Silviculture

DEVELOPMENT OF OAK REGENERATION NINE YEARS AFTER SHELTERWOOD CUTTING AND CLEARCUTTING ON THE COASTAL PLAIN OF WEST TENNESSEE

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Abstract—Quantity, size and species composition of hardwood reproduction were compared in oak-hickory (*Quercus* spp.-*Carya* spp.) stands following clearcutting and two intensities of shelterwood cutting (leaving 40 and 60 ft^2 of basal area) on Chickasaw State Forest in the Coastal Plain of west Tennessee. Measurements were taken prior to the timber harvest and at 3-year intervals for 9 years after the harvest. The clearcut treatment had the greatest number of oaks per acre, while the shelterwood treatments had a greater proportion of oaks compared to total stems. After 9 years, the total number of stems in each treatment decreased while the percentage of oaks greater than 1-foot tall increased. The development of oak regeneration and the resulting stand dynamics are discussed based on these 9-year regeneration data.

INTRODUCTION

Concerns about the aesthetics of clearcuts have caused a renewed interest in the shelterwood method of regeneration within the even-aged silvicultural system for regenerating oaks. Several authors have prescribed guidelines for regenerating oaks using the shelterwood method (Hannah 1987, Loftis 1983, Loftis 1990, Sander 1979, Sander and Graney 1993). However, Smith (1981) states that "many shelterwood recommendations contain the statement that details are uncertain and more research is needed." The complexity and variability of natural hardwood stands with their multitude of species, differential growth rates, varying site productivities, different stand structures and conditions, silvical characteristics, past disturbances, and previous management regimes are not amenable to a single prescription.

In theory, the shelterwood method should create the microenvironment required by oaks for successful establishment and nurturing early seedling growth. In practice, a fine line exists on how much overstory to leave in promoting oak regeneration. Heavy shelterwood cuts favor the development of fast-growing intolerant species such as yellow-poplar (*Liriodendron tulipifera* L.) rather than oaks. Lighter cuts may encourage more tolerant, less desirable species such as maples (*Acer* spp.), beech (*Fagus grandifolia* Ehrh.), and elms (*Ulmus* spp.) at the expense of oaks (Clatterbuck and Meadows 1993, Hodges 1989).

This study provides a 9-year history of the development of regeneration following three overstory treatments: clearcutting and two intensities of shelterwood cuts leaving 40 and 60 ft^2 of residual basal area. The objective of the research is to compare the regeneration dynamics between treatments in size, number and species composition. Although this is an unreplicated case study, it provides information about the oak regeneration process.

STUDY AREA

The study was conducted on a 46-acre upland hardwood stand at Chickasaw State Forest (CSF) in Hardeman County, TN, located approximately 20 miles south of Jackson in southwestern Tennessee and managed by the Tennessee Department of Agriculture, Division of Forestry. Soils are Typic Hapludults (Smithdale series), formed in loamy Coastal Plain deposits, severely eroded and moderately drained (Ditzler and others 1994). The study area is on a convex, moderately steep (8 to 20 percent), strongly dissected slope. Annual precipitation averages 50 inches, usually evenly distributed in all seasons. Average site index (base age 50) for upland oaks ranges from 75 to 80 feet (Schnur 1937).

The CSF was part of the federal Resettlement Administration purchase of land during the 1930's. The area occupied by this study was formerly a portion of two farms. Old fences indicate that all or part of the area was grazed, cultivated, or both. Fire scars on many of the trees attest to burning before state acquisition.

Ages of the dominant and co-dominant trees range from 60 to 90 years. The predominant species are oaks: white (*Q. alba* L.), northern red (*Q. rubra* L.), scarlet (*Q. coccinea* Muenchh.), black (*Q. velutina* Lam.), and southern red (*Q. falcata* Michx.). Other species include hickories, sweetgum (*Liquidambar styraciflua* L.), yellow-poplar, American beech, dogwood (*Cornus florida* L.) and blackgum (*Nyssa sylvatica* Marsh.).

METHODS

The 46-acre stand was divided into four subunits of approximately equal size, each of which represented the stand as a whole with regard to site quality, aspect, position on slope, and slope gradient. Four treatments were imposed, one for each subunit: clearcut and three shelterwood cuts leaving 40, 50 and 60 ft^2 of residual basal area respectively in dominant and codominant trees of desirable species.

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Table 1—Treatment size, number of plots, initial stocking and summary of timber harvest volumes in 1982 at Chickasaw State Forest, Tennessee

Treatment	Area	Plots	Initial stocking	Average total volume cut	Volume/acre cut
	Acres	*#*	*Ft^2/acre*	*Board feet*[a]	*Bd.ft./acre*
Clearcut	10	23	75	110,700	11,070
40-ft^2 BA	12	23	85	34,780	2,900
60-ft^2 BA	12	26	80	15,200	1,270

[a] International ¼ inch log rule.

Before the actual timber harvest in 1982, 97 permanent, 0.1-acre plots were established over the entire 46 acres (Table 1). Plots were spaced 2.2 chains apart on parallel lines 2.2 chains apart. All stems 1.5 inches dbh and larger were recorded by species, diameter, and merchantable height (height to base of crown). Cut and leave trees were tallied for each plot. Regeneration was measured on a 0.02 acre circular plot at the plot center of the 0.1 acre plot. Height of all woody stems 1 foot and taller to 1.5 inches dbh were counted by species. All woody stems less than 1 foot were also recorded by species.

For the clearcut, all trees greater than 12 inches in diameter at breast height (dbh; 4.5 feet) were commercially harvested. The remaining stems over 1.5 inches dbh were cut and left on the site. Leave trees for the shelterwood cut were selected on the basis of species, form, vigor, and crown position class. Oaks were favored as leave trees, particularly white, northern red, southern red, and black oaks. Hickories were also favored, but were secondary to the oaks. Species such as yellow-poplar, sweetgum, American beech, and blackgum were not favored. However, trees of these species were left when necessary to maintain the required residual basal area. Midstory and understory stems in the shelterwood treatments were not intentionally cut, but may have been disturbed during the removal of overstory trees during the commercial harvest. Volumes harvested for each treatment area are presented in Table 1.

Regeneration data were collected in 1982 before the harvest and at 3-year intervals: 1985, 1988 and 1991. The data for the shelterwood cut with 50 ft^2 of residual basal area are not presented in this paper.

RESULTS

Total Stems per Acre

The clearcut unit had the greatest number of stems per acre, both less than and greater than 1-foot tall, at the time of the harvest (Table 2). Nine years later, the clearcut treatment with more than 4,700 stems/acre, increased by three times the stems over 1-foot tall, while the amount of reproduction less than 1 foot in height decreased.

Table 2—Reproduction present in three treatment areas before and 9 years after harvest, Chickasaw State Forest, Tennessee

Treatment	1982		1991	
	≤1 ft.	>1 ft.	≤1 ft.	>1 ft.
	----------------	*Stems/acre*	----------------	
Clearcut	4,845	1,537	2,974	4,783
40-ft^2 BA	3,193	964	5,068	2,011
60-ft^2 BA	3,216	986	3,408	657

Both shelterwood treatments had fewer stems than the clearcut treatment in 1982. The number of stems less than 1 foot in height increased for the 40 ft^2 of residual basal area (BA) treatment and remained essentially the same for the 60-ft^2 BA treatment. The total number of stems greater than 1-foot tall was approximately 2,000 stems/acre, doubling in the 9 years following the harvest in the 40-ft^2 BA treatment, but decreased from 986 to 657 for the 60-ft^2 BA treatment.

The total number of stems per acre greater than one foot in height increased dramatically between the initial measurement in 1982 to the next measurement in 1985 for all three treatments (Figure 1). The amount of reproduction decreased progressively in the clearcut and the 60-ft^2 BA shelterwood treatments during the next two measurement periods in 1988 and 1991. The 40-ft^2 BA treatment continued to increase to a measured high point in 1988, then decreased.

Species Composition

For all three treatments, the other species category, primarily of shade-tolerant species such as red maple (*A. rubrum* L.), sourwood (*Oxydendrum arboreum* (L.) DC.), blackgum, dogwood, serviceberry (*Amelanchier arborea* (Michx.f.) Fern.), sassafras (*Sassafras albidum* (Nutt.) Nees), hophornbeam (*Ostrya virginiana* (Mill.) K. Koch), and the intolerant black cherry (*Prunus serotina* Ehrh.),

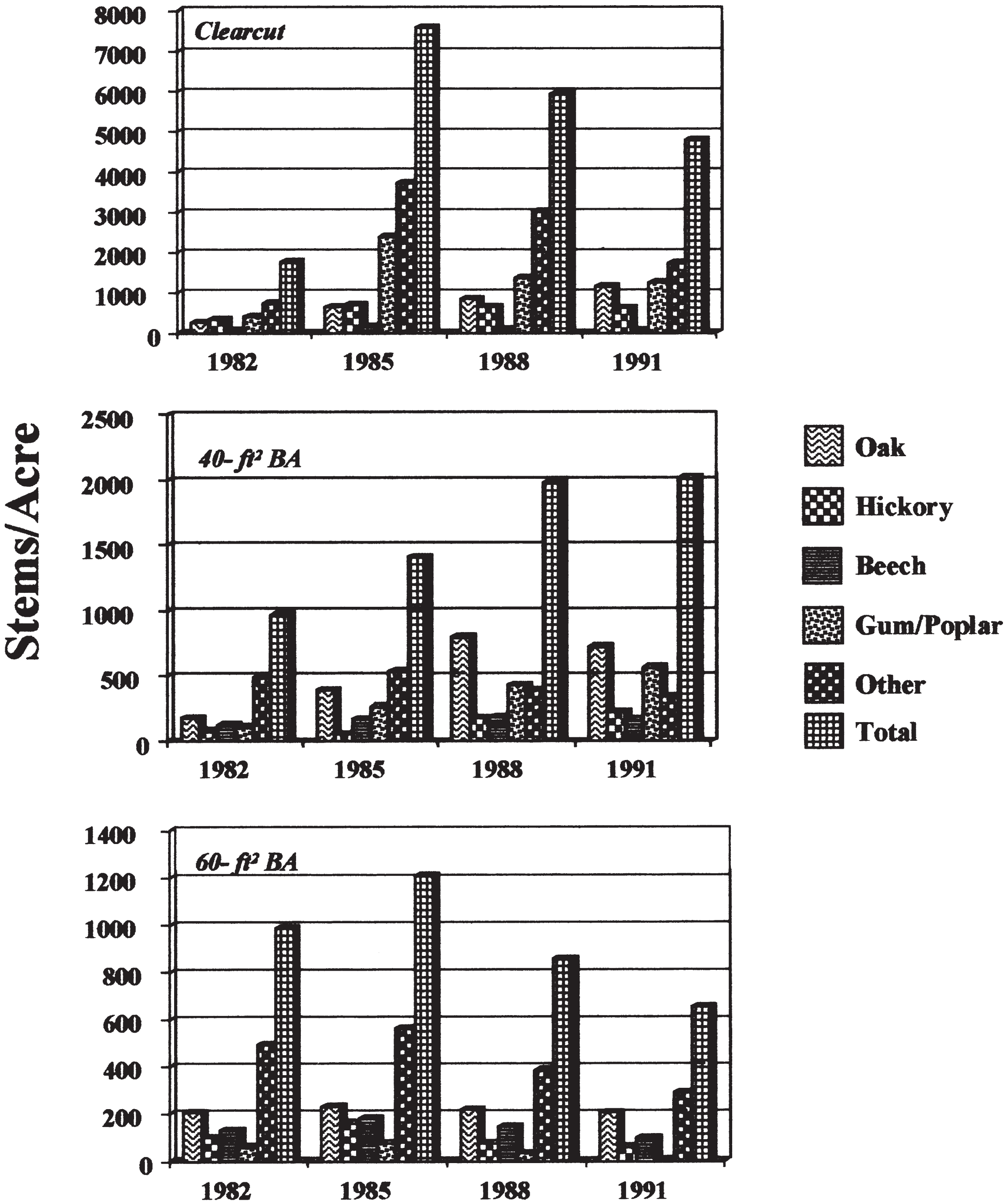

Figure 1—Stems per acre of reproduction greater than 1-foot tall for each species group by the clearcut and two shelterwood treatments for four measurements from 1982-1991, Chickasaw State Forest, Tennessee.

composed the majority of the reproduction greater than 1-foot tall before the harvest (Table 3). Oak species ranged from 14 to 21 percent of the stems, hickory from 8 to 18 percent, beech 3 to 13 percent and gum/poplar 6 to 23 percent. After 9 years, the percentage of oaks increased for every treatment. The gum/poplar percentage component increased for the clearcut and the 40-ft^2 BA treatment, but decreased for the 60-ft^2 BA treatment. Hickory remained steady after 9 years for both shelterwood treatments, but decreased for the clearcut treatment. Beech was a minor component in the clearcut treatment, but maintained or increased its presence in the shelterwood treatments. After 9 years, the other species category was still prominent in the clearcut and the 60-ft^2 BA shelterwood treatments, but decreased by more than half in the 40-ft^2 BA treatment.

The change in the amount of reproduction greater than 1 foot in height by species and by treatment for each

Table 3—Species composition of stems greater than 1 foot in height before and 9 years after timber harvest by treatment, Chickasaw State Forest, Tennessee

	1982			1991		
Species	Clearcut	40-ft^2 BA	60-ft^2 BA	Clearcut	40-ft^2 BA	60-ft^2 BA
	Percent			*Percent*		
Oaks[a]	14	18	21	24	36	31
Hickories	18	8	10	13	11	9
Beech	3	13	13	1	8	15
Gum/poplar[b]	23	11	6	26	28	1
Other[c]	42	50	50	36	17	44

[a] White, black, northern red, southern red, scarlet oaks.
[b] Yellow-poplar and sweetgum.
[c] Red maple, blackgum, black cherry, sassafras, dogwood, elms, sourwood, serviceberry, hophornbeam.

measurement period is shown in Figure 1. The number of stems per acre for each species category increased for each treatment from 1982 to 1985 except for the hickory component in the 40-ft^2 BA treatment that decreased slightly. The amount of reproduction for the gum/poplar and other species components decreased from 1985 to 1991, the oak component increased, and the hickory component remained essentially the same. Beech was not a significant species in the clearcut treatment.

In contrast, for the 40-ft^2 BA shelterwood treatment, the number of stems per acre for oaks increased from 1982 to 1988 and decreased slightly in 1991 (Figure 1). Other species increased initially, then progressively decreased in 1988 and 1991. Gum/poplar increased steadily from 106 stems/acre in 1982 to 563 stems/acre in 1991. Beech remained between 125 and 185 stems/acre for the duration of the study. Hickory slowly increased from 54 stems/acre in 1985 to 221 stems/acre in 1991.

The amount of reproduction per acre increased for each species from 1982 to 1985 in the 60-ft^2 BA treatment (Figure 1). The number of stems for each species decreased slowly after 1985. The gum/poplar component had the fewest number of stems of any species category.

Height Growth

The initial mean height measurements in 1982 for each species were similar for each of the treatment areas (Table 4). Heights for the 9 years from 1982 to 1991 increased the most in the clearcut treatment with other species (primarily dogwood and blackgum) and gum/poplar as the tallest components, followed by oaks and hickories.

Table 4—Mean heights of regeneration greater than 1 foot in height before and 9 years after harvest by treatment, Chickasaw State Forest, Tennessee

	1982			1991		
Species	Clearcut	40 ft^2 BA	60 ft^2 BA	Clearcut	40 ft^2 BA	60 ft^2 BA
	Feet			*Feet (range)*		
Oaks[a]	1.8	2.0	2.0	6.8 (1-17)	2.4 (1-6)	1.8 (1-8)
Hickories	4.2	3.1	2.8	4.0 (2-15)	3.2 (1-4)	2.3 (1-5)
Beech	4.6	5.0	3.9	—	5.8 (1-11)	3.9 (1-7)
Gum/poplar[b]	2.6	1.9	2.7	9.2 (2-15)	5.2 (1-10)	—
Other[c]	4.2	3.4	3.6	8.5 (2-22)	4.6 (1-10)	4.5 (1-14)

[a] White, black, northern red, southern red, scarlet oaks.
[b] Yellow-poplar and sweetgum.
[c] Red maple, blackgum, black cherry, sassafras, dogwood, elms, sourwood, serviceberry, hophornbeam.

Height growth was less for each species in the 40-ft^2 BA shelterwood treatment. Beech, gum/poplar, and other species were the tallest reproduction (Table 4). Hickory and oaks remained the same with little increase. The 60-ft^2 BA treatment had the least height growth. The mean height for all species decreased. Other species and the beech components were the most prominent reproduction. Gum/poplar was not a component in this treatment.

DISCUSSION

Clearcut

The total number of stems per acre increased from more than 1,500 in 1982 to more than 7,500 stems/acre in 1985, a five-fold increase (Figure 1). Most of this increase occurred in the gum/poplar component and sprouting from severed stems between 1.5 to 12 inches dbh in the other species category (dogwood, red maple, and blackgum). Clearcutting tends to initially favor the establishment and growth of shade-intolerant, fast-growing, light-seeded species such as yellow-poplar and sweetgum and sprouting stems with established root systems. The number of stems decreased from the 1985 measurement through the 1988 and 1991 measurements indicating that the site was fully-occupied and that a sorting of stems was occurring. The larger, more competitive stems were beginning to express dominance to form the upper canopy, while the less competitive stems were being relegated to the subcanopy or dying. The poplar/gum component was the most aggressive and tallest species in the overstory with the mostly shade-tolerant, other species category beginning to slip into the lower canopy. The number of oaks per acre increased steadily during each measurement period from less than 250 in 1982 to almost 1,150 stems in 1991 (Figure 1), but their mean height was shorter than the gum/poplar component (Table 4).

40-Ft^2 Basal Area

Compared to the clearcut treatment with more than 7,500 stems/acre at its peak in 1985, the highest amount of total reproduction per acre for the 40-ft^2 basal area treatment was at just over 2,000 stems/acre in 1991 (Figure 1). The 40-ft^2 per acre residual basal area cut provided space and sunlight to favor growth of species present in the lower canopy layers. The rate of increase for the total number of stems per acres decreased between the 1988 and 1991 measurement periods, indicating the gaps in the upper canopy were beginning to close, thus limiting the amount and intensity of sunlight received by lower canopy stems. The proportion of oaks and gum/poplar increased during the measurement periods for this shelterwood cut, while the other species category decreased after a peak in 1985. However, mean heights for oaks were substantially less than those of gum/poplar, beech and other species (Table 4).

