech. Rept. NE-126. 75p.

Mistretta, P. A., C. E. Affeltranger, D. A. Starkey, S. A. Covington, and Z. M. Wortham. 1981. Evaluation of oak mortality on the Ozark National Forest, Arkansas. USDA For. Serv., SE Area, State and Private For., Rpt. 81-2-26. Alexandria, LA. 15p.

Neuvonen, S., and M. Lindgren. 1987. The effect of simulated acid rain on performance of the aphid *Euceraphis betulae* (Koch) on silver birch. Oecologia 74:77-80.

Pallardy, S. G., T. A. Nigh, and H. E. Garrett. 1988. Changes in forest composition in central Missouri: 1968-1982. Amer. Midl. Natr. 120:380-390.

Reich, P. B., A. W. Schoettle, and R. G. Amundson. 1986. Effects of O_3 and acid rain on photosynthesis and growth in sugar maple and northern red oak seedlings. Environ. Pollut. A 40:1-16.

Schroeder, P., and A. R. Kiester. 1989. The Forest Response Program: National research on forest decline and air pollution. J. For. 87(1):27-32.

Spencer, H. J., N. E. Scott, G. R. Port, and A. W. Davison. 1988. Effects of roadside conditions on plants and insect. I. Atmospheric conditions. J. Appl. Ecol. 25:699-707.

Starkey, D. A., and S. W. Oak. 1989. Site factors and stand conditions associated with oak decline in southern upland hardwood forests. In Proc. 7th Central Hardwood Forest Conference, Carbondale, IL, March 5-8, 1989. USDA For. Serv. Gen. Tech. Rept. NC-132. p. 95-102.

Stinner, D. H., B. R. Stinner, and D. A. McCartney. 1988. Effects of simulated acidic precipitation on plant-insect interactions in agricultural systems: corn and black cutworm larvae. J. Environ. Qual. 17:371-376.

Stringer, J. W., T. W. Kimmerer, J. C. Overstreet, and J. P. Dunn. 1989. Oak mortality in eastern Kentucky. South. J. Appl. For. 13:86-91.

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 Dis. 67:195-197.

Thompson, G. E. 1963. Decay of oaks caused by *Hypoxylon atropunctatum*. Plant Dis. 47:202-205

Trumble, J. T., J. D. Hare, R. C. Musselman, and P. M. McCool. 1987. Ozone-induced changes in host-plant suitability: interactions of *Keiferia lycopersicella* and *Lycopersicon esculentum*. J. Chem. Ecol. 13:203-218.

Van Arsdel, E. P. 1972. Some cankers on oaks in Texas. Plant Dis. 56:300-304.

Wargo, P. M. 1977. *Armillariella mellea* and *Agrilus bilineatus* and mortality of defoliated oak trees. For. Sci. 23:485-492.

BLACK WALNUT TREE GROWTH IN A MIXED SPECIES, UPLAND HARDWOOD STAND IN SOUTHERN INDIANA

Richard K. Myers and Burnell C. Fischer[1]

Abstract: A study was initiated in 1971 on Purdue University woodlands in southern Indiana to monitor the growth of black walnut trees in a natural, unmanaged evenaged stand. Objectives included documentation of walnut growth rates and survival in the absence of management, as well as establishing stand and tree development data baselines prior to initiation of management activities. Individual-tree periodic diameter growth rates were determined and analyzed in relation to tree crown class, stem diameter, and both overstory and understory stocking levels. Growth and survival data suggest that walnuts of intermediate or suppressed crown classes are of doubtful suitability as potential crop trees. Basal area measurements on .05-acre plots surrounding study trees were segregated into overstory and understory components. Results suggested the importance of concentrating timber stand improvement efforts on releasing crowns of walnut crop trees rather than controlling understory vegetation.

INTRODUCTION

The occurrence of black walnut (*Juglans nigra* L.) as a component of mixed-species upland hardwood forests has historically been an important aspect of forestry and a key factor in the wood products industry in the Central States Region. An unwavering demand for the wood of black walnut has kept it at the top of the hardwood market. Intensive procurement of walnut has resulted in a dwindling supply of naturally occurring trees of high quality. As a consequence, the number of acres of agricultural land being converted to black walnut plantations continues to increase. There is also a high degree of interest in managing natural hardwood stands to produce an improved supply of walnut timber.

A remarkable shortage of information exists concerning the growth of individual black walnut trees in natural stands and their subsequent response to silvicultural practices. This paper lends some insight into the growth characteristics of black walnut trees in unmanaged mixed stands based on observations of a population of walnut trees made over the past 19 years in southern Indiana. The intent is to provide foresters and landowners with information that will

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assist in making rational decisions relating to improving walnut growth in the mixed hardwood type.

METHODS AND ANALYSIS

In 1971, 92 black walnut trees were located and chosen for study in a mixed-species hardwood stand on the Southern Indiana Purdue Agricultural Center (SIPAC) in Dubois County, Indiana. These trees are situated on a moist, generally north-facing site, on middle to lower slope positions. Soils are of the Gilpin-Berks complex, have silt loam surface textures, are moderately deep to sandstone and shale parent material (20-36 inches), and are well drained (Wingard 1980). Slopes range from 20 to 50 percent. In 1989, the stand was fully stocked (Gingrich 1967), averaging 119 sq. ft. per acre basal area. Common associated overstory trees are hickories (*Carya* spp. Nutt.), yellow-poplar (*Liriodendron tulipifera* L.), sugar maple (*Acer saccharum* Marsh.), white ash (*Fraxinus americana* L.), red oak (*Quercus rubra* L.), white oak (*Q. alba* L.), and chinkapin oak (*Q. muehlenbergii* Engelm). The stand is evenaged, as indicated by observed stand structure. Site index for red oak is 80-85. Increment borings of 7 codominant trees from different parts of the stand gave ages ranging from 76 to 85 years in 1989. A strong component of sapling and pole-sized sugar maple is currently present in the understory.

In 1971, all black walnut study trees were assigned a permanent identification number and were measured for diameter at breast height (DBH) to the nearest 0.1 inch. Initial tree diameters for the 92 walnuts ranged from 6.8 to 19.5 inches. In 1982, DBH of surviving walnuts was remeasured, providing diameter growth information over twelve growing seasons. Diameter was the only tree characteristic recorded in both the initial and second measurements.

Following the 1989 growing season, another remeasurement was made of surviving study trees, providing a second, seven-year period of known growth rates. In this recent survey, a variety of tree characteristics and stand parameters were recorded. These included walnut DBH, individual tree crown class (dominant, codominant, intermediate, suppressed), basal area of all stems 3.0 inches or larger DBH on a .05-acre circular plot surrounding each walnut, basal area of overstory trees only (trees competing with walnuts for crown space) on the same .05-acre plots, a 10 BAF prism sample of basal area surrounding each walnut, and number of epicormic branches on merchantable stems of each study tree. Diameter growth rates of trees during this 19-year study period were analyzed using analysis of variance and regression techniques.

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Table 1.--Black walnut diameter growth by crown class.

1989 Crown Class	Number trees per class	19-year average annual growth	Period 1 (1971-82) Annual Increment	Period 1 (1971-82) Range	Period 2 (1983-89) Annual Increment	Period 2 (1983-89) Range
		(in.)	(in.)	(in.)	(in.)	(in.)
Dominant	13	.18	.20 a[1]	.12-.29	.15 a	.10-.21
Codominant	48	.13	.14 b	.05-.28	.11 b	.01-.24
Intermediate	22	.08	.09 c	.03-.19	.07 c	.01-.18

[1] Column values followed by the same letter are not significantly different ($p < .05$), based on Duncan's New Multiple Range Test.

Table 2.--Black walnut diameter growth by DBH class for 2 measurement periods.

Initial DBH Class (1971)	Number trees per class	Period 1 (1971-82) Avg. Annual Growth	Period 1 (1971-82) Range	Period 2 (1983-89) Avg. Annual Growth	Period 2 (1983-89) Range
(in.) (in.)		(in.)	(in.)	(in.)	
8	15	0.11 a[1]	.05-.21	0.08 a	.01-.18
10	30	0.13 a	.03-.29	0.10 ab	.03-.18
12	14	0.15 ab	.05-.26	0.12 ab	.01-.24
14	15	0.14 a	.05-.22	0.11 ab	.01-.20
16	5	0.16 ab	.07-.24	0.14 b	.06-.21
18	4	0.21 b	.08-.28	0.16 b	.09-.21

[1] Column values followed by the same letter are not significantly different ($p < .05$), based on Duncan's New Multiple Range Test.

Diameter growth rates are decreasing for walnut trees in all crown classes (Table 1). For dominant trees, diameter increment averaged 0.20 inch per year for 1971-1982, but dropped to 0.15 inch per year during the 1983-1989 growing seasons. Codominant and intermediate DBH growth averaged 0.14 and 0.09 inches per year, respectively, during 1971-1982, but was down to 0.11 and 0.07 inches per year for 1983-1989. Increases in stem circumference, increasing stand density, and drier-than-normal growing conditions during the latter growth period are likely contributing causes of this decline in DBH increment. It is apparent that some type of partial harvest or timber stand improvement (TSI) treatment would be appropriate in the near future if a management goal is to improve the growth of walnut trees in this stand.

Diameter of trees 3.0 inches DBH and greater was measured on .05-acre plots and on 10 BAF prism points around each walnut tree, and basal area was compared with tree diameter increment. It was hypothesized that total plot or point basal area (including both overstory and understory trees) might provide an easily obtainable competition index for predicting current diameter growth. However, correlation analysis showed no evidence of a relationship between walnut DBH growth and either total plot or point basal area. An attempt was also made in this study to identify some combination of observable factors in a mixed stand that may be used to predict walnut growth and survival. A multiple regression analysis showed that crown class, in combination with current DBH (relative to average stand diameter) was the most consistent predictor of diameter increment ($r^2 = 0.3516$, $F = 21.7$; $df = 82$), and was somewhat better than using crown class alone ($r^2 = 0.3096$). Although the relationship is not strong, this evidence does indicate that a refinement of a multi-variable growth prediction model for naturally-occurring walnut trees should certainly include some measure of crown competition. However, non-subjective methods for evaluating crown competition in natural, mixed species hardwood stands have yet to be developed.

Interestingly, the largest and fastest growing walnut trees (dominants) in this study also had the heaviest understory competition, as measured by basal area of suppressed and intermediate trees in the .05-acre plot around each walnut (Table 3). Such results strongly support the idea that the growth of black walnut and other intolerant species on good sites is influenced more by availability of light (crown space) than by any other factor. At any rate, faster diameter growth rates in this stand are clearly not associated with lower levels of understory competition.

Table 3.--Average basal area around walnut trees in three crown classes, as measured on 0.05-acre plots with individual trees as plot center.

1989 Crown Position	Total Basal Area 0.05-acre Plot	Per Acre	Understory Basal Area 0.05-acre Plot	Per Acre
	(ft^2)	(ft^2)	(ft^2)	(ft^2)
Dominant	4.80 a[1]	96.0	2.76 a	55.2
Codominant	5.20 a	104.0	1.77 b	35.4
Intermediate	5.29 a	105.8	1.45 b	28.9

[1] Column values followed by the same letter are not significantly different ($p < .05$), based on Duncan's New Multiple Range Test.

Correlation analysis (Figure 1) showed that diameter growth for the second measurement period is strongly dependent on diameter growth rate in the first period ($r^2 = 0.5570$). In other words, past growth predicts future growth in unmanaged/undisturbed stands. The implication is that periodic measurements may provide especially useful information for the management of woodlands containing high value trees. However, foresters rarely have such

information available and are understandably hesitant to obtain growth rate information by the increment coring of potentially high value trees.

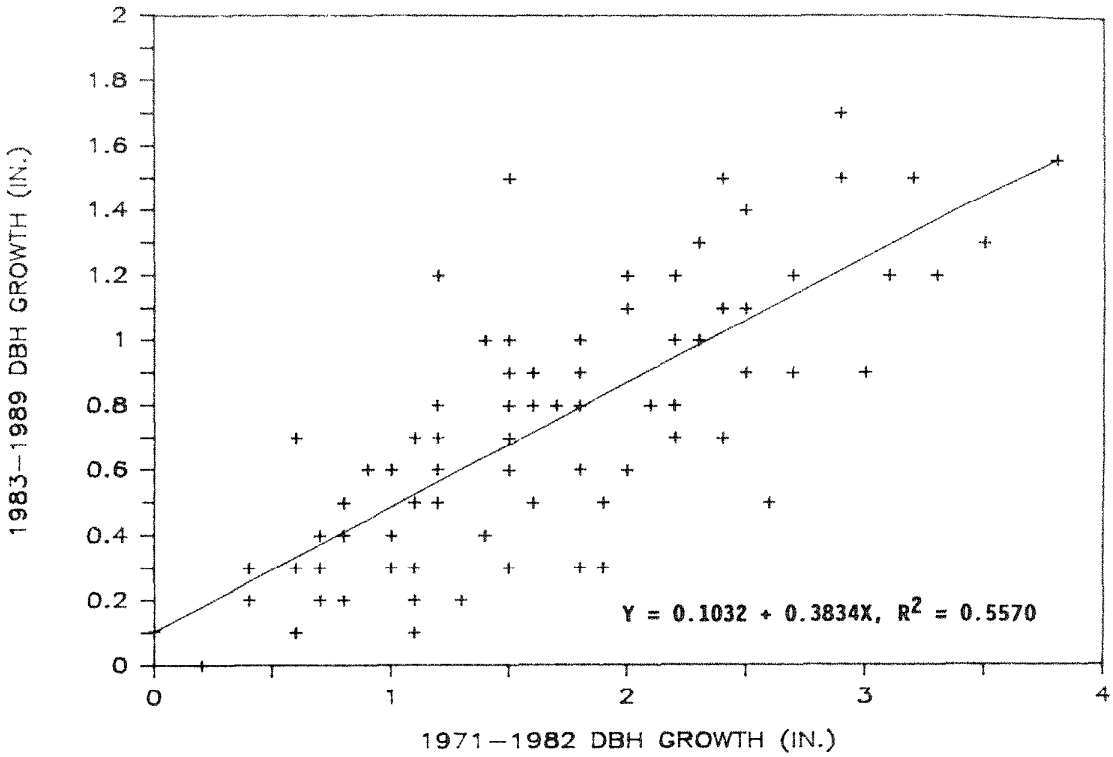

Figure 1. Diameter growth for 83 black walnut trees showing relationship of the first period rate (1971-82) to the second period (1983-89).

What then, is the best method for obtaining information concerning individual tree growth rates? One approach would be to implement continuous forest inventory (CFI) systems involving permanent re-measurement plots or mapped individual trees. Though intensive and time-consuming, systematic approaches for quantifying growth and yield should be considered as potentially useful management tools, especially for high-value hardwood stands with a substantial black walnut component.

SUMMARY

A goal of this investigation was to identify single factors or a combination of tree and stand attributes that can be used to give a consistent prediction of current individual walnut diameter growth rates. Such a system should aid in crop tree identification, assist in avoiding unnecessary TSI work, and improve timber marking decisions. Crown class, in combination

with tree diameter relative to the stand average, was found to be the best indicator of current DBH increment.

One of the measurements in this study included a separate tally of understory tree basal area. Such a description of stocking density can be used as an indirect expression of root competition, since understory trees in this study stand were in no way competing with walnuts for crown space. Since higher levels of understory stocking were not correlated with lower rates of walnut diameter increment, it may be inferred that walnut growth is not influenced nearly as strongly by competition for root space as it is for crown space. Therefore, TSI efforts should be concentrated on releasing black walnut crowns from low-value trees and grapevines, and not on removing understory trees. Research by Phares and Williams (1971) resulted in a similar conclusion.

Black walnut has been shown to be capable of responding to release, if trees have sufficiently full crowns and vigorous root systems (Phares and Williams 1971). However, the size and duration of the growth response must be large enough to offset the cost of the release in order to be considered a sound management decision. The ability to make such decisions depends on further study of walnut response to release in a combination of stand conditions, soil types, geographic locations, and economic situations.

LITERATURE CITED

Gingrich, S. F. 1967. Measuring and evaluating stocking and stand density in upland hardwood forests in the Central States. For. Sci. 13: 39-53.

Kershaw, Jr., J. A. and B. C. Fischer. 1985. Diameter growth of sawtimber size trees in Indiana. Indiana Forest Products Marketing and Wood Utilization Report, Bull. No. 181, p. 21-24.

Phares, R. E. and R. D. Williams. 1971. Crown release promotes faster diameter growth of pole-sized black walnut. USDA For. Serv. Res. Note NC-124. 4 pp.

Shifley, S. R. and W. B. Smith. 1982. Diameter growth, survival, and volume estimates for Missouri trees. USDA For. Serv. Res. Note NC-292, p. 7.

Smith, W. B. and S. R. Shifley. 1984. Diameter growth, survival, and volume estimates for trees in Indiana and Illinois. USDA For. Serv. Res. Pap. NC-257, 10 p.

Wingard, R., Jr. 1980. Soil survey of Dubois County, Indiana. USDA Soil Conservation Service, Purdue Univ. Ag. Exp. Stat. and Indiana Dept. of Nat. Res. 117 p.

EFFECTIVENESS OF ELECTRIC DEER FENCES TO PROTECT PLANTED SEEDLINGS IN PENNSYLVANIA

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Abstract: Electric fences are used in Pennsylvania following a timber harvest to reduce deer browse on natural regeneration. In 1984, five-strand electric deer fences were constructed around two central Pennsylvania clearcuts. Northern red oak, white ash, white pine, and yellow-poplar seedlings were planted inside each fenced clearcut area in 1984 and 1985. One-half of the 1280 seedlings for each species were maintained free from herbaceous and woody vegetation competition with annual applications of glyphosate. Seedling survival, height and deer browsing in the growing season were recorded annually for four years. These data were analyzed to evaluate the effectiveness of electric deer fences to reduce deer browsing on planted seedlings with emphasis on (a) years from construction, (b) species, and (c) species specific height growth. The fences were effective in reducing deer browsing on the planted seedlings for the first two years after construction. After this time, browsing during growing season increased Frequency of browsing was dependent on species and seedling height. White pine was the least frequently browsed and northern red oak was the most frequently browsed. Practices to enable the seedlings to grow >1.2 m in height in two or three years after fence construction will produced the most successful tree planting programs in Pennsylvania.

INTRODUCTION

Post-harvest artificial regeneration in mixed oak stands may be used when regeneration stocking is inadequate or the species composition of the regeneration is not desirable. When stands have abundant herbaceous vegetation and high deer populations, artificial regeneration programs should include steps to control competing vegetation and deer browsing. Effects of competing vegetation on species desirable in mixed oak stands have be reported for planted seedlings (Von Althen 1972, Farmer 1981, Johnson 1984, and Bowersox and McCormick 1987) and planted seeds (Kolb et al. 1990). The use of deer exclosures to reduce the incidence of deer browsing on natural regeneration is well documented (Jordan 1967, Marquis and Brenneman 1981 and Trumbull et al. 1989). Electric fences similar to those described by Brenneman (1982) are currently used to minimize deer browsing to seedlings from natural sources in Pennsylvania. However, the incidence of deer browse to planted seedlings inside

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an electric deer fence has not been well documented. Electric fence designs can vary but principle components are high tensile strength wire and energizers capable of charging the fence with at least 5500 volts. Effectiveness of the various designs may depend on local conditions. In Pennsylvania, properly constructed and maintained five-to-seven strand vertical fences have performed satisfactory.

This study reports on the effectiveness of electric fences to protect planted seedlings of four species (white pine (*Pinus strobus* L.), white ash (*Fraxinus americana* L.), northern red oak (*Quercus rubra* L.), and yellow-poplar (*Liriodendron tulipifera* L.)) from deer browsing in two central Pennsylvania clearcuts.

