SHELTERWOOD CUTTING AND UNDERSTORY CONTROL INCREASE GROWTH OF OAK, ASH, AND CHERRY REPRODUCTION IN NORTHERN ARKANSAS[1]

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Abstract—Five- and nine-year growth of white oak, red oaks, white ash, and black cherry advance reproduction was evaluated in upland oak stands representing a range in site quality, residual overstory stocking, and three competition control treatments. Analysis of covariance was used to test and describe the growth relationships for individual species as affected by initial stem height, groundline diameter, site quality, overstory stocking, and intensity of competition control. Reproduction growth varied significantly by species. Growth was significantly affected by intensity of competition control, initial height, and time since treatment for all species. Height development for black cherry was also affected by site quality and residual overstory stocking.

INTRODUCTION

Mixed oak types occupy most of the upland commercial forest in northern Arkansas, and oaks are the dominant timber species. However, there is serious concern that oak reproduction is not adequate to replace the present stands, especially on the more productive sites (Graney and Rogerson 1985, Graney 1989). Although declines in oak dominance may result in greater species diversity, the oaks are prized for their timber and wildlife values.

Commercially desirable, fast-growing species such as yellow-poplar, *Liriodendron tulipfera* L., do not occur in western Arkansas, and valuable species such as black walnut, *Juglans nigra* L., black cherry, *Prunus serotina* L., and white ash, *Fraxinus americana* L., occur infrequently, and primarily on the more productive sites. Most associated species in these upland stands are either slower growing or of lower value than the oaks, so it is important to ensure that oaks will be a major component of new stands after harvest.

The oak component of future hardwood stands depends on sprouts from cut overstory stems and the number, size, and distribution of oak advance reproduction present at harvest (Sander 1971, 1972; Sander and Clark 1971; Sander and others 1984; Loftis 1990a). Newly established oak seedlings and small advance reproduction grow too slowly to compete successfully after harvest (Sander and Clark 1971, McQuilkin 1975). In contrast, large oak advance reproduction grows rapidly after harvest and has a high probability of becoming dominant in the new stand (Carvell 1979, Sander and others 1984, Loftis 1990a).

Upland hardwood stands in the Boston Mountains of northern Arkansas may have more than 1,000 stems per acre of advance oak reproduction and other desirable species, but most are less than 1 foot tall, and larger reproduction is often absent. Many of these stands are mature and fully stocked, and have well-developed understories of shade-tolerant noncommercial species. Given the size and status of existing reproduction, new stands that develop after harvest will almost certainly contain a low proportion of oak. In several areas, researchers are trying to stimulate the growth of small advance reproduction with light to medium shelterwood cutting plus partial to complete midstory and understory control (Sander 1979, 1987, 1988; Sander and Graney 1993; Loftis 1990b).

Variants of the shelterwood method for regenerating oaks has shown promise in the Missouri Ozarks (Schlesinger and others 1993) and the southern Appalachians (Loftis 1990b). In these studies, development of oak reproduction on productive sites has been enhanced.

Most oak shelterwood studies have measured changes in numbers of stems in various size classes for (1) a single oak species, (2) for several combined oak species, or (3) all commercially desirable species combined. But individual oak and other desirable species may respond differently to various combinations of overstory and understory shelterwood treatments, and the responses may vary over time. Although models have been derived to predict the

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development of oak advance reproduction after overstory removal (Dey 1993, Sander and others 1984, Loftis 1990a), there is little information about development of oak and other desirable reproduction under a shelterwood.

In this paper, we report height development of advance regeneration for 9 years after overstory and understory density control. Data are reported for white oak, *Quercus alba* L., black and northern red oaks, *Q. velutina* Lam. and *Q. rubra* L., black cherry, and white ash.

METHODS

Study Region

The Boston Mountains are the highest and southernmost member of the Ozark Plateaus physiographic province (fig. 1). They form a band 30 to 40 miles wide and 200 miles long from north-central Arkansas westward into eastern Oklahoma.