60-Ft^2 Basal Area

The total number of stems per acre for the 60-Ft^2 BA treatment increased from the initial measurement in 1982 to a peak in 1985, then decreased through 1991 (Figure 1). Compared to the clearcut and 40-ft^2 BA treatments with maximums of approximately 7,500 and 2,000 stems/acre respectively, the 60-ft^2 BA reached a peak of slightly more than 1,200 stems in 1985. This shelterwood treatment had fewer trees cut in the overstory (or more trees retained) and canopy gaps were smaller allowing the canopy to close more quickly than the 40-ft^2 BA treatment, thus limiting continued growth and development of reproduction. The 60-ft^2 BA treatment after 9 years favored the development of shade-tolerant species in the understory such as beech, red maple, blackgum, dogwood and elms. The gum/poplar component averaged 7 stems per acre and heights less than 1 foot after 9 years. Oaks were present at 200+ stems/acre, but their mean heights were less than 2 feet after 9 years. Mean heights for all species categories for the 60-ft^2 BA treatment were greatly diminished compared to the other treatments.

Oak Regeneration

Oaks are present in different numbers and proportions for each treatment (Table 5). The clearcut treatment has the greatest number and size of oaks (Table 4), but the lowest proportion of stems of the three treatments. Most mature oak stands did not start as fully-stocked stands. Usually oaks are a component of mixed stands in their infancy; during stand development they emerge as the dominant or codominant species (Clatterbuck and Hodges 1988; Oliver 1980a). During the stand initiation stage (Oliver 1980b), oaks are present, but often are inconspicuous in the jungle of woody and non-woody vegetation found after clearcutting. However, some oak stems will persist and stratify above other vegetation forming a dominant canopy. Research in other areas suggest as few as 50 to 100 well-spaced oak stems per acre are needed, if those oaks are assured of becoming upper canopy trees (Clatterbuck and Hodges 1988, Oliver 1980a).

Although this study follows for 9 years the development of oak regeneration in relation to other species, the research is inconclusive whether the oaks present will become dominant or codominant trees. The data indicate that even though the oaks are smaller, on the average than other species, there are individuals (Table 4) that will be dominant with time. However, the fast growth of yellow-poplar will surpass many of the oaks (O'Hara 1986). The question then remains how many oaks are needed and how many oaks will actually succeed to become mature trees.

Table 5—Oak regeneration greater than 1-foot tall by treatment in 1991, Chickasaw State Forest, Tennessee

	Stems/acre	Proportion of total stems
	Number	*Percent*
Clearcut	1,128	24
40 ft^2 BA	680	36
60 ft^2 BA	188	31

With the 40-ft^2 BA shelterwood cutting, most species in the lower canopy benefited from the increased light duration and intensities. The cutting was heavy enough to allow species to grow and develop throughout the 9 years. Canopy closure was just beginning after 9 years. Oaks composed 36 percent of the total stems per acre (Table 5) and a greater number of stems than the gum/poplar component (Figure 1), but were less than half the average height of yellow-poplar. This treatment favored an increase in height of gum/poplar and beech. When released from the overstory, the gum/poplar and beech are positioned to become the dominant canopy. Oaks, though greater in number, are not in a position to grow with the taller species. The tallest oak individual sampled in the reproduction plots and the only individual over 6 feet tall measured 6.4 feet. Although few stems from the other species category of shade-tolerant species will be part of the overstory, most of these stems will probably be relegated to the midstory or succumb.

Loftis (1983, 1990) has successfully used the shelterwood method in the southern Appalachian mountains to increase the size of oak regeneration in relation to other species before release from the overstory. The method used was not to create gaps in the overstory, but to cut trees in the midstory to allow sunlight to filter through the overstory and not be intercepted by an additional canopy layer. This study used a different approach by not treating the midstory in the shelterwood treatments but by creating gaps in the overstory. Either method should be satisfactory if the microenvironment (primarily light conditions) created will favor the oaks at the expense of the shade-tolerant species or the faster-growing intolerant species (Hodges 1989).

The 60-ft^2 BA shelterwood treatment had the lowest mean heights for each of the species categories (Table 4). Most species groups increased in quantity from 1982-1985, then decreased as the canopy closed from the growth of the residual overstory (Figure 1). Oaks composed 31 percent of the reproduction after 9 years (Table 5), but only averaged 1.8 feet tall. The gum/poplar component was non-existent, while the more tolerant beech and other species categories were the tallest and composed a greater proportion of stems. This treatment promoted the more tolerant species at the expense of the oaks and intolerant species.

CONCLUSIONS

Both the clearcut and the 40-ft^2 BA shelterwood treatment appear to provide conditions conducive to promoting the development and growth of oak regeneration. The clearcut treatment had the greatest number of oaks, while the shelterwood had the greatest proportion of oaks in relation to the total number of stems. In both treatments, the oaks will continue to compete with the faster-growing gum/poplar component for overstory prominence. Even if oaks are not the primary component of the overstory, they will be a part of the overstory. The shade cast by the overstory in the light shelterwood cutting (60-ft^2 BA) promoted the shade-tolerant species and not the oaks.

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RELEASING SHELTERED NORTHERN RED OAK DURING THE EARLY STEM EXCLUSION STAGE

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Abstract—The utility of releasing sheltered northern red oak was examined in mesic hardwood stands in north central West Virginia. Different levels of release were applied in the spring of 1996 - six growing seasons after planting 2-0 seedlings that were protected with 5 ft corrugated plastic shelters. The planting was done in a 7.77 acre forest opening that developed abundant natural regeneration, but lacked a self-sustaining oak component. The most intensive release consisted of cutting all stems within a 5 ft radius of the sheltered tree (n = 20). A less intensive release consisted of the removal of only stems that were significantly overtopping the sheltered tree (n = 20). A control group in which the trees were not released was also incorporated into the study (n = 19). Trees at the beginning of the study either were codominant or intermediate in crown class. Total height of northern red oak prior to treatment averaged 9.7 ft and did not differ among treatments. Height growth after two growing seasons was statistically different among treatments (p = 0.0151). Average height growth was 4.09 ft and 3.96 ft for the minimal release and the control group, respectively, and 2.78 ft for the full release. Height of the competing vegetation after two growing seasons also differed by treatment (p = 0.0045) and was 16.10 ft in the minimal release, 17.88 ft in the control, and 20.80 ft in the full release. There was also strong statistical evidence that crown class distribution differed among treatments after two growing seasons (p = 0.0032). In the control group, 26 percent of the trees were newly classified as overtopped in two growing seasons. In the full release, 5 percent of the trees were overtopped and none were classified as overtopped in the minimal release. Considering the height variation between the desired tree and the competing vegetation, preliminary results indicate release operations that leave a moderate level of woody competition around trees like red oak with weak epinastic control, may prove to be the most effective at retaining a favorable competitive status of the desired tree.

INTRODUCTION

The retention of oak species in mixed-oak forest ecosystems throughout the eastern and central United States has been an enduring problem for the last four decades (e.g. Carvell and Tyron 1961, Johnson 1993, Lorimer 1984, McGee 1975, Weitzman and Trimble 1957). Throughout this period, substantial reductions in the oak component of mixed species stands followed most harvesting and regeneration efforts. Leading Noss and others (1995) to conclude that high-quality oak-hickory forests had declined significantly in parts of the central and southern Appalachians. Furthermore, the problem is not avoided in older second-growth and old-growth forests excluded from harvesting. Such protected areas are currently undergoing changes in species composition toward greater abundance of shade-tolerant species and a reduction in oaks and other mid-seral species (Abrams and Downs 1990, Parker and others 1985, Smith and Miller 1987).

Restoration of the oak component following harvesting using natural regeneration methods continue to be evaluated (Loftis 1990, Schlesinger and others 1993, Schuler and Miller 1995) and the use of prescribed fire to improve oak competitiveness has recently received more attention (Keyser and others 1996, Kruger and Reich 1997). However, such methods may require a period of 10 to 20 years, or significantly longer, to develop sufficient oak regeneration. This time period may deter acceptance of such practices in forests characterized by short ownership tenure. An alternative regeneration technique being evaluated is the use of plastic tree shelters to protect planted or natural oak seedlings during the early stages of stand development after overstory removal (Lantagne and others 1990, Schuler and Miller 1996, Smith 1993).

Much has been reported on the operational use of tree shelters during the first few years after installation to enhance seedling establishment and early growth (Brissette 1996). Tree shelters have been shown to increase height growth, root growth, and total biomass of northern red oak seedlings (*Quercus rubra*) for several years after planting in new forest openings and in old fields (Lantagne 1996, Ponder 1996, Schultz and Thompson 1996). However, accelerated growth rates of sheltered trees return to normal after the tree's crown emerges from the shelter (Schuler and Miller 1996). As the effect of the shelter diminishes on northern red oak growth rates, sympatric species often exhibit accelerated rates of height growth as competition for growing space intensifies during the early stem exclusion stage. Black cherry (*Prunus serotina*), yellow-poplar (*Liriodendron tulipifera*), sweet birch (*Betula lenta*) and other species in the central Appalachians often reach 60 ft in total height 20 years after a major disturbance (Miller and others 1995). A vigorously growing codominant oak is expected to be about 40 ft tall in the same time period (Schnur 1937). In general, red oak height growth will lag behind black cherry and yellow-poplar on good to excellent growing sites (Lamson and Smith 1978, Smith 1983). To offset this discrepancy in height growth, silvicultural treatments may be useful to sustain the planted oaks until they are firmly established as codominant trees in the developing stand.

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The extent, number, and timing of needed treatments is unknown. In this paper, we evaluate the utility of releasing sheltered northern red oak in mesic hardwood stands. In doing so, we examined different levels of cleaning and assessed the effects on the crop tree, the competing vegetation and their competitive interaction.

METHODS

Study Area

The study took place on the Fernow Experimental Forest (39.03°N, 79.67°W) near Parsons, West Virginia. The area is referred to as the Allegheny Mountains Section of the Central Appalachian Broadleaf Forest (M221B) as designated by the U.S. Department of Agriculture, Forest Service National Hierarchical Framework of Ecological Units (McNab and Avers 1994). The draft landtype association has been nominally referred to as the Allegheny Front Sideslopes (M221Ba10) and represents over 99,000 acres within the Monongahela National Forest alone (DeMeo and others 1995). The potential natural vegetation of this area is referred to as mixed mesophytic (Braun 1950). Overstory species composition is often quite varied and may include over 20 different species within a spatial scale of roughly 10 or more acres. Common species include northern red oak, sugar maple (*Acer saccharum*), basswood (*Tilia americana*), yellow-poplar, black cherry, and sweet birch. The local climate is characterized by an annual precipitation of 55 to 58 inches (Pan and others 1997), a mean temperature of 61.5°F from April through September and 35.1°F from October through March, resulting in 120 to 140 frost-free days. Distinguishing topographic features of this landtype association include sideslopes of plateau blocks ranging from 2200 to 3500 ft in elevation.

This study was part of a larger study designed to develop an operational method for establishing northern red oak and other difficult to regenerate hardwood seedlings. The portion of the study reported here was initiated in a new forest opening in the spring of 1990. The study area was prepared by clearcutting the overstory during the 1989 growing season in 7.7 acre research compartment nominally referred to as Fork Mountain Gate. Sawlog-size material (11.0 inches dbh and larger) was skidded from the site, and all other stems (1.0 inch dbh and larger) were felled and left in place. Merchantable material removed from the site averaged 19,000 board feet•acre^{-1} (International 1/4 inch). The study area is classified as an excellent growing site equivalent to a northern red oak site index of 80. The initial study included treatment combinations involving 5-ft corrugated plastic tree shelters and transplanted northern red oak seedlings. Partial two-year results were reported by Smith (1993) and referenced as Site 4. Oak seedlings in all treatments involving shelters were significantly taller than those in unsheltered treatments.

Release Test Procedures

Different levels of release were applied in the spring of 1996 - six growing seasons after the initial outplanting. All saplings selected were protected by shelters from the beginning of the study. The shelters were still in place after the most recent remeasurement in the spring of 1998 without any notable decrease in structural integrity. The most intensive release consisted of cutting all stems within a 5-ft radius of the sheltered tree. A less intensive release consisted of the removal of only stems that were significantly overtopping the sheltered tree. A control group in which the trees were not released was also incorporated into the study. Trees at the beginning of the study either were codominant or intermediate in crown class. Dominant trees that were developing in the absence of significant competition from woody vegetation were not included. Total height of northern red oak prior to treatment averaged 9.7 ft and did not differ among treatments ($p = 0.433$) according to analysis of variance results. Three levels of thinning were replicated 20 times for each thinning level and 19 times for the control group. The assignment of treatments to individual trees was randomized. Therefore the design was an unbalanced completely randomized one-way analysis of variance.

Data Analysis

A fixed-effects model was assumed for all statistical analysis. Following data acquisition, the data were assembled and tested for model adequacy using graphical and statistical techniques two years after experimental implementation. The Shapiro-Wilkes statistic and p-value were generated using the SAS univariate procedure for each dependent variable of interest. The results did not indicate the error component deviated from normality for crop tree height growth ($p = 0.8481$). However, the normality assumption did not hold when the height of competing vegetation was used as the response variable in the model ($p = 0.0398$). Therefore, a transformation of the response variable was employed using the natural logarithm which yielded acceptable results with respect to the normality assumption ($p = 0.7473$).

The Brown-Forsythe test was used to evaluate the equal variance assumption related to height growth ($p = 0.9516$) and the log transformed height of competing vegetation ($p = 0.5105$). The associated large p-values do not provide any statistical evidence that the variance associated with either variable differed for the level of thinning. Graphical analysis of residuals corroborated these conclusions. Based on these findings, we established that the model format was adequately describing the response to the treatments and proceeded with tests of significance for both crop tree height growth and height of the competing vegetation. The Duncan's multiple range test was used to further break down the response to treatments when significant differences were found. This test controls the comparison-wise error rate, not the experiment-wise error. So the actual probability of incurring a type I error among all comparisons is greater than the stated alpha. Finally, the chi-square statistic was used to assess the treatment effects on crown class distribution two years after experimental implementation.

RESULTS

Height growth two years after release was significantly related to the degree of release ($p = 0.0151$). To interpret these findings we conducted a Duncan's multiple range test ($\alpha = 0.05$) on height growth response. The results identified two distinct responses and associated the minimal release procedure, hereafter referred to as a codominant release, and the no release as one group and the 5-ft release as another. The codominant release and the no release responses were superior to the 5-foot radial release in terms of height growth (Table 1). Similar to height growth, the average total height of released trees among treatments stratified in accordance with differences in height growth (Table 1, Fig. 1), although treatment means were not significantly different (p = 0.4603).

Not clear from the height growth response was the effect of the release treatment on the height of the competing vegetation. This requires consideration because it is the height of the released tree relative to the height of the competing vegetation that determines the potential vigor and survival of the released tree. The log-transformed height of the competing vegetation did not differ by release method (p = 0.1583) prior to treatment and averaged 12.57 feet. After two growing seasons, the log-transformed height of the competing vegetation differentiated by treatment (p = 0.0060). Transformation of the dependent variable was necessary both prior to and after treatment because the residuals from the general linear model were not normally distributed (p = 0.0398). The Duncan's multiple range test identified the codominant release and the 5-ft release as distinct responses (Table 2). The 5-ft release had a positive effect on the height of the competing vegetation relative to no release, while the codominant release had a negative effect. The mean total height of the competing vegetation with respect to the 5-ft release was more than 4 feet taller than the competing vegetation of the codominant release. Based on the results presented in Table 1, this difference equates to two or more years of red oak height growth. Such a discrepancy in total height could lead to substantial differences in northern red oak survival during the early stages of stand development.

Table 1—Treatment means for two-year northern red oak height growth response as a function of release procedure

Treatment	2-yr height growth	Total height	N
	feet[a]	*feet*	
Codominant release	4.09a	13.73	20
No release	3.96a	13.25	19
5-foot release	2.78b	12.83	20

[a] Means with the same letter are not significantly different (α = 0.05).

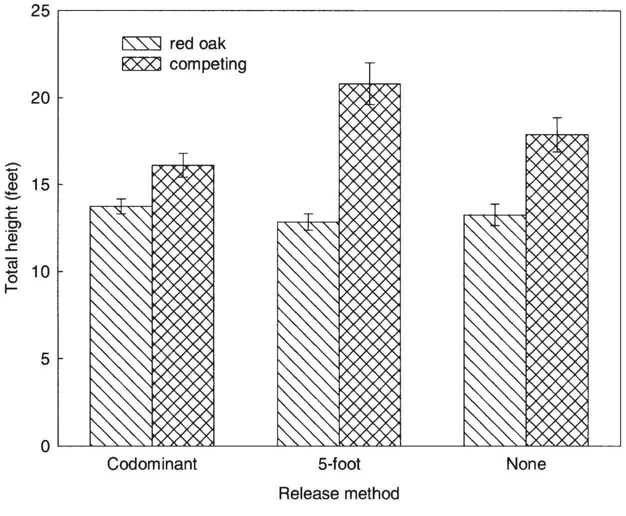

Figure 1—Mean total heights and standard errors of previously sheltered northern red oak and the natural regeneration two years after initiating release procedures and eight years after stand reinitiation.

The crown class distribution of the released oak trees further characterizes the relationship between the height of the competing vegetation and the height of released trees. In 1996 prior to treatment, crown class distribution did not differ by treatment (chi-square = 1.061, p = 0.588). Prior to treatment, 61 percent of the trees were classified as codominant and 39 percent of the trees were classified as intermediate. After two years, crown class distribution had changed among treatments (chi-square = 11.457, p = 0.022). The trees that were not released declined substantially in terms of competitive status. Only 37 percent of the unreleased trees retained codominant classification, while the same percentage was classified as intermediate, and 26 percent were newly classified as overtopped (Table 3). This illustrates the rate of which conditions can change during this stage of stand development. In only two growing seasons, one of every four unreleased northern red oak trees became overtopped. It is unlikely that an overtopped red oak will regain a more competitive crown position and high rates of mortality are anticipated for such trees.

In contrast to the unreleased red oak trees, crown class distribution improved for the group of trees that received the codominant release. No trees in this category were classified as overtopped either prior to or after two growing

Table 2—Treatment means for height of the competing vegetation two years after implementation as a function of release procedure

Treatment	Duncan group[a]	Total height	Total height
		log-feet	*feet*
5-foot release	A	3.00280	20.14
No release	AB	2.85793	17.43
Codominant release	B	2.76181	15.83

[a] Means with the same letter are not significantly different (α=0.05).