METHODS

Two mixed oak stands in the Ridge and Valley Provenience of central Pennsylvania were used as study sites. The two sites were located 14 km south of State College and within 1 km of each other. The sites were similar, except one had a southeastern aspect and the other had a northwestern aspect. Additional site information and soil chemical properties have been reported by Kolb et al. (1990). The stands had received shelterwood cuts to increase the quantity of desirable seedlings. Neither stand had acceptable stocking of seedlings 10 to 15 years after treatment. Red maple (*Acer rubrum* L.) dominated the average of 2050 to 5250 commercially important seedling per hectare for the two sites. Ground vegetation was dominated by hay-scented fern (*Dennstaedtia punctilobula* L.) and poverty oat grass (*Danthonia spicata* (L) Beauv.).

In the winter of 1983-84, approximately 6 ha of each stand were clearcut. A vertical five-strand, high tensile steel electric fence was constructed around 4 ha. Vertical arrangement of the wires were 20 cm above ground for the lowest wire, then spacings of 25, 30, 30 and 30 for a total fence height of 135 cm. Wires were attached to insulators installed on low value trees. Horizontal distance between insulators ranged 4 and 25 m, depending on topography and tree spacing. Electrical ground was established by four 1.22 m sections of copper coated rod. Deep cycle marine batteries were used to power Gallagher E-12 energizers. The batteries were changed once per month throughout the study.

In August 1983, four replications of four 80 m^2 plots were established in fern or grass dominated locations at each site. At this time, two plots per replication was treated with an application of 1.7 kg/ha of glyphosate to kill existing fern or grass vegetation. The remaining plots were maintained in the fern or grass condition. In May 1984, twenty bare root seedlings of each species were planted with a pointed planting bar at a 1.0 x 1.0 m spacing in each plot. Hardwood seedlings were 1-0 stock which were top-clipped at the time of planting to a height of 10 cm. The white pine seedlings were 2-0 stock and averaged 10 cm at planting time. Data for the fern and grass (Weedy) plots, and fern- and grass-free (Weed-free) plots were combined for this study. At each site, there was a total of 320 seedlings per species with 160 planted in Weedy plots and 160 planted in Weed-free plots. The 1984 planting methods and treatments were duplicated in 1985. Annual shielded applications of glyphosate

(1.7 kg/ha) were used to control competing vegetation on the weed-free plots. Seedling survival, height and deer browse on the terminal shoot during the growing season were recorded annually for four growing seasons (1984-1988). Deer densities for the area surrounding the study sites were estimated to be about 1 deer per 13 hectares.

RESULTS

Annual seedling survival values for both planting years and both sites were combined and are presented in Table 1. Survival one year after planting was generally above 80% and not strongly affected by herbaceous condition. As years after planting increased survival decreased, more on the Weedy plots than on the Weed-free plots. Survival of the hardwood species averaged 23 to 40% lower on the Weedy plots than on the Weed-free plots.

Table 1.--Average[1] survival for the four species by herbaceous condition and years after planting.

Species	Years After Planting			
Herbaceous Condition	1	2	3	4
	---%			---
White Pine				
Weedy	84	78	73	68
Weed-free	89	82	79	75
Northern Red Oak				
Weedy	94	74	61	58
Weed-free	94	89	82	81
White Ash				
Weedy	92	85	78	71
Weed-free	98	98	95	95
Yellow-poplar				
Weedy	76	53	41	38
Weed-free	87	82	80	78

[1]Values were averaged over planting years and sites, n= 640.

Differences in seedling height between the Weedy and Weed-free plots was species and time dependent (Table 2). The effect of herbaceous competition on height was moderate for white pine and northern red oak, and substantial for white ash and yellow-poplar. Average four years after planting height advantage of the Weed-free plots as compared to the Weedy plots was 1.2x for white pine, 1.3x for northern red oak, 2.2x for white ash and 1.7x for yellow-poplar.

Table 2.--Average[1] height of seedlings that were not browsed by deer for the four species by herbaceous condition and years after planting.

Species	Years After Planting			
Herbaceous Condition	1	2	3	4
	cm			
White Pine				
Weedy	22	44	66	97
Weed-free	22	42	77	115
Northern Red Oak				
Weedy	22	42	66	101
Weed-free	24	55	94	132
White Ash				
Weedy	29	55	87	121
Weed-free	39	99	178	265
Yellow-poplar				
Weedy	34	65	126	189
Weed-free	40	128	230	321

[1]Values were averaged over planting years and sites.

Deer tracks and feces inside the fence were rare during the first and second years after construction. Signs of deer inside the fence increased in the third and following years after construction. This observed pattern of deer penetration was also reflected in the frequency of browsing (Figure 1). The frequency of growing season browsing increased with increasing years after construction and varied among the four species. Northern red oak and yellow-poplar suffered the highest level of browsing. White pine and white ash were browsed less frequently. This browsing had a major impact on seedling height (Table 3). Over all treatments and conditions, browsed white pine, northern red oak, white ash and yellow-poplar seedlings averaged 51, 67, 76 and 74 cm four years after planting, respectively. These average species specific height values were considerably lower than the unbrowsed values.

DISCUSSION

Five strand vertical electric deer fences can be an effective tool in reducing the incidence of deer browse to planted seedlings. To maximize the effectiveness in protection, seedlings should be planted as soon after fence construction as possible and competing herbaceous vegetation should be controlled. In our study, deer penetrations of the fence were low in the first two years after fence construction. Initially, there were low frequencies of growing season browsing to the planted seedlings. Once the deer were frequently penetrating the

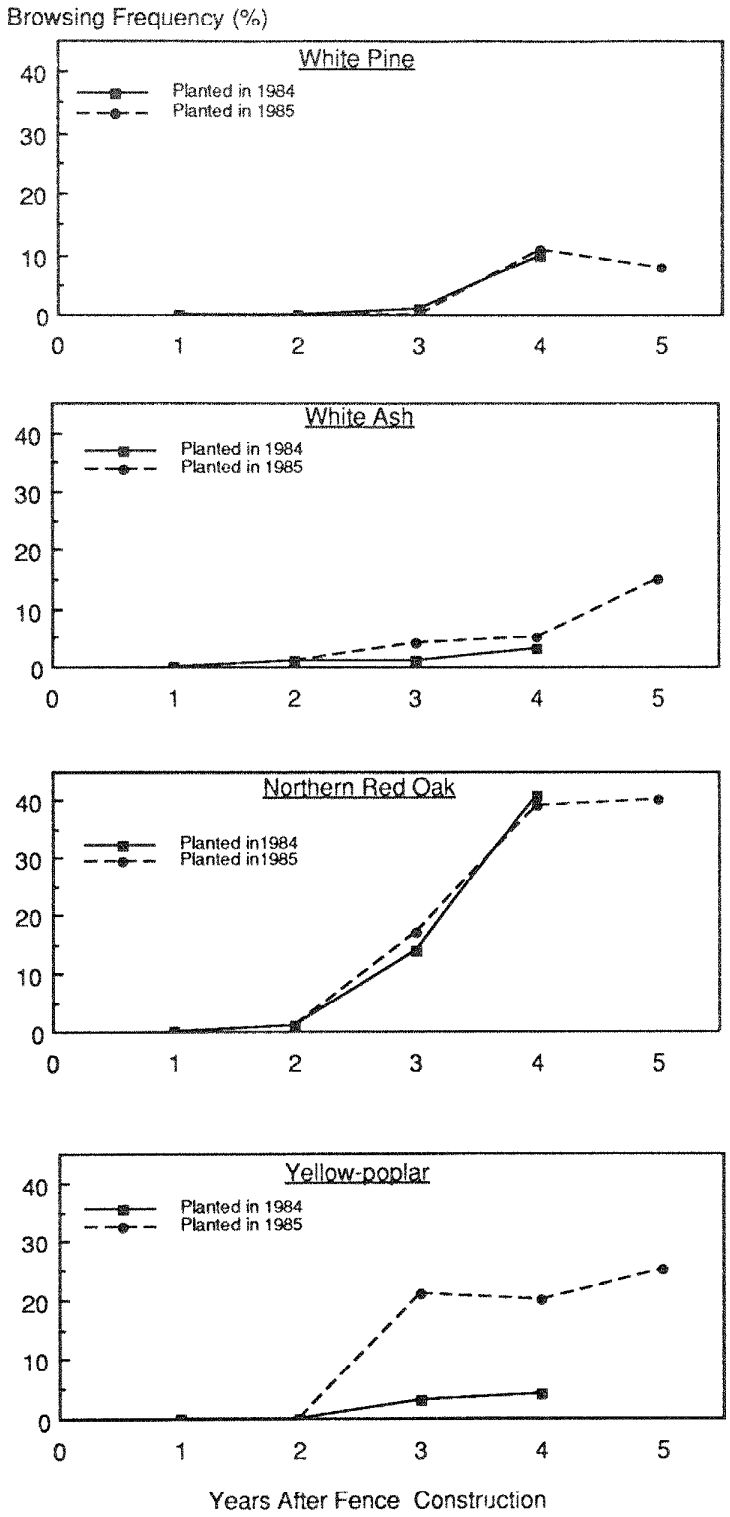

Figure 1. Frequency of deer browsing in the growing season for the four study species as a function of years after fence construction in 1984. Deer browsing activity was measured for four years after the 1984 and 1985 plantings.

Table 3.--Average[1] height of seedlings that were browsed by deer, by species.

Species	Years After Planting			
	1	2	3	4
	cm			
White Pine	--	15	39	51
Northern Red Oak	24	51	58	67
White Ash	30	81	71	76
Yellow-poplar	28	71	70	74

[1]Values were averaged over herbaceous condition, planting years and sites. N ranged from 0 for 1 year after planting to 72, 370, 94 and 81 for fours years after planting for white pine, northern red oak, white ash and yellow-poplar, respectively.

fence, browsing increased and most browsing was to seedling that were <1.2 m in height. Controlling the fern and grass vegetation enabled yellow-poplar and white ash to obtain an average height of >1.2 m in two and three growing seasons, respectively. White pine did not achieve an average height beyond the 1.2 m in four years for either herbaceous condition but it also was not frequently browsed. Northern red oak was frequently browsed by the deer, and its height growth was moderately responsive to reductions in herbaceous vegetation. Additional treatments should be explored to enable northern red oak seedlings to rapidly achieve heights that are beyond the terminal browsing height of deer. These treatments can be the use of larger stock, avoid top-clipping, and selecting seed sources or nursery practices which maximize juvenile growth.

We have maintained these and other fences in Pennsylvania. We have observed deer challenges to the fences and we will use this knowledge plus the experiences of others (PA Bureau of Forestry 1987 and deCalesta et al. 1989) to modify our future installations. Our observations have been that the deer first try to go under the fence. If this fails, they jump through the strands of wire before jumping over the fence. The increase in deer penetrations with time may be attributed to an acquired "knowledge" by deer, desire for favorable habitat inside the fence, and periods of low voltage or conductivity to ground. There were occasions when there was low or no voltage to the fence. These occasions usually followed high wind and electrical storms when downed trees or branches caused shorts in the fence or lighting caused overloads to the energizer. During dry soil conditions or periods of snow pack, resistance to ground was high and differential wire to ground voltage would drop below 3500 volts. An adjustment to minimize deer penetrations was to alternate the electrical charge to each successive strand of the fence. When all the strands are positively charged an airborne deer will not sense an electrical shock, since there is no ground to carry the electricity to the deer. At times we alternated positive and negative strands of the fence to try and negate this access route by deer. Other potential adjustments could include constructing a six or seven strand fence to minimize the distance between strands, frequent maintenance inspections, and using standard electrical service instead of batteries as the power source. However, once deer

penetrated the fence there was little incentive to leave the area due to the greater abundance of food and cover within the fenced area.

LITERATURE CITED

Brenneman, R. 1982. Electric fencing to prevent deer browsing on hardwood clearcuts. J. For. 80(10): 660-661.

Bowersox, T.W. and L.H. McCormick. 1987. Herbaceous communities reduce the juvenile growth of northern red oak, white ash, yellow-poplar, but not white pine. In. Proc. Sixth Central Hwds. For. Conf. Knoxville, TN. p. 39-43.

deCalesta, D., R. Brenneman, D. Dorn and J. Worrall. 1989. Manual for constructing electric fences to protect forest regeneration from deer browsing. Special report to the PA Game Comm. Harrisburg, PA. 25 p.

Farmer, R. E. Jr. 1981. Early growth of black cherry, oaks and yellow-poplar in southern Appalachian plantings. Tree Planters Notes 21: 4-6.

Johnson, P. S. 1984. Responses of planted northern red oak to three overstory treatments. Can. J. of For. Res. 14: 536-542.

Jordan, J. S. 1967. Deer browsing in northern hardwoods after clearcutting. USDA For. Serv. Res. Paper NE-57. 15 p.

Kolb, T. E., T. W. Bowersox and L. H. McCormick. 1990. Influences of light intensity on weed-induced stresses of tree seedlings. Can. J. For. Res. 20: 503-507.

Marquis, D.A. and R. Brenneman. 1981. The impact of deer on forest vegetation in Pennsylvania. USDA For. Serv. Gen. Tech. Report NE-65. 7 p.

PA Bureau of Forestry. 1987. Deer fencing exclosures progress report. Internal report from the Tioga District, Bureau of Forestry, Department of Environmental Resources, Pennsylvania. Harrisburg, PA. 6 p.

Trumbull, V.L., E.J. Zielinski and E.C. Aharrah. 1989. The impact of deer browsing on the Allegheny forest type. NJAF (6): 162-165.

Von Althen, F. W. 1972. Eight-year results of an afforestation study. For. Chron. 48: 325-362.

RELEASING 75- TO 80-YEAR-OLD APPALACHIAN HARDWOOD SAWTIMBER TREES: 5-YEAR D.B.H. RESPONSE

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Abstract: Generally, mature trees on good growing sites are seldom thinned or released. Instead, at maturity the trees are harvested. Data were summarized from north-central West Virginia study areas (northern red oak site index 70 feet and above) where mature trees were released on all sides of the crown (full release). Five-year d.b.h. growth and rates of return information indicate that several species respond to release. Yellow-poplar and northern red oak were the fastest growing species, averaging 1.8 and 1.6 inches d.b.h. Thus, some mature trees will respond and it may be economical in some instances to retain mature trees for esthetics, seed production, and so on, while continuing to earn a good rate of return.

INTRODUCTION

All of us have wondered if a particularly large or "mature" sawtimber tree would respond to a thinning. Growth rings from freshly cut large stumps often indicate that an individual tree had periods of fast growth. There is little information about mature, larger hardwood trees responding to a thinning and this is expected. Simply, managed stands with mature trees usually are scheduled for a harvest cut such as some form of clearcutting, shelterwood, or diameter-limit.

A major problem in eastern hardwood stands is that many trees are about the same age due largely to activities in the past--especially logging and associated site or fire disturbance. These tree stands are now nearing maturity. Once the trees are mature and approach overmaturity they become more vulnerable to insect, disease, and climatic problems. One way to maintain tree-stand-forest health in maturing and mature trees is to try to stimulate growth through a thinning or release. Admittedly, these sawtimber trees often are economically mature since they may be growing, but earning less than an acceptable real rate of return. Also, some forest managers have an underlying belief that larger, mature trees do not respond to release.

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There are a number of concerns when releasing larger mature trees.

1. How much will trees in the dominant-codominant crown class position respond? With normally larger crowns, aren't these trees already growing as fast as possible?

2. Is the growth response for mature trees economical? A real rate of 4 percent is about the breaking point for an alternative investment.

3. How long are the desired species expected to live after release? Options for some current management plans are to grow trees up to 150 to 200 years (Sander and Smith 1989). Longer rotations may become reality due to landowner objectives or physical limitations, that is, too much land base for available personnel to manage.

4. What is the diameter breast height (d.b.h.) response of mature trees left for a short period (shelterwood concept), or two-age, or esthetic management where trees could remain from a short to an indefinite period?

The purpose of this paper is to report the 5-year d.b.h.-growth results of released, mature 75- to 80-year-old sawtimber Appalachian hardwood trees.

METHODS

This study was done on the Fernow Experimental Forest (USDA Forest Service research forest near Parsons, WV) and on the Monongahela National Forest in north central West Virginia. The study areas (four treated areas, plus three controls) were established on good-to-excellent growing sites with a site index for northern red oak (*Quercus rubra* L.) of 70 feet or higher. Annual precipitation ranges from about 55 to 60 inches. During the early 1900's, study areas were logged using forms of clearcutting and high grading.

There were two study treatments. Trees were released to a free-to-grow position, that is, tree crowns released on all sides: and tree crowns not released. Mature, dominant- and codominant-crown class Appalachian hardwood trees were selected as study trees. The average number of mature, released trees in the residual stands ranged from 12 to 20 trees per acre. Average residual basal area was about 20 ft^2/acre with one exception of 30 ft^2/acre. After logging, a stand with released trees resembled a seed-tree cut (Figure 1).

Growth of released trees was compared to similar trees in three uncut fully-stocked mature stands. The trees were in areas set aside for non-management (control areas), where cutting was not permitted and were the only available comparison areas. The three areas were on excellent growing sites--northern red oak site index 80. Also for comparison purposes, the overall growth rates should generally be higher on the control versus the released areas. Thus, any significant differences in results would be conservative. In general, study trees in

Figure 1. Stand with released dominant-codominant, mature 75- to 80-year-old hardwood trees.

the control area had larger initial d.b.h. than the released sample trees. This indicates that trees were growing on better sites and that some trees, such as sugar maple (*Acer saccharum* Marsh.), red maple (*Acer rubrum* L.), and beech (*Fagus grandifolia* Ehrh.), were older and more mature.

Five-year data were collected for 11 Appalachian hardwood species. Sawtimber trees treated included hickory (*Carya* spp.), beech, white oak (*Quercus alba* L.), chestnut oak (*Quercus prinus* L.), red oak, yellow-poplar (*Liriodendron tulipifera* L.), black cherry (*Prunus serotina* Ehrh.), sugar maple, red maple, basswood (*Tilia americana* L.), and white ash (*Fraxinus americana* L.). Initially, all trees 1.0 inch d.b.h. and larger were cut except the study trees. The d.b.h. growth was recorded at the same point on the trees using the Fernow Experimental Forest tree-identification wiring technique as indicated in Figure 2 (Lamson and Rosier 1984).

Figure 2. Permanent tree identification and d.b.h. measuring point using Fernow Experimental Forest technique.

Data were collected before release and 5 years later for treated and untreated trees. Data were analyzed using Analysis of Variance techniques with significance tested at the 1- or 5-percent level, and graphics were developed using SYSTAT software.

RESULTS

Average initial d.b.h. for the 742 released trees was 16.5 inches while the 268 non-released trees had an average d.b.h. of 19.8 inches (Table 1). Overall 5-year d.b.h. growth for the 742 released trees averaged 1.6 inches while similar growth for the 268 non-released trees was 1.0 inch d.b.h.--a difference of 60 percent. If the current growth rates continue, within 10 years after initial treatment periodic growth of released trees will exceed that of non-released trees by more than 1.0 inch, 3.2 inches compared to 2.0 inches.

Five-Year Growth.

The faster growing species for the 5-year period were yellow-poplar and red oak. A surprise was beech, a noted slow grower (Trimble 1969). However, we had only a few sample beech trees.

Five-year results are summarized for individual species in Table 1. For the 742 released trees, 38 percent (281) were yellow-poplar and 31 percent (232) were red oak. Yellow-poplar grew 1.8 inches d.b.h. in 5 years with red oak at 1.6 inches. Beech grew about 1.5 inches d.b.h. Red maple, basswood, and white oak were grouped around 1.4 inches while black cherry and sugar maple grew 1.0 to 1.2 inches d.b.h. Chestnut oak, hickory, and white ash were in the group with the lowest 5-year d.b.h., with a growth response between 0.8 and 0.9 inches d.b.h.