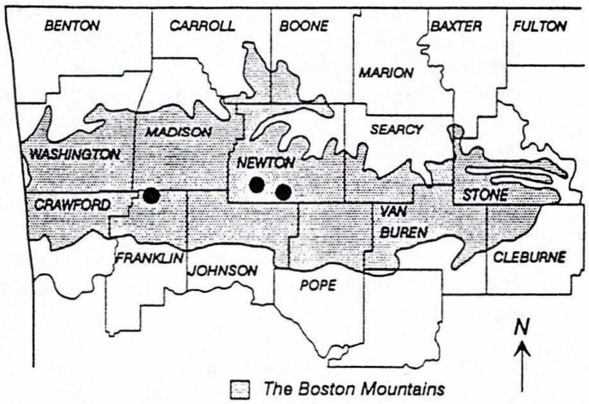

Figure 1.–Location of study areas (two stands per area) in the Boston Mountains of northern Arkansas.

Elevations range from about 900 feet in the valley bottoms to 2,500 feet 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 inches, 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

Six mature upland hardwood stands were selected for study at three locations on the Ozark National Forest (fig. 1). Three stands are on upper north- or east-facing slopes, which have oak site indexes of 55 to 65 feet for northern red oak, base age 50. The other three stands are on north- or east-facing mountain benches with red oak site indexes of 66 to 80 feet. Six plots (approximately 1 acre in size) were established in each stand, and one of six overstory-understory treatments was randomly assigned to each plot.

Overstory (stems ≥1.6 inches d.b.h.) densities were reduced to either (1) 40 or (2) 60 percent relative stocking density (Gingrich 1967). Understory (stems <1.6 inches d.b.h.) treatments were: (A) no understory treatment (low), (B) kill all less-desirable stems taller than 4.5 feet (intermediate), or (C) kill all less-desirable stems (intensive).

Pretreatment overstory stocking for all plots averaged 106 percent and basal area averaged 118 ft^2 per acre (table 1). The overstory was cut from below. All subcanopy stems 1.6 inches d.b.h. and larger were

Table 1.–Original and residual overstory stand values.

Stand condition	Site index		Basal area		Stocking[a]	
	Mean	Range	Mean	Range	Mean	Range
	—Ft—		—Ft^2—		—Percent—	
Before treatment	66	56-80	118	95-130	106	90-120
After treatment	66	56-80	63	43-81	50	37-62

[a]Based on stocking equation from Gingrich (1967).

removed first, then the overstory canopy was cut to the prescribed stocking goal. Stumps of all less-desirable overstory stems were sprayed with 2,4-D plus picloram to reduce sprouting. Understory control treatments were imposed by cutting target stems near ground level and spraying stumps with the 2,4-D plus plicoram herbicide immediately after cutting. Understory treatments were completed in May 1980, and overstories were thinned during May to July 1980.

Overstories on all plots were predominantly oak. Northern red, black, and white oaks accounted for 80 percent of the overstory stocking before thinning and more than 90 percent after treatment. Ash and cherry represented less than 1 percent of the stocking on all plots.

Understories on medium sites were dense and mixtures of tolerant brushy or less-desirable species such as red maple, *Acer rubrum* L., serviceberry, *Amelanchier arborea* Michx. f. Fern., redbud, *Cercis canadensis* L., and blackgum, *Nyssa sylvatica* Marsh. Dogwood, *Cornus florida* L., hophornbeam, *Ostrya virginiana* (Mill.) K. Koch.), pawpaw, *Asimina triloba* L., and sugar maple, *Acer saccharum* Marsh., were common on good sites.

Reproduction was measured on a series of sixteen 1/735-acre subplots systematically distributed across the interior 0.25 acre of each plot. On each subplot, all reproduction up to 1.5 inches d.b.h. was tallied by species and 1-foot height classes. In addition, all oak, ash, and cherry stems were identified and mapped for remeasurement. For these stems, height and basal diameter (1 inch above groundline) were measured to the nearest 0.1 foot and 0.1 inch, respectively. Reproduction was measured before treatment and 1, 3, 5, and 9 years after treatment.

Data Analyses

In this report, we analyzed only the reproduction that existed before treatment and that survived the study period (table 2). Mortality for oaks was relatively high, especially in the small height and basal diameter classes, and varied by understory treatment. Because only survivors were analyzed, average numbers of stems for each species may be smaller and mean height and basal diameter values may be larger than would be expected for undisturbed stands.