Table 3—Change in northern red oak crown class two years after release by treatment category. Table values are frequency and column percent in parentheses

	Treatment			
Crown class	Initial	Codominant release	5-foot release	No release
Codominant	36	16	13	7
	(61)	(80)	(65)	(37)
Intermediate	23	4	6	7
	(39)	(20)	(30)	(37)
Overtopped	0	0	1	5
	(0)	(5)	(5)	(26)

seasons and the ratio of codominant to intermediate trees changed from roughly 60/40 in the spring of 1996 to 80/20 after two additional growing seasons. This is to be expected because any and all overtopping trees were cut. However, this procedure has also resulted in greater height growth relative to the full 5-ft release. It is this combination of factors that led to a more favorable crown class distribution.

The 5-ft release resulted in one tree becoming overtopped and had little effect on the remaining crown class distribution (Table 3). However, the disparity between the height of the released tree and the height of the competing vegetation was greatest in this category (Fig. 1). A continuation of this trend will likely result in a substantial, and perhaps an abrupt, decline in the competitive status of these trees.

When release treatments began, competing vegetation comprised 16 species and did not differ by treatment category (chi-square = 31.975, p = 0.369). Sweet birch was the principal species with 37 percent of the total number of dominant competing stems. This species is an aggressive competitor during early stand development and has little commercial value in the central Appalachian region. The eventual species composition of third-growth stands dominated by this species is uncertain. Other major competitors included yellow-poplar (10 percent), pin cherry (*P. pennsylvanica*) (10 percent), and black cherry (7 percent). Only one sampled northern red oak representing about 2 percent of the total dominant competing stems was recorded in 1996 at the onset of release efforts.

Two years after initial release, species composition of the competing vegetation did not yet differ by treatment, but some evidence suggests a trend may be developing toward more stratification (chi-square = 31.458, p = 0.087). We anticipate that species with slower juvenile growth rates will dominate the competing vegetation of the codominant release method in the future because faster growing species will have been selectively removed. Species richness in 1998 declined to 11 species with sweet birch continuing to dominate the young stand (36 percent), while yellow-poplar increased to 20 percent and pin cherry increased to 22 percent over all treatment categories. Black cherry declined slightly to about 5 percent of the total and northern red oak was no longer represented in the sample.

DISCUSSION

Variations in stand density generally are assumed to have little effect on individual tree height growth (Smith 1986). Height growth is so closely associated with the productive potential of a site that the concept of site index, height of dominant and codominant trees at a convenient base age, is based on an understanding that height growth is relatively independent of stocking level. However, the height growth of trees used in site index equations are predicated on trees that have retained dominant or codominant status throughout their development. The use of dominant or codominant trees implies competition for above ground growing space is one factor that determines growth characteristics. This is evident when trees are isolated or are grown at low stocking levels. In particular, species with weak epinastic control (i.e., relatively minimal influence by the tree’s terminal bud over the length and orientation of lateral branches) that are grown at low stocking levels might exhibit reductions in height growth (Oliver and Larson 1996). Weak epinastic control is a trait of northern red oak and many other angiosperms native to the eastern United States (Kramer and Kozlowski 1979).

A decline in height growth associated with extreme reductions in stand level density was documented for oak and yellow-poplar saplings in southeastern Ohio by Allen and Marquis (1970). They concluded that short-term height growth was maximized at about 70 percent stocking based on experimental manipulation of density. Codominant oaks thinned to 70 percent of full stocking grew 1.5 ft annually which was three times the growth rate of trees grown at 20 percent stocking. Concomitant yellow-poplar height growth at the same site was also optimized at the same stocking level. As such, total release of an individual oak (e.g. as in thinning to a 5-ft radius) may inadvertently provide a partial release to a bordering yellow-poplar. The unintentional consequence of such a cleaning would be to slow oak height growth and increase height growth of the competition. This may partially explain the results reported here regarding the accelerated height growth of the competing vegetation in the full release treatment (Fig. 1).

Some investigators have also concluded the effects of a full release on hardwood saplings decreases height growth, whereas a partial release can improve height growth. A full release of suppressed sapling-sized hickories in Ohio and Indiana generally slowed height growth for the first three years after release relative to unreleased trees (Nixon and others 1983). The authors speculated that release cutting around hardwood saplings would have been beneficial if the crown release had not been complete. In an extensive study conducted in Connecticut, Ward (1995) reported significant height growth depression of released codominant black (*Q. velutina*) and scarlet (*Q. coccinea*) oaks four years after treatment. Moreover, fully released dominant northern red oak also exhibited less height growth than partially released individuals. But response to release can also change over time and variable responses have been reported. In a seven-year-old even-aged hardwood stand in West Virginia, fully released red oak grew slower in height than unreleased trees for the first two years but differences were not evident after five years (Trimble 1974). Similar results were noted for yellow-poplar (Johnson and others 1997). Others have found that crop tree release did not affect height growth in young Appalachian hardwood stands (Smith and Lamson 1983, Wendel and Lamson 1987).

The results of this study and the work of others previously noted suggests release thinning in very young stands has the potential to be a useful silvicultural tool. It is apparent that partial release thinning has stimulated short-term juvenile height growth in some cases. It is not yet apparent if long-term survival and competitive status of mesic site oaks can be maintained or improved by release thinning in young stands. Existing recommendations indicate it is better to delay stand manipulations until competitive pressures have selected the most vigorous individuals. For example, to select the best quality timber trees for crop tree release, Perkey and others (1993) recommend waiting until the trees are at least 25 ft tall. However, to influence species composition, release work may need to begin before codominant trees reach this stage of development. This is especially true when objectives for the stand include the retention of oak that is often not abundant relative to other species. The need for work in very young stands when oak perpetuation is an objective is illustrated by the sharp decline in crown classification of unreleased oaks reported in this study (Table 3). Moreover, in a practical sense, the release of previously sheltered oaks protects the existing investment in tree shelters.

Oak regeneration problems continue to plague forest managers throughout the eastern and central United States. Forest stands that included a significant oak component during both old-growth and second-growth stages, are often characterized by a greatly diminished oak component following second-growth harvesting. Silviculturists continue to explore ways to develop abundant understory oak to promote oak regeneration following harvesting activities. However, harvesting and the regeneration of new stands continues unabated while prescriptions for abundant natural oak regeneration remain unresolved. As such, to meet common timber, wildlife, and diversity goals that include the retention of oak, forest managers will need to develop techniques for increasing the survival rate of the scarce oak stems common in many young third-growth forests. Release thinning in very young stands may be beneficial in that respect. Release thinning of previously sheltered northern red oak is essential to maintain competitive status of these trees on mesic sites. Future research needs to focus on the long-term survival of released trees and the degree, timing, number, and cost of releases necessary to achieve oak retention relative to site characteristics and the competing vegetation.

MANAGEMENT IMPLICATIONS

Preliminary results indicate that releasing previously sheltered northern red oak can be beneficial to retaining this species during the early stages of stand development. The following suggestions are offered as guidelines for implementing release procedures on small to medium-sized operations:

- Wait as long as possible to do the release work but not until the desired oak trees are overtopped by competing vegetation, usually five to six years after planting on good sites.

- Retain all trees not overtopping the desired tree. This will induce the released tree to sustain rapid height growth and maintain strong epinastic control.

- Schedule annual release work for individual stands for the best results. Individual trees receiving a codominant release require very little treatment time. With initial planting density on a 25-foot basis, it is reasonable for a two person crew to inspect and release, if required, 600 to 1,000 trees per day. Simple hand tools are sufficient for doing the release work. Do not plant and shelter more northern red oak than can be released in the central Appalachians as release work will be vital to their survival.

- Target faster growing, short-lived species with lower commercial value for removal and retain slower growing species, if possible. Altering the species composition immediately surrounding the desired oak by favoring slower growing species may lessen the need for repeated release efforts.

- Release work should be done during the dormant season to take advantage of better visibility. When releasing sheltered oaks, it is easier to find the desired trees when the shelters are retained on the tree, even though the shelter may be providing no protection to the tree. Occasionally, manually splitting the tree shelter is necessary because diameter growth becomes restricted by a shelter that has not degraded sufficiently.

- Scheduling early stand release work for sheltered oaks also facilitates selecting highly desirable natural regeneration for similar cultural efforts. If such trees are included, flag the tree so that it can be more easily relocated during the following years.

- On good to excellent growing sites in the central Appalachians, it may require a period of 10 to 15 years (e.g., from 5 to 15 years after stand reinitiation) of release work before long-term survival of oak throughout stand development will be achieved. The frequency of required release work will decline as tree sizes increase.

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UNDERPLANTED NORTHERN RED OAK 17 YEARS AFTER THINNING AND UNDERSTORY CONTROL AND 8 YEARS FOLLOWING OVERSTORY REMOVAL

Ron Rathfon and Wayne Werne[1]

Abstract—Thinning-from-below and understory vegetation control treatments were applied to an oak-dominated stand in 1981 and 1982. Northern red oak seedlings (*Quercus rubra* L.) were planted in the understory to determine whether artificial regeneration was a viable option in ensuring that oak remain a prominent component of the succeeding stand. The overstory was removed in a harvest in 1991. Eight years following overstory removal, the thinning plus understory control treatment combination had many more underplanted red oaks in a competitive position than either treatment alone. The underplanted red oaks made up 40 percent of the total oak regeneration in the thinning plus understory control treatment.

METHODS

The study was established on a south-facing, 6 to 20 percent slope site in the unglaciated region of southern Indiana. White Oak Site Index was 70 feet. Oak (white, red, black and scarlet) comprised 75 percent of the sawtimber basal area of the original stand. In 1981, a small feller-buncher was used to thin-from-below (THIN) one-half of the area of each of four two-acre blocks creating one-acre harvest units. In September 1982, an understory vegetation control treatment (VEGCON) was applied to a one-half acre area within each THIN treatment plot by mist-blowing herbicides (Wright and others 1985).

Northern red oak seedlings were planted on a 9.5 foot by 9.5 foot grid for a total of 96 seedlings per VEGCON split plot, or 432 seedlings per acre. Various types of planting stock were tested for suitability in underplantings (Wright and others 1985).

The overstory was removed in a harvest in early 1991. Underplanted red oaks were remeasured in 1998. Natural regeneration was also assessed. A 1-inch dbh tree was considered to be the minimum size for viable, competitive growing stock in 1998.

RESULTS

The THIN treatment produced far fewer underplanted red oaks meeting minimum size requirements (greater or equal to 4.5 feet in height) at the time of overstory removal than recommended by Sanders and others (1976) to ensure red oak prominence in the final stand (Table 1). VEGCON produced over 2-1/2 times more underplanted red oaks per acre meeting the minimum size criteria than did THIN. While THIN+VEGCON had over 5-1/2 times the number of

Table 1—Survival, mean height, and stocking of underplanted red oak just prior to overstory removal and 8 years after overstory removal

	1990			1998				
						Viable trees[a]		
Treatment	Survival	Mean height	Viable trees	Survival	Mean height	1-in d.b.h. class	2-in d.b.h. class	Total stocking
	Percent	*Feet*	*Stems/ac*	*Percent*	*Feet*	--------- *Stems per acre* ---------		
Untreated	46.6	1.32	0.0	-	-	-	-	-
VEGCON	58.3	2.63	101.1	30.7	10.1	38.3	5.6	43.9
THIN	30.2	2.48	38.6	19.8	9.2	20.3	2.3	22.6
THIN+VEGCON	52.9	3.25	216.7	38.5	13.4	72.1	27.0	99.1

[a] Stems greater than or equal to 4.5 feet in height.

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criteria-meeting trees than did THIN, it still did not meet the minimum stocking required to result in an oak dominated stand (Sanders and others 1976). Eight years following overstory removal, 99.1 underplanted red oaks per acre remained in a competitive position (greater or equal to 1 inch dbh) in THIN+VEGCON (Table 1). THIN+VEGCON had almost 4-1/2 times more competitive underplanted red oak stems than that of THIN and over twice that of VEGCON.

Natural oak regeneration (red, black and white oak) was a significant component of the stand. It comprised 9.4 percent, 18.9 percent and 12.1 percent of the total 1-inch-dbh-and-greater stocking for VEGCON, THIN and THIN+VEGCON, respectively (Table 2). The combined natural and underplanted oak in THIN+VEGCON accounted for one-third of all stems over 2 inches dbh. Forty percent of the total oak stocking in THIN+VEGCON was from underplanted red oaks.

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Table 2—Stocking by species, treatment, and d.b.h. class 8 years after overstory removal

	VEGCON		THIN		THIN+VEGCON	
	D.b.h. class		D.b.h. class		D.b.h. class	
Species	1 in.	2 in.	1 in.	2 in.	1 in.	2 in.
	Stems per acre					
Oaks[a]	144.4	28.9	182.9	38.5	166.9	83.5
Tulip-poplar	447.7	86.6	0.0	9.6	70.6	32.1
Black cherry	43.3	67.4	57.8	67.4	32.1	70.5
Ash	9.6	0.0	19.3	9.6	19.3	6.4
Hickory	9.6	0.0	173.3	9.6	70.6	0.0
Sugar maple	115.5	24.1	163.7	19.3	218.3	6.4
Misc.	370.7	28.9	260.0	28.9	423.7	51.3

[a] Natural regeneration plus underplanted red oak.

INFLUENCE OF CUTTING METHODS ON 12-YEAR-OLD HARDWOOD REGENERATION IN CONNECTICUT

Jeffrey S. Ward and George R. Stephens[1]

Abstract—Many upland oak forests are approaching economic and biological maturity. This has led to concern over species composition following stand regeneration. A case study of hardwood regeneration was established in 1984 in central Connecticut to study the effects of cutting method on regeneration composition. The six harvest treatment plots (4-6 acres) were on medium quality sites (SI=60). Harvest treatments were: shelterwood, diameter limit, coppice with standards, commercial clearcut, silvicultural clearcut, and uncut control. Regeneration was sampled by species and height class prior to harvest, and 5 and 12 years post-harvest using 16-28 1/300 acre plots per treatment.

Preharvest inventories found fewer than 50 oaks/acre ≥ 5 feet tall, much less than the 433/ac recommended for the western branch of the Central Hardwood region. However, oak regeneration accounted for 13 percent (150 oak/acre) of codominant and dominant trees 12 years after harvest on the silvicultural clearcut plot. This strongly suggests that there should be regional standards for evaluating oak regeneration. All treatments, except diameter limit, increased regeneration density. Shelterwood, but not other partial cuts, increased the number of oaks ≥ 5 feet tall. Five years after the shelterwood cut red maple and black birch densities had also increased by 88 percent and 1500 percent, respectively. Clearly, this will increase the competition oaks experience following final harvest. Partial cutting should not be prescribed when management goals include obtaining oak regeneration in future stands.

INTRODUCTION

There are 14 million acres of mature oak forest in the Northeast, and 14 million in the North Central states (Powell and others 1993). The present forest is a mixture of land continuously forested, but repeatedly cut, and land abandoned from agriculture during the 19th or 20th centuries. Many forests were established early in the 20th century following harvests for fuelwood and charcoal production. In Connecticut, sawtimber stand area has increased from 17 percent of the 1.8 million acres of commercial forest land in 1952 to 63 percent in 1985 (Dickson and McAfee 1988). Seedling and sapling stands account for only 10 percent of forested area. The unbalanced age class and economic maturity of the forest, combined with favorable stumpage prices, have recently led to increased harvest and regeneration activity.

As many forests are approaching biological maturity, concern over forest regeneration has increased. Commercially less valuable red maple (*Acer rubrum*) and birch (*Betula lenta* and *B. alleghaniensis*) now account for half of all stems in the sapling size class in Connecticut (Dickson and McAfee 1988). The lack of adequate oak regeneration is a well-recognized problem and challenge for foresters throughout the oak-hickory region (Holt and Fischer 1979, Lorimer 1989, Loftis and McGee 1993). Nearly two-thirds of the pole and sawtimber stands in Connecticut are classified as oak-hickory (Dickson and McAfee 1988). Even-aged systems are recommended for regenerating oak forests, except on low quality sites (Roach and Gingrich 1968, Sander 1977, Hibbs and Bentley 1983, Johnson 1993). There is a consensus that oak regeneration should be present before final harvest in mature stand if the succeeding stand is to contain abundant oak. However, the minimum size and amount of oak advance regeneration (seedlings and saplings established before final overstory removal), and ability of various cutting methods to provide the regeneration, varies among studies. Prescriptions or guidelines for regenerating oak are largely derived from research in the western portion of the central hardwood forest. Their applicability to the eastern branch of the central hardwood forest, specifically southern New England, remains untested.

This research was established to provide information on hardwood regeneration in the eastern section of the central hardwood forest. The general objectives of this research are: 1) determine whether the minimum size requirements for oak regeneration developed in the Midwest are too stringent for southern New England, and 2) determine the effect of different treatments (i.e., cutting methods) on regeneration composition by species group. The specific objective of this paper was to examine how regeneration differed among treatments 12-years after cutting.

METHODS

Research plots were established in 1984 in North Madison, Connecticut to examine the effect of various cutting methods on hardwood regeneration, especially oak. Six cutting method plots (4-6 acres each) were established on medium quality sites. Cutting methods were silvicultural clearcut, commercial clearcut, coppice with standards,

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diameter limit, shelterwood, and uncut control. These results should be treated as a case study due to the lack of replication. Specific treatment guidelines were:

Silvicultural clearcut—All residual trees > 2 inches dbh were cut after sawtimber and cordwood harvests;

Commercial clearcut—All merchantable trees ≥ 11 inches dbh were harvested;

Coppice with standards—Approximately 55 “crop trees” per acre were selected from among desirable poles and sawtimber. All other trees ≥ 5 inches dbh were harvested. At 10 to 15-yr intervals 5 crop trees per acre will be harvested and 5 new crop trees will be selected;

Diameter limit—the diameter limit was 16 inches for desirable species (oaks, ash, sugar maple) and 14 inches dbh for other species and low quality desirable species;

Shelterwood—stands were marked to remove 50 percent of basal area and 50 percent of upper canopy (dominant and codominant trees) by removing undesirable species and favoring retention of oak; and

Control—No cutting

The coppice with standards treatment was the first step of converting a relatively, even-aged stand into a multi-aged stand. Therefore, we selected crop tree by diameter classes rather than by age. With time we hope to convert this stand to a traditional coppice with standards stand. The coppice with standards is designed to favor selected crop trees for the production of high value timber or veneer logs while periodically removing all other merchantable material at regular intervals. This system, originally developed in Europe to provide fuel and waddle for tenant farmers and timber for estate owners, may be useful for small accessible tracts were a market for fuelwood exists. About 40-50 standards, potential crop trees, are selected on each acre from existing pole and sawtimber. Preference is given to desirable species, single stems, and excellent form. Eight to ten new standards are selected 10-20 year intervals. Then one fifth of crop trees are harvested along with all other stems larger than 5 inches dbh. Harvesting intervals are flexible to accommodate market conditions and growth.