For the non-released trees, the fastest growing species were black cherry (1.2 inches d.b.h.) with red maple, red oak, yellow-poplar, and white ash averaging about 1.0 inch. The slowest growing trees were hickories.

The released trees had significantly greater d.b.h. growth response than non-released trees for the following species--yellow-poplar, red oak, beech, basswood, and hickory. Though released white oak trees grew significantly faster than non-released trees, we had only a three-tree sample for non-released trees. This sample size was definitely too small to make any meaningful comparisons between treatments. However, a number of species did not indicate a significant d.b.h. growth-response difference between released and non-released trees. These species were red maple, chestnut oak, sugar maple, black cherry, and white ash. Also, in two instances (black cherry and white ash), the average d.b.h. growth response for non-released trees was higher than that for released trees, though not significantly higher ($p > 0.05$).

Table 1.--Five-year d.b.h. growth and rate of return for released and non-released, sawtimber-size hardwood trees.

Species	No. trees	Initial d.b.h. (in.)	D.b.h. growth (in.)	Rate of return (%)	No. years before RR (<4%)
			Released		
Yellow-poplar	281	17.6	1.8**	12.8	20+
Red oak	232	17.1	1.6**	5.6	20+
Beech	7	18.2	1.5**	17.9	20+
Red maple	10	13.5	1.4NS	6.1	20+
Basswood	20	15.7	1.4**	9.6	20+
White oak	59	14.6	1.4*	17.6[a]	20+
Black cherry	91	14.8	1.2NS	11.1[a]	0-10
Sugar maple	8	12.8	1.0NS	7.9	0-10
Chestnut oak	12	14.4	0.9NS	4.2	0-10
Hickory	6	13.2	0.9**	14.2	20+
White ash	16	13.1	0.8NS	4.1	0-10
Totals/mean	742	16.5	1.6		
			Non-Released		
Yellow-poplar	46	18.3	1.0	6.5	20+
Red oak	65	21.1	1.1	3.2	0-10
Beech	7	25.9	0.7	3.2	20+
Red maple	11	15.5	1.1	5.4	0-10
Basswood	9	19.4	0.8	3.9	0-10
White oak	3	26.9	0.9	2.4	0-10
Black cherry	52	18.0	1.2	3.8	0-10
Sugar maple	28	25.9	0.7	2.0	0-10
Chestnut oak	6	18.0	0.8	2.4	0-10
Hickory	11	17.4	0.5	3.4	0-10
White ash	30	17.8	1.0	3.3	0-10
Totals/mean	268	19.8	1.0		

*;** Indicate average growth for released tree species significantly different from non-released species at 5 percent (*) or 1 percent (**) level of testing.
[a]Improved from grade 2 to grade 1 in 5 years.
+ More than 20 years
RR=Rate of return

Table 2.--Differences in 5-year average d.b.h. growth among released mature Appalachian hardwood tree species.

Species	5-year growth*
Yellow-poplar	1.8b
Red oak	1.6b
Beech	1.5ab
Red maple	1.4a
Basswood	1.4a
White oak	1.4a
Black cherry	1.2a
Sugar maple	1.0a
Chestnut oak	0.9a
Hickory	0.9a
White ash	0.8a

*Columns with means having same letter are not significantly different. Significance tested at the 1 percent level.

Species growth differences.

Using ANOVA techniques and the Tukey HSD for multiple comparisons, differences in 5-year growth rates were evaluated among the released species. Results indicated d.b.h. growth rates were significantly different among the following species or species groups (Table 2). Yellow-poplar, red oak, and beech grew significantly faster in d.b.h. than the other species, but growth response was not significantly different among the three species. Also, growth for beech was not significantly different from any evaluated species. Differences were not detected among any other species.

Predicted 10-year growth.

Often it is easier relating 10-year growth response than 5-year (Table 3, Figure 3) and we assumed the 10-year growth was twice as much as the 5-year growth. At 5 years, released trees remained in a free-to-grow crown position. As indicated, released yellow-poplar, red oak, and beech grew 3 or more inches in 10 years while released white ash, hickory, and chestnut oak grew less than 2.0 inches d.b.h. for the same period. Overall the released trees averaged 3.1 inches d.b.h. growth and the non-released trees 2.0 inches growth, a 56 percent increase.

Comparing d.b.h. growth of larger trees.

In general, trees from the non-released areas were larger in d.b.h. than trees from the released areas. Smaller and sometimes younger trees have a tendency to grow faster than larger and perhaps older trees. For this reason, the data were divided into two d.b.h. classes, trees ≤22.9 inches and ≥23.0 inches d.b.h. Five-year d.b.h. growth for the released and non-released large trees (d.b.h. ≥23.0 inches) averaged 1.9 and 0.9 inches, respectively. For small trees (≤22.9 inches d.b.h.), the released trees grew 1.5 inches while the non-released trees averaged 1.0 inches d.b.h. Red oak and yellow-poplar were the only species having enough samples to make comparisons. For red oak, it was apparent that when released, the larger trees grew more than the smaller (2.0 compared to 1.5 inches d.b.h.). However, the larger yellow-poplar trees grew the same as the smaller sawtimber trees (1.8 inches d.b.h. in 5 years).

For the non-released tree species, red oak and sugar maple had adequate samples in the diameter-class categories. There was little difference in d.b.h. growth among the two d.b.h. categories.

Table 3.--Ten-year predicted d.b.h. growth for released and non-released sawtimber hardwoods.

	Released		Nonreleased		
Species	No. trees	D.b.h. growth (in.)	No. trees	D.b.h. growth (in.)	Difference (%)
Yellow-poplar	281	3.6	46	2.0	82.8
Red oak	232	3.1	65	2.2	43.5
Beech	7	3.0	7	1.3	138.8
Red maple	10	2.9	11	2.2	31.8
Basswood	20	2.8	9	1.6	71.6
White oak	59	2.7	3	1.8	51.1
Black cherry	91	2.3	52	2.4	- 3.3
Sugar maple	8	2.1	28	1.5	41.1
Chestnut oak	12	1.9	6	1.5	20.8
Hickory	6	1.8	11	1.0	91.7
White ash	16	1.7	30	2.0	-16.2

RATE OF RETURN

Real rates of return (net of inflation) were determined for both released and non-released trees (Table 1). Individual tree values were determined using updated tree- value conversion

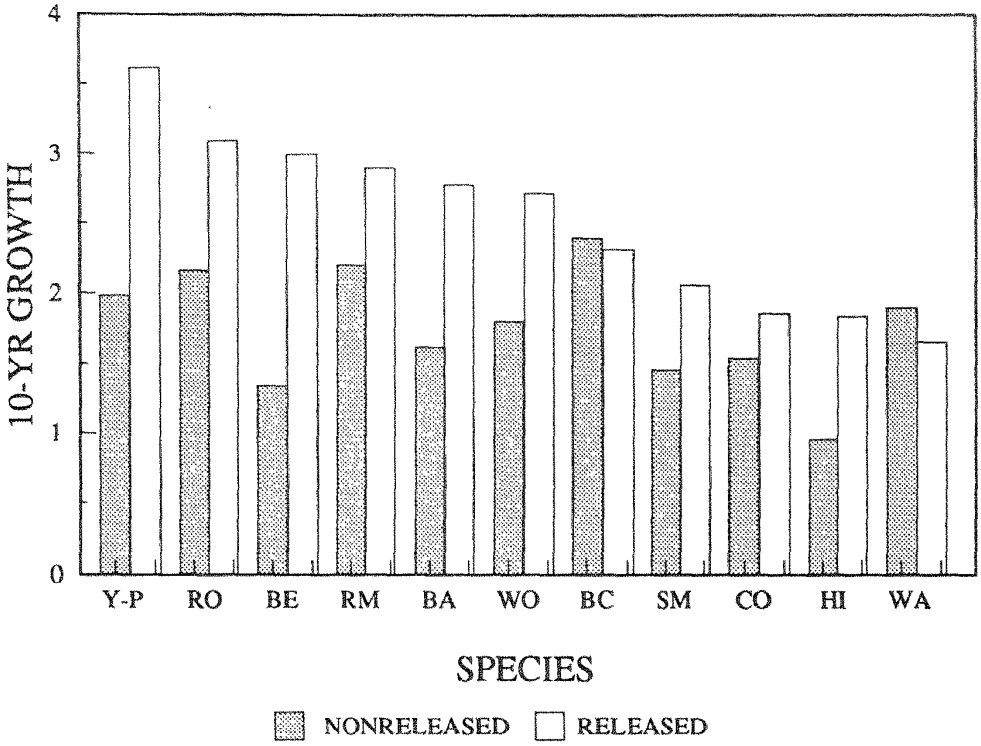

Figure 3. Anticipated 10-year growth information for species of released compared to non-released mature, Appalachian hardwood tree species.

standards, whereby tree values are derived from the value of lumber contained in a particular size and quality tree (DeBald and Dale 1990). Rate of return over the 5-year study period was based on observed growth, initial d.b.h., and merchantable height, assuming trees qualified for the highest possible grade in their size class. Projected rate of return was based on assuming that the observed d.b.h. growth would continue in the future; maximum merchantable height was fixed at 2.5 16-foot logs and trees qualified for grade 1 beyond 16 inches d.b.h.

In general, released trees earned a competitive rate of return over the 5-year period, and we expect many of them to earn at least a 4 percent return for more than 20 years in the future (Table 1). Most non-released trees earned less than 4 percent over the study period. It is clear that release improved the earning power of individual trees, but growth rates must continue for more than 5 years to make release of mature trees a desirable practice from a financial point of view.

If observed d.b.h. growth continues, several species have the potential to earn competitive rates of return for more than 20 years following release. Among released trees, black cherry, chestnut oak, sugar maple, and white ash will earn at least 4 percent for about 10 years after release. All other species will earn at least 4 percent for 20 years or more after release.

Among non-released trees, yellow-poplar and red maple will earn at least 4 percent for 20 years or more. Other species will earn less than 4 percent if not released.

The initial size of released trees influences potential rate of return following release. Rate of return decreases as d.b.h. increases, even though returns can remain positive for large trees. Returns were projected for each species using the observed 5-year d.b.h. growth, assuming individual trees were 18 inches d.b.h., with butt-log grade 1 and merchantable height of 2.5 logs at the time of release. By projecting value increases for trees of similar initial size and quality, we were able to isolate the effect of d.b.h. growth response to evaluate individual species as candidates for release.

Black cherry, sugar maple, chestnut oak, and white ash do not appear to provide an acceptable rate of return for more than 10 years following release. Other species studied will earn at least a 4 percent rate of return for 20 years or more following release. Without release, only yellow-poplar and beech promise competitive earnings for more than 20 years.

DISCUSSION AND CONCLUSIONS

What does this information mean to the forest manager? The bottom line is that some dominant and codominant sawtimber-size tree species on good growing sites will respond to a free-to-grow crown release. For yellow-poplar, the growth response is expected to be more than 3.5 inches 10 years after release. Similarly, northern red oak, red maple, and perhaps beech may grow about 3.0 inches d.b.h. Though all sides of the mature tree crown were released, we do not know the response when releasing two or three sides of the crown. However, in small sawtimber- and pole-size stands dominant and codominant tree crowns should be released on at least three sides for a significant growth response (Lamson and others 1990).

Recommended stand rotation lengths in the Appalachians are often 80 to 120 years based on site index, but in reality, the actual rotations may be 150 to 200. Also, butt-log quality on large mature trees is not influenced by release (Smith and others 1989). In a sample of more than 300 large trees, 20 trees (less than 7 percent) had a loss of quality in the butt log due to epicormic branching. Ten of these trees had epicormic branches on the tree bole before release and most of the individual trees were basswood.

The butt log is the most valuable log in the tree and at this time, 5 years after release, there is little reason to be concerned with the loss of butt log value due to epicormic branching, particularly if the tree boles do not have any epicormic branches before release. Also, a release that is heavy enough to stimulate butt- or second-log epicormic branching on codominant trees would also stimulate the establishment of reproduction--as in a shelterwood. Five years after a heavy release, the reproduction in most hardwood stands provides shade on much of the butt log, and within 10 years after release the crowns of the taller regeneration should shade most of the second log (Smith and others 1989).

Though the number of trees released in the study averaged 12 to 20 per acre, we know that for mature, fully-stocked, sawtimber-size Appalachian hardwood stands, we could expect to release about 20 to 25 good quality timber trees per acre. Most of these trees would be released on at least three sides of their tree crowns. Thinning mature hardwood stands could become more significant in the future as stands continue to mature and then become overmature, that is, trees are maturing faster than buyers are willing to harvest them (Arner and others, this proceedings).

A very heavy thinning in a mature stand where at least three and preferably four sides of the tree crown are released will most likely stimulate a worthwhile diameter-growth increase. Released trees can earn 4 percent or more for up to 10 years following release. If the observed d.b.h. growth continues (an unknown at this time), most species evaluated in this study will earn in excess of 4 percent for 20 years or more. Black cherry, sugar maple, chestnut oak, and white ash may not earn competitive returns beyond 10 years after release. For the cherry and oak trees, 5-year d.b.h.-growth data indicated non-released trees grew faster than released trees. Since study trees were codominant and the released trees were free to grow, it is quite possible these 75- to 80-year-old black cherry and chestnut oak trees will not respond to release.

Normally, fully stocked, even-aged stands on good Appalachian sites with overstory trees at least 75 to 80 years old and pole-sawtimber trees averaging 16 inches d.b.h. can be considered mature and ready for a regeneration harvest cut such as clearcutting. However, clearcutting may not be acceptable to the landowner. Besides partial cuts such as single-tree selection, diameter-limits, shelterwoods, or perhaps no cutting, the forest manager and landowner may have another option on good hardwood growing sites. If an economic cut is possible, consider giving the most desirable dominant and codominant sawtimber trees in the stand room to grow. The residual stand has a shelterwood or seed-tree look but these trees would not be harvested for several years. Many large trees will respond and become more valuable as a result of the release. Even if these trees can be released only on two or three sides of the crown and none of the understory is removed, there should be a d.b.h. response without loss of butt-log value due to the release. Tree vigor and perhaps seed production would increase too. There are site limitations to consider when applying this practice such as shallow soils or soils with fragipans. Also, at the higher elevations trees may become susceptible to glaze-snow damage. All of these limitations could lead to possible blowdown and/or loss of stem quality/value. However, retaining some mature hardwood trees for timber, esthetics and/or sources of seed for wildlife food or the regeneration of difficult species such as oak, is an option that could be acceptable to some landowners. This option could become even more acceptable, if continuing to earn a desirable rate of return is possible.

LITERATURE CITED

Dale, Martin E.; DeBald, Paul S. (in preparation). Tree value conversion standards revisited.

Lamson, Neil I.; Rosier, Robert L. 1984. Wires for long-term identification of trees. J. For. 82(2):110-111.

Lamson, Neil I.; Smith, H. Clay; Perkey, Arlyn W.;Brock, Samuel M. 1990. Crown release increases growth of crop trees. Res. Pap. NE-635. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 8 p.

Sander, Ivan L.; Smith, H. Clay. 1989. Managing mature, even-aged stands. In: Clark, F. Bryan; Hutchinson, Jay G., eds. Central Hardwood Notes. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. p. 6.07-6.07.4.

Smith, H. Clay; Lamson, Neil I.; Miller, Gary W. 1989. An esthetic alternative to clearcutting? J. For. 87:14-18.

Trimble, G.R., Jr. 1969. Diameter growth of individual hardwood species. Res. Pap. NE-145. Upper Darby, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 25 p.

A STAND DENSITY MANAGEMENT DIAGRAM

FOR SAWTIMBER-SIZED MIXED UPLAND CENTRAL HARDWOODS

John A. Kershaw, Jr. and Burnell C. Fischer[1]

ABSTRACT: Data from 190 CFI plots located in southern and west-central Indiana are used to develop a stand density diagram for sawtimber-sized mixed upland hardwoods in the Central States. The stand density diagram utilizes the concepts of self-thinning to establish a maximum size-density curve, and the stocking standards of Gingrich (1967) to formulate intermediate stocking levels. Like Gingrich's diagram, the stand density diagram can be used to determine thinning needs and other intensive management operations. Additionally the diagram has the advantages of relating volume rather than basal area to stand density and is organized in such a manner as to allow stand development patterns to be followed and predicted. Simulation runs from the Central States version of TWIGS are used to compare stand development trajectories on the density management diagram versus the traditional stocking diagram.

INTRODUCTION

The determination of criterion for the expression of stand density or stocking has been a frequent subject of forestry research. The most widely used stocking standard in the Central States is the tree-area equation developed by Gingrich (1967). Gingrich developed stocking standards for upland hardwood forests by utilizing tree-area ratios (Chisman and Schumacher 1940, Krajicek et al. 1961) for trees grown in natural stands under competition, and grown in open conditions free from competition. The tree- area equations express growing space (i.e. - tree area) as a function of number of trees, sum of diameters, and sum of diameters squared. Gingrich presented his results in the form of stocking guides based on number of stems per acre, basal area per acre, and quadratic mean stand diameter (Fig. 1).

Gingrich's stocking guide, and others of similar format (Solomon and Leak 1969; Roach 1977; Tubbs 1977; Hibbs and Bentley 1983), are widely used by practicing foresters in the East as a basis for deciding thinning needs, residual basal areas, and intensive management practices in even-aged stands (Leak 1981). A major reason for the wide utility is that the standards are not considered to be significantly influenced by site quality, stand age, or stand structure (Gingrich 1967).

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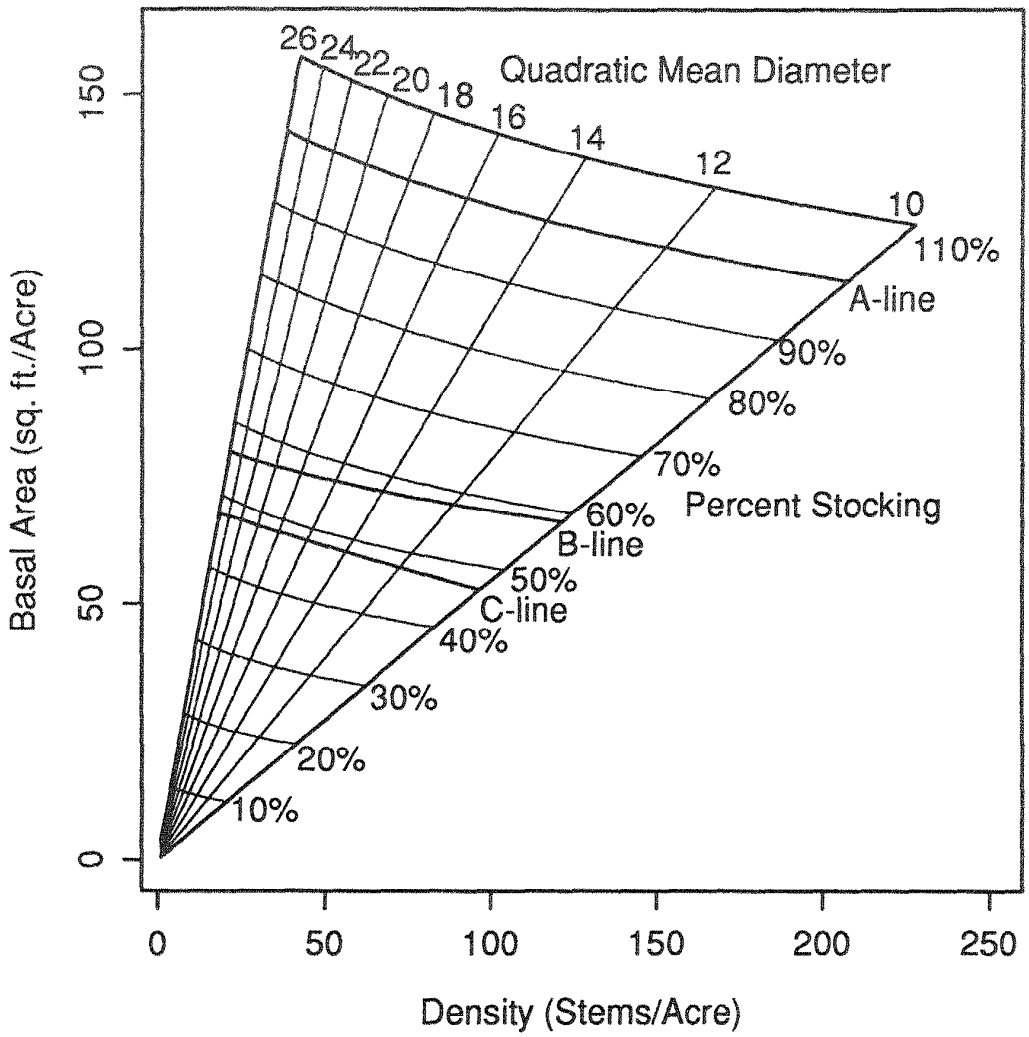

Figure 1. Gingrich's (1967) Upland Central Hardwood stocking guide.