Initially, the data were subjected to an analysis of covariance in which reproduction height 5 and 9 years after treatment was the response variable; species group, understory treatment, and measurement period (time since treatment) were class variables; and initial height, basal diameter, site index, and stocking were covariates. The model is as follows:

$$Y_{ijk1} = \mu + \alpha_i + \delta_j + \gamma_k + (\alpha\delta)_{ij} + (\alpha\gamma)_{ik} + (\alpha\delta\gamma)_{ijk} + \beta_{1ijk}H_{ijk1} + \beta_{2ijk}G_{ijk1} + \beta_{3ijk}S_{ijk1} + \beta_{4ijk}Q_{ijk1} + \epsilon_{ijk1}.$$

where,

μ = overall mean,
α_i = species effect, i=1,2,3,4,
δ_j = time effect, j=1,2,
γ_k = understory treatment effect, k=1,2,3,
$(\alpha\delta)_{ij}$ = interaction effect between species and time,
$(\alpha\gamma)_{ik}$ = interaction effect between species and understory treatment,
$(\delta\gamma)_{jk}$ = interaction effect between time and understory treatment,
$(\alpha\delta\gamma)_{ijk}$ = interaction effect among species, time, and understory treatment,
H_{ijkl} = initial height,
G_{ijkl} = initial basal diameter,
S_{ijkl} = initial stocking,
Q_{ijkl} = site index,
β's = coefficients,
ϵ_{ijkl} = error term, and
Y_{ijkl} = future height.

This initial model identified group differences for species, time period, and understory treatment and heterogeneity of slopes if the covariates contributed significantly to the model. Scatterplots were also used to evaluate model adequacy. Variables were selected

Table 2.–Heights and basal diameters of white oak, red oaks, black cherry, and white ash advance reproduction before treatment.

Species	Number of stems	Height		Basal diameter	
		Mean	Range	Mean	Range
		—Ft—		—In—	
White oak	375	1.6	0.2-9.3	0.25	0.10-1.50
Red oaks	1,158	1.1	0.2-7.4	0.18	0.10-1.40
Black cherry	483	1.8	0.2-8.8	0.23	0.10-1.20
White ash	509	1.8	0.2-11.0	0.28	0.10-2.10

for a reduced model on the basis of the results. The most parsimonious model that could adequately explain the data was sought. Anamalous observations were detected by residual analysis. These anomalies were further analyzed to see if they should be dropped from the analysis.

RESULTS

Tests with the initial model indicated that species, treatment, time since treatment, initial height, and the interactions among these variables were significant for all four species groups. In addition, stocking and site index were important for black cherry. Further study also indicated that the square of initial height should also be added to account for some curvilinearity in the relation of initial to subsequent stem height. Therefore, separate regression analyses were done for each species group, treatments, and time since treatment combination with initial height and the square of initial height as independent variables. Site index and stocking were also used as independent variables for black cherry. The results are presented in tables 3 and 4.

Although the understory treatments affected subsequent height development, initial stem height was the single most important explanatory variable. Thus, stem size is a key indicator of likely response to treatment. The fit statistics for white and the red oaks are relatively good. Black cherry and ash both have less impressive R-squares and root mean square errors of 3.08 and 1.88, respectively (table 4).

Height Development of White Oak

White oak height growth was increased most by intensive competition control. The rate of increase was greatest for the small to medium stems (<1.0 to 3.0 feet tall at the outset) (fig. 2). Very small stems (<0.5 foot) grew about 0.3 to 0.5 foot during the first 5 years after treatment, but grew little over the next 4 years. However, stems initially larger than 0.5 foot increased in total height throughout the study period. The best response was to the most intensive competition control treatment.

White oak height development for the first 5 years was relatively slow after all understory treatments. Best 5-year growth was on large stems after intensive control. For stems of intermediate size, height growth responses to the intermediate and intensive treatments were about the same. Stems taller than 1.0 foot at the outset had no net increase in height over the initial 5 years on low intensity plots.

Between years 5 and 9, height growth of white oak reproduction in all but the smallest size classes increased significantly. Greatest increases were for stems >3.0 feet tall after intensive and intermediate competition control, but stems >4.0 feet tall on low intensity plots also grew about 2.0 feet over the 4-year period.

Height Development of Red Oaks

Black and northern red oak advance reproduction generally responded positively to understory density control (fig. 2). Height growth for the 9-year period ranged from 0.5 to 0.6 foot for the smallest to 1.9 to 3.9 feet for the largest initial stem size. Response was greatest after intensive competition control. Stems on plots receiving intermediate- and low-intensity understory control averaged about 70 percent and 40 percent of the growth observed for the intensive treatment.