Poles (4.5-10.5 inches dbh) and sawtimber (> 10.5 inches dbh) were inventoried prior to harvest using 4-7 prism plots (10 factor) per treatment. Prism point centers were randomly placed and then permanently marked using treated stakes. The following data were recorded for all trees ≥ 4.5 inches dbh: species, diameter, and crown class. For this paper, regeneration is defined as stems < 4.5 inches dbh. Regeneration was sampled prior to harvest, and 5 and 12 years post-harvest using 4 1/300 acre plots per each prism point, each 33 ft from the prism plot center in a cardinal direction (16-28 plots/treatment). Regeneration plot centers were also permanently located using treated stakes. For each inventory the following data were recorded for all stems: species, height (<1 ft, 1-1.9 ft, … 8-8.9 ft, ≥ 9 ft), and crown class. All regeneration, including 1-year-old seedlings, was tallied.

To simplify analysis and discussion, the 26 species found on the plots were collapsed into 5 species groups: Oak—*Quercus alba, Quercus coccinea, Quercus prinus, Quercus rubra, Quercus velutina*; Maple—*Acer rubrum, Acer saccharum*; Birch—*Betula alleghaniensis, Betula lenta*; Other—*Carya cordiformis, Carya glabra, Carya tomentosa, Fagus grandifolia, Fraxinus americana, Juglans cinerea, Liriodendron tulipifera, Nyssa sylvatica, Prunus serotina, Sassafras albidum*; and Minor—*Amelanchier arborea, Betula populifolia, Carpinus caroliniana, Castanea dentata, Cornus florida, Juniperus virginiana, Ostrya virginiana*.

RESULTS AND DISCUSSION

Prior to harvest, seedling density (< 5 feet tall) was high on all treatments, 15-29,000/acre (Table 1). Maple and oak were found on nearly every regeneration sample plot, 99 and 96 percent respectively. Birch was found on only 58 percent of the 1/300 acre plots. Maple dominated the seedling size class with an average of nearly 10,000/acre. Oak seedlings were quite numerous, 4,700/acre. Although oak seedling densities were high, there were few oak saplings (≥ 5 feet tall, Table 2). Only 25 of the 144 plots (17 percent) had an oak sapling. This is far below the 60 percent stocking recommended by Sander (1977). It should be noted our estimate of stocking was optimistic because

Table 1—Density (stems/acre) of seedlings (< 5 feet tall) prior to harvest by cutting method and species group in North Madison, CT

	Oak	Maple	Birch	Other	Minor	Total
Silvicultural clearcut	4489	9707	1093	3139	1693	20121
Shelterwood	2368	16404	2604	6000	1757	29132
Diameter limit	3814	13939	868	3171	1232	23025
Commercial clearcut	6840	7920	1185	1200	1245	18390
Coppice with standards	6638	3694	844	3319	300	14794
Uncut	4100	6663	4963	4325	675	20725
Mean	4700	9721	1926	3526	1150	21031

Table 2—Density (stems/acre) of saplings (≥ 5 feet tall) prior to harvest by cutting method and species group in North Madison, CT

	Oak	Maple	Birch	Other	Minor	Total
Silvicultural clearcut	11	311	129	107	418	975
Shelterwood	0	107	43	32	171	354
Diameter limit	11	300	11	129	214	664
Commercial clearcut	105	180	165	30	195	675
Coppice with standards	113	131	150	19	94	506
Uncut	13	250	163	113	225	763

we used a larger sampling plot (1/300 acre) than indicated by Sander (1/735 acre) and we assumed that 100 percent of pole and sawtimber oaks would resprout.

Five years after harvest, distinct differences had developed among the cutting methods (Table 3). Overall sapling (≥ 5 feet tall) and oak sapling density was higher on treatments that removed pole sized material, i.e., shelterwood and silvicultural clearcut. Oak sapling density increased on both the shelterwood and silvicultural clearcut plots, but decreased on the diameter limit, commercial clearcut, and coppice with standards plots. There was a much greater concurrent increase in maple and minor species density on the silvicultural clearcut and birch and minor species on the shelterwood plot. Sapling density had actually decreased on the other plots.

A clearer picture had emerged 12 years after cutting (Table 4). Oak sapling density remained high on the silvicultural clearcut plot after canopy closure. Although oak only accounted for 13 percent of upper canopy stems (Table 5), the 150 oaks/acre in the codominant and dominant crown class should be more than adequate to meet management goals. The mystery is where did the other upper canopy oaks come from? Only 2 of the 7 plots with an oak in the upper canopy at age 12 had had an oak at least 5 feet tall prior to the harvest. Three of the other 5 plots did have an oak 2-5 ft tall. On the remaining 2 plots, all oak regeneration was less than one foot tall prior to harvest.

Table 3—Density (stems/acre) of saplings (≥ 5 feet tall) 5 years after harvest by cutting method and species group in North Madison, CT

	Oak	Maple	Birch	Other	Minor	Total
Silvicultural clearcut	257	1296	171	300	1050	3075
Shelterwood	96	236	589	43	600	1564
Diameter limit	21	214	0	107	225	568
Commercial clearcut	90	105	105	30	255	585
Coppice with standards	19	75	113	0	19	225
Uncut	13	263	163	75	163	675

Table 4—Density (stems/acre) of saplings (≥ 5 feet tall) 12 years after harvest by cutting method and species group in North Madison, CT

	Oak	Maple	Birch	Other	Minor	Total
Silvicultural clearcut	889	804	450	900	1468	4511
Shelterwood	86	268	1511	107	696	2668
Diameter limit	21	257	461	129	268	1136
Commercial clearcut	105	60	195	60	285	705
Coppice with standards	19	19	56	0	19	113
Uncut	0	188	150	38	288	663

Table 5—Density (stems/acre) 12 years after a silvicultural clearcut by crown class and species group in North Madison, CT

	Oak	Maple	Birch	Other	Minor	Total
Dominant/codominant	150	332	107	193	386	1168
Intermediate	171	161	75	107	343	857
Suppressed (≥ 5 ft tall)	568	311	268	600	739	2486
Suppressed (1-4 ft tall)	461	54	96	793	193	1596
Suppressed (< 1 ft tall)	1018	568	32	1500	2057	5175

Thus, it appears that minimum size standards to obtain oak in the upper canopy at crown closure in the Northeast may be smaller than for the central (Sander 1977) and southeastern states (Loftis 1990).

The initial gain in oak sapling density on the shelterwood plot was not lost, but was being overwhelmed by a three-fold increase in birch sapling density through 12 years after cutting (Table 4). Shelterwood success has been spotty in other studies (Sander and Graney 1993), especially where deer herds are large (Smith 1993). Recommendations for regenerating oak involve two or three shelterwood cuts extended over a 10-30 year period (Hibbs and Bentley 1983, Martin and Hix 1988, Loftis 1993). Small diameter maple and birch readily sprout after cutting and respond well to release (Ward and Stephens 1993, 1996). Therefore, it is likely that shelterwood cuts extended over a long period will increase the proportion of birch and maple in the next stand.

This case study provides strong evidence that a new standard should be developed for evaluating oak regeneration in the Northeast. Furthermore, when increasing oak regeneration is part of the management objectives, partial cutting from above (cutting the largest trees) is counter-productive. Care should also be taken to not delay overstory removal with partial cutting from below. Assuming the relative competitive status is correlated with height; a long interval between the initial cut and the final harvest increases the competitive status of maple and birch relative to oak.

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METHODS TO IMPROVE ESTABLISHMENT AND GROWTH OF BOTTOMLAND HARDWOOD ARTIFICIAL REGENERATION

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Abstract—With ongoing attempts to reforest both cut-over and abandoned agricultural land in the lower Mississippi alluvial plain, it has become evident that there exists a need for an efficient regeneration system that makes biological and economic sense. Also, there is a need to address how to minimize competition from invading weeds, to deter predation by small mammals, and to achieve adequate tree establishment. This study was designed as a randomized complete block experiment with treatments arranged as factors (3 species X 2 levels of protection X 4 weed control treatments) with three replications, to assess efficacy of seedling protection and weed control to improve seedling growth and survival. The study was conducted on a cleared area in the Delta Experimental Forest, Stoneville, MS. Three tree species, Nuttall oak (*Quercus nuttallii* Palmer), green ash (*Fraxinus pennsylvanica* Marsh.), and persimmon (*Diospyros virginia* L.) were planted as 1-0 bareroot seedlings in March 1997. Each treatment plot had 25 seedlings, spaced at 0.75 meters X 0.75 meters. Shelter protection was installed on half of the seedlings. Shelters were 1 meter tall, 15 centimeter diameter plastic tree shelters. Each shelter treatment (with or without shelter) received one of four weed control treatments: mechanical mowing (gas-powered weed cutter), fabric mat (woven, black polypropylene material), chemical herbicide (Oust, sulfometuron-methyl at 210 grams per hectare), or undisturbed (control). Response of shelters and weed control treatments on seedling survival, height and diameter were followed for one growing season. Seedlings in shelters had greater survival (98 percent) than seedlings without shelters (93 percent). For all three species, height growth was significantly greater for sheltered seedlings (43 centimeters) compared to unsheltered seedlings (15 centimeters). For the unsheltered seedlings, fabric mat weed control increased survival relative to chemical weed control. All seedlings had significantly greater height and diameter growth under the fabric mat weed control compared to growth under the other treatments except for unsheltered oak seedlings.

INTRODUCTION

In the lower Mississippi alluvial plain (LMAP), some land cleared for soybean production is being converted back to bottomland hardwood forests under the Wetland Reserve Program (WRP). Large-scale reforestation of former agricultural lands faces many challenges. Newly planted trees are subjected to harsh site conditions, including heavy clay soils, herbaceous competition, herbivory, drought and flooding. Proper matching of species to soil and site conditions is necessary to successfully establish seedlings. Species commonly used in reforestation under WRP include Nuttall oak (*Quercus nuttallii* Palmer), willow oak (*Quercus phellos* L.), water oak (*Quercus nigra* L.), green ash (*Fraxinus pennsylvanica* Marsh.), cottonwood (*Populus deltoides* Marsh.) and persimmon (*Diospyros virginia* L.). Natural invasion on these sites is usually minimal, as few seed sources exist (Allen 1990). Those species that do invade usually include sweetgum (*Liquidambar styraciflua* L.), green ash and sugarberry (*Celtis laevigata* Willd.). Therefore, the most common reforestation strategy in the LMAP is to introduce hardmast species and rely on wind and water dispersal of light seeded species. With this strategy, fields may or may not be prepared by disking, oaks are established by planting 1-0 bareroot seedlings or direct seeding, and post-planting weed control is typically not used (Haynes and others 1995, Stanturf and others 1998).

Hardwoods have been established successfully on many sites. Krinard and Kennedy (1987) observed 69-97 percent survival rates two years after planting hardwood seedlings on Sharkey clay soil. In their study, Nuttall oak seedling survival averaged 85 percent. Wittwer (1991) recorded a survival rate of 78 percent three years after planting bottomland oaks in eastern Oklahoma. Savage and others (1989) reported a 64 percent survival rate for seedlings on reforested bottomlands in Louisiana, while Schweitzer and others (1997) reported 63 percent survival one year after planting oak seedlings on a former farmed wetland dominated by heavy clay soils. Despite these successes, operational reforestation under WRP has proven difficult. A recent survey of reforested former agricultural lands in west-central Mississippi enrolled in the WRP found that only 23 percent of the land planted with 1-0 bareroot seedlings had at least 100 trees per acre after three growing seasons (Personal communication. 1998. Callie Jo Schweitzer, Research Forest Ecologist, Southern Research Station, P.O. Box 227, Stoneville, MS 38776). The higher survival reported in the studies cited above were on smaller tracts, while the average tract size in the 1992 WRP survey was approximately 210 acres. Nevertheless, Allen (1990) evaluated oak plantations established by USDI Fish & Wildlife Service personnel on refuges in west-central Mississippi. Similar establishment techniques were used on these tracts as the WRP tracts. Seven out of ten stands Allen assessed had over 200 trees per acre.

In addition to animal browsing stress, seedlings must also compete with invading weeds. In areas where climatic

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conditions tend toward droughty, weeds compete for available water. A fabric weed barrier, more commonly used in western states for shelterbelt establishment, may aid in short-term moisture retention while mitigating the effects of herbaceous competition. However, damage from deer and small rodents may still pose a threat to the newly planted seedlings.

The benefits of tree shelters have been well documented, mostly in cut-over sites in more northern climates. Seedling survival is increased by minimizing losses from animal damage and by stimulating early height growth that can result in earlier crown closure (Strobi and Wagner 1995). Tree shelters may increase the competitiveness of slower growing, desirable species on bottomland sites.

We investigated the impact of tree shelters and four different weed control treatments on the survival and growth of three bottomland hardwood species. Our objective was to evaluate whether weed control, with or without tree shelters, could increase survival and growth of bottomland species.

METHODS

The study was conducted on the Delta Experimental Forest, approximately 7.24 kilometers north of Stoneville, MS. The site is dominated by Alligator clay soils (very fine, montmorillonitic, acid, thermic, Vertic Haplaquepts). Alligator soils are poorly drained and developed in sediments deposited by the Mississippi River. These montmorillonitic clays have high shrink-swell capacity and are common in bottomland forests and land offered for reforestation in this area. In Delta Experimental Forest, an area of approximately 1.62 hectares was cleared in 1967 and has been maintained in grass by bushhogging. The study area was surveyed and prepared for planting by double disking in the fall of 1996.

In February 1997, three blocks of 24 plots were delineated on the study site. Each treatment plot (4.27 X 4.27 meters) contained 25 planting spots equally spaced at 0.75 X 0.75 meters, and plots were surrounded by a 0.61 meter buffer. Treatment plots were marked with wooden corner stakes and all planting spots were marked with a flag prior to planting and weed control treatment. Seedlings were hand planted using planting shovels on March 12, 1997. Nuttall oak, green ash and persimmon were chosen to study because of their compatability on bottomland sites, and their widespread use in reforestation efforts in the LMAP. The bareroot stock (1-0) used in this experiment was purchased from a local nursery.

Shelter protection was installed on half of the seedlings immediately after planting. Shelters were 1 meter tall, 15 centimeter diameter, commercially available opaque, plastic tree shelters, each secured with plastic ties attached to a wooden stake. Seedlings also received one of four weed control treatments: mechanical, fabric mat, herbicide or none. Mechanical mowing was implemented manually using a gas-powered weed cutter, applied every other week from March until December 1997. The chemical herbicide Oust (sulfometuron-methyl) was applied using a back-pack sprayer on March 21, 1997 at 210 grams per hectare. The fabric mat (woven, black polypropylene material) was placed on plots in 0.91 meter wide strips and secured in place using ground staples. Fabric mat strips overlapped slightly at each seedling row, allowing for the seedling (and seedlings in shelters) to be completely surrounded by mat. No weed control was performed on the control or undisturbed plots after the initial disking for site preparation.

All seedlings were measured immediately after planting and again in January 1998. Height was measured with a meter stick to the nearest centimeter, and diameter was measured with a digital caliper to the nearest millimeter. In July 1997, square meter plots for vegetation sampling were placed in three plots for each weed control treatment. A seedling in the selected plot was randomly selected, and the square meter frame was place next to that seedling. All vegetation was removed, dried and weighed.

Data were analyzed using SAS software (SAS Institute 1988) according to a randomized complete block design with three replications and a factorial treatment arrangement. First-year height and diameter growth were computed by subtracting initial values from final values. Survival rates in decimal fractions were transformed with inverse sine transformation as they covered a wide range of values (Steel and Torrie 1980). Analysis of variance (ANOVA) and Duncan’s new multiple range test were used to test for significant differences among treatment means. One-way ANOVA was used to compare survival and growth of seedlings with and without shelters. A three-way ANOVA was used to analyze the effects of weed control, species and blocks on variation in mean seedling growth and survival. Significant differences were reported at the 0.05 percent level.

RESULTS

Seedling Survival and Growth

Survival of all species was exceptionally high. Of the total 1800 seedlings planted, only 81 seedlings died. Ash seedlings had significantly higher survival (588/600, 98 percent) than persimmon (550/600, 92 percent), while oak survival (581/600, 96.8 percent) did not differ from that of ash or persimmon. Unsheltered seedlings showed significantly lower survival (841/900, 93 percent) than sheltered seedlings (878/900, 97.6 percent).

Unsheltered ash seedlings had significantly greater survival than persimmon; oak survival was not significantly different than ash or persimmon (Figure 1). Sheltered oak and ash seedlings had significantly greater survival than sheltered persimmon seedlings (Figure 1).

Sheltered seedlings grew significantly taller than seedlings without shelters (height growth with shelter=43.3 centimeters, n=878, without shelter=14.9 centimeters, n=841). However, diameter growth of unsheltered seedlings was greater than diameter growth of sheltered seedlings (diameter growth without shelter=3.9 millimeters, n=841, with shelter=3.3 millimeters, n=878).

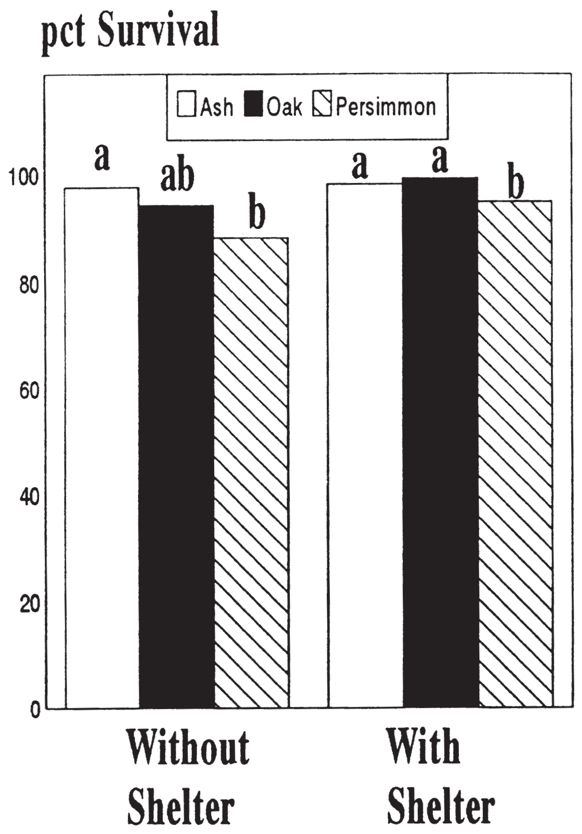

Figure 1—Percent survival comparisons among three bottomland hardwood species with tree shelters and without tree shelters. Means in each shelter grouping followed by different letters are significantly different at the 0.05 level.