In an alternative approach to the expression of optimum stand density and stocking Drew and Flewelling (1977) utilized concepts developed by Japanese scientists to determine size-density and yield-density relationships. By recognizing the relationship between a given density (stems per unit area) and the maximum mean tree size (weight or volume) a maximum size-density relationship utilizing the -3/2 power rule of self- thinning (Yoda et al. 1963) was developed. Further recognizing there are regions of both random and competition induced mortality, the zone of imminent competition mortality was identified (approximately .51 maximum size-density). Then locating the point of crown closure (.15 maximum size-density) Drew and Flewelling developed a density diagram for Radiata Pine based on density and mean tree volume (cubic feet), thus providing foresters with a simple biological model relating stand density and yield at any stage of stand development. This concept of stand density management has also been applied to Douglas-fir (Drew and Flewelling 1979),

western hemlock (Flewelling, Wiley, and Drew 1980), western redcedar (Smith 1989), and to natural mixed deciduous forests in Japan (Kikuzawa 1982).

Like the stocking guides developed in the East the stand density diagrams developed in the West apply to all stages of stand development (Drew and Flewelling 1977), and have the additional advantage, through the use of volume, of providing a forester with a simple biological model relating density and stand development to yield (Drew and Flewelling 1977). In this paper we develop a stand density diagram for sawtimber-sized mixed upland hardwoods in the Central States and use simulations from the Central States version of TWIGS to compare stand development trajectories on the traditional stocking diagram versus the density management diagram.

DATABASE

Data from 190 0.2-acre Continuous Forest Inventory (CFI) plots located throughout southern and west-central Indiana were utilized to formulate the density relationships. The woodlands are typical of the unmanaged or under- managed mixed species woodlands found throughout the Central States. In the early 1950's, when many of the CFI plots were established the woods were understocked, often the result of previous high-grading. Since then only limited improvement cutting or timber stand improvement (TSI) have been done.

The data collected on the CFI plots at each measurement include plot characteristics as well as tree characteristics. Trees are divided into two classes: sawtimber ($\geq$ 9.0 inches dbh) and poletimber (3.0 inches dbh to 8.9 inches dbh). The poletimber data were not collected during all measurement periods and therefore are not used in this study (thus restricting the scope of this paper to sawtimber-sized stands). The span of measurement ranges from 9 to 30 years. The measurement intervals range between 3 and 14 years with an average of 5 years. A total of 919 plot measurements are utilized in this study. For a complete description of data collection and the woodlands see Schroering and Fischer (1982), Fischer and Kershaw (1985), and Fischer (1986).

The species composition of these plots was fairly typical of central hardwood stands (Table 1). White oak (*Quercus alba* L.) average 15% of the stems per plot. Yellow poplar (*Liriodendron tulipifera* L.) averaged 12%. American beech (*Fagus grandifolia* Ehrh.), sugar maple (*Acer saccharum* Marsh.), and hickory (*Carya* spp.) each represented an average of 11% of the stems. Black oak (*Quercus nigra* L.), and northern red oak (*Quercus rubra* L.) represented 10% and 8% respectively. White ash (*Fraxinus americana* L.) averaged 5% abd black walnut (*Juglans nigra* L.) averaged 3%. The remaining species included American basswood (*Tilia americana* L.), eastern cottonwood (*Populus deltoides* Bartr. ex Marsh.), black cherry (*Prunus serotina* Ehrh.), elm (*Ulmus* spp.), black locust (*Robinia pseudoacacia* L.), chinquapin oak (*Quercus muhlenbergii* Engelm.), pin oak (*Quercus palustris* Muenchh.), sassafras (*Sassafras albidum* (Nutt.) Nees), and red maple (*Acer rubrum* L.). All nomenclature follows Kartesz and Kartesz (1980).

Table 1.--Average percent distribution of stems/plot by species and diameter class for mixed upland central hardwood CFI plots located in southern and west-central Indiana.

Species	Diameter Class										
	10	12	14	16	18	20	22	24	26	28+	Total
White Ash	1.95	1.56	0.79	0.28	0.20	0.18	0.18	0.02	0.06		5.23
Am Beech	1.50	1.38	1.22	0.89	1.20	1.60	0.75	0.77	0.67	0.99	10.97
Hickory	3.88	3.22	2.23	1.01	0.54	0.43	0.06	0.06	0.02		11.45
Su. Maple	2.84	2.72	1.56	0.97	0.79	0.57	0.73	0.30	0.12		10.60
N Red Oak	2.13	1.52	1.20	0.89	0.51	0.65	0.36	0.28	0.10	0.16	7.80
Black Oak	1.60	2.78	2.09	0.97	0.49	0.73	0.39	0.32	0.24	0.44	10.05
White Oak	2.37	2.53	2.55	1.82	1.40	1.16	0.51	0.59	0.36	0.88	14.19
Y. Poplar	3.75	3.63	2.09	1.16	0.71	0.30	0.26	0.06	0.06	0.12	12.14
Bl. Walnut	1.03	0.81	0.41	0.53	0.12	0.14	0.08			0.02	3.14
Misc.	3.64	3.47	2.85	1.09	0.68	0.36	0.10	0.04	0.04	0.04	14.41
Total	25.68	24.63	17.01	9.63	6.65	6.12	3.43	2.49	1.68	2.67	100.00

DERIVATION OF THE RELATIVE DENSITY INDEX

As stated above the maximum size-density relationship utilizes the -3/2 power law of self-thinning to identify the maximum average tree size obtainable at a given density (Drew and Flewelling 1977). The maximum size- density relationship is defined as the natural log-log relationship between mean tree volume and trees per acre:

$$\ln(\overline{V_{max}}) = \ln(C) - \frac{3}{2} * \ln(N) \tag{1}$$

where,

ln = natural log,

V_{max} = Maximum mean tree volume,

C = a constant,

and N = Number of trees per acre.

By solving (1) for ln(N) the following is obtained:

$$\ln(N) = \frac{2}{3} * \ln(C) - \frac{2}{3} * \ln(V_{max}) \tag{2}$$

or (by taking the antilog):

$$N = C^{\frac{2}{3}} * \overline{V_{max}}^{-\frac{2}{3}}. \tag{3}$$

By substituting the current mean tree volume, V, into (3) an expression for the maximum number of trees that can support the current mean tree volume is thus obtained. The relative

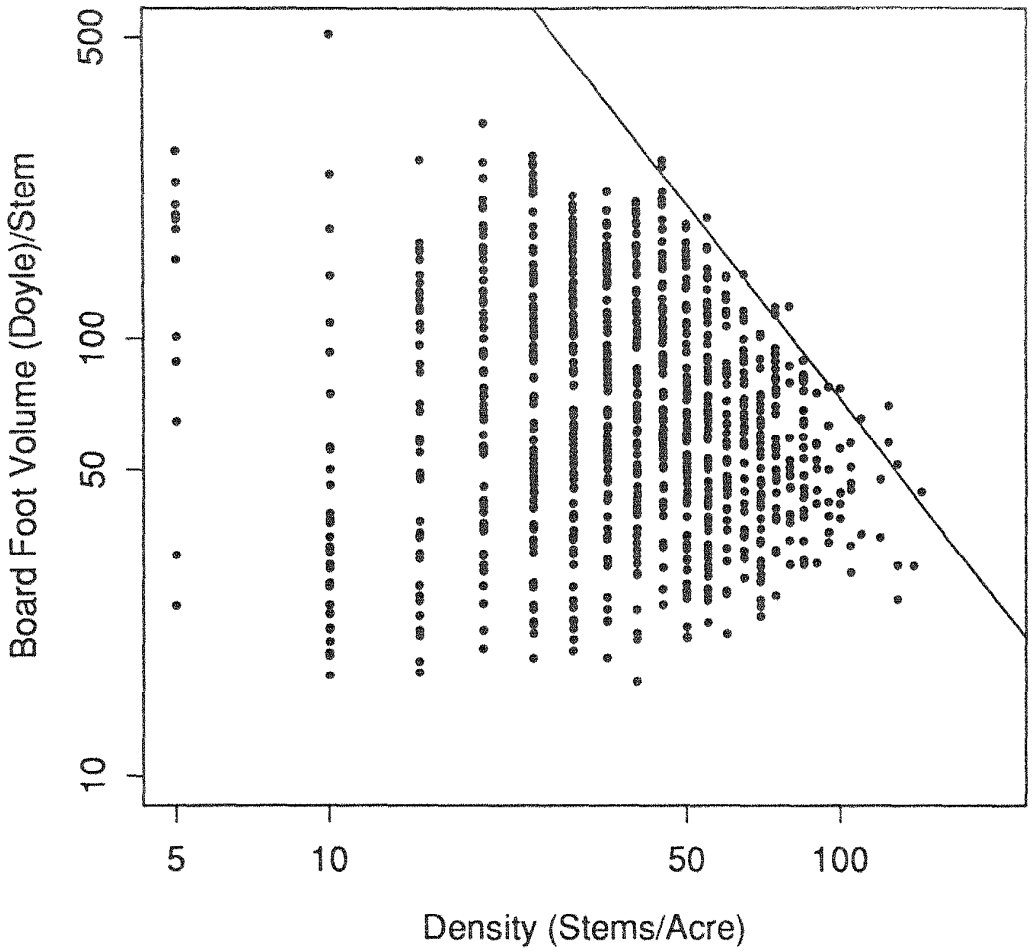

Figure 2. Natural log-log plot of board foot volume (Doyle)/stem over sensity (stems/acre) showing the location of the maximum size-density line. Based on 190 CFI plots located in southern and central Indiana.

density index (RDI) is calculated as the ratio of current number of trees per acre, N, to the maximum number of trees per acre, N_{max}, that can support the current mean tree volume:

$$RDI = \frac{N}{N_{max}}. \tag{4}$$

Since mean tree volume, V, is simply V/N, where V is total volume per acre, (3) can be substituted into (4) and simplified to obtain:

$$RDI=\left(\frac{V}{C}\right)^{\frac{2}{3}}*N^{\frac{1}{3}}. \tag{5}$$

For convenience RDI can be multiplied by 100 so that relative density is expressed as a percentage of maximum density rather than a fraction. In the diagram developed here RDI is expressed in this manner.

Since there is no statistical procedure to estimate maximum relationships, the constant, C, is typically found by placing (1) across the observed maxima on a natural log-log graph of mean tree size (volume or weight) over number of trees per acre, and interpolating (Drew and Flewelling 1977). For each plot, mean board foot volume over number of trees per acre was plotted on a natural log-log scale (Fig. 2). As can be seen from figure 2 there appears to be a maximum mean tree size (board foot volume Doyle) obtainable for a given density (number of trees/acre). Quantification of the maximum size-density relationship was accomplished by constructing lines with slopes of -3/2 at various intercepts until it appeared to represent the observed maximum (Fig. 2). The line placed across this maximum was interpreted to be:

$$\ln(\overline{V_{max}})=11.2-\frac{3}{2}*\ln(N). \tag{6}$$

The line selected was thought to be a more obvious maximum because of the developmental pattern of the plots rather than across the highest point as done in previous studies (Drew and Flewelling 1977, 1979; Flewelling, Wiley, and Drew 1980). Placing the maximum size-density line to allow stands to exceed the maximum size-density relationship temporarily, and thus becoming "overstocked" reflects the thinking of Gingrich (1967) and appears reasonable.

The coefficients in (6) can be rearranged as before to obtain expressions for maximum density (N_{max}) and relative stand density (RDI). The expression for maximum density (3) becomes,

$$N_{max}=(73130)^{\frac{2}{3}}*(V)^{-\frac{2}{3}}, \tag{7}$$

and,

$$RDI=\left(\frac{V}{73130}\right)^{\frac{2}{3}}*(N)^{\frac{1}{3}}. \tag{8}$$

DEVELOPMENT OF THE DENSITY MANAGEMENT DIAGRAM

A relative density measure such as RDI is not very useful unless it is presented diagrammatically relation to easily measured stand parameters. The relationship between

mean tree volume, density, and either basal area or quadratic mean diameter was examined in a variety of equation forms, transformations, and weighting schemes. The equations were compared on the basis of Furnival's Index (1961) and residual analyses. The following equation was selected as "best" based on the above criteria:

$$V = b_0 * N^{b_1} * BA^{b_2} \tag{9}$$

where,

V, N are as defined above,
BA = Basal Area (sq. ft./acre),
and b_i,s are regression parameters.

The parameter estimates, standard errors, and approximate t values are given in table 2. All parameter estimates were significant at the .01 level, the adjusted R^2 was .63 and the root MSE was 41 (bd. ft./stem). This equation will be subsequently used to establish quadratic mean diameter contours on the density management diagram.

Mortality trends were not always as obvious as they were in the data used by Drew and Flewelling (1977, 1979) primarily because of the initial under-stocking and subsequent partial cutting of many of the plots; therefore, another set of relative density criteria needed to be utilized. The stocking standards of Gingrich (1967) was thought to be the most logical criteria to examine.

Table 2.--Parameter estimates, standard errors, and approximate t values for equation 9.

Parameter	Estimate	Standard Error	t-value
b_0	28.69	3.42	8.38
b_1	-1.42	.038	-37.77
b_2	1.52	.044	34.51

Gingrich's stocking standards were translated onto the maximum size- density relationship utilizing the tree-area equations developed by Gingrich and equation (9). Because Gingrich did not provide an equation for the C- line, the equation was derived by interpolating points from the stocking diagram and fitting a simple quadratic equation. The resulting equation was:

$$BA = 72.00 - 0.224 * N + 0.000254 * N^2. \tag{10}$$

The R^2 was .97 and the root MSE was 4.5 (sq. ft.). Figure 3 shows the relationship between the maximum size-density curve and the stocking standards of Gingrich. Based on the equations developed here the maximum size-density curve and the A-line are almost equivalent over the range of data in which the size-density relationship is most evident (45 - 100 trees/acre). As a result of this relationship the density management diagram and the stocking guide are essentially equivalent merely representing a transformation. The final density management diagram is shown in figure 4. The A-line was not included because of

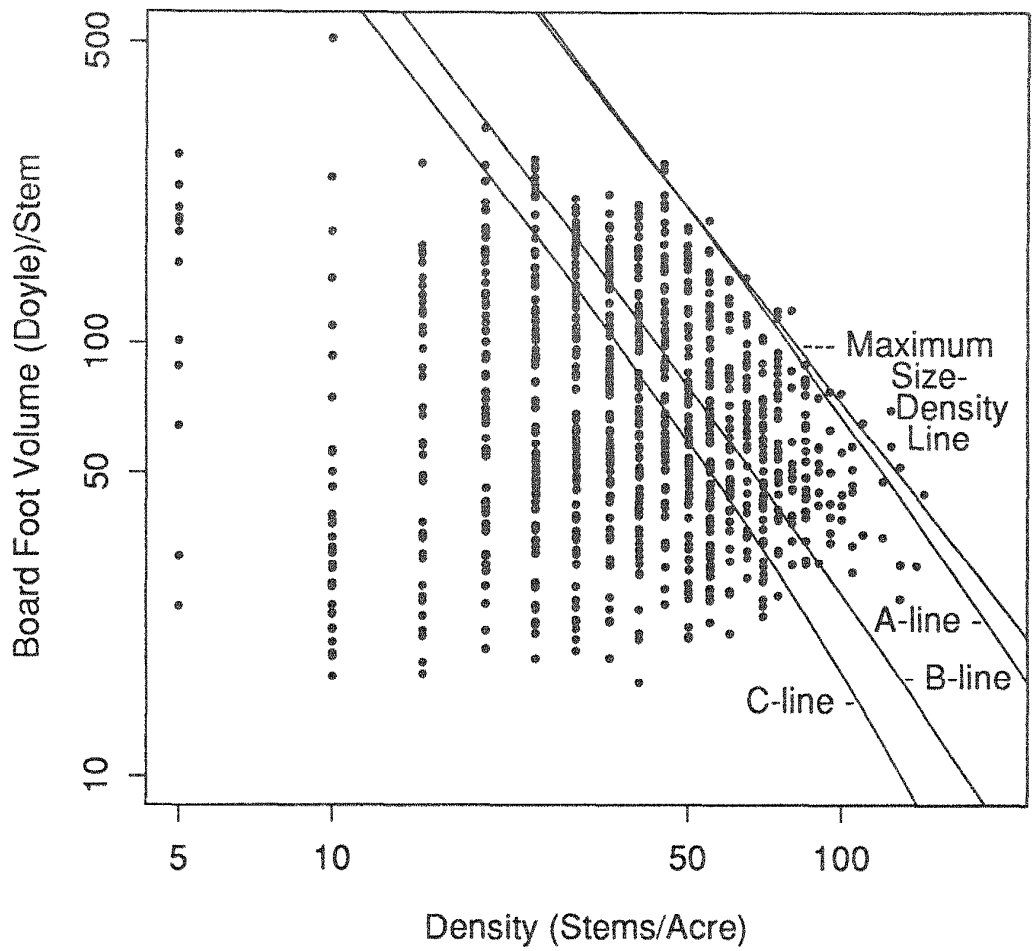

Figure 3. Density management diagram for mixed upland hardwood sawtimber- sized stands (An 8.5 X 11" copy of this diagram is available upon request from the Authors).

it's equivalence to the maximum size-density line (100% relative density line).

APPLICATIONS OF THE DENSITY MANAGEMENT DIAGRAM

TWIGS (The Woodsman's Ideal Growth Simulator) was used to develop a series of examples with which to compare the density management diagram with the stocking guide in relationship to stand development patterns. A stand of average composition was developed from the Feldun Purdue Agricultural Center (FELPAC) CFI database (Fischer et al. 1984). Three initial stand density levels were selected: low - 25 trees per acre; average - 50 trees per acre; and high - 100 trees per acre. The low and high densities represent the range for most of the CFI plots.