Rate of height growth for the 9-year measurement period declined slightly with increasing initial stem size on the intensive and intermediate competition control plots. On the low-intensity control plots, growth remained constant for stems larger than 1.0 foot at the outset.

Although response of red oak reproduction to treatment was not rapid, it was somewhat faster than that of white oak. Five-year height growth of red oaks ranged from about 0.2 foot on the low-intensity plots to about 1.3 feet on the intensive plots. The initial lag in red oak height growth was most pronounced for 3.0-5.0 foot stems on the intermediate- and low-intensity plots. Red oak height growth increased significantly over the last 4 years of the measurement period. While all understory treatments increased height growth, larger stems on the intensive and intermediate control treatments produced the greatest response.

Height Development of White Ash

In previous reports from the Boston Mountains, growth response for ash and cherry reproduction were combined (Graney and Rogerson 1985, Graney 1989). Results of the present study indicate that ash and cherry reproduction respond differently to varying overstory and understory densities and possess significantly different height-growth potentials (fig. 2).

White ash advance reproduction responded positively to each of the overstory and understory treatments. The initial lag in response that was so apparent for the oak species was pronounced only for the largest ash stems. Over the 9-year measurement period, growth of ash reproduction ranged from about 1.0 foot for the smallest ash stems receiving the low-intensity treatment to about 4.5 feet for large stems on the high-intensity treatment plots. Height growth was slowest for the low-intensity treatment. It was about equal after the intermediate- and intensive treatments.

Height Development of Black Cherry

In terms of height growth of reproduction, black cherry may be the most aggressive species on upland sites in

Table 3.–Regression coefficients by species, treatment, and time period.

Species, treatment[a], and time period	Coefficients				
	Intercept	Height	Height^2	Stocking	Site index
White oak:					
Treatment A, 5 years	0.57146	0.60808	0.04242	—	—
Treatment A, 9 years	0.33251	1.30156	-0.00340	—	—
Treatment B, 5 years	0.03377	1.56488	-0.14578	—	—
Treatment B, 9 years	-0.22336	2.80624	-0.28840	—	—
Treatment C, 5 years	0.32288	1.07916	0.01206	—	—
Treatment C, 9 years	-0.00071	2.59058	-0.17865	—	—
Red oaks:					
Treatment A, 5 years	0.47705	0.81080	0.02834	—	—
Treatment A, 9 years	0.47654	1.27371	0.00374	—	—
Treatment B, 5 years	0.32118	1.26188	-0.06008	—	—
Treatment B, 9 years	0.36760	2.06242	-0.11682	—	—
Treatment C, 5 years	0.33940	1.35149	-0.03334	—	—
Treatment C, 9 years	0.31108	2.55141	-0.16762	—	—
Black cherry:					
Treatment A, 5 years	10.95365	2.14695	-0.12851	-0.26548	-0.12433
Treatment A, 9 years	10.96173	3.81155	-0.27886	-0.02668	-0.12604
Treatment B, 5 years	4.43350	2.61708	-0.18561	-0.04868	-0.01304
Treatment B, 9 years	4.90850	3.59990	-0.19518	-0.09351	0.03046
Treatment C, 5 years	11.67576	2.01111	-0.03946	-0.07772	-0.09176
Treatment C, 9 years	11.41406	4.28817	-0.26548	-0.07429	-0.07953
White ash:					
Treatment A, 5 years	0.92504	1.31324	-0.05738	—	—
Treatment A, 9 years	1.62486	1.64940	-0.06350	—	—
Treatment B, 5 years	0.94239	1.67879	-0.12301	—	—
Treatment B, 9 years	1.78527	2.44456	-0.23207	—	—
Treatment C, 5 years	1.10079	1.38060	-0.03277	—	—
Treatment C, 9 years	2.68191	1.31608	0.00303	—	—

[a]A, B, and C are low, intermediate, and intensive understory control treatments.

the Boston Mountains. It may be the only species that will outgrow red maple stump sprouts. But height development of cherry reproduction on a given site is significantly influenced by a number of factors including initial stem height, understory density, overstory density, site quality, and time since treatment.