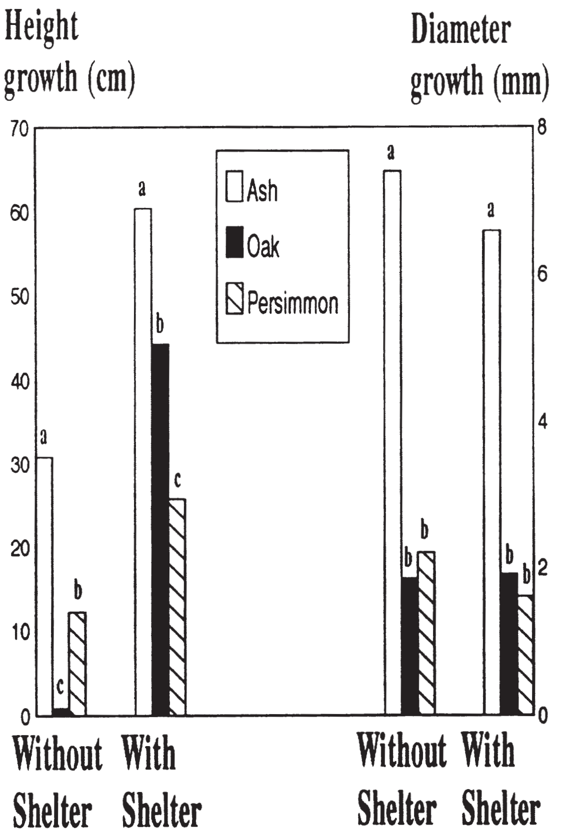

Figure 2—First year height and diameter growth (initial minus final) for three bottomland hardwood species. Means in each shelter grouping followed by different letters are significantly different at the 0.05 level.

Height growth was significantly different among all three unsheltered species, with ash > persimmon > oak (Figure 2). Unsheltered ash seedlings also had significantly greater diameter growth compared to persimmon and oak (Figure 2).

Oak seedlings showed favorable growth in shelters, increasing height growth by 5400 percent. Ash seedlings still grew the tallest, showing 96 percent increase with shelters. For seedlings with shelters, ash diameter growth was significantly greater than oak or persimmon (Figure 2).

However, height growth was significantly greater for sheltered seedlings compared to unsheltered seedlings for each species, under all four weed control treatments. In general, diameter growth was greater for unsheltered seedlings across all weed control treatments. Under the herbicide treatment, unsheltered ash, oak and persimmon seedlings had significantly greater diameter growth than sheltered. Unsheltered ash and persimmon under mechanical weed control also had significantly greater diameter growth than sheltered, and unsheltered persimmon under no weed control had significantly greater diameter growth compared to sheltered persimmon under no weed control.

Weed Control Treatment

For all seedlings without shelters, those under fabric mat weed control had significantly greater survival than herbicide treatment. Survival of seedlings in the mechanical and no weed control treatments was not significantly different from those in the fabric mat treatment (Figure 3). For any one species without shelters, survival was not significantly different among weed control treatments (Figure 4). Sheltered seedlings under both fabric mat and no weed control treatments had significantly greater survival than seedlings treated with herbicide (Figure 3). Results were mixed for survival of sheltered seedlings, by species and weed control combinations. Sheltered seedlings in the mechanical weed control treatment had survival rates that were not significant from the other three treatments (Figure 3). Sheltered ash seedlings under herbicide treatment had significantly lower survival than those in mechanical, fabric mat or no weed control treatments (Figure 5). There were no significant differences in survival among the four weed control treatments for sheltered oak seedlings. For sheltered persimmon, fabric mat treatment resulted in significantly greater survival than mechanical or herbicide; survival under no weed control treatment did not vary significantly from any of the other treatments.

Seedlings with shelters and without shelters had significantly greater height and diameter growth under the fabric mat weed control treatment except for unsheltered oak seedlings (Table 1). Unsheltered oaks with no weed control had significantly greater height growth than those seedlings grown with fabric mat as weed control. Height

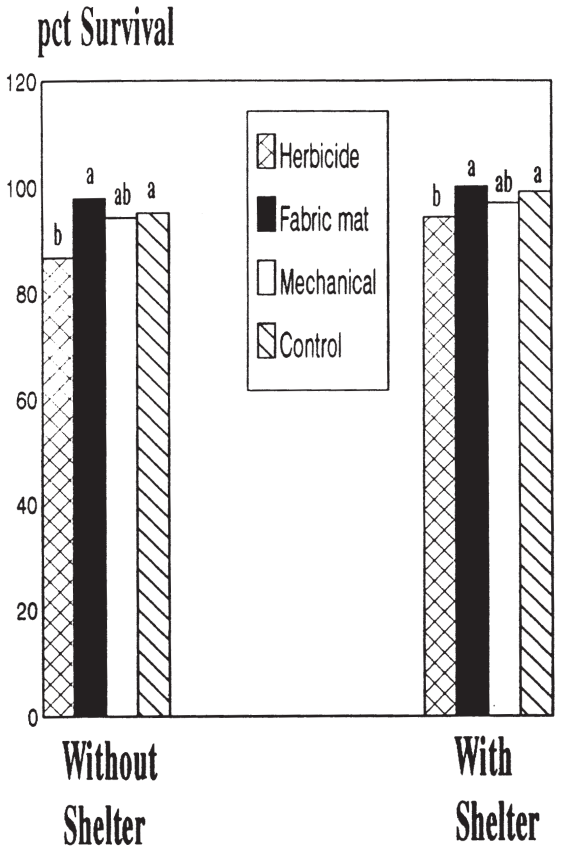

Figure 3—First year survival of all seedlings under four weed control treatments. Means in each shelter grouping followed by different letters are significantly different at the 0.05 level.

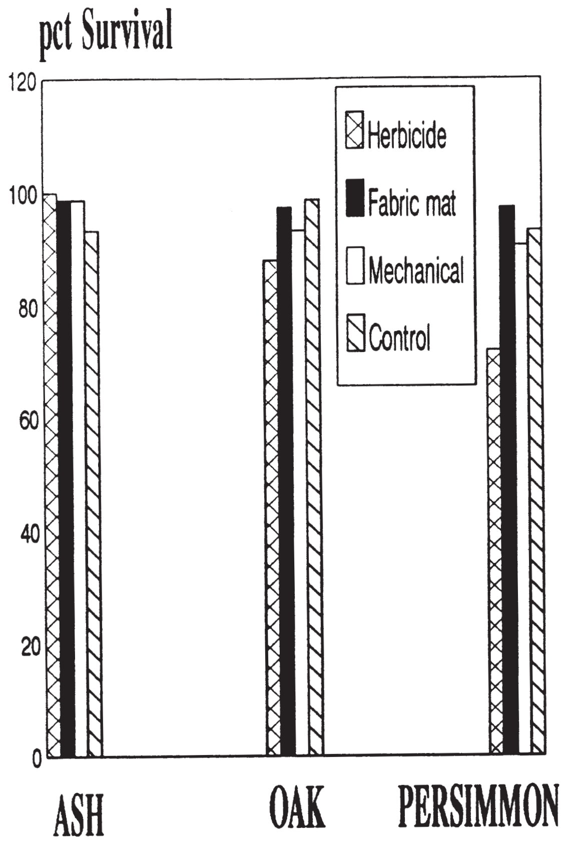

Figure 4—First year survival of three bottomland hardwood species without tree shelters. There were no significant differences in survival means among the four weed control treatments.

Table 1—Results of weed control treatment on height and diameter growth (final - initial) of ash, oak and persimmon seedlings, with and without shelters. Different letters within a row indicate significant difference at the 0.05 level. (Negative values indicate dieback and resprouting)

		Herb	Mat	Mech.	None
		------------------------ *Cm* ------------------------			
Height					
Ash	With shelter	38.6c	95.3a	55.4b	50.3b
Ash	W/out shelter	23.7c	43.1a	33.7b	22.2c
Oak	With shelter	13.4c	42.1a	23.5b	23.9b
Oak	W/out shelter	1.0ab	-1.3b	0.2ab	3.4a
Per.	With shelter	24.3c	59.7a	46.7b	44.2b
Per.	W/out shelter	3.5c	20.3a	11.3b	11.5b
Diameter					
Ash	With shelter	3.8c	12.1a	4.7b	5.2b
Ash	W/out shelter	5.9c	10.9a	7.3b	5.4c
Oak	With shelter	1.1c	3.1a	1.9b	1.7b
Oak	W/out shelter	1.8a	1.7a	2.1a	1.8a
Per.	With shelter	1.2b	3.0a	1.0b	1.3b
Per.	W/out shelter	1.7b	3.3a	1.8b	1.9

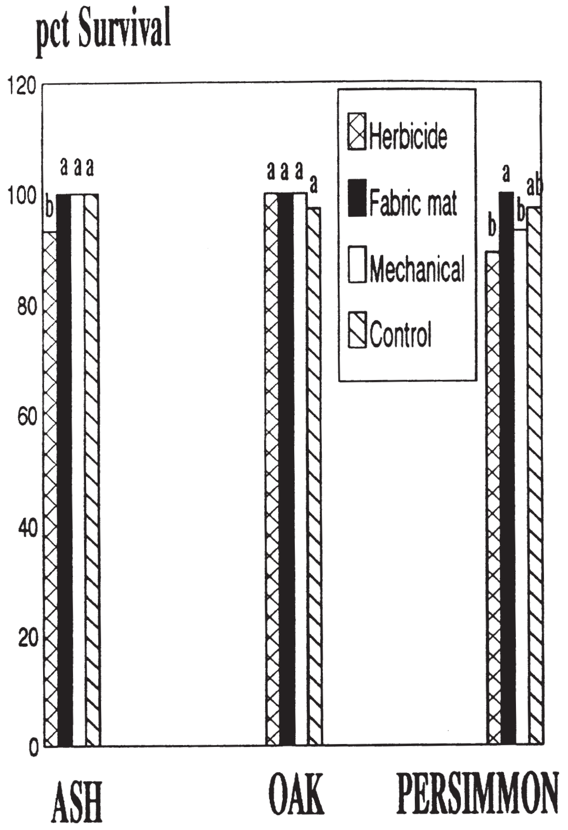

Figure 5—First year survival of three bottomland hardwood species with tree shelters. Means in each species grouping followed by different letters are significantly different at the 0.05 level.

growth for seedlings in the herbicide and mechanical treatments did not differ from either no weed control or fabric mat treatment. Unsheltered oak diameter growth was not different among the four weed control treatments. The herbicide treatment resulted in the smallest height and diameter growth rates, compared to fabric mat, no weed control, and mechanical treatments. This was significant across all species, for seedlings with and without shelters, except for persimmon seedlings with shelters and oak seedlings without shelters. Diameter growth of persimmon seedlings, with shelters, in the herbicide treatment differed significantly only from the fabric mat treatment. Oak seedlings without shelters had the greatest height growth in the no weed control treatment, which was significantly greater than height growth in the fabric mat. There was no difference in diameter growth among the four weed control treatments for oak seedlings without shelters.

DISCUSSION

Survival of all seedlings was high. Successful establishment may be attributed to proper species selection for the study site, adequate site preparation, and quality control on seedling handling and planting.

Shelter Effects

Seedlings with shelters had significantly higher survival than seedlings without shelters. In concurrence with literature reports (Tuley 1983, Frearson and Weiss 1987, Lantagne and others 1990) shelters increased survival of the three species we studied.

In addition to improving survival, shelters also enhanced seedling height growth. However, diameter growth was depressed by the shelters. Ponder (1995) reviewed several studies which showed tree shelters accelerated height growth of young trees. These studies have shown that it is not unusual for diameter growth to be less with shelters than without them during the first year or two of growth. Gillespie and other (1996) observed etiolation of sheltered trees. They noted that shifts in light quality or quantity may contribute to this, as well as stems allocating more carbon to height growth and less to caliper or diameter growth with mechanical support coming from the shelter. Lantagne and others (1990) suggested that the modified growing environment created by shelters results in the reallocation of growth from roots, stem diameter and branches to the main stem. The effect of shelters on root growth was not examined in this study. Many of the seedlings in the present study have emerged from the shelters with good apical dominance which should increase their chance of growing into dominant and codominant crown positions.

Weed Control

The fabric mat used to control weeds had a significant effect on the survival and growth of the seedlings. In reforestation, mulch mats appear to suppress competing vegetation primarily by blocking light necessary for photosynthesis, and to a lesser extent, by mechanically impeding growth (Clarkson and Frazier 1957). To control weeds effectively, mulches must be applied early, remain intact, and be large enough. The fabric mulch mat used in this study was applied prior to weed establishment on a disked field. We did encounter some difficulties installing the mat. Ground staples were used to secure the corners, and additional staples had to be placed 0.5 m apart to hold the mat in place. In addition to the staples, we also placed clay pots on all the corners to aid in keeping the mat from blowing around. Installment was difficult in the heavy clay soil, as the mat became stuck with mud before it could be spread out evenly. The cost of the mat may also prohibit its use in large-scale reforestation efforts.

The fabric mat treatments had significantly lower weed biomass compared to the other weed control treatments (Table 2). Although the herbicide treatment reduced weeds compared to no weed control treatment, height and diameters of all seedlings studied were reduced compared to the other three weed control treatments. Kennedy (1981) used disking, mowing and no weed control on several bottomland species to examine survival and growth under different cultural treatments. After four growing seasons, he found that there was no difference in seedling survival, height or diameter for seedlings that were mowed versus those in the control. Disking did improve survival and growth. Kennedy (1981) concluded that competition still exists whether weeds are allowed to grow and cut back by mowing or to grow continuously as in the control, therefore mowing was not an acceptable substitute for disking.

Table 2—Total weed biomass collected from three plots in each weed control treatment. Different letters within weight column indicates significant difference at 0.05

Weed control treatment	Total weight	n	Dominant vegetation
	G		
None	605.38a	9	Bundle weed[a], vines, grass
Herb	404.42b	9	Bundle weed
Mech.	298.32b	9	Grass
Mat	167.83c	9	Grass, bundle weed

Means in each shelter grouping followed by different letters are significantly different at the 0.05 level.
[a] Bundle weed (*Desmanthus illinoensis* Michaux).

CONCLUSIONS

The results of this study indicate that a potential exists for the use of tree shelters in bottomland hardwood reforestation. Herbivory was not a major stress in this study, although browsing damage has been reported by others who have artificially reforested in this area. Therefore, protection benefits of tree shelters need to be more thoroughly tested under heavy animal pressure. The accelerated height growth of sheltered seedlings after one year compared to the unsheltered seedlings showed promise that those seedlings will rise above the competing vegetation and herbivores. This increase in height growth may also be beneficial in areas that receive late season flooding, common on bottomland sites. Seedlings that are above the flood water levels have a greater chance of survival.

It is premature to prescribe a method for regenerating bottomland hardwood species based on the first growing season. Based on first growing season results, however, data from this study show that an application of sulfometuron-methyl herbicide reduced the amount of competing vegetation, but appeared to suppress seedling survival and growth. Best survival and growth, and the lowest weed invasion, was found with the fabric mat. Although both the shelters and the fabric mat gave positive survival and growth results, cost may be a prohibitive factor in their large-scale use.

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THINNING EFFECTS ON BASAL AREA GROWTH OF RED MAPLE (*ACER RUBRUM* L.)

H. Alexis Londo, Terry R. Strong, Helga Soares, David D. Reed[1]

Abstract—Red maple (*Acer rubrum* L.) is one of the most abundant and wide spread tree species in North America. Due to the characteristic poor form and wood quality of red maple, it is often categorized as a soft maple and most commonly merchandised as pulp. Because of the increasing interest and occurrence of red maple, a study analysis was conducted to test several silvicultural thinning treatments on red maple growth in even-aged stands located in Upper Michigan and northern Wisconsin by examining stand dynamics over a 14 year study period.

The effects of the silvicultural treatments of 40, 60, 80, 100, 120, and 140 ft^2 residual basal area per acre respectively, were examined. Plots were remeasured every 5 years. The increase in stand parameters such as basal area, average percent DBH (diameter at breast height), stand density and stand volume were calculated and analyzed. Diameter and volume growth of the 40 ft^2 were shown to increase the most over time.

INTRODUCTION

Red maple (*Acer rubrum* L.) is one of the most abundant and wide spread tree species in North America, with a contiguous range from Newfoundland to the southern tip of Florida, extending to southeastern Manitoba and East Texas (Burns and Honkala 1990). This species thrives on a wide range of sites and is becoming evermore present as a primary producer in forest communities (Crow 1978). Red maple follows only sugar maple (*Acer saccharum* Marsh.) in terms of growing stock volume on Michigan's timberland, with an annual net increase of over 114 million ft^3 of growing stock in Michigan alone (Leatherberry and Spencer 1996). Red maple has become an important resource on over 1 million acres in Upper Michigan and Northern Wisconsin (Erdmann and others 1981).

Red Maple is often categorized as a soft maple due to its characteristically poor form and wood quality and is most commonly merchandised as pulp for the production of high quality paper products. On good sites, red maple may grow fast with good form and quality, producing a better grade of saw logs. Good quality red maple may be substituted for hard maple in furniture production, thereby raising its value.

Stumpage prices since 1971 for red maple have increased at a higher rate than those of sugar maple (Niese and others 1995). Management efforts for this species, however, are tenuous due to the lack of growth and yield information for even-aged management (Erdmann and others 1981). The objective of this study is to analyze the effectiveness of several levels of residual basal area regimes in red maple stands located in Upper Michigan and northern Wisconsin by examining stand dynamics over a 14 year study.

METHODOLOGY

Permanent study sites were established in fully stocked, even-aged, undisturbed stands growing under uniform conditions with 75 percent or more of the overstory composition in red maple (Erdmann and others 1981). These sites were chosen in even-aged red maple stands on good, medium and poor sites in northern Wisconsin and Michigan. Two or more plots, each consisting of two 1/4 acre (1000 m^2) subplots, were established at each study site. Trees greater than 4.0 in. (10 cm) were numbered, species recorded and dbh measured in 1980. After the growing season of 1981 and before the growing season of 1982, plots at each of the study sites received one of seven thinning treatments: no thinning, or reducing basal area to 40, 60, 80, 100, 120, and 140 ft^2/ac.

Plots were thinned from below to the desired basal area to create a stand of uniformly spaced, defect free, dominant and codominant red maple trees. Smaller suppressed and intermediate red maple trees were removed. Pole size species other than red maple trees were removed to increase the stocking of red maple. Stocking levels were then checked and corrections were made where possible.