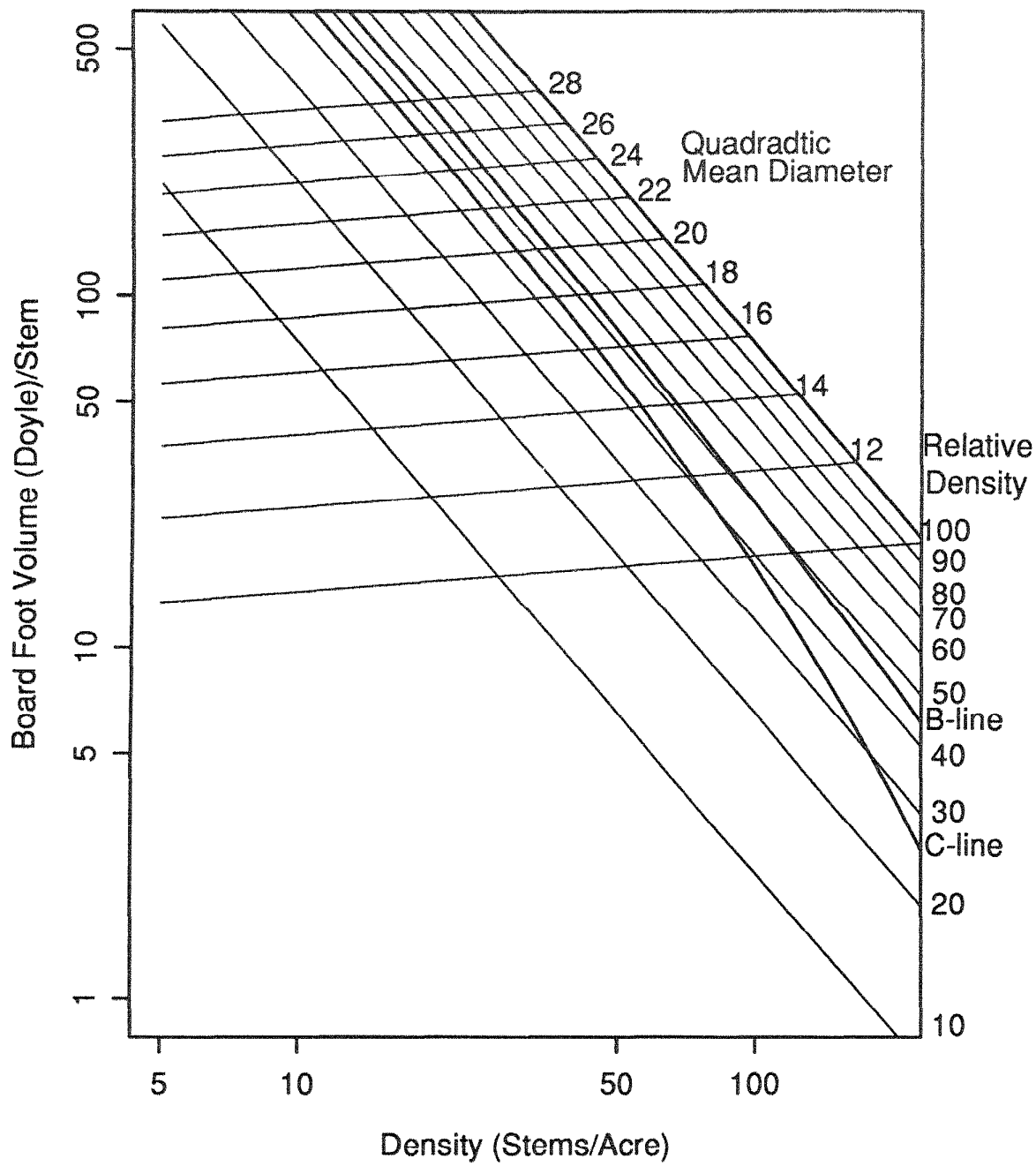

Figure 4. Plot of the maximum size-density relationship showing the location of the stocking criteria of Gingrich (1967).

In the first set of growth simulations (Fig. 5) the stands were allowed to develop without the influence of ingrowth. As can be seen from figure 5a the development of the low density stand is somewhat erratic, while the development of the high density stand is a rather smooth trajectory along the maximum size-density curve. This agrees with the theories of Drew and

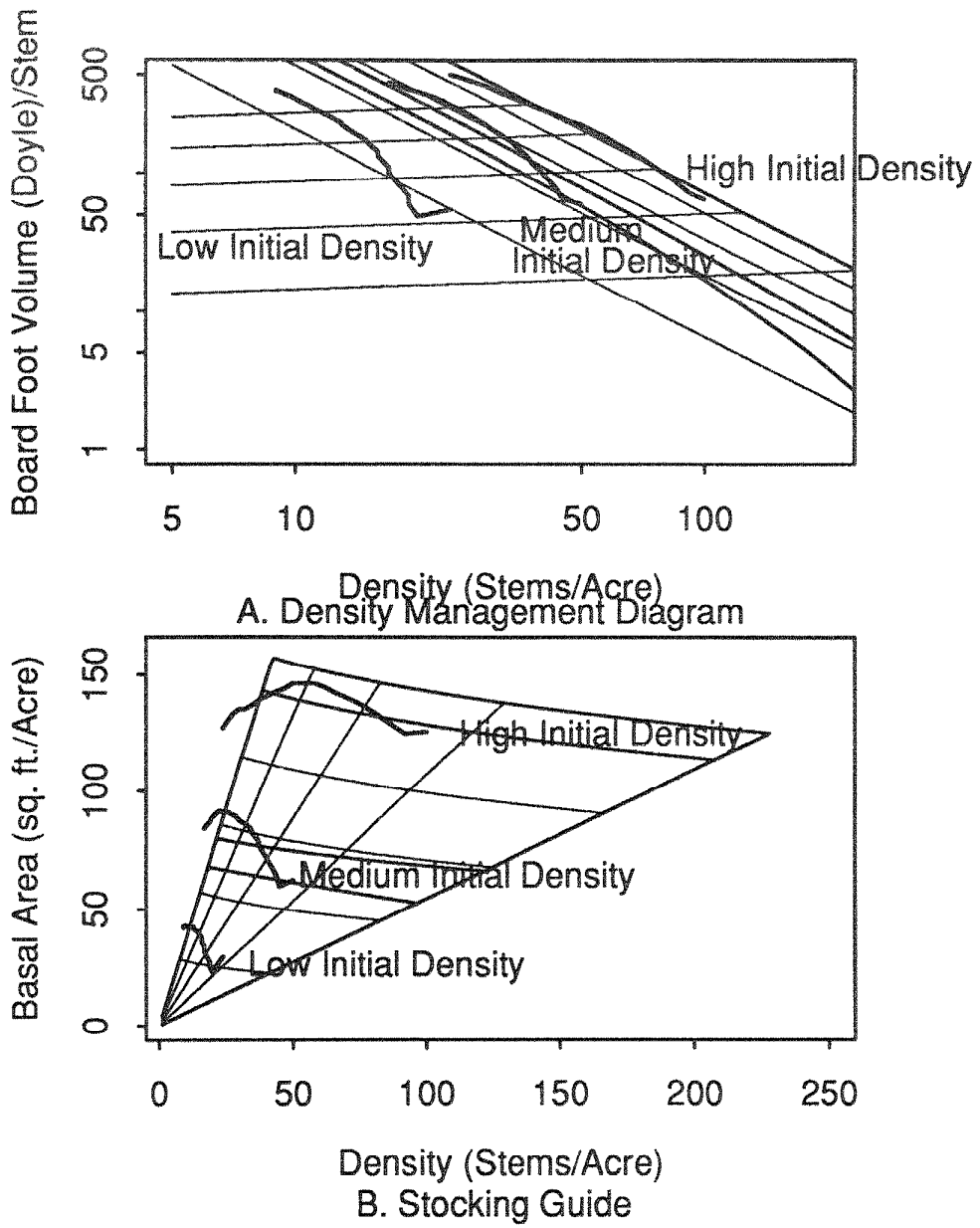

Figure 5. Comparisons of stand development trajectories on the stocking guide versus the density management diagram using simulation results from TWIGS and not accounting for ingrowth.

Flewelling (1977) in which stands below the B-line are subject to "random" mortality, and, therefore, have more erratic development pattern; while stands above the B-line experience "competition-induced" mortality, and have more predictable patterns. Comparing the same data plotted on the stocking guide (Fig. 5b) the trajectories are not nearly as obvious and it is

very difficult to discern exactly what stand development processes are occurring especially with the high density stand.

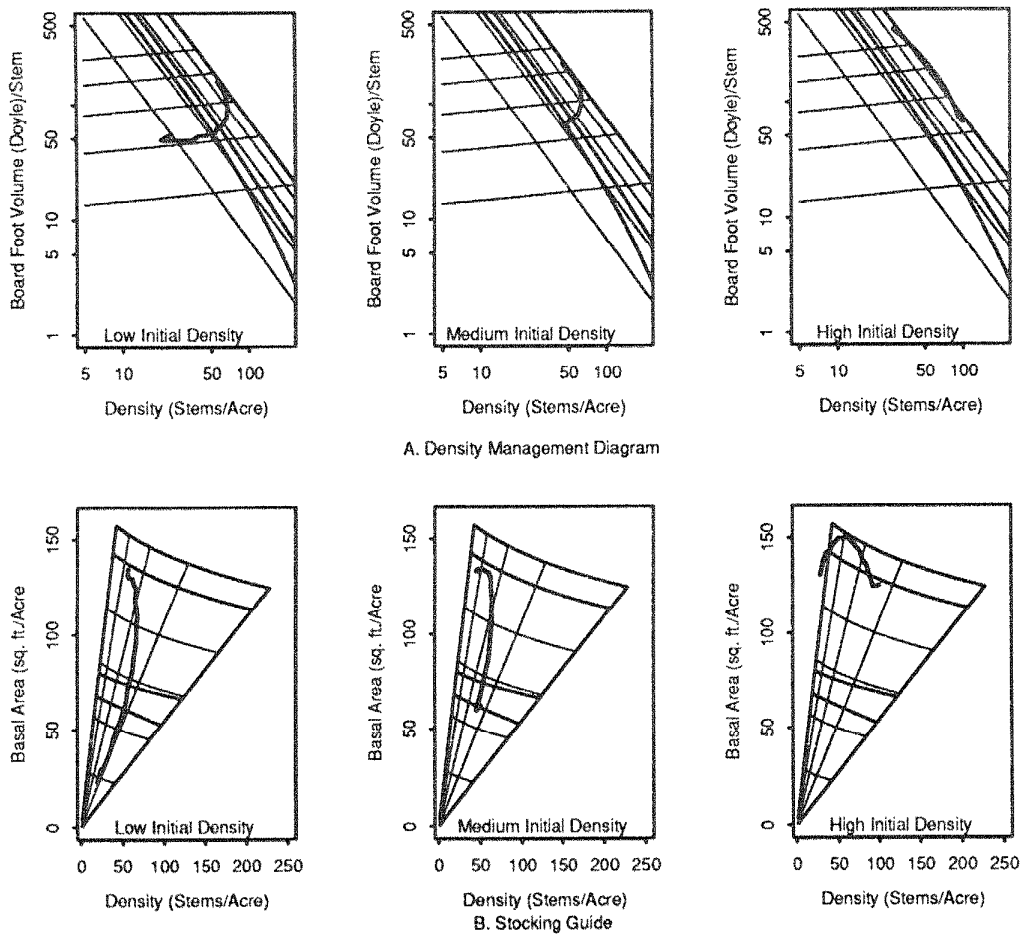

Figure 6. Comparisons of stand development trajectories on the stocking guide versus the density management diagram using simulation results from TWIGS adding ingrowth at an average rate by species and density.

In the second set of simulations (Fig. 6) ingrowth was allowed to influence stand development. Ingrowth was added at an average rate (percentage) by species and density level as computed from the FELPAC database (Fischer et al. 1984). In this set of simulations the stand development processes are again more clearly reflected in the density management trajectories. The stocking guide trajectories for the low and average initial densities do make sense; however, on the density management diagram the process of self-thinning is more evident. Above a relative density of 80 self-thinning is the major stand development process occurring in these simulated stands. On the density management diagram the results of self-thinning are illustrated by the "bend" in trajectory and the movement along the maximum

size-density curve. On the stocking guide the "bend" occurs but is not as pronounced and the stand development processes are not as easily interpreted.

Finally, the last set of simulations introduce partial harvesting into the stand development history. Using the high density stand a series of 1, 2, or 3 partial harvests are simulated to illustrate the use of the diagrams for making management decisions. Cuts are made initial and at 25 year intervals. All harvests attempt to reduce the relative density to the B-line. In this set of simulations both diagrams do an excellent job at depicting the stand development processes and management activities (Fig. 7). In this case the major advantage that the density management diagram has over the stocking guide is the depiction of relative density in terms of volume and stems/acre. Since forest managers typically manage for volume being able to view management decisions and stand development in terms of volume is extremely advantageous.

DISCUSSION AND CONCLUSIONS

The relative density diagram presented in figure 4 provides practicing foresters with a valuable management tool relating volume yield per tree to stand density. The significance of this work to the problem of forest stocking evaluation cannot be underestimated. Results of intermediate operations can now be examined in the units of interest to foresters managing timber: volume and trees per acre rather than in basal area.

The density management diagram integrates relative stocking and stand development theory providing foresters with a tool that not only allows point estimation of stocking but also serves as a stand monitoring system in which stand development and treatment can be traced throughout the stand management history. As the landbase available for commodity production continues to decrease foresters are going to need to intensify management efforts on the remaining acreage. This effort is going to require the development and implementation of innovative management techniques and plans. Utilizing this diagram as a diagnostic and monitoring tool should enable foresters to better evaluate management activities and develop a more adaptive approach to stand management.

The relative density measures presented here do not depart from the measures developed by Gingrich (1967) but are a transformation of Gingrich's standards and an incorporation of the ideas of self-thinning and maximum size-density. The density management diagram is a simple biological model relating yield and density at any stage of stand development, and, although the theoretical constancy of the self-thinning slope (-3/2) has come under criticism (Weller 1987, Zeide 1987), the utility of these diagrams for monitoring stand development and making management decisions should not be overlooked (Smith 1989). Additionally, the criticisms do not reject the concept of self-thinning, but rather question whether the slope of the maximum size-density curve should be constant for all species.

A potential shortcoming of this diagram is the lack of information about trees less than 9.0 inches dbh. It needs to be emphasized that this diagram is for sawtimber-sized stands.

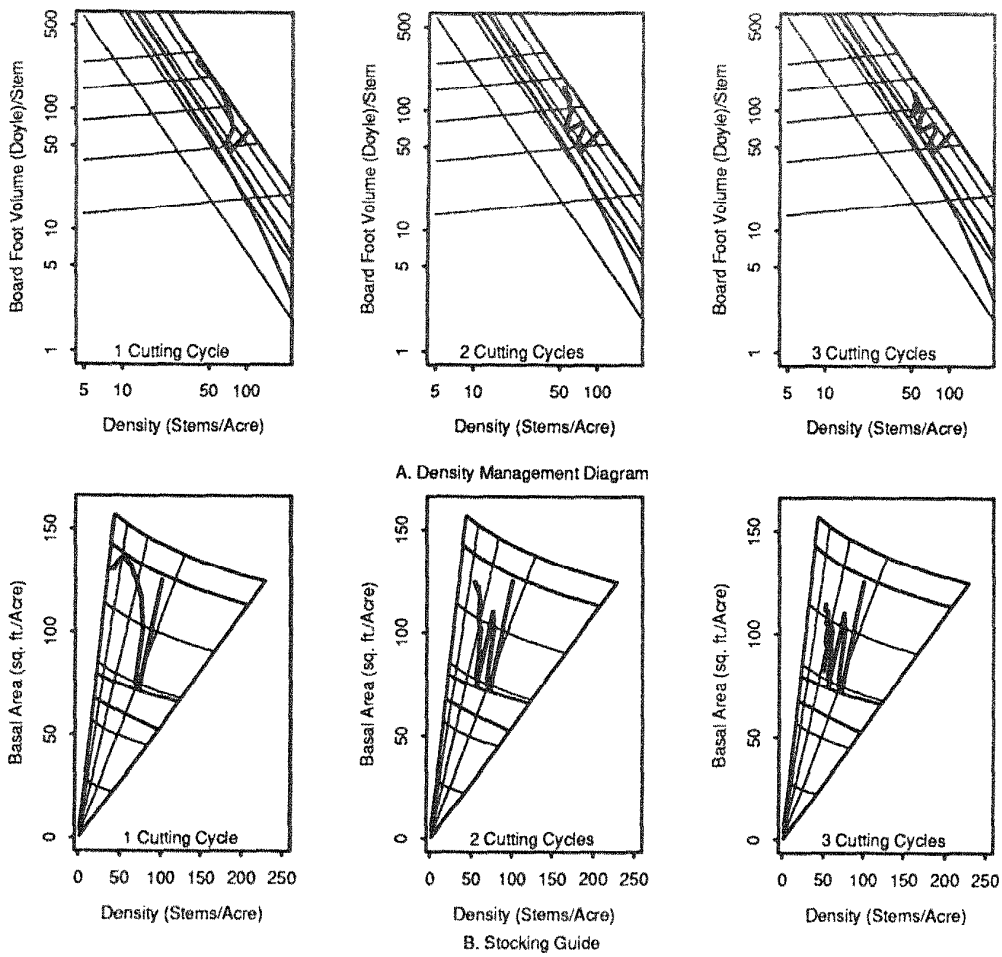

Figure 7. Comparisons of stand development trajectories on the stocking guide versus the density management diagram using simulation results from TWIGS illustrating the influence of management activities on stand development.

Stands which fall below the C-line are considered understocked in sawtimber-sized trees and, therefore, not sawtimber-sized stands. It should also be pointed out that Gingrich's (1967) stocking chart only utilizes trees within the main canopy (i.e. - dominant or codominant). So even though trees down to 2 inches dbh were utilized, very few would be contributing to the overall percent stocking in sawtimber-sized stands. Additionally, the density management diagram is based on merchantable volume; therefore, inclusion of trees below 9.0 inches dbh, which have little or no merchantable volume, would have little or no effect on relative density because mean tree volume will decrease proportionally as the number of trees with no volume increase. Management guidelines for non-sawtimber-sized stands are definitely a gap in our stand management knowledge in the central hardwoods.

Further development of the maximum size-density relationship presented here, including the incorporation of quality related information, will be important future improvements. Much

work continues to be needed in the area of optimal stand density and yield in mixed upland hardwoods. This work represents a first step in linking the two together.

LITERATURE CITED

Chisman, H. H., and F. X. Schumacher. 1940. On the tree-area ratio and certain of its applications. J. For. 38:311-317.

Drew, T. J., and J. W. Flewelling. 1977. Some recent Japanese theories of yield-density relationships and their application to Monterey pine plantations. For. Sci. 23:517-534.

Drew, T. J., and J. W. Flewelling. 1979. Stand density management: an alternative approach and its application to Douglas-fir plantations. For Sci. 25:518-532.

Fischer, B. C. 1986. Development and analysis of the Indiana CFI data base. Purdue Univ. Dept. For. and Nat. Res. Unpublished Report. 12p.

Fischer, B. C., J. A. Kershaw Jr., and G. M. Wright. 1984. Growth and yield of upland hardwoods at FELPAC. In: Indiana For. Prod. Marketing and Wood Util. Rep., Purdue Univ. Bull. No. 177: 17-19.

Fischer, B. C., and J. A. Kershaw Jr. 1985. Growth relationships for upland hardwood sawtimber stands in Indiana. Proc., 5th Central Hardwood Forest Conference. 111-117.

Flewelling, J. W., K. N. Wiley, and T. J. Drew. 1980. Stand- density management in western hemlock. Weyerhaeuser For. Res. Tech. Rep. 042- 1417/80/32. Western For. Res. Center. Centralia, WA. 16p.

Furnival, G. M. 1961. An index for comparing equations used in constructing volume tables. For. Sci. 7:337-341.

Gingrich, S. F. 1967. Measuring and evaluation stocking and stand density in upland hardwood forests in the Central States. For. Sci. 13:38-53.

Hibbs, D. E., and W. R. Bentley. 1983. A management guide for oak in New England. Univ. Conn. Coop. Ext. Serv. Bull. 83-12. 12p.