Cherry grew fastest of the species observed in our study. Nine-year height growth ranged from about 3 feet for the smallest stems in stands on the most productive sites thinned to 60 percent overstory stocking with no competition control to more than 12 feet for large stems on average sites thinned to 40 percent overstory stocking with intensive competition control. Greatest height growth for each measurement period was associated with the intensive treatment, and the difference between understory treatments increased with time and initial stem size. The intermediate treatment produced a somewhat lower response, while the low-intensity treatment produced the least response over all initial stem sizes. Black

Table 4.–Fit statistics for regression equations.

Species	R-square	Root mean square error
		—Ft—
White oak	0.86	0.78
Red oaks	0.82	0.62
Black cherry	0.56	3.08
Ash	0.54	1.88

cherry stems with initial heights of 1.0 foot and larger in stands receiving the intensive treatment produced height growth during the second measurement period (4 years) equal to or greater than that produced during the initial 5 years. On the other hand, cherry stems in stands receiving intermediate- and low-intensity treatments generally produced less height growth during the second than the first measurement period. Cherry height growth was also slightly greater in stands

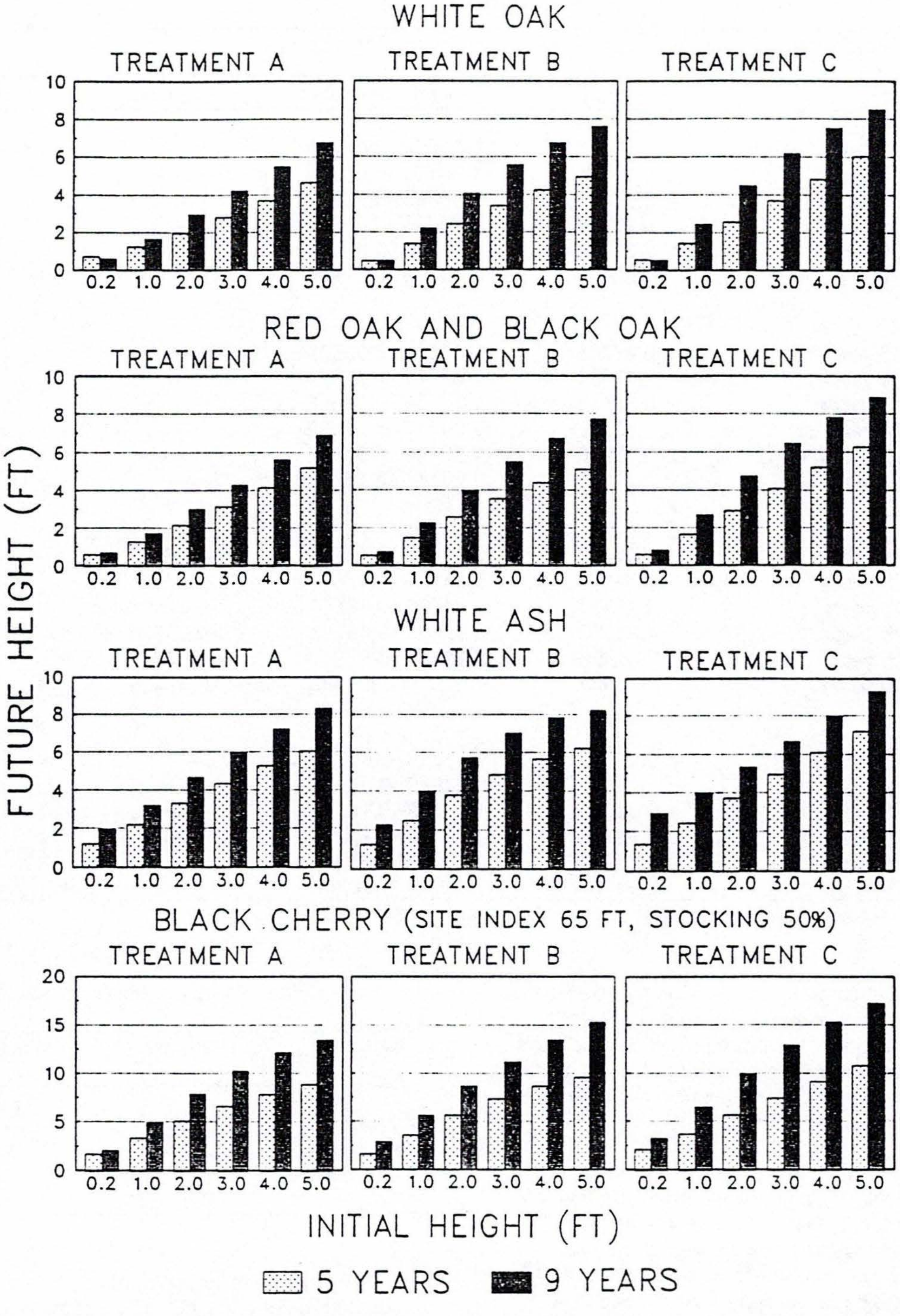

Figure 2.–Height development of advance reproduction as affected by initial stem size and intensity of understory control (A=low, B=medium, C=Intensive) by species 5 and 9 years following treatment in upland oak stands in the Boston Mountains.

thinned to 40 percent overstory stocking on medium sites.