Remeasurements of the study sites were conducted in 1985, 1990, and 1996. Observations due to ingrowth, defined as trees reaching 4.0 inches dbh after establishment, were added and remeasured during subsequent measurement periods. To create a post thinning profile of the sites, the 1980 data set was used excluding any ingrowth trees and those recorded as cut in the 1985 measurement data.

Basal area calculations were made using the dbh measurements for each tree and these calculations were summarized by species for each plot. Total stem outside

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bark volume calculations for red maple trees were made using the equation of Crow and Erdman 1984. All calculations were then averaged for plots contained in each basal area category.

RESULTS AND DISCUSSION

A total of 53 sites were selected and 226 plots established. Each treatment contained from 6 to 66 plots (table 1). Initial basal area measurements varied from 65.4 ft^2/ac to 238.1 ft^2/ac over all the plots with an average of 136.8 ft^2/ac. In 1982, basal area values decreased due to the application of the thinning treatments. Using a F-test of the general linear hypothesis, thinnings were determined to have an affect on the basal area of the stands ($p < 0.05$) over all the subsequent measurement dates. By 1996, basal area measurements for sites thinned to 40 ft^2/ac and the control sites were the only treatments to surpass their initial (1980) basal area measurements. All other sites increased for each of the remeasurements (fig. 1). A Student-Newman-Kuels (SNK) test of the means (Montgomery 1984) indicated that, for each of the measurement cycles, thinning operations produced different basal area values from the control and each other ($p > 0.05$), except for the 140 ft^2/ac thinning treatment which did not differ from the control ($p > 0.05$). The ordering of the means remains constant for all the measurement cycles until 1996, with basal area values being statistically different ($p > 0.05$) and ordered by thinning intensity. There was an interaction between thinning treatments and time, confirming that the treatments resulted in different basal area growth rates over time. Following the 1996 measurement, plots thinned to 40 ft^2/ac had basal area values larger than those thinned to 60 ft^2/ac ($p > 0.05$).

The average percent dbh growth for each stand following treatment over the study period was computed. These values illustrate the response of dbh of each of the treatments (fig. 2). Plots where basal area was reduced to 40 ft^2/ac and 60 ft^2/ac showed the greatest increases in percent dbh growth. All other treatments exhibited an increase in average percent dbh growth ($p > 0.05$) for each of the measurement cycles. One exception occurred in 1996, when areas thinned to 140 ft^2/ac declined slightly from the 1990 average diameter.

While percent diameter growth increased through time for each of the study sites, trees per acre (TPA), in most cases, did not increase ($p > 0.05$) after the thinning applications were applied in 1982 (Figure 3). Where basal area was reduced to 40 ft^2/ac, the number of trees increased over the subsequent measurement cycles. Plots incurring the intermediate thinning applications, 60 ft^2/ac, 80 ft^2/ac and 100 ft^2/ac, exhibited slight increases in trees per acre in the years following thinning. When light thinnings (120 ft^2/ac and 140 ft^2/ac) were applied, trees per acre decreased slightly by the last measurement year, as was the case for the unthinned (control) plots.

Figures 2 and 3 indicate that thinnings applied to red maple stands increase diameter growth for individual trees. With steady or decreasing trees per acre, the increase in basal area growth is distributed among the individual residual trees. This indicates thinning from below operations in red maple stands increased larger stem size, sawtimber yield. Heavier thinnings (residual $\leq$ 100 ft^2/ac) result in ingrowth, recruitment of smaller stems into the merchantable size classes over time. The effects of the thinning treatments on volume were investigated (fig. 4). These results when compared with the thinning effects on basal area prove to be very similar. Statistical evaluation of thinning effects on volume production also proved to be analogous to the basal area results.

Table 1—Number of study plots and initial conditions by treatment

Treatment	No. of observations	Initial basal area values: Mean	Minimum	Maximum
		Ft^2/ac		
Control	22	141.6	111.3	193.2
40 ft^2/ac	6	93.5	72.5	102.4
60 ft^2/ac	42	119.2	65.4	146.2
80 ft^2/ac	66	136.3	87.7	238.1
100 ft^2/ac	56	144.3	105.8	192.6
120 ft^2/ac	28	149.2	117.4	195.6
140 ft^2/ac	6	163.6	130.0	194.4
Total	226	136.8	65.4	238.1

CONCLUSIONS

Rates of increase in basal area growth are greatest in the most heavily thinned stands. These stands also exhibited the highest gain in trees per acre. Actual growth per tree is minimal in stands with intermediate levels of thinning. All treatments except the 40 ft^2/ac treatment, reduced trees per acre to between 215 and 255 individuals. These stocking densities remained constant with little or no ingrowth for the remainder of the study. Target basal area values for these treatments were from 60 ft^2/ac to 140 ft^2/ac. This implies largest trees occur where BA's are the highest. This is a result of the reduction of stand density from below to attain target basal area.

At last measurement, 14 years after treatment, the basal area growth rates were starting to decrease in treatments with higher target basal areas. Sites reduced to 140 ft^2/ac and 100 ft^2/ac increased very little in basal area from 1990 to 1996. The stands where smaller stand densities of 40 ft^2/ac, 60 ft^2/ac and 80 ft^2/ac were retained, basal area is still increasing at a steady and similar rate over time.

Reducing basal area proves to be effective in increasing the growth rates of red maple, however caution should be taken not to open the site too much. Thinning to 40 ft^2/ac produced improved growth rates, but also dramatically increased trees per acre due to regeneration and

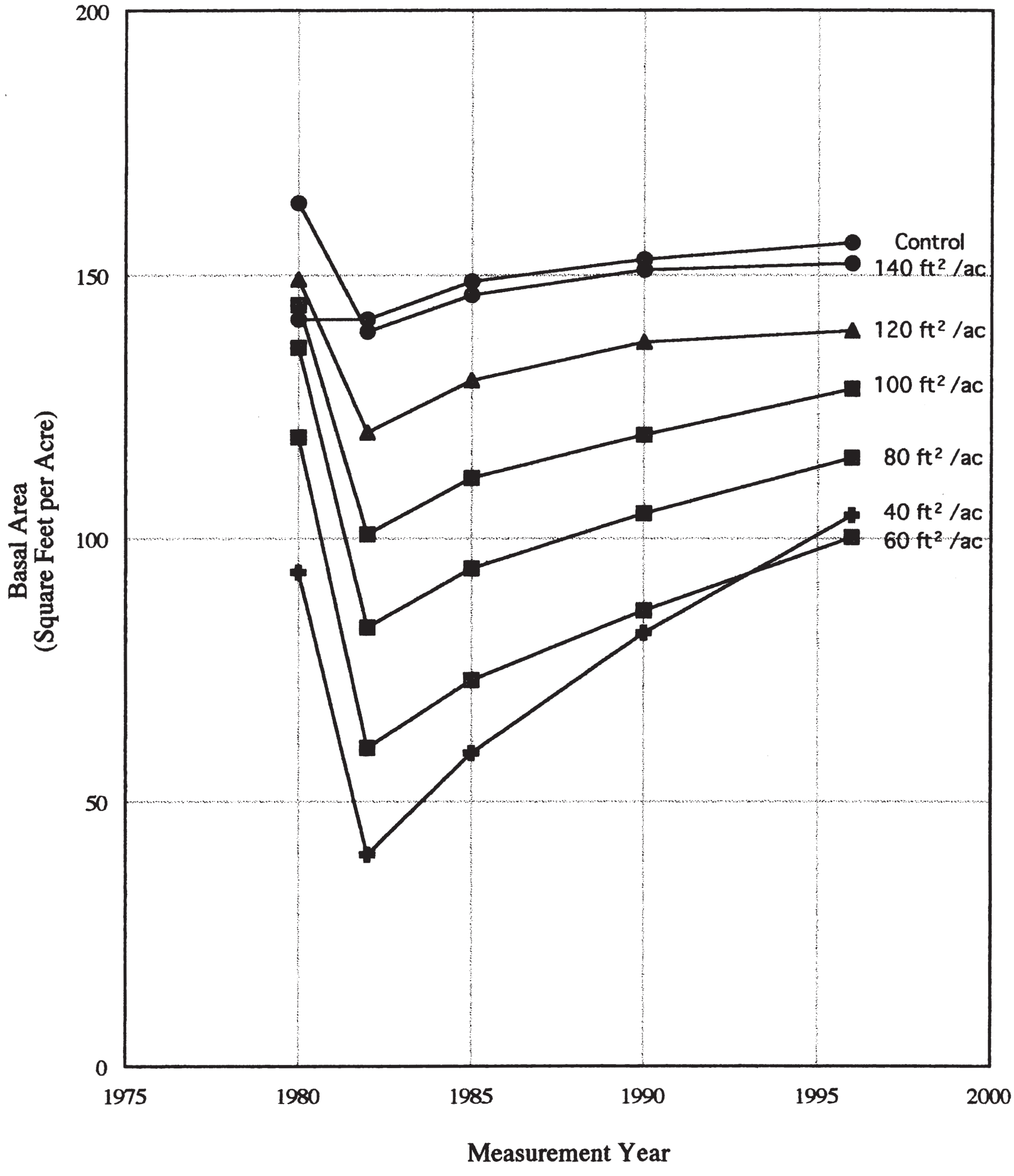

Figure 1—Average basal area (ft^2/ac) given for each thinning treatment and measurement date.

recruitment. Better growth per tree may be attained by reducing trees per acre to between 215 and 235, while keeping basal area between 60 ft^2/ac and 80 ft^2/ac.

These results expand and substantiate the work of Trimble (1974) in which he concluded red maple diameter growth increased after thinning. Consistent with these results, similar work by Voorhis (1990) with yellow poplar (*Liriodendron tulipifera* L.) and paper birch (*Betula papyrifera* Marsh.) showed significant increases in diameter growth after light and heavy thinnings. However, when Voorhis (1990) investigated sugar maple in this same study, diameter growth responses did not increase.

Lamson (1988) investigated cleaning (eliminating trees of similar age but less desirable species or form than that of the target trees) in 7- and 12-year-old stands of basswood (*Tilia americana* L.), red maple, black cherry (*Prunus serotina* Ehrh.) and northern red oak (*Quercus rubra* L.). His research indicated diameter growth increased most

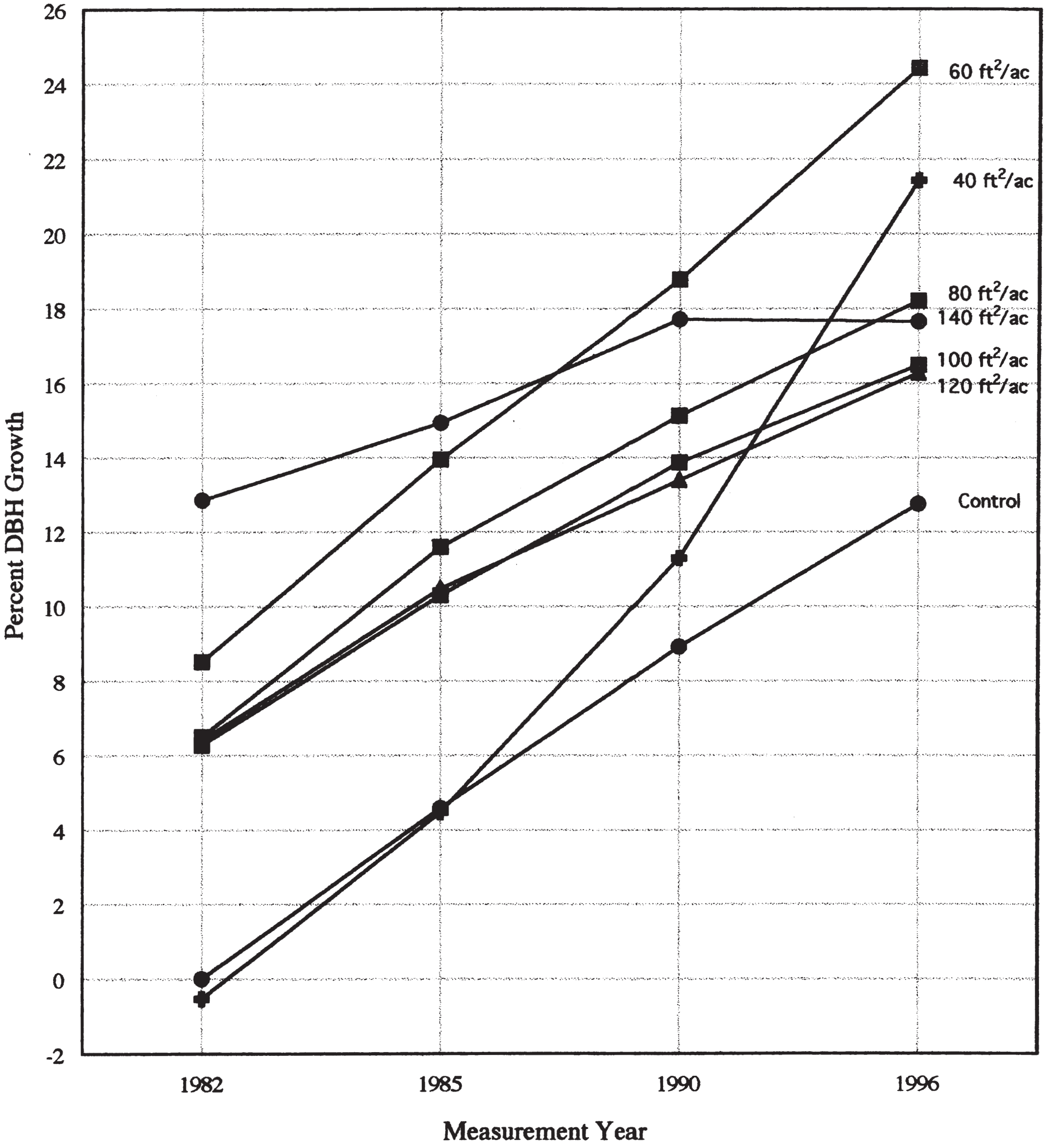

Figure 2—Percent growth of each thinning treatment and measurement cycle.

during the first 5 years after treatment. In this study, this period of increased growth has been extended.

Further research is needed to determine which time is best for these thinnings to occur. The duration of these effects and their influence on the pruning habits, growth patterns and height development of individual trees also needs to be investigated. Finally, research to on the interactions of red maple with the northern hardwood forest species and how relative stand densities influence the volume increment of merchantable wood is another area worthy of research (Nowak 1996).

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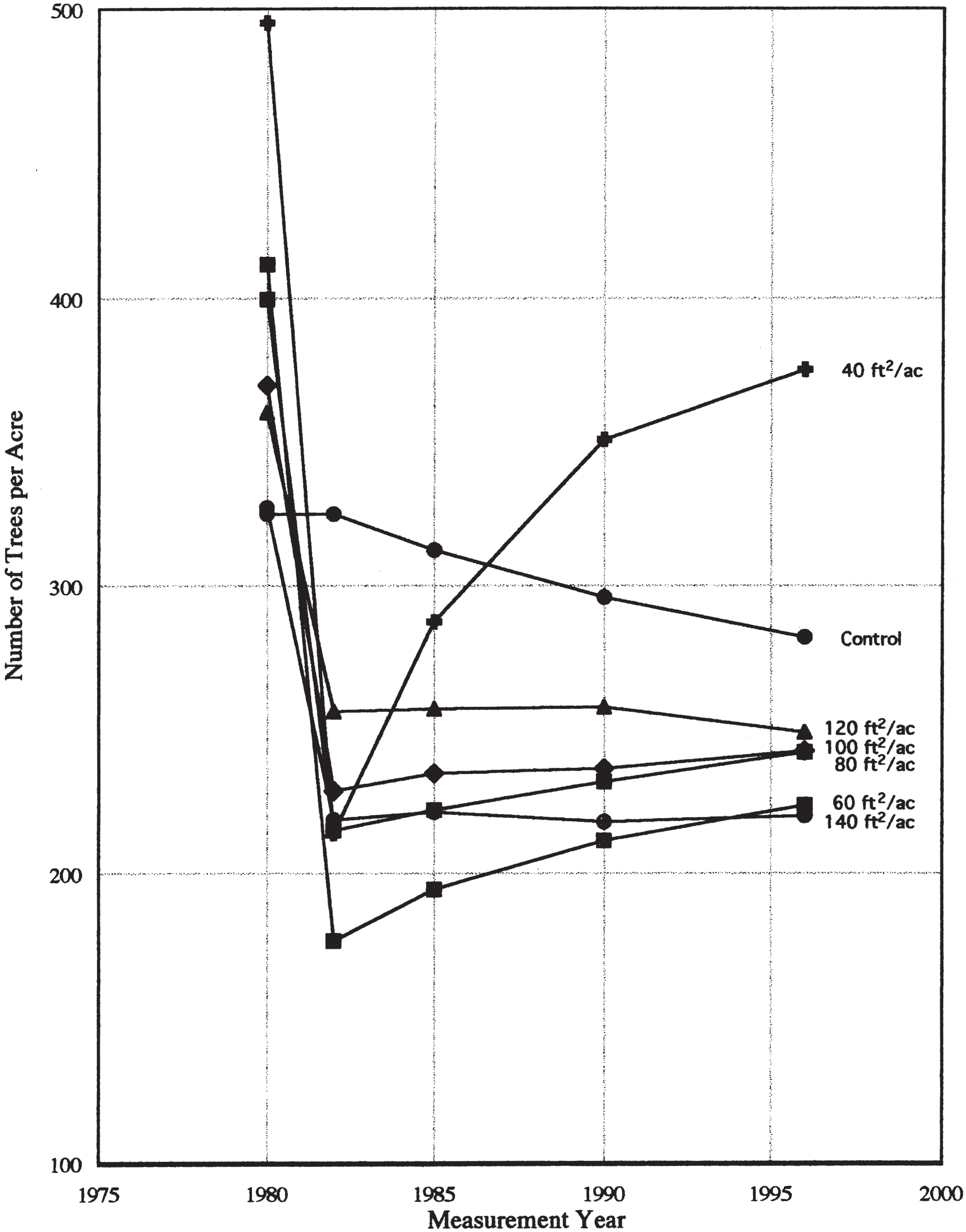

Figure 3—Trees per acre (TPA) of each thinning treatment and measurement cycle.