Kartesz, J. T., and R. Kartesz. 1980. A Synomized Checklist of the Vascular Flora of the United States, Canada, and Greenland. Vol. II: The Biota of North America. The Univ. of North Carolina Press. Chapell Hill, NC. 498p.

Kikuzawa, K. 1982. Yield-density diagram for natural deciduous broad-leaved forests stands. For. Ecol. and Mgmt. 4:341-358.

Krajicek, J. E., K. A. Brinkman, and S. F. Gingrich. 1961. Crown competition - a measure of density. For. Sci. 7:35- 42.

Leak, W. B. 1981. Do stocking guides in the Eastern United States relate to growth? J. For. 79:661-664.

Roach, B. A. 1977. A stocking guide for Allegheny hardwoods and its use in controlling intermediate cuttings. USDA For. Serv. Northeast For. Exp. Sta. Res. Pap. Ne-373. 30p.

Schroering, J. D., and B. C. Fischer. 1982. Growth and yield on upland hardwoods in Southern Indiana. Proc. 4th Central Hardwoods Forest Conference. 141-157.

Smith, N. J. 1989. A stand-density control diagram for western red cedar, Thuja plicata For. Ecol. and Manag. 27:235-244.

Solomon, D. S., and W. B. Leak. 1969. Stocking, growth, and yield of birch stands. Birch Symposium Proc. USDA For. Serv. 106-118.

Tubbs, C. H. 1977. Managers handbook for: Northern hardwoods in the North Central States. USDA For. Serv. North Central For. Exp. Sta. Gen. Tech Rep. NC-39. 29p.

Weller, D. E. 1987. A re-evaluation of the -3/2 power rule of self-thinning. Ecol. Monog. 57:23-43.

Yoda, K., T. Kira, H. Ogawa, and K. Hozumi. 1963. Intraspecific competition among higher plants. XI. Self-thinning in overcrowded pure stands under cultivated and natural conditions. J. Biol. Osaka City Univ. 14:107-129.

Zeide, B. 1987. Analysis of the 3/2 power law of self-thinning. For. Sci. 33:517-537.

EVALUATION OF AN APPROACH TO IMPROVE ACORN PRODUCTION DURING THINNING

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Abstract: Large poletimber size, mixed oak (*Quercus* spp.) stands in Centre County, Pennsylvania were thinned to determine whether acorn production could be improved by retaining the best acorn producing oaks as compared with conventional thinning practices. Sound acorn production averaged 291 and 339 kg/ha in the acorn production and conventionally thinned stands, respectively, prior to thinning. Average yields declined by 79 and 129 kg/ha in the acorn production and conventionally thinned stands, respectively, following thinning. Although declines were less in stands thinned for acorn production, they were not significantly different (P>0.25) from those in conventionally thinned stands. Crown dominance was an important factor affecting acorn production in this study. Ninety-six and 76 percent of the dominant and co-dominant oaks produced acorns. Conversely, only 40 and 8 percent of the intermediate and suppressed oaks were productive. Results of this study indicate that improvements in acorn yields were not sufficient to justify the additional effort and cost of identifying and retaining to best acorn producing oaks prior to thinning.

INTRODUCTION

Factors affecting the acorn production of oaks have been intensively studied over the years because of the importance of acorns in regenerating oak stands and as a food source for many wildlife species. Vigorously growing oaks with well developed crowns are regarded as generally superior acorn producers (Downs and McQuilken 1944, Cypert 1951, and Sharp 1958). Numerous studies also indicate that some individual oaks are consistently good or poor acorn producers and suggest that this may be due to their inherent genetic potential for producing acorns (Downs and McQuilken 1944, Harlow and Eikum 1963, Sharp and Sprague 1967, Goodrum et al. 1971, and Christisen and Kearby 1984).

Harlow and Eikum (1963), Sharp and Sprague (1967), Shaw (1971) and Goodrum et al. (1971) recommended that good acorn producing oaks be retained during thinning to improve acorn yields relative to conventionally thinned stands. This study was undertaken to evaluate the effectiveness of such a recommendation.

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METHODS

Study Sites

Three mixed oak stands were selected as study sites (replications). Two of the stands were on State Game Lands No. 33 and the third one was on State Game Lands No. 60 near Philipsburg in Centre County, Pennsylvania. All 3 stands were within 3.2 km of each other. Three replications were in fully stocked large poletimber size, mixed oak stands ranging from 42 to 58 years of age. The basal area, mean d.b.h. and percentage of oak in the 3 replications are given in Table 1. Measurements of site index within and between replications were not taken.

Table 1.--Basal area, mean d.b.h. and percentage of oak in 3 replications.

Replication	Basal Area (m^2/ha)	Mean d.b.h. (cm)	% Oak*
1	24.2	19.6	69
2	19.9	23.9	66
3	21.7	20.1	75

*Includes red oak (*Quercus rubra*), black oak (*Q. velutina*), scarlet oak (*Q. coccinea*), white oak (*Q. alba*) and chestnut oak (*Q. prinus*).

Study Design

A 3 x 3 randomized block design was used with 3 treatments within each replication:

1. Acorn production thinning (APT) - trees were selected for retention during thinning according to their acorn production.
2. Conventional thinning (CT) - trees were selected for retention during thinning according to conventional thinning criteria.
3. Control (C) - unthinned.

Treatments were applied on adjacent 0.8 ha square blocks in each replication. Assignment of treatment to blocks within replications was random.

Treatments

All oaks in the 3-0.8 ha APT treatment blocks were tagged with aluminum labels. Their potential for acorn production was evaluated by inspection of branches in the crown with binoculars (Sharp 1958). Numbers of acorns on the 6 most heavily bearing branches were counted for each oak (1,318 trees) for 3 years prior to thinning (1974 thru 1976). Those oaks with the best acorn production for 3 years prior to thinning were retained in APT treatment blocks. All non-oaks were removed first during thinning to maximize acorn yields. Then all non-producing and a few of the poorest producing oaks were removed until residual basal area in the APT blocks was the same as that in the CT blocks. Also, each of the oaks in the APT blocks were visually inspected prior to thinning and placed in a dominant, co-dominant, intermediate or suppressed crown dominance category.

CT treatment blocks were thinned by Pennsylvania Game Commission foresters. In addition to conventional silvicultural considerations such as commercial value, spacing and crown dominance, den trees, snags and less common tree species and shrubs were retained for their value to wildlife. C treatment blocks were left untreated to compare their acorn yields with those in both thinning treatments.

Table 2.--Pre-thinning species composition (% of basel area) in APT and CT treatments for 3 replications - January, 1977.

Species	Replication #1		Replication #2		Replication #3	
	APT	CT	APT	CT	APT	CT
red oak	32	30	25	26	59	49
black oak	23	20	8	18	5	8
scarlet oak	10	6	10	11	3	3
white oak	4	2	16	9	3	1
chestnut oak	5	6	6	8	4	15
red maple	25	35	35	28	20	18
sassafras	1	trace	0	0	5	4
hickory spp.	trace	1	0	trace	1	2
black gum	0	0	0	0	trace	trace
aspen spp.	0	0	0	0	0	trace
Totals	100	100	100	100	100	100

In January, 1977, diameter measurements of all trees in all 3 replications of the APT and CT treatment blocks were conducted to determine pre-thinning species composition (Table 2), size class composition and basal area (Table 3). Prism plot cruises were used to determine basal area in the C blocks. Pre-treatment basal area means were 22.9, 23.9 and 20.7 m^2/ha in the APT, CT, and C treatment blocks, respectively .

Table 3.--Pre-thinning size class composition (% of basal area) in APT and CT treatments for 3 replications - January, 1977.

Size class (dbh-inches)	Replication #1 APT	Replication #1 CT	Replication #2 APT	Replication #2 CT	Replication #3 APT	Replication #3 CT
2	39	42	49	55	37	32
4	22	20	13	9	23	26
6	15	15	12	11	15	18
8	13	14	15	12	17	15
10	8	6	5	7	6	7
12	1	2	3	4	2	2
14	1	1	2	2	trace	trace
16	1	trace	1	trace	0	trace
18	trace	trace	trace	trace	trace	trace
20	trace	trace	trace	0	0	trace
22	0	0	0	0	0	0
24	0	0	0	trace	0	trace
BA(ft^2/acre)	99.0	103.0	94.3	104.6	105.7	105.3
BA(m^2/ha)	22.7	23.6	21.7	24.0	24.3	24.2

In March, 1977, the CT blocks were reduced by about 30 percent to 16.3 m^2/ha of basal area using established forestry and wildlife practices. The APT blocks were thinned to the same basal area by removal of all non-oaks as well as the non-producing and poorest acorn producing oaks. Post-thinning APT treatment species and size class composition for Replications #1, #2 and #3 are in Tables 4, 5 and 6, respectively. Post-thinning CT treatment species and size class composition for Replications #1, #2 and #3 are in Tables 7, 8 and 9, respectively.

Beginning in the 1980 growing season, the study area experienced 5 years of gypsy moth (*Lymantria dispar*) defoliation. Defoliation was moderate in 1980, nearly complete in 1981 and 1982, light in 1983 and very light in 1984. By 1984, there was significant oak mortality throughout all 3 replications. To insure equal stocking levels following mortality, the basal area of all live trees in the APT and CT blocks was measured in May of 1984 and June of 1985 and 1986. By 1984, basal area in the APT blocks had had declined by an average of 34 percent from the original thinning in 1977. CT blocks had consistently less mortality. Basal area in the CT blocks was the same in May, 1984 (16.1 m^2/ha) as that remaining following

Table 6.--Post-thinning species and size class composition (ft^2/acre) in Replication #3 - APT treatment - March, 1977.

Size Class (dbh - inches)	Species: Red Oak	Black Oak	Scarlet Oak	White Oak	Chestnut Oak	TOTALS	%
2						0.0	0
4						0.0	0
6	3.2	0.4		0.2	0.8	4.6	6
8	21.0	1.4	1.7		2.1	26.2	36
10	23.7	2.2	1.1		0.5	27.5	38
12	8.7	1.6				10.3	14
14	1.0	1.1				2.1	3
16						0.0	0
18				1.8		1.8	3
TOTAL	57.6	6.7	2.8	2.0	3.4	72.5*	
%	79	9	4	3	5		100

*BA = 16.6 m^2/ha

RESULTS AND DISCUSSION

Annual Acorn Production Trends

Trends in mean acorn production in 3 treatments over 13 years are presented in Table 11. As in other studies (Downs and McQuilken 1944, Goodrum et al. 1971, and Christisen and Kearby 1984), acorn yields varied considerably between years. There were bumper crops (>700 kg/ha or > 600 pounds/acre) of acorns in 3 of 13 years. One (1976) was before and 2 (1979 and 1985) were after thinning (Figure 1). Only 1 other year (1984) had mean acorn yields in excess of 150 kg/ha. The acorn crops of 1980 thru 1984 were heavily affected by gypsy moth defoliation. Trends in annual acorn yields between treatments were fairly consistent throughout the study. All treatments had excellent yields in bumper years and vice versa in years of poor acorn production.

Acorn Production Thinning Versus Conventional Thinning

Mean pre-thinning acorn yields for APT and CT treatment blocks were 291 and 339 kg/ha, respectively. Mean acorn yield declined during the 10 years following thinning in both APT

Table 7.--Post-thinning species and size class composition (ft^2/acre) in Replication #1 - CT treatment - March, 1977.

Size Class (dbh - inches)	Species: Red Oak	Black Oak	Scarlet Oak	White Oak	Chestnut Oak	Others**	TOTALS	%
2		trace				trace	trace	trace
4					0.1	0.2	0.3	1
6	0.6	0.4	0.4	0.2	0.4		2.0	3
8	12.6	3.9	1.7		1.4		19.6	28
10	18.1	5.5	2.8	0.5		0.6	27.5	39
12	4.7	3.2					7.9	11
14		2.1	1.1		1.1		4.3	6
16		1.4	1.4				2.8	4
18		3.5					3.5	5
20		2.2					2.2	3
TOTALS	36.0	22.2	7.4	0.7	3.0	0.8	70.1*	
%	51	32	11	1	4	1		100

*BA = 16.1 m^2/ha
**Includes red maple, hickory spp. and sassafras.

and CT blocks to 217 and 210 kg/ha, respectively (Table 11). Post-thinning declines may have been partially due to gypsy moth defoliation. Acorn yields declined less following thinning in the APT blocks (-74 kg/ha) than in the CT blocks (-129 kg/ha). Friedman's test indicated that changes in acorn yields were not different (X^2r=1.962, P>0.25, 2 df) regardless of the thinning techniques used.

There could be several reasons why acorn yields were not improved significantly by retaining the best acorn producing oaks during thinning. Perhaps oaks with the best genetic potential for consistantly good acorn production were not well identified by counting acorns on the 6 best producing branches. However, this should be a practical phenotypic criteria for selecting oaks with the best genetic potential for acorn production (Sharp 1958). In addition, all 5 oak species (red, black, scarlet, white and chestnut) had at least 1 year of good acorn production during the 3 years when branches were inspected prior to thinning. All 5 oak species had at least fair acorn production during the bumper 1976 crop. If poor or superior acorn producing oaks are relatively consistant in this respect, they should have been easily identified.

Results of this study were heavily influenced by bumper acorn yields in 1979 and 1985. Perhaps continuation of the study would have given different results. However, if the acorn production potential of the oaks retained during thinning was a relatively consistant factor affecting acorn yields, it should have been demonstrated in these bumper years.

Table 8.--Post-thinning species and size class composition (ft/²acre) in Replication #2 - CT treatment - March, 1977.

Size Class (dbh - inches)	Species: Red Oak	Black Oak	Scarlet Oak	White Oak	Chestnut Oak	Others**	TOTALS	%
2	0.2	trace		trace		0.2	0.4	1
4			0.1			0.3	0.4	1
6				0.2	0.2	0.2	0.6	1
8	1.7	2.5	0.7	1.1	0.7		6.7	9
10	4.9	6.6	2.7	1.7	2.7	0.6	19.2	26
12	8.7	4.7	2.4	0.8	0.8		17.4	24
14	11.8	2.1	3.2				17.1	24
16	2.8	1.4	1.4				5.6	8
18				1.8			1.8	2
20							0.0	0
22							0.0	0
24	3.1						3.1	4
TOTALS	33.2	17.3	10.5	5.6	4.4	1.3	72.3*	
%	46	24	14	8	6	6	2	100

*BA = 16.6 m^2/ha
**Includes red maple and hickory spp.

Crown Dominance Versus Acorn Production

Studies by Downs and McQuilken (1944), Cypert (1951), Burns et al. (1954), Sharp and Sprague (1967) and Goodrum et al. (1971) have indicated the importance of crown dominance on acorn yields. The importance of crown dominance was also apparent in the study. Ninety-six and 76 percent of the dominant and co-dominant oaks produced acorns, respectively. Conversely, only 40 and 8 percent of the intermediate and suppressed oaks, respectively, were productive (Table 12). Crown dominance was an extremely important factor ($H=10.37$, $P<0.001$) influencing whether or not oaks in the APT treatment blocks produced acorns.

All the non-producing oaks as well as some of the poorest producers, were removed during thinning. Poorest producing oaks also tended to be suppressed and intermediates. Since many of the suppressed and intermediates were removed in the CT blocks, size class distributions of trees retained in the APT blocks were similar to those in the CT blocks (see Tables 4 through 9). Even the spacing of residual trees was observed to be similar in the

Table 9.--Post-thinning species and size class composition (ft²/acre) in Replication #3 - CT treatment - March, 1977.

Size Class (dbh - inches)	Species: Red Oak	Black Oak	Scarlet Oak	White Oak	Chestnut Oak	Others**	TOTALS	%
2						0.1	0.1	trace
4						0.3	0.3	1
6	2.4	0.4	0.2	0.2	0.4	1.0	4.6	6
8	14.0	1.8	0.3	0.4	4.5	1.1	22.1	31
10	19.8	2.7	1.7		2.2	0.5	26.9	38
12	8.7				0.8		9.5	14
14	1.0	1.1					2.1	3
16		1.4	1.4				2.8	4
18							0.0	0
20		2.2					2.2	3
TOTALS	45.9	9.6	3.6	0.6	7.9	3.0	70.6*	
%	65	14	5	1	11	4		100

*BA = 16.2 m²/ha
**Includes red maple, hickory spp., sassafras, aspen spp., and blackgum.

Table 10.--Mean basal area (m²/ha) in 3 treatments.

Date	Treatment: APT*	CT*	C**
	Prior to thinning		
January, 1977	22.9	23.9	20.7
	Following thinning		
March, 1977	16.3	16.3	?
	Following gypsy moth mortality		
May, 1984	10.6	16.1	?
June, 1984	10.6	10.6	?
June, 1985	10.3	10.3	?
June, 1986	11.3	11.3	15.6

* Based on diameter measurement of all trees in 3 replications.
**Based on 10 BAF-10 prism plots in all 3 replications.

Table 11.--Mean pre- and post-thinning acorn production for 3 treatments*.

Year	Treatment APT	CT	C
		Pre-thinning	
1974	44	39	44
1975	46	35	79
1976	783	944	658
Mean (3 yrs.)	291	339	260
		Post thinning	
1977	22	33	33
1978	5	2	7
1979	771	952	618
1980	93	62	68
1981	0	5	11
1982	0	1	0
1983	0	8	2
1984	63	293	122
1985	1081	680	734
1986	135	59	30
Mean (10 yrs.)	217	210	163
Change	-74	-129	-97
% change	-25.4	-38.1	-37.5

*Figures represent mean (for 3 replications) estimated sound acorn production in kg (fresh weight)/ha.

Table 12.--Percentage of producing oaks, by crown dominance category in 3 APT replications- 1974 thru 1976.

Replication	Crown Dominance Category Dominant	Co-Dominant	Intermediate	Suppressed
1	90.7	71.3	30.0	0.0
2	97.8	80.9	53.5	9.7
3	100.0	75.3	37.2	13.9
Mean	96.2	75.8	40.2	7.9

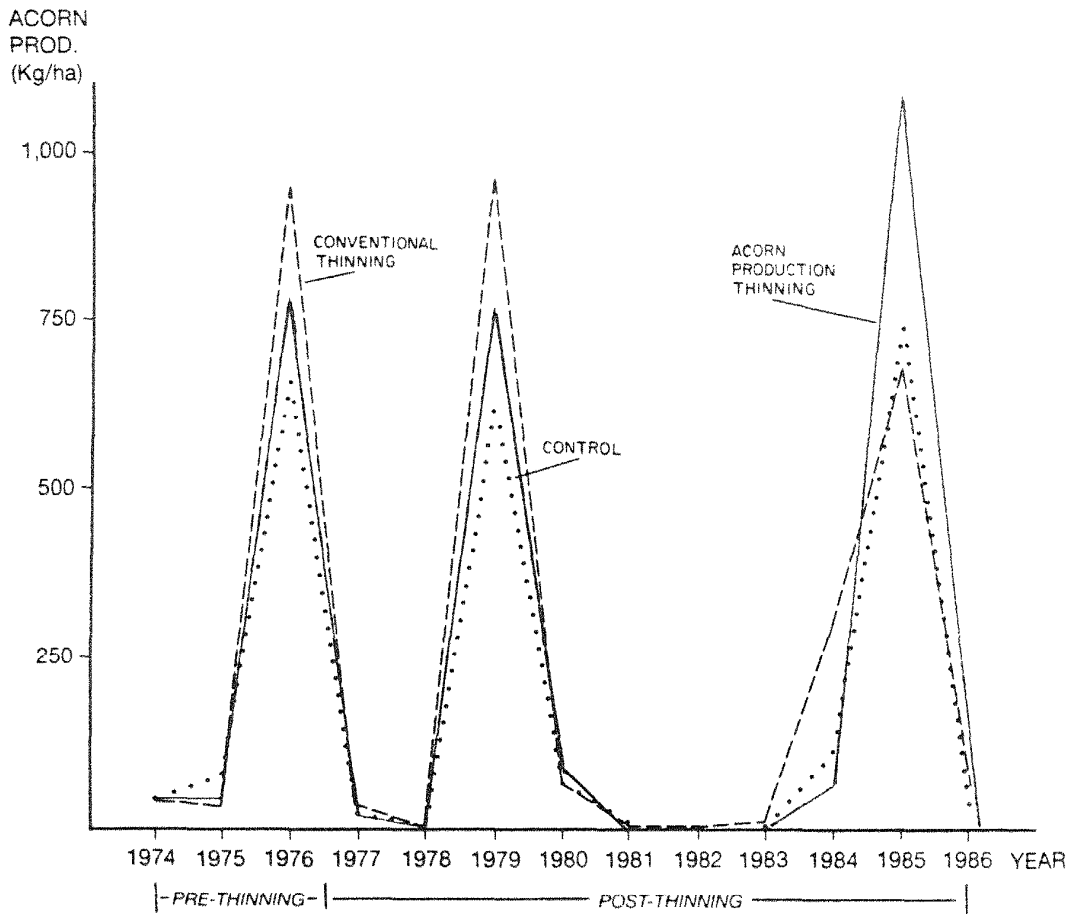

Figure 1. Mean pre- and post-thinning acorn production for three treatments.