DISCUSSION

The primary objective in applying the shelterwood method in mature upland oak stands is to increase the amount of large oak advance reproduction that can compete successfully after the shelterwood is removed. Theoretically, this goal can be accomplished by establishing new seedlings and stimulating their growth and by increasing the growth of small established stems. One problem is that reducing overstory density provides excellent conditions for the growth of species that compete with oaks. Often, therefore, oak regeneration is not improved by shelterwood cutting alone (Loftis 1983, Sander 1979). An appropriate combination of overstory density reduction and understory competition control, however can stimulate the growth of oak reproduction under shelterwoods (Loftis 1990b, Schlesinger and others 1993, Wolf 1988) while retarding development of competing species (Loftis 1990b).

In the Boston Mountains, established advance oak reproduction is present in adequate numbers in most upland stands (table 5). However, most of the oak reproduction is less than 1.0 foot tall, and few stems are taller than 4.0 feet. Ash and cherry advance reproduction, though generally fewer in number in upland stands, often represent most of the desirable reproduction taller than 1.0 foot (table 5). Height growth of surviving oak, ash, and cherry reproduction in undisturbed stands is very slow and varies by species (fig. 3). Few small oak stems grow into the larger height classes because of poor survival (table 5). Conversely, numbers of medium- to large-size ash and cherry reproduction increase over time, resulting in a pool of large advance reproduction that develops rapidly after harvest.

During the first 5 years after treatment development of the white and red oak, reproduction was very slow. Nearly all oak reproduction died back and resprouted during this period. Stems on plots receiving the most intensive understory control resprouted within 1 to 3 years after treatment, while resprouting after the less intensive treatment occurred throughout the initial 5-year period. Also, large oak stems generally resprouted later than small stems. Another factor that may have contributed to the poor overall response of the small oak reproduction is the typical rainfall pattern for northwestern Arkansas. While long-term monthly precipitation for June-September averages 3 to 4 inches, extended dry periods resulting in severe soil moisture deficits are common. Even where overstory density and understory competition are reduced, moisture stress is likely to reduce growth of all reproduction, and particularly that of small stems.

After intensive and intermediate competition control, red and white oak stems initially 2.0 feet and taller generally grew to heights of 4 to 8 feet over the 9-year period. However, upland stands on average to good sites in the Boston Mountains will typically have fewer than 100 oak stems per acre over 2 feet tall as advance reproduction. Therefore, continued development of the small oak stems will be required to achieve adequate numbers of large oak reproduction.

Redevelopment of the competing understory varied considerably with the intensity of the understory and overstory treatment. On plots thinned to 60 percent stocking with the intensive understory treatment, redevelopment of competing understory was very slow. Stems of desirable species in all size classes were essentially free to grow for the first 5 years after treatment. Although numbers of competing stems increased considerably over the 9-year measurement period, only the smallest desirable stems were overtopped after 9 years. However, on plots thinned to 40 percent stocking, the intensive control treatment was effective for only about 5 years. By the end of the fifth year, many of the small oak stems were overtopped and by the ninth year only ash, cherry, and oak stems initially taller than 3 feet were free to grow. Competition on the heavily thinned plots was also

Table 5.–Mean height distribution per acre of oak, ash and cherry, and other species reproduction stems before treatment.