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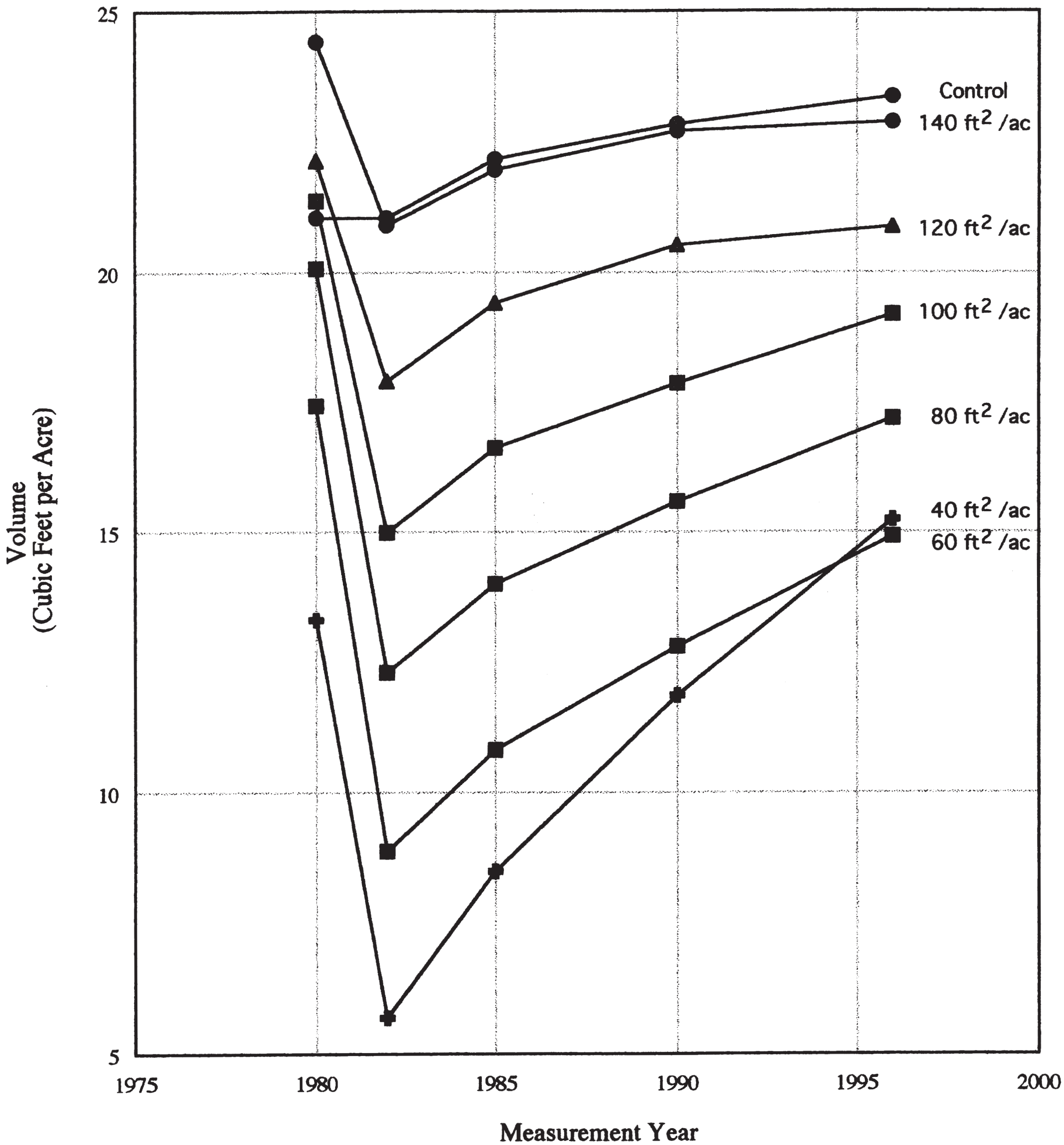

Figure 4—Volume per hectare (ft^2) for each thinning treatment and measurement cycle.

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RESIDUAL STAND QUALITY FOLLOWING IMPLEMENTATION OF UNEVEN-AGED SILVICULTURE IN EVEN-AGED OAK-HICKORY FORESTS IN THE BOSTON MOUNTAINS OF ARKANSAS

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Abstract—A test of group-selection and single-tree selection was installed in 80-year-old even-aged oak-hickory stands in the Boston Mountains of northern Arkansas. Twenty-four 11-acre plots were installed in well stocked stands representing north or east and south or west aspects. Stands between group openings were cut to residual basal areas of 65 and 85 ft^2 per acre using free thinning or structural control. Tree quality in residual stands was evaluated using U.S. Forest Service tree grades for factory lumber and Grosenbaugh tree classes. Trees 11.6 in. and larger in dbh were considered sawtimber and included in the analysis. The effects of density, cutting method, and aspect on tree grade were evaluated using 2,225 sawtimber-sized trees. Results indicate no difference among treatments due to the short time interval since cutting. However, 53 percent of sawtimber either were or have the potential to develop into high quality trees. A residual basal area of 65 ft^2 or less is more likely to effectively increase tree quality and control species composition in the Boston Mountains than an 85 ft^2 target basal area. Overall, this study indicates that there is excellent potential to improve stand tree quality in the Boston Mountains of northern Arkansas using uneven-aged silviculture.

INTRODUCTION

Public concern over the dramatic visual impact of clearcutting has stimulated interest in alternative forest management systems for upland oak forests in the Midsouth. To address these concerns alternatives should avoid the negative visual impacts of clearcutting and must provide the biological conditions necessary for regenerating and maintaining the oaks and other valuable hardwood species. Uneven-aged methods have been suggested as an alternative. Uneven-aged cutting methods are designed to create and maintain at least three age classes within the stand. In single-tree selection, all trees marked for cutting are selected for removal based upon their individual merit. But in group selection, the trees removed in regeneration cuts are selected as a group or aggregate, not as individuals; however, the trees removed between the group openings are selected on individual merit. Group selection can be considered a variant of single-tree selection. For instance, periodic cuts are required in both methods to (1) establish and develop reproduction, (2) improve stand structure and quality, and (3) control residual stocking for sustained yield. They differ in how the periodic cuts are made and their effect on species composition. Recent papers (Miller and others 1995, Murphy and others 1993) have provided an excellent description of both methods and discussed the advantages and disadvantages of each.

Although the feasibility of these uneven-aged cutting methods with upland oak types are being investigated, most research emphasis has been on regeneration and stand structure development (Graney and Murphy 1997, Loewenstein and others 1995). However, no research has concentrated on the long-term effect of the cutting methods on tree quality.

A study has been installed to evaluate effectiveness of group-selection and single-tree selection methods in mature even-aged oak-hickory stands on dry mesic and mesic upland sites in the Boston Mountains of northern Arkansas (Graney and Murphy 1997). The specific objectives are:

(1) To test the feasibility of using group-selection and single-tree selection methods to convert even-aged oak-hickory stands to uneven-aged ones.

(2) To test two methods of regulation and two density levels in combination with group selection.

(3) To compare growth and yield of stands that are managed and regenerated under group selection, two methods of regulation, and two density levels.

As part of objective 3, log grades and tree quality classes (tree quality classes defined using Grosenbaugh 1955 tree classes) were assigned to each sawtimber-sized tree on the growth and yield plots to assess the change in tree quality over time. This also addresses the feasibility of using the Grosenbaugh tree classes on trees in oak-hickory forests of the Boston Mountains. In this paper we describe the preharvest conditions of the sawtimber and any effect of the initial harvest treatments on the residual sawtimber component.

METHODS

Study Region

The Boston Mountains are the highest and most southern member of the Ozark Plateau physiographic province (fig. 1). They form a band 30 to 40 miles wide and 200 miles long from northcentral Arkansas westward into eastern Oklahoma. Elevations range from about 900 ft in the valley bottoms to

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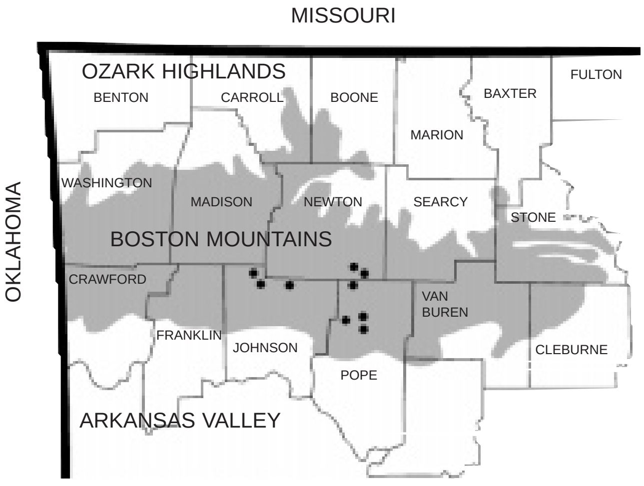

Figure 1—Location of study areas.

2,500 ft at the highest point. The plateau is sharply dissected, and most ridges are flat to gently rolling and are generally less than 0.5 mile wide. Mountainsides consist of alternating steep simple slopes and gently sloping benches.

Soils on mountaintops and slopes usually have shallow to medium depth and are represented by medium-textured members of the Hartsells, Linker, and Enders series (Typic Hapludults). They are derived from sandstone or shale residuum, and their productivity is medium to low. In contrast, soils on mountain benches are deep, well-drained members of the Nella and Leesburg series (Typic Paleudults). They developed from sandstone and shale colluvium, and their productivity is medium to high. Rocks in the area are alternating horizontal beds of Pennsylvanian shales and sandstones. Annual precipitation averages 46 to 48 in., and March, April, and May are the wettest months. Extended summer dry periods are common, and autumn is usually dry. The frost-free period is normally 180 to 200 days long.

Study Description

The regulation study design is a split-plot factorial layout, replicated three times, with aspect as the main plot treatment and residual stand density and regulation as sub-plot treatments. The aspects are northeast and southwest, residual densities are 65 and 85 ft^2/ac, and the regulation methods are free thinning and structural control. Although the study is a straightforward test of group selection with two residual stand treatments (i.e., free thinning versus structural control), it can also be used to evaluate single-tree selection by analyzing the structural control treatment.

Stand Density Treatments

The two residual density levels are 65 and 85 ft^2/acre of basal area in trees 5.6 in. and larger. The overstory density treatments were applied on the plot and buffer areas outside the group opening. The 65 ft^2 density level approximates the B-level of stocking for upland oak stands and should be near the optimum for stand and crop tree growth (Gingrich 1967). The 85 ft^2 density represents about 70-75 percent stocking and is appropriate for a first thinning in older stands that have relatively high stocking levels (Sander 1977).

Plot Location and Layout

The study was installed on the Ozark National Forest in well-stocked hardwood sawtimber stands with no history of previous cutting for at least 50 years. Twenty-four 11-acre plots were installed in nine forest stands on the Buffalo, Bayou, and Pleasant Hill Ranger Districts (fig. 1). Study plots were located on north/east and south/west facing mountain slopes and benches in oak-hickory stands representative of the sites and stand conditions that are designated for uneven-aged management by the Ozark National Forest. These plots were replicated by National Forest Districts with 8 plots established on each District. Harvesting was done by each National Forest District using standard timber sales. Logging at all study locations utilized chainsaw felling and tree-length skidding by standard rubber-tired skidders.

Sample plots consist of a 7.2-acre net plot plus a 66-ft buffer for a total of 11 acres (fig. 2). In addition, each 7.2-acre net plot was subdivided into twelve 0.6-acre subplots. Of the twelve subplots on each net plot, three subplots located on one end of the plot (numbers 1-3 or 10-12) were randomly selected for a separate competition control study (fig. 2) (Graney and Murphy 1997). The remaining 9 subplots were used in the regulation study.

Measurements

A complete preharvest tally of all overstory trees, dbh 5.6 in. and larger, was taken by species, tree class [per Grosenbaugh 1955 (see footnote, table 2)], and 1-in. dbh classes. This tally was used to apply the treatments.

In the postharvest phase, overstory growth and yield were measured on a series of 0.2-acre circular plots located in the center of each 0.6-acre subplot (fig. 2). On each 0.2 acre plot all overstory trees 5.6 in. dbh and greater were numbered and mapped by azimuth and distance from plot center. The following information was collected:

(1) diameter to nearest 0.1 in.,

(2) total height for a sample of trees in each 1-in. dbh class,

(3) log grade for the butt log of all sawtimber trees,

(4) damage to crowns and boles resulting from logging,

(5) tree quality by Grosenbaugh tree class, and

(6) age of selected dominants or codominants.

The 16-foot butt log on sawlog trees (trees larger than 11.6 in. dbh) was graded using the U.S. Forest Service log grading system (Hanks 1976). We will monitor the effects of treatments on stem quality at 5-year intervals. The plots will be cut every 10 years.

Regulation Techniques

The regulation techniques applied to the residual stand are (1) area regulation with free thinning and (2) area

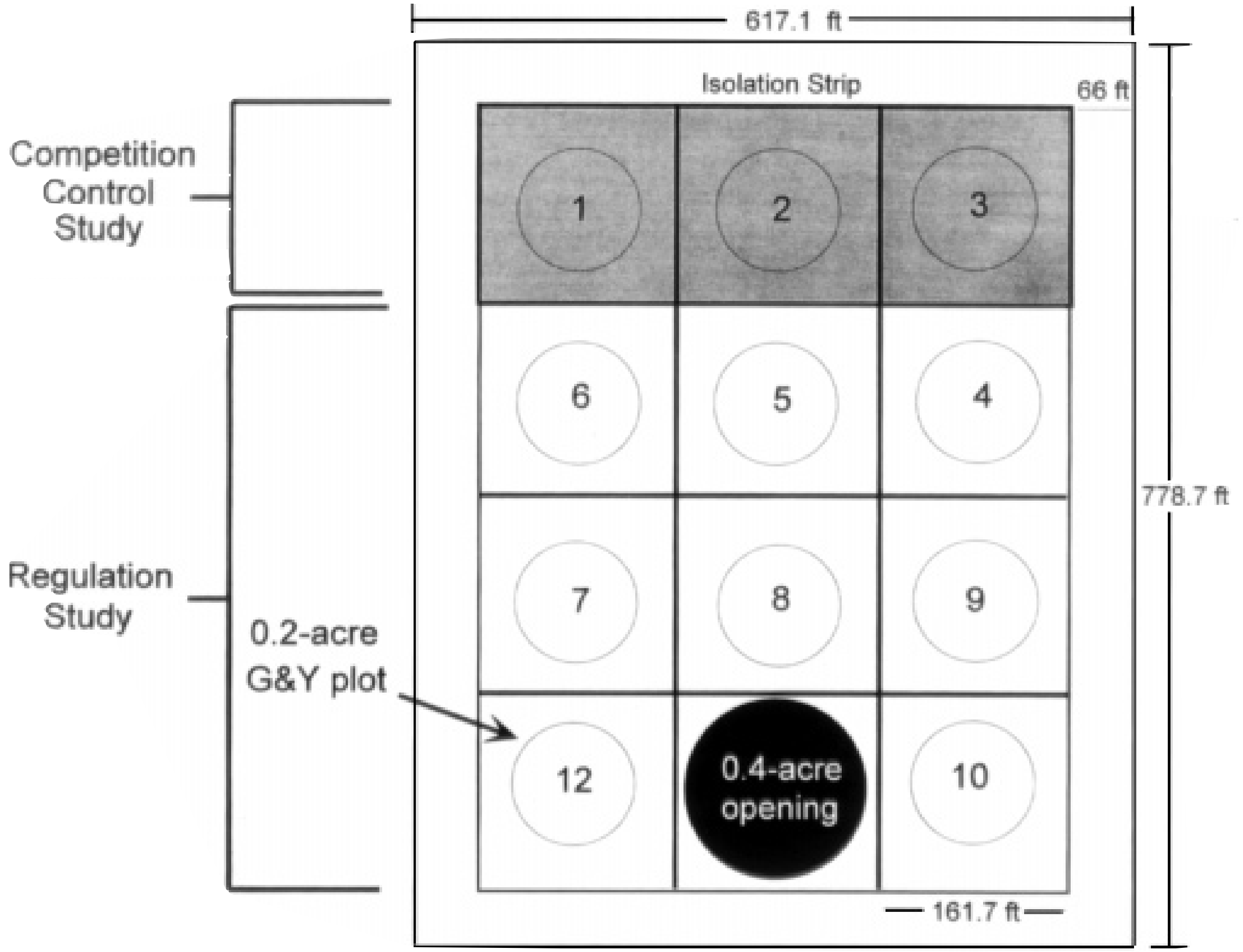

Figure 2—Layout of the plot, subplots, 0.2-acre growth plots, and group opening.

regulation with structural control. Group selection will be used with area control. Assuming an 80-year conversion period and a 10-year cutting cycle, one-ninth of the area would be regenerated each cutting cycle.

Opening size was approximately two times the average height in the dominant trees in the adjoining stand. This resulted in an average opening size of 0.4 acres (range 0.25 to 0.47 acres) in typical stand conditions. Selection of the initial group opening subplots were based on the presence of large reproduction or saplings of desirable species, sprouting potential of desirable species in the small poletimber class, and overstory stocking. A subsequent group opening will be created every 10 years. Group opening diameter and subplot dimensions restrictions precluded complete overstory removal in group opening subplots. Non-opening areas of group opening subplots were cut to the residual stand basal area target.

In the first regulation method, the residual stand (the area not in group openings) was cut to the target density by free thinning. Trees were removed in the following priority: (1) larger cull and defective trees, (2) competing trees of poor form and quality, and (3) intermediate and suppressed trees of lower quality and value. The primary objective was to improve residual stand quality and vigor.

In the second method, the residual stand was thinned to a target stand structure. The target stand structure has a minimum dbh of 5.6 in., a maximum dbh of 18.5 in., a *q* of 1.3 (assuming 2-in. diameter classes), and residual densities of 65 and 85 ft^2/ac. Law and Lorimer (1989) suggested *q* values of 1.3, 1.5, or 1.7 for 2-inch classes in upland hardwoods, and Smith and Lamson (1982) recommended a 1.3 q-value for sawtimber production and higher *q*'s for smaller-product objectives. Because our objective is quality sawtimber production, we chose a *q* of 1.3. We selected the maximum dbh to produce a grade one butt log, also in accordance with a quality sawtimber objective.

When marking to achieve the residual structure for areas outside openings, we divided the trees into four size classes—small poletimber (6-8 in. dbh), large poletimber (9-11 in. dbh), small sawtimber (12-15 in. dbh), and large sawtimber (>15 in. dbh). We calculated the target residual basal area for each class and marked the stand to conform to the target. However, when marking in the poletimber classes, we discriminated against the noncommercial and low-value species and did not always achieve the target structure for the small poletimber class. In these cases, we left more stocking in better-quality trees in the larger classes. We did, however, leave some low vigor oak stems in the small diameter classes to evaluate survival and growth. The main goal was to leave the residual basal area in the best quality trees available on the plot.

Statistical Tests

To test for differences in the proportion of grade 1 trees as the result of the treatments, a split-plot analysis was performed with the arc-sine square root transformation of proportion of grade 1 trees as the dependent variable, aspect as the main plot, and density and regulation as factors with three replications. None of the variables were significant. The results were probably confounded by 4 of the south aspect plots having site indices similar to north aspects.