APT and CT blocks. This may have been due to the majority of dominants and co-dominants being retained and the similarity of their spacing in both treatment blocks.

The importance of crown dominance may partially explain why acorn yields were not improved by retaining the best producers. Perhaps the suppressed and intermediate oaks with good genetic potential for acorn production did not display a phenotype expression of their potential (i.e. good acorn production) because of shading and were outproduced by dominants and co-dominants with moderate or even poor genetic potential whose crowns were exposed to higher intensities of sunlight. If so, it again reflects the importance of crown dominance relative to the selection of phenotypically superior acorn producers and points out the practical difficulty of improving acorn yields by retaining the best producers.

SUMMARY

Crown dominance was an important factor affecting the acorn production of individual oaks in this study. Conversely, acorn yields were not appreciably improved by retaining good acorn producing oaks during thinning relative to conventionally thinned stands. Results of this study indicate that improvements in acorn yields were not sufficient to justify the additional effort and cost of identifying and retaining the best acorn producing oaks prior to the thinning.

LITERATURE CITED

Burns, P.V., D.M. Christisen and J. M. Nichols. 1954. Acorn production in the Missouri Ozarks, Univ. of Missouri Agr. Expt. Sta. Bull. 611. 8 pp.

Christisen, D. M. and W. H. Kearby. 1984. Mast measurement and production in Missouri (with special reference to acorns). Terrestrial Series #13, Missouri Dept. of Cons., Jefferson City, MO. 34 pp.

Cypert, E. 1951. Suggestions for the management of oak forests for mast production. Presented at the Southeastern Assoc. Game and Fish Commissioners Conf. 8pp Mimeo.

Downs, A.A. and W. E. McQuilken. 1944. Seed production of southern Appalachian oaks. J. Forestry 42(12):913-920.

Goodrum, P.D., V. H. Reid and C.E. Boyd. 1971. Acorn yields, characteristics and management criteria of oaks for wildlife. J. Wildl. Mgmt. 35(3):520-531.

Harlow, R.F. and R. L. Eikum. 1963. The effect of stand density on the acorn production of turkey oaks. 17th Ann. Conf. S.E. Assoc. of Game and Fish Commissioners: 126-133.

Liscinsky, S.A. 1971. Measuring seed tree crops. Prog. Rept. W-48-R, Job 2 -5, PA Game Commission, Hbg. 3pp.

Sharp, W. M. 1958. Evaluating mast yields in the oaks. PA Ag. Exper. Sta. Bull. No. 635, Univ. Park, PA. 22pp.

Sharp, W. M. and V. G. Sprague. 1967. Flowering and fruiting in the white oaks: pistillate flowering, acorn development, weather and yields. Ecology 48(2): 243-251.

Shaw, S.P. 1971. Wildlife and oak management in oak. Symposium Proceedings, USDA NE For. Exper. Sta., Upper Darby, PA: 84-89.

Zar, J. H. 1974. Biostatistical analysis. Prentice-Hall Inc., Englewood Cliffs, NJ. 611 pp.

INDEPENDENT EFFECTS AND INTERACTIONS OF STAND DIAMETER, TREE DIAMETER, CROWN CLASS, AND AGE ON TREE GROWTH IN MIXED-SPECIES, EVEN-AGED HARDWOOD STANDS

David A. Marquis[1]

Abstract: Many studies have shown that initial tree diameter is closely correlated with subsequent tree growth. But initial tree diameter is actually a confounded variable, incorporating both competitive position (crown class) and age. A study in hardwood stands in Pennsylvania has shown that the two latter variables were more reliable predictors of tree growth than initial diameter. These two variables lack the confounding of initial diameter, and are biologically more appropriate parameters for inclusion in growth simulators.

Surrogate variables calculated from typical cruise data were found to be nearly as well correlated with growth as the more difficult-to-measure crown class and age. Relative tree diameter (the ratio between actual tree diameter and stand diameter) provided a useful surrogate for crown class, and effective age (calculated from the average diameter of the major species groups present in each stand) provided a useful surrogate for actual age in these even-aged cherry-maple forests.

INTRODUCTION

Many studies have shown that initial tree diameter is closely correlated with subsequent tree growth (Hilt 1983, Hough and Taylor 1946, Marquis 1969, Trimble 1969). Often, other factors studied have added little to the correlation after initial tree diameter was fitted. As a result, initial tree diameter is a good predictor of future growth. It is often used as one of the major independent variables in tree growth-prediction equations (Hilt 1983, Miner and others 1988, Solomon and others 1987). This is probably unfortunate because it tends to mask the biological relationships involved. Initial tree diameter is a variable that actually expresses two more basic factors: competitive position and age.

Large trees in even-aged stands grow faster in large part because of their competitive advantage over their neighbors. In a single stand of trees of the same age, use of initial tree diameter to predict growth causes no problems, because diameter is an expression of competitive position in this case.

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But old trees grow slower than young trees of the same species and competitive position. Individual-tree-diameter growth peaks at an early age, and even trees that retain dominant crown positions decline in growth as they get older and, therefore, larger in diameter.

So, initial tree diameter is confounded as an indicator of future tree growth: large trees grow faster than small trees when comparing trees within an even-aged stand because tree size is a measure of competitive position. But large trees grow slower than small trees when trees of similar species and competitive position are compared across stands of different ages. In this situation, tree size is a measure of age.

To determine how important this confounding might be in growth predictions, and to test other parameters that express competitive position and age more directly, the long term growth records of a group of cherry-maple stands were examined in northwestern Pennsylvania; the records included direct measurements of age and competitive position (crown class). Because crown class and age are difficult to measure accurately and are seldom included in inventory data, several surrogates of these parameters that can be calculated from typical inventory data were tested. This is a report on the results of that investigation.

STUDY METHODS

Individual-tree growth records from three unrelated studies were used in this investigation. The three studies were:

1. Wolf Run Crop Tree Plots--consisted of individual-tree diameter records spanning 37 years, with remeasurements at approximately 5-yr intervals. Trees in this study were open-grown trees left after an overstory removal cut. Records included only d.b.h at each measurement period, plus age from ring counts of stumps at the time of harvest cut. These data are from a single stand on the former TG Forest Industries property adjacent to the Allegheny National Forest. The stand was 44 years old at the first measurement. There were 83 black cherry, 101 sugar maple, and 5 red maple trees available in the Wolf Run Plots. These data were used only for correlations of diameter growth and age.

2. Kane Weeding Study--consisted of stand and individual-tree-diameter records spanning a 35-year period with remeasurements every 5 years. Records included d.b.h. and crown class of each tree at each measurement, plus stand age derived from records of stand origin. Only data from the control plots were used. Each plot was 1/2-a in size. There were four separate stands in this study. Stand ages varied from 13 to 18 years at the start of the study, and from 48 to 53 years at the last measurement. All four stands were located on the Kane Experimental Forest, a part of the Allegheny National Forest.

Three of the seven growth periods available lacked data on crown class, so these three periods were omitted from investigations of the effect of crown class on diameter growth, and on tests of surrogate measures of crown class. In the summaries that follow, data from the four stands and four measurement periods on each stand are presented in groups based on stand age at the start of the period, as follows: 10-20 yr, 30-40 yr, and 40-50 yr. There were approximately 500 trees in this data set on which individual tree growth records were available, in four species: black cherry (*Prunus serotina* Ehrh.), sugar maple (*Acer saccharum* Marsh.), red maple (*Acer rubrum* L.), and American beech (*Fagus grandifolia* Ehrh).

All seven growth periods were used for investigation of the effect of age on diameter growth.

3. Fertilizer Study--consisted of stand and individual-tree diameter records spanning a 6-yr period, with remeasurements each year. Records included d.b.h. and crown class of each tree at each measurement, plus stand age derived from increment cores of ten dominant black cherry trees in each stand. There were six separate stands in this study. Stand ages ranged from 55 to 65 yr at the start of the study, and data from these stands are presented in the 55-65-yr age group in the summaries that follow. Only data from the control plots were used. Each plot was 1/2-a. All six stands were located on the Allegheny National Forest. There were approximately 2,000 trees in this data set on which individual growth records were available, in four species: black cherry, sugar maple, red maple, and American beech. These data were used for correlations of diameter growth with competitive position, and for testing of surrogate measures of crown class and age.

Descriptive data on stands from the Kane Weeding Study and Fertilizer Study are presented in Table 1. These data characterize the stands used for investigations of crown class, relative diameter, and tree growth and provide a summary of the distribution of trees into crown classes.

The study reported in this paper was conducted in several separate parts, each designed to test or illustrate a specific point. Investigation 1 illustrates the point that initial tree diameter expresses both stand age and the competitive position of individual trees within a stand, and that these two factors affect subsequent tree growth in opposite directions. Investigation 2 tested the hypothesis that competitive position (crown class) and age together provide better growth predictions than initial tree diameter alone when applied to stands that span a wide range of ages. Investigation 3 tests relative tree diameter as a surrogate measure of crown class or competitive position. And Investigation 4 tests effective age as a surrogate measure for actual age.

Table 1.--Characteristics of stands used in the investigation of the effect of crown class and relative diameter on tree growth.

Variable	Age class			
	10-20 yr	30-40 yr	40-50 yr	55-65 yr
	Entire Stand			
Age (yr)	14	36	44	58
Basal area (sq ft/acre)	54	110	133	147
Trees (no./acre)	3599	1569	1071	658
Relative density (%)	68	76	99	99
Medial diameter (in.)	2.7	6.3	8.0	9.5
Quadratic diameter (in.)	1.7	3.7	4.8	5.9
	Dominants and codominants			
% of no. trees	29	14	22	14
% of basal area	55	55	67	51
Average diameter (in)	2.4	7.0	8.6	11.6
	Dominants, codominants, intermediates			
% of no. trees	92	23	30	31
% of basal area	92	70	76	81
Average diameter (in)	2.0	6.2	7.9	9.7

The basic calculations were made as follows: diameter growth was calculated for each individual tree for each growth period; stand parameters (medial stand diameter, quadratic stand diameter, relative density or stocking, basal area/a, numbers of trees/a.) were calculated for each plot for each measurement period using the computer program SILVAH (Marquis 1986); then, diameter growth averages were calculated by crown and age classes.

In several investigations, simple and multiple regressions were run to relate individual-tree growth (by species) to various tree or stand parameters involved in the investigation. Only those regressions with an F-test that exceeded the 0.05 level were considered significant, and only signicant regressions are shown in this paper. Coefficients of determination (r^2) for the individual regressions are shown where appropriate. In other investigations, differences among crown class means were tested with analysis of variance. Only those F-tests that exceeded the 0.05 level were considered significant.

Relative diameter was calculated for each tree as a possible surrogate expression of crown class or competitive position. Relative diameter is simply the diameter of the individual tree divided by the average stand diameter. Thus, a 12-in tree in a stand with an average diameter of 12 in would have a relative diameter of 1.0. A 6-in tree in that same stand would have a relative diameter of 0.5. Using this expression, dominant trees in this study had a relative diameter of over 1.0, while suppressed trees had a relative diameter of 0.5 or less.

Codominant and intermediate trees had intermediate values. Thus, relative diameter is a continuous variable that can be related to the four discrete crown classes actually observed. In the calculation of relative diameter, both medial diameter (diameter of a tree at the mid-point of the basal area distribution) and the quadratic diameter (tree of average basal area) were used as measures of stand diameter.

Effective age was calculated as a possible surrogate for actual age. Age for each of two major species groups in cherry-maple stands was estimated from their medial diameters, using the average increase in medial diameter expected for that group. The two species groups are: a) fast-growing black cherry, white ash (*Fraxinus americana* L.), yellow-poplar (*Liriodendron tulipifera* L.), red maple, and northern red oak (*Quercus rubra* L.); and b) slower growing sugar maple and American beech. The average increase in medial diameter (herein called the growth factor) for these two species groups was derived from approximately 120 Allegheny hardwood stands in northwestern Pennsylvania (Marquis and others 1984). The growth factors are: a) .20 inches/yr for fast growing species group 1, and b) .15 inches/yr for slower growing species group 2). Thus, effective age provides an estimate of actual age based on the diameters of two major species groups. The equation is:

$$Effective\ age = \frac{\frac{(MD1 * BA1)}{GF1} + \frac{(MD2 * BA2)}{GF2}}{Total\ BA} \qquad (1)$$

where:

BA = basal area in trees 1" dbh and larger
MD = medial stand diameter of trees 1" dbh and larger
GF = growth factor
1 = species group 1
2 = species group 2

RESULTS AND DISCUSSION

Investigation 1 -- Is initial dbh a reliable predictor of tree growth?

A common way to express the competitive position of a tree is by the use of crown class -- a subjective grouping of trees into dominant, codominant, intermediate, and suppressed classes. These crown classes reflect the tree's height relative to its competing neighbors in the crown canopy, and they also indicate the proportion of the tree's crown that receives direct sunlight for tree growth.

Data from both the Kane Weeding Study and the Fertilizer Study were used to calculate the average diameter growth for trees of various crown classes. Average initial dbh was also calculated for these same crown classes.

Differences among crown classes in both average initial dbh and average diameter growth rate were highly significant within any of the 10-year age ranges tested (Table 2). Thus, the dominant trees are the largest trees in their stands, and they grow faster than trees of lower crown class or smaller initial dbh. Within a crown class, older trees are also larger in dbh.

All trees in the Kane Weeding Study that remained in the dominant or codominant crown class throughout the 35-year period were selected for analysis of the effect of age on diameter growth rate. Average growth at various ages between 13 and 48 years were plotted. There were 124 black cherry and 41 sugar maple trees in this sample. There were too few trees of other species in the dominant and codominant classes to provide reliable results.

Table 2.--Average dbh and average diameter growth for trees of different crown class, by age ranges.

Crown class	Average initial dbh	Average diameter growth (in/5 yrs)
	Ages 10-20 years (Kane Weeding Study)	
Dominant	2.7	1.24
Codominant	2.2	0.86
Intermediate	1.5	0.55
Suppressed	1.2	0.52
	Ages 30-40 years (Kane Weeding Study)	
Dominant	8.4	1.02
Codominant	6.3	0.64
Intermediate	4.4	0.36
Suppressed	2.7	0.13
	Ages 40-50 years (Kane Weeding Study)	
Dominant	10.7	0.73
Codominant	7.8	0.46
Intermediate	5.1	0.20
Suppressed	3.2	0.12
	Ages 55-65 years (Fertilizer Study)	
Dominant	13.0	1.10
Codominant	10.7	0.67
Intermediate	8.2	0.36
Suppressed	2.9	0.07

Diameter growth rates of dominant and codominant black cherry trees had peaked by age 18. Sugar maple growth was erratic up to aproximately age 30, but it declined at a steady rate thereafter (Figure 1).

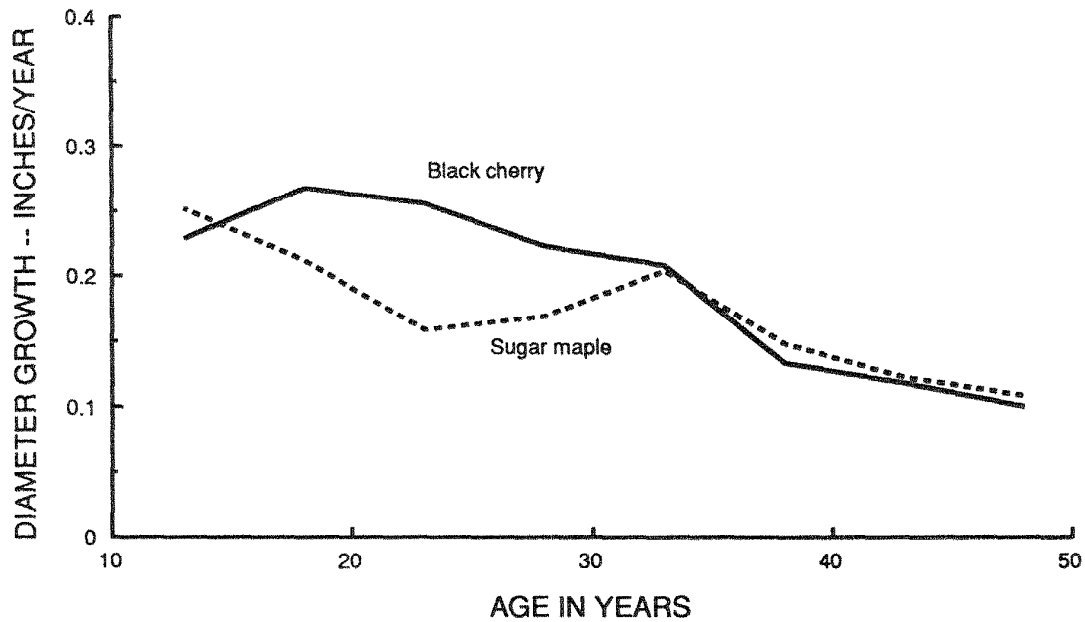

Figure 1. The effect of age on diameter growth (dbh) of individual trees (age 13 to 48).

Data from the Wolf Run plots provide data from older trees than available in the Kane Weeding Study. These data were analyzed in the same manner as above. Diameter growth rate of all three species (black cherry, sugar maple, and red maple) had peaked before the start of measurements (44 yr), and declined steadily throughout the 37-yr growth period (Figure 2).

These several sets of data illustrate that initial tree dbh affects individual tree diameter growth in two conflicting ways. Within stands of similar age, initial dbh is an indicator of competitive position, and large trees grow faster than smaller ones. But across a range of stand ages, initial dbh is an indication of age; large trees grow slower than small trees of the same crown class because the large trees are older. Thus, initial dbh is not a desirable predictor of individual tree growth when used across a range of stand ages and crown classes. Initial diameter is a confounded expression of two other variables that affect tree growth in different directions.

Investigation 2 -- Are crown class and age better predictors than initial dbh?