Species	Height class (ft)					
	<1.1	1.1-2.0	2.1-3.0	3.1-4.0	4.1-5.0	>5.0
	Number of stems per acre					
Oaks	1,600	84	17	12	5	0
Ash and cherry	690	200	109	55	36	5
Other species	4,577	2,648	1,435	1,170	1,033	1,489

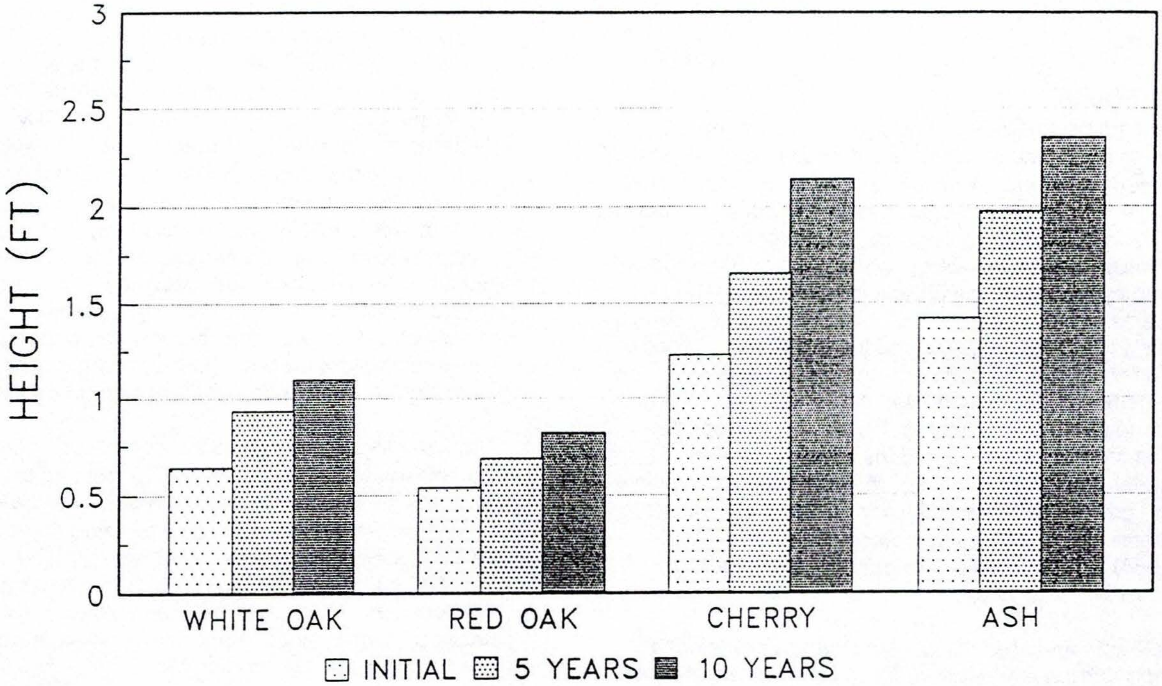

Figure 3.–Height development of advance reproduction in undisturbed upland oak stands in the Boston Mountains by species.

increased by a surge of herbaceous vegetation and vines, especially on the most productive sites.

The intermediate intensity of understory control increased growth of desirable reproduction, but its effect probably will not continue much beyond the ninth year. Understory development is most pronounced on plots thinned to 40 percent stocking where all small oak stems and most large stems are overtopped by competing stems. With that overstory stocking, only ash and cherry have maintained a favorable competitive position on plots receiving the intermediate intensity of understory control.

Although growth of desirable stems was significantly greater on plots receiving the intensive and intermediate understory control treatments, overstory thinning and midcanopy removal (stems > 1.6 inches) also increased growth of larger desirable reproduction. Ash and cherry produced the better response, but oak stems initially taller than 3 feet also responded.

MANAGEMENT IMPLICATIONS

On average to good upland sites in the Boston Mountains, numbers of oak advance reproduction is plentiful, but most oak stems are too small to successfully compete with less-desirable species after harvest. Consequently, the overall regeneration potential of the oaks is inadequate. Overstory thinning plus removal of midcanopy stems larger than 1.6 inches d.b.h. increases growth of oak advance reproduction initially taller than 3.0 feet, but few stems of this size are present in most mature upland stands. To enhance development of existing oak stems less than 3.0 feet, intensive understory treatment may be required. Removal of all or most of the competing understory may be necessary for oaks initially 1- to 2-feet tall to attain adequate size before final overstory removal. In fact, two understory treatments may be required. A relatively high overstory density would have to be retained to retard the redevelopment of the competing understory.

Small ash and cherry advance reproduction also is stimulated by intensive understory control, and one treatment would appear sufficient. Large advance ash and cherry reproduction require only overstory and midcanopy density reduction to compete successfully with other reproduction.

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