RESULTS AND DISCUSSION

Preharvest Conditions

The total overstory basal area of trees ≥ 5.6 inches dbh was remarkably uniform across all plots, ranging from 92 to 114 ft^2/acre for north aspects and from 91 to 112 ft^2/acre for plots on the south aspects. The mean stand age and range for north aspects was 79 years and 71 to 93 years respectively. Stands on south aspects were slightly younger with a mean of 74 years and a range from 68 to 81 years. Red or white oak site index on north aspects ranged from 62 to 72 ft (base age, 50 years) and 55 to 69 ft for south aspects. Mean site index was 67 ft and 62 ft for north and south aspects, respectively.

Sawtimber basal area was slightly greater on north aspects (table 1). The basal area in desirable species was 90 percent for both aspects, and the oaks comprise 80 percent of the basal area. There were some minor differences in species mix by aspect. Basal area for red oaks and hickory was greater on north aspects, while white oak basal area averaged more on south aspects.

The tree class "grower" (Grosenbaugh 1955) designates trees that are the objective of management for quality timber. Table 2 shows that these crop trees are a much larger proportion of the stand on north aspects. This larger proportion occurs partly because the red oaks are found more often on north aspects, and red oaks tend to have a larger proportion of growers than white oaks. The incidence of culls and high-risk trees (riskers/killers/culls) occurs with equal proportions on both aspects.

Postharvest Conditions

The treatments affected residual species composition. The more desirable species were retained, and the other groups were discriminated against when making the cut. Therefore, there was a larger reduction in the proportion of other overstory species groups (table 3). We now have about 96 percent of the residual sawtimber basal area in desirable species. The 85 ft^2 basal area treatments for both structural control and free thinning did not give as much freedom in molding species composition as the 65 ft^2 treatment, because less basal area was removed. There was also no apparent difference in species composition between the two regulation methods.

Table 1—Preharvest species composition by basal area and aspect for sawtimber trees (d.b.h.>11.5 inches)

Species groups[a]	North aspect[b]	South aspect
------------ Basal area (*square feet per acre*) ------------		
Hickory-shortleaf pine	5.3	2.9
Other overstory[c]	6.6	5.4
Ash-cherry-walnut	1.4	1.0
White oaks	19.4	24.0
Red oaks	32.4	23.3
All species	65.1	56.6

[a] Species preferred for management: white oaks, red oaks, ash, cherry, walnut, hickory, shortleaf pine.
[b] Means are based on twelve 7.2 acre plots for each aspect.
[c] Other overstory = basswood, beech, blackgum, cucumber tree, sugar maple, sweetgum.

A major objective was to improve residual stand quality; therefore, culls and lower quality trees had the highest priority for removal regardless of stem size. In table 4, the largest reduction in basal area occurred in culls and the lower quality classes. Culls were reduced from 10 to 13 percent in preharvest conditions to 0 to 2 percent in the residual stands. Any culls that were left occurred in the 85 ft^2/acre treatment to meet this residual basal area target. The reduction in basal area was least in the grower and sleeper categories, which are the best potential crop trees. The proportion of basal area in these trees was increased.

Tree Grade Distribution

The 16-ft butt logs of all sawtimber-sized trees on the 0.2-acre growth and yield plots were evaluated using the U.S. Forest Service tree grading system (Hanks 1976). The total number of sawtimber-sized trees was 2,225, about a third of the sawtimber on the study areas. About 40 percent of the residual sawtimber trees were graded as 1 or 2. More of the grade 1 and 2 trees were located on north aspects (table 5). More of the grade 3 trees were located on south aspects, while the number of grade 4 trees were evenly distributed on both aspects.

There are greater differences in tree grades 1 and 2 on north and south aspects if site index is considered. Four of the south aspect plots had site indexes more comparable to north slopes. These 4 plots confounded the differences between aspects and accounted for 60 percent of the

Table 2—Preharvest structure by Grosenbaugh tree class and aspect for sawtimber trees (diameter greater than 11.5 inches)

Grosenbaugh tree class[a]	North aspect[b]	South aspect
	Basal area (*square feet per acre*)	
Grower	24.5	14.8
Sleeper	5.7	8.2
Cipher/topper/slower	28.1	26.4
Risker/killer/cull	6.8	7.2
All species	65.1	56.6

[a] Adapted from Grosenbaugh (1955):

Grower: A merchantable tree that is vigorous and has no serious defects that would affect growth or desirability of the tree as potential sawtimber growing stock. A grower should also have the potential of developing a grade 1 butt log and have an expectancy of at least 0.90 of living until the next cutting cycle. Some people call such trees "crop trees" or "good growing stock."

Cipher: A merchantable tree whose expectancy of living for the next cutting cycle is at least 0.90, but does not meet the qualifications of a grower because of slow growth or undesirable characteristics, and is not competing with desirable reproduction or saplings. This tree can either be "financially mature" or may have limitations that disqualify it as a grower.

Sleeper: A cipher which has the potential to become a grower if it is released by removing competing trees.

Topper: A merchantable tree similar to a cipher but overtopping desirable reproduction or saplings.

Slower: The least potentially productive of several merchantable trees (but not riskers or killers—see below) competing in inadequate growing space. It should be cut in thinning.

Risker: A merchantable tree whose life expectancy for the next cutting cycle is less than 0.90. It should be cut to salvage potential loss through mortality.

Killer: A merchantable tree infested with contagious pathogens.

Cull: A tree that is merchantable size but not salable because of defect or other factors.

[b] Means are based on twelve 7.2 acre plots for each aspect

grade 1 and 2 trees on south aspects. The remaining south aspect plots were composed mainly of grade 3 and 4 trees.

Regulation method (free thinning versus structural control) had no apparent effect on tree grade distribution (table 5). One of the principal objectives in both free thinning and structural control was to improve the residual stand by cutting the worst trees and leaving the best ones. Thus, the results from both types of cuts were very similar. In structural control, we discriminated against poorly formed stems, low-value species, and noncommercial stems. Therefore, the residual stand structure was not always attained, but the residual stand was of better quality.

Residual basal area apparently did not affect the distribution of tree grade (table 5). Although the higher

Table 3—Postharvest species composition by aspect for sawtimber trees (diameter greater than 11.5 inches)

Species groups[a]	North aspect[b]	South aspect
	Basal area (*square feet per acre*)	
Hickory-shortleaf pine	3.9	2.1
Other overstory	1.3	1.6
Ash-cherry-walnut	0.9	0.6
White oaks	15.5	18.6
Red oaks	24.5	16.3
All species	46.1	39.2

[a] See footnote a in table 1 for species list.
[b] Means are based on twelve 7.2 acre plots for each aspect.

Table 4—Postharvest Grosenbaugh tree class distribution by aspect for sawtimber trees (diameter greater than 11.5 inches)

Grosenbaugh tree class[a]	North aspect[b]	South aspect
	Basal area (*square feet per acre*)	
Grower	23.8	14.3
Sleeper	5.7	8.1
Cipher/topper/slower	16.3	15.9
Risker/killer/cull	0.3	0.9
All species	46.1	39.2

[a] See footnote a in table 2.
[b] Means are based on twelve 7.2 acre plots for each aspect.

basal area treatment allowed more trees to be retained, the relative proportion of tree grades was not affected. The difference in the proportion of grade 1 trees is probably due to the marking of the structural control plots where the target structure could not be attained in the smaller diameters. Therefore, more of the larger trees were retained to satisfy density requirements.

While the proportion of quality trees was the same for the 65 ft^2 and 85 ft^2 density treatments, the economic operability of the cut and potential effects on future stand and tree quality development will vary. The 85 ft^2 target permitted removal of approximately 16 ft^2 of basal area per ac, mostly in cull and low quality trees. Although higher quality trees will be removed in future 10-year cycle cuts, basal area removed will be less than 20 ft^2 per acre and will be further reduced by mortality expected in the higher density mature stands (Graney and Murphy 1994). Increasing the numbers of grade 1 and grade 2 trees in current stands will depend on maintaining or increasing growth of pole- and small sawtimber-size stems in the higher quality (grower and sleeper) tree classes. Quality

Table 5—Postharvest distribution of sawtimber trees by tree grade, aspect, regulation method and residual basal area

Tree grade	Aspect		Regulation method		Basal area		Overall mean
	North	South	Free thinning	Structural control	65 ft^2	85 ft^2	
	Percent						
Grade 1	16	11	13	15	11	16	14
Grade 2	29	22	25	26	24	26	25
Grade 3	32	43	36	37	39	36	37
Grade 4	23	24	26	22	26	22	24

stems in 70- to 80-year-old Boston Mountain hardwood stands respond with increased diameter growth following intermediate cutting to medium or lower stand densities (Graney and Murphy 1994). Cutting residual stands to 65 ft^2 allows more flexibility in the removal of lower quality stems and the crown release of potentially higher quality stems in the grower and sleeper tree classes.

Growers are trees that have attained or will probably attain a grade 1 butt log during their lifetime; these trees are the crop trees of management. Of the total number of trees classified as growers, 73 percent were classified as grade 1 or 2 (table 6). The primary reason that some growers are not grade 1 is that they do not yet meet the size requirements but have the potential to do so, given time. As they grow, however, they will eventually satisfy the criteria for grade 1 logs. Sleepers are trees that have good stem quality and could develop into growers if some remedial management is done, such as thinning. Trees classified as sleepers in our study were usually in the large poletimber or small sawtimber classes and could not attain log grade 1 or 2 because they did not meet the size requirements. These trees are unlikely to grow into a size class large enough to meet log grade 1 or 2 in the absence of management. Fifty-three percent of the sawtimber trees were classified as growers or sleepers, which indicates that the potential for high quality sawtimber of upland oak stands in the Boston Mountains is excellent.

CONCLUSIONS

Although 39 percent of the sawtimber trees in the study qualify for grade 1 and grade 2 trees, the 60 percent that are now growers and sleepers indicates that the potential for increase in tree quality is good. These trees are now too small to qualify for the higher grades. It will take time and management before these smaller trees reach the merchantability standards for grade 1 and 2 logs. A major reason for the relatively low proportion of higher grade stems in the 70- to 80-year-old Boston Mountain oak-hickory stands is residual stand diameter. Of the residual stand component, only 50 percent met the minimum diameter requirements for grade 1 or grade 2 logs. However, in the remaining stocking of the small sawtimber class, more than 60 percent are in the grower and sleeper classes and should develop into grade 1 and grade 2 trees as they grow into the larger sawtimber-sized classes.

One reason for the lack of differences among treatments is likely the short time interval since cutting. The high site indices for benches on some southwest facing slopes also may be masking any immediate differences. Aspect alone does not adequately separate high site index sites from low site index sites, as evidenced by the similarity of some of the south aspect plots to north aspect plots. In the Boston Mountains, productive oak sites are also associated with the deep, well drained colluvial soils commonly found on concave, gently sloping inner bench positions that are typical of upper mountain slopes at all aspects (Graney 1977).

Table 6—Postharvest distribution of sawtimber trees by Grosenbaugh tree class and tree grade

Tree grade	Grower	Sleeper	Other classes	All classes
	Percent			
Grade 1	36	0	1	14
Grade 2	37	4	25	25
Grade 3	25	42	44	37
Grade 4	2	54	30	24

The residual basal area of 85 ft^2 is likely too high to be used as an effective management tool and is not likely to produce an economically feasible sale. In the 85 ft^2 treatment the harvest consisted mainly of low quality and cull material. The residual stand of 65 ft^2 produced a harvest of merchantable material and shows promise in increasing tree quality. A residual stand of less than 65 ft^2 of basal area may enhance these effects if carefully applied. Overall, this study indicates that there is excellent potential to improve stand quality in the Boston Mountains of northern Arkansas.

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PREDICTING SAPLING GROWTH AND RECRUITMENT IN DIFFERENT SIZE CANOPY GAPS

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Abstract—Accurate simulation of the effects of uneven-aged management on future stand structure and species composition requires good empirical data on sapling growth, survival, and canopy recruitment, particularly as these dynamics are influenced by the number and size of canopy openings created at each harvest. In order to examine the response of various species to different levels of understory light and woody competition, we measured annual growth increments (1993-97) on tree saplings in 30 northern hardwood stands in north-central Wisconsin and adjacent western Upper Michigan. Understory conditions in the 100 "gap" plots sampled ranged from closed canopy to group selection openings (>400 m^2). Average daily radiation received by individual saplings was estimated from computer analysis of hemispherical canopy photographs taken directly above the 510 subject saplings (size 25 cm tall to 10 cm dbh). In addition, data on woody competition experienced by subject trees were collected for all sapling and overstory trees in the plot.

Shade-tolerant sugar maple reached close to its maximum height growth rate (30-40 cm/yr) at surprisingly low light intensities typical of small single tree gaps (2-15 percent full sunlight). Increasing gap size had little further effect on growth rate for maple. In contrast, height growth rates of midtolerant species continued to increase with increasing light intensity, consistent with the normal expectation that midtolerant species will have a substantial competitive advantage in larger openings. At moderately high gap light intensities (40-60 percent full sunlight, typical of gaps 100-300 m^2), growth rate increased substantially for both red oak and white ash (~60 cm/yr). For all species, height growth rate clearly increased with sapling size (fig. 1). For example, at a given light intensity of 25 percent full sunlight, the height growth rate of a large white ash sapling (>2.5 cm dbh) was nearly three times greater than that of a smaller white ash sapling (<1.5 m tall) in the same light environment. Species specific regression equations for height growth as a function of sapling height and PPFD (photosynthetic photon flux density) had R^2 values in the range of 0.47 - 0.62.

Sapling growth rates can be expected to continually change over time as a result of increasing sapling size, changes in sapling height relative to competitors, and decreasing gap size due to lateral gap closure. To forecast interspecific competition over time in response to canopy gap formation and closure, we sought to develop predictive equations for sapling growth and mortality based on simple measures that could be easily updated within the context of an iterative model. While irradiance levels increased with gap size, light reaching individual saplings was also strongly influenced by its horizontal position within the gap and its relative height. Almost half of the variation in PPFD could be explained by four variables (i.e., subject tree height, square-root of gap area, distance of the sapling north of the gap's southern border, and a competition index based on the aggregate crown projection area of all taller saplings; R^2=0.48). These four variables were also found to be among the most significant in regression equations predicting sapling height growth. Coefficients of determination (R^2) for height growth equations ranged from 0.54 for the sugar maple up to 0.85 for red oak. These equations are being incorporated into a spatially explicit, crown-based model of forest dynamics (CROWN) that keeps track of the size, growth, and mortality of individual trees within a stand.

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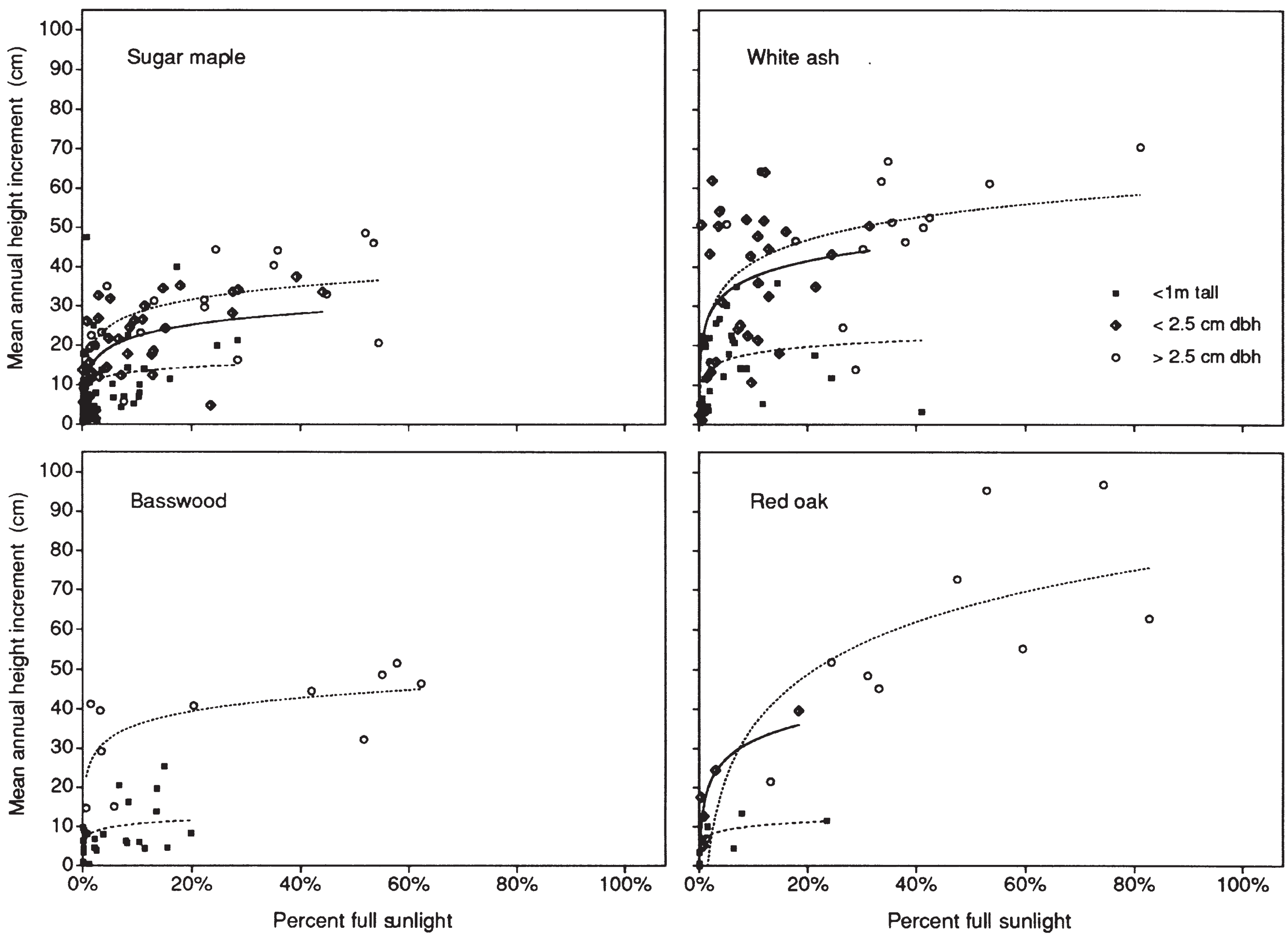

Figure 1—Mean annual height growth versus the amount of solar radiation reaching the sapling. For each species, separate response curve are displayed for three different sapling size classes (< 1.5 m tall, >1 m tall but <2.5 cm dbh, >2.5 cm dbh).