Using individual tree data from both the Kane Weeding Study and Fertilizer Study, regression equations were calculated to predict individual tree growth based either on: a) initial dbh, or

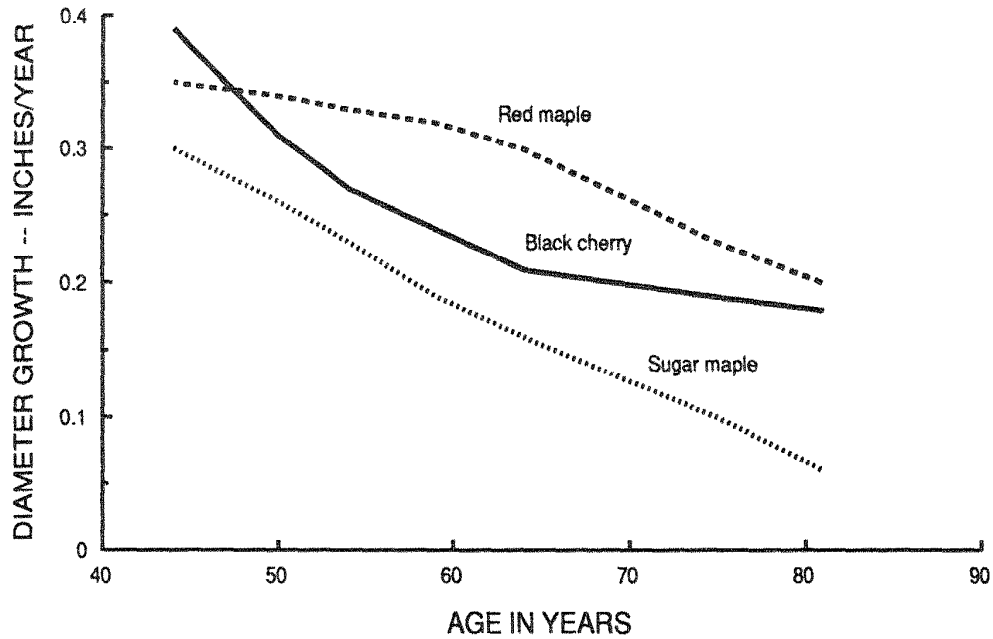

Figure 2. The effect of age on diameter growth (dbh) of individual trees (age 44 to 81).

b) crown class plus age. Crown class was entered into the equations as a set of dummy variables. Separate equations were calculated for black cherry and sugar maple.

Coefficients of determination showed that equations including two independent variables to express both competitive position and age were much better (had higher r^2 values) than equations including only initial dbh as an independent variable (Table 3). In fact, initial dbh was only poorly correlated with diameter growth across the range of ages included in these equations, and regressions with dbh were not statistically significant.

Table 3.--Coefficients of determination (r^2) between individual tree diameter (dbh) growth and either initial dbh or age plus crown class.

Species	Independent variable(s)	
	Initial dbh	Age + Crown Class
Black cherry	0.00	0.41
Sugar maple	0.08	0.62

Investigation 3 -- Relative diameter as a measure of competitive position

Crown class is a subjective measure of competitive position, and therefore not evaluated equally by all observers. It provides estimates of competitive position in discrete classes, and is therefore inconvenient to include in prediction equations. Furthermore, it is an observation not commonly included in inventories made on an operational basis. Therefore, crown class has limitations as an independent variable in growth prediction equations.

It would be very desirable to find a continuous variable that provides a measure of competitive position that can be objectively estimated from commonly available inventory data. Relative diameter (diameter of the tree relative to the average stand diameter) is a variable that expresses the size of a tree relative to its competitors in the same stand, and therefore appears promising as a measure of competitive position and a surrogate for crown class.

The Kane Weeding Study and Fertilizer Study data were used to calculate the average diameter growth of all species stratified into four crown classes and five relative-diameter classes. Both crown classes and relative-diameter classes had a strong influence on diameter growth, with a clear trend of best growth from trees in the better competitive positions (Table 4).

Table 4.--Diameter growth rates (inches/5 yrs) as affected by competitive position for stands of four age groups (all species together).

Variable	Age class			
	10-20 yr	30-40 yr	40-50 yr	55-65 yr
Crown class				
Dominant	1.24	1.02	0.73	1.10
Codominant	0.86	0.64	0.46	0.67
Intermediate	0.55	0.36	0.20	0.36
Suppressed	0.52	0.13	0.12	0.07
Relative diameter class (based on medial diameter)				
1.25+	1.45	0.97	0.72	0.92
1.00 - 1.25	1.15	0.78	0.59	0.63
0.75 - 1.00	0.92	0.53	0.39	0.38
0.50 - 0.75	0.67	0.29	0.25	0.18
0.00 - 0.50	0.43	0.01	0.07	0.05

When diameter growth is predicted using regressions of diameter growth as a function of relative diameter and compared to predictions of diameter growth based on crown class averages, the two measures perform about equally. There was a slight tendency for crown class to predict growth better than relative diameter, but the differences were minor (Table 5). This indicates that relative diameter can be used in place of crown class as a predictor of diameter growth.

Table 5.--Standard errors for diameter growth estimates based on crown class averages versus those based on regressions with relative diameter.

Age range	Crown class	Relative diameter
	30-40 years	
black cherry	.32	.32
sugar maple	.18	.18
	40-50 years	
black cherry	.22	.21
sugar maple	.13	.12
	55-65 years	
black cherry	.25	.26
sugar maple	.11	.08

Data from both the Kane Weeding Study and the Fertilizer Study were then used to calculate regressions of diameter growth as a function of initial diameter and as a function of two different relative diameters. Relative diameter was calculated using both the medial diameter and the quadratic diameter. The regressions were run within single stands (where age was constant), and across all stands in the data set (where age varied from 10 to 65 years).

The coefficients of determination (r^2) for three regressions of diameter growth on d.b.h., relative medial diameter, and relative quadratic diameter were identical within each stand. And correlations between d.b.h. and the two relative diameter measures were perfect -- r^2 of 1.00 (Table 6). This is to be expected since the two relative diameters are equivalent to d.b.h. divided by a constant. Within a single stand, where all the trees are the same age, all three measures provide identical results as expressions of competitive position.

However, when the same regressions are calculated across a group of stands of varying ages, r^2 for regressions containing relative diameter are much higher than those for regressions on initial d.b.h. (Table 6). In this situation, the two relative diameter measures continue to provide an expression of the competitive position of each tree's position that is unconfounded with age. But initial d.b.h. is now expressing both competitive position and age, two factors that affect diameter growth in opposite ways as demonstrated earlier. Thus, relative diameter appears promising as a measure of competitve position in place of crown class; and it is a measure that is not confounded by age as is initial dbh.

Table 6.--Coefficients of determination (r^2) for initial diameter and relative diameter (based upon medial stand diameter and quadratic stand diameter) as affected by age range in the data.

Age range	No. of stands	Dependent variables				
		Diameter Growth			D.b.h.	
		Independent variables			Independent variables	
		Dbh[1]	RMD[2]	RQD[3]	RMD	RQD
		Black cherry				
Within a single stand*						
age 10-20	4	0.40	0.40	0.40	1.00	1.00
age 30-40	7	0.51	0.51	0.51	1.00	1.00
age 40-50	3	0.42	0.42	0.42	1.00	1.00
age 55-65	6	0.54	0.54	0.54	1.00	1.00
Across a wide range of stand ages*						
age 10-65	22	0.00	0.22	0.23	0.53	0.49
age 30-65	18	0.28	0.48	0.45	0.66	0.56
		Sugar Maple				
Within a single stand*						
10-20	4	0.25	0.25	0.25	1.00	1.00
30-40	7	0.60	0.60	0.60	1.00	1.00
40-50	5	0.55	0.55	0.55	1.00	1.00
55-65	6	0.51	0.51	0.51	1.00	1.00
Across a wide range of stand ages*						
10-65	22	0.08	0.57	0.50	0.42	0.48
30-65	18	0.36	0.58	0.59	0.83	0.70

[1]Dbh = diameter at breast height at the beginning of the growth period
[2]RMD = relative diameter based upon medial stand diameter
[3]RQD = relative diameter based upon quadratic stand diameter

*Values shown within a single stand are the mean of the r^2 values for each individual stand in the age range shown. Values shown across a wide range of stand ages are the single r^2 value from a regression using all stands in the specified age range.

Differences between the two relative diameter measures were small. The one based on medial diameter gave slightly better results in most cases than the one based on quadratic diameter. The exception was in very young stands where results were erratic (Table 6).

Medial diameter has the added advantage that it provides a much more realistic estimate of tree size than quadratic diameter in these mixed-species hardwood stands. Quadratic diameter is heavily influenced by the large number of suppressed trees, so it gives an estimate of stand diameter that does not adequately reflect the size of the crop trees in the stand.

To illustrate, the quadratic stand diameter and the medial stand diameter are plotted against the arithmetic average diameter of the dominant plus codominant trees and against the arithmetic average diameter of the dominant, codominant, and intermediate trees in the Kane Weeding Study and Fertilizer Study data sets (Figure 3). Medial stand diameter closely approximates the average diameter of the dominants, codominants, and intermediates--the trees that make up the main crown canopy. Quadratic stand diameter is much lower, and does not adequately represent the diameter of the important trees in the stand.

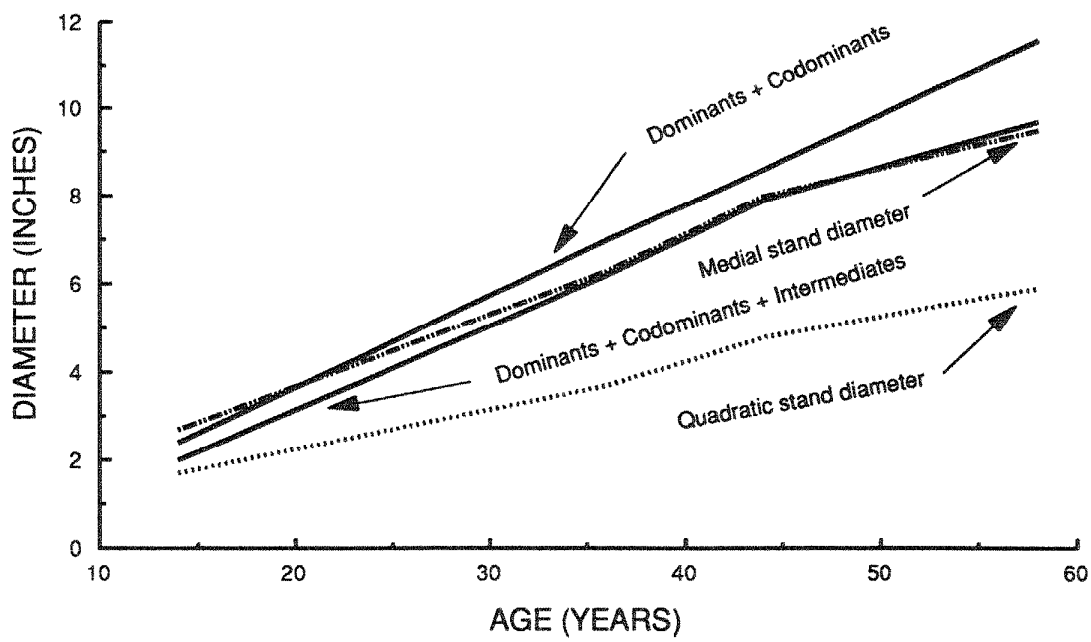

Figure 3. A comparison of medial stand diameter and quadratic stand diameter as expression of average tree dbh of various crown class groups in cherry-maple stands.

So, medial stand diameter clearly seems to be a better measure of stand size class, and is better correlated with diameter growth than quadratic stand diameter. Its use as an expression of average stand diameter is recommended.

Data from the Kane Weeding Study and Fertilizer Study were examined to determine whether or not relative diameter might be used to segregate trees into crown classes when direct measures of crown class are not available. The relative diameter breaking points used to separate one crown class from another were estimated by regressing the relative diameter limits from each age class over age (Figure 4). The results of segregations made on this basis were compared with actual crown class observations (Table 7).

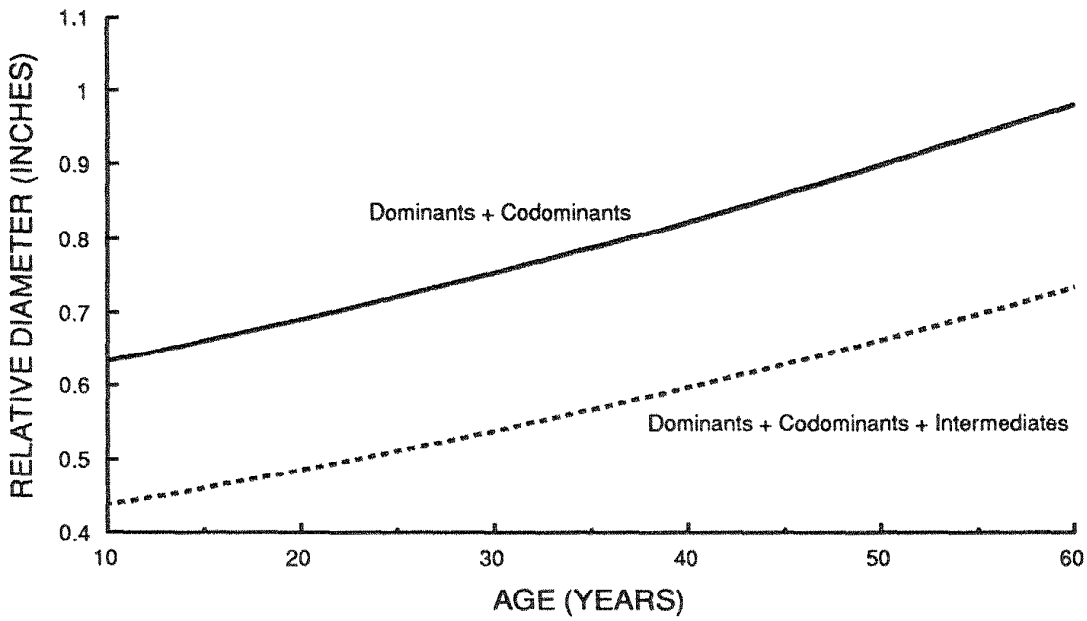

Figure 4. Relative diameter limits used to separate crown classes in cherry-maple stands, as a function of age.

These trials suggest that it is possible to select those trees in a stand which represent any crown class (or group of crown classes) by using relative diameter as a surrogate. The group of trees selected as representing a particular crown class will not correspond exactly to the actual crown classes, but will contain approximately the same number of trees and have approximately the same growth rate and average diameter as that crown class (Table 6). These trials also suggest that the relative diameter that separates one class from another is not a constant, but varies with both age and species. Thus, additional study would be needed to define the relative diameter breaking points appropriate to a wide range of stand compositions and ages. Nevertheless, relative diameter appears to be a useful surrogate for crown class.

Table 7.--Conformity among crown class and relative diameter in selection of the trees in the upper crown canopy over four age classes -- all species.

Competitive position*	Age class			
	10-20 yr	30-40 yr	40-50 yr	55-65 yr
	Number of trees/acre			
D & C crown classes	299	319	238	284
D & C via Relative dia.	302	325	234	273
D, C & I crown classes	481	449	294	619
D, C & I via Relative dia.	481	459	287	619
	Average diameter (dbh)			
D & C crown classes	2.4	7.0	8.6	11.6
D & C via Relative dia.	2.3	7.2	8.7	11.8
D, C & I crown classes	2.0	6.2	7.9	9.7
D, C & I via Relative dia.	2.0	6.4	8.1	9.8
	Diameter growth, inches/5 yrs			
D & C crown classes	0.98	0.76	0.53	0.80
D & C via Relative dia.	0.99	0.74	0.53	0.78
D, C & I crown classes	0.82	0.64	0.47	0.56
D, C & I via Relative dia.	0.82	0.63	0.49	0.56

*D = dominant crown class
*C = codominant crown class
*I = intermediate crown class

Investigation 4 -- Effective age as a measure of actual age

Like crown class, age is difficult to measure in the field, and is seldom available from inventory data. The effective age calculated by the SILVAH program, and described earlier, provides a possible surrogate for actual age.

To test the value of effective age in prediction equations, a series of multiple regressions that included relative diameter plus either actual age or effective age was run. Effective age had r^2 values nearly as high as actual age in most regressions, and slightly better than actual age in one regression. Thus, effective age appears to be a useful surrogate for actual age that can be used in growth prediction equations. The regressions also show that the combination of relative diameter and effective age is considerably better as a predictor of diameter growth than either variable alone (Table 8).

Table 8.--Coefficients of determination (r^2) for regressions of diameter growth (dbh) and various combinations of relative stand diameter, age, and effective age.

Independent variable	Black cherry	Sugar Maple
Relative diameter	0.22	0.57
Age	0.08	0.26
Effective age	0.07	0.23
Rel. dia. + Age	0.41	0.62
Rel. dia. + Eff. age	0.39	0.63

CONCLUSIONS

These investigations show that initial tree diameter may express either a tree's competitive position in stands of similar age, or a tree's age when viewed across stands of many ages. Since a large initial dbh produces fast growth in the former situation, and slow growth in the latter, initial tree dbh is a confounded variable that may provide inaccurate growth predictions when applied to trees of a wide range of ages and competitive positions. Separate measure of age and competitive position provide more accurate growth prediction than use of initial dbh alone.

Since neither age nor competitive position (crown class) are commonly included in the data from operational inventories, easily calculated surrogates of these variables are needed. Relative diameter provides a useful measure of competitive position, and effective age provides a useful measure of actual age in Allegheny hardwood stands. Both of these measures can be calculated from the species and diameter records commonly collected in forest inventories. Predictions of growth based on these surrogates provide estimates with accuracy similar to those based upon crown class and actual stand age.

Medial diameter is a better measure of average stand diameter in Allegheny hardwood stands than quadratic diameter. When used to calculate relative diameter, it also provides better correlation with tree growth than relative diameter calculated from quadratic stand diameter.

LITERATURE CITED

Erdmann, Gayne G.; Peterson, Ralph M., Jr. 1985. Crown releasing of red maple poles to shorten high-quality sawlog rotations. Canadian Journal of Forest Research 15:694-200.

Hilt, Donald E. 1983. Individual-tree diameter growth model for managed, even-aged, upland oak stands. Res. Pap. NE-533, U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station, Broomall, PA: 15 p. 15p.

Hough, A. F.; Taylor, R. F. 1946. Response of Allegheny northern hardwoods to partial cutting. Journal of Forestry 44:30-38.

Hughes, Garrett A.; Sendak, Paul E. 1985. Key algorithms used in GRO2: A computer simulation model for predicting tree and stand growth. Res. Pap. NE-570, U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station, Broomall, PA: 17 p.

Lamson, Neil I. 1985. Thinning increases growth of 60-year-old cherry-maple stands in West Virginia. Res. Pap. NE-571, U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station, Broomall, PA: 8 p.

Marquis, David A. 1969. Thinning in young northern hardwoods: 5-year results. USDA Res. Pap. NE-139, U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station, Broomall, PA: 22 p.

Marquis, David A. 1986. SILVAH: A stand analysis, prescription and management simulator program for hardwood stands in the Alleghenies. In Waint, Harry V., Jr.; Yandle, David O.; Kidd, William E., eds. Proc., Forestry microcomputer software symposium, July 29 - June 2, 1986; West Virginia Univ., Morgantown, WV. p. 224-240.

Marquis, David A.; Ernst, Richard. L.; Stout, Susan L. 1984. Prescribing silvicultural techniques in hardwood stands of the Alleghenies. Gen. Tech. Rep. NE-96, U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station, Broomall, PA: 90 p.

Miner, Cynthia L.; Walters, Nancy R,; Belli, Monique L. 1988. A guide to the TWIGS program for the north central United States. Gen. Tech. Rep. NC-125, U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station, Broomall, PA.

Solomon, Dale S.; Hosmer, Richard A.; Hayslett, Homer T., Jr. 1987. FIBER handbook: A growth model for spruce-fir and northern hardwood types. Res. Pap. NE-RP-602, U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station, Broomall, PA: 19 p.

Trimble, G. R., Jr. 1969. Diameter growth of individual hardwood trees: The effect of certain tree and environmental factors in the growth of several species. For. Serv. Res. Pap. NE-145, U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station, Broomall, PA: 25 p.