FIRST-YEAR RESPONSE OF AN UPLAND HARDWOOD FOREST TO FIVE LEVELS OF OVERSTORY TREE RETENTION

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Abstract—Response of a north Alabama upland oak-hickory forest to five levels of overstory tree retention was compared following treatment. Fifty-acre experimental blocks were established on the mid-Cumberland Plateau, which included the highly dissected margins and sides of the southern subregion. Blocks were replicated three times. Each of the five retention treatments (corresponding to 100-, 75-, 50-, 25-, and 0-percent basal area retention) was randomly assigned within 10-acre units of each block. Leave trees within treatments were marked based on species and crown position, and the harvest was implemented by chain saw felling and grapple skidding. The 75-percent retention treatment was accomplished using stem-injected herbicide, and most injected stems were midstory canopy trees. An average of 381 stems per acre were treated with herbicide, and the average diameter of treated trees was 2.9 inches diameter at breast height. Following treatment, canopy tree basal area was not significantly different between the control and the 75-percent retention treatments, but these two treatments retained significantly greater basal area than the other three. The residual basal area between the 25-percent retention (28 percent retained) and the 50-percent retention (38 percent retained) treatments was not significantly different but did differ significantly from the clearcut, control, and 75-percent retention treatments. The treatments created a gradient in light levels and percent canopy cover. One year after harvest, the number of sugar maple and oak seedlings < 1 foot tall has decreased, the number of oak seedlings > 1 foot increased, and yellow-poplar seedlings of all sizes increased.

INTRODUCTION

The oak-hickory forest type dominates forests of northeastern Alabama. In Jackson County, located in the northeastern corner of the State, 79 percent of the 451,000 acres of timberland were classified as oak-hickory (Hartsell and Brown 2002). These forested systems have faced similar stresses as other Southern Appalachian hardwood systems, including a mixed history of indiscriminant logging, fire, and sporadic, severe weather events. Over 50 to 100 years, the result of these large-scale disturbances was a massive intrusion of oaks (*Quercus* spp.), yellow-poplar (*Liriodendron tulipifera* L.), ash (*Fraxinus* spp.), and other important species. Today's upland hardwood forests in the Tennessee Valley of north Alabama and adjacent regions contain a mixture of species with wide ranges of shade tolerance and growth rates. Our research now focuses on how to manage the resulting stand structures and species compositions to meet current utilization goals and achieve our desired future conditions.

Regenerating hardwood stands in similar systems has been documented in key studies by Loftis (1983a, 1983b, 1985, 1990), McGee (1967, 1975, 1979), McGee and Hooper (1970), Sander (1971, 1972), Sander and Clark (1971), and Sander and others (1976). These studies have shown that growth rates of oak reproduction following a harvest are a function of the size of advance reproduction, and that it is important to consider preexisting vegetative structure, including both stump sprouts and advance reproduction.

Shelterwood harvest is an alternative regeneration method that requires a sequence of cuttings over a 5- to 20-year interval and multiple entries into the stand. Where an oak component is favored, this technique has shown promise in regenerating stands. The residual basal area in a shelterwood must be high enough to prevent light-seeded species, in many cases yellow-poplar, from becoming established and growing. Stands that contain species of opposing shade tolerances, such as those in northeastern Alabama, present yet another challenge. The change in canopy structure and below-canopy light conditions may also favor shade-tolerant species such as sugar maple (*Acer saccharum* Marsh.). In addition to overstory reduction, treating the subcanopy may promote the development of desired species.

The main objective of this study was to quantify forest regeneration, by source and species composition, using a range of crown covers and basal areas. The effects of varying the intensity of forest overstory retention on oak reproduction establishment and growth will be followed and light conditions created by these stand manipulations will be used in quantifying the changes among treatments.

METHODS

Study Sites

To assess the shelterwood method of regenerating upland hardwood stands, three sites on the mid-Cumberland Plateau in Jackson County, AL, were chosen. The stands are located on strongly dissected margins and sides of the plateau (the escarpment). On the escarpment study sites, soils are characterized as deep to very deep and loamy. They are considered well drained, with moderate to moderately low soil fertility. Slopes range from 15 to 30 percent. Upland oak site index was 75 to 80, and yellow-poplar site index was 100 [base age 50 years, Smalley Landtype 16, plateau escarpment and upper sandstone slopes and benches—north aspect (Smalley 1982)]. Canopies were dominated by oaks (*Q. velutina* Lamarck, *Q. rubra* L., *Q. alba* L., *Q. prinus* L.), yellow-poplar, hickories (*Carya* spp.),

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and sugar maple, with a lesser proportion of ash and blackgum (*Nyssa sylvatica* Marsh.). Depending on the site, dogwood (*Cornus florida* L.), sourwood (*Oxydendrum arboreum* DC.), Carolina buckthorn (*Rhamnus caroliniana* Walt.), and eastern redbud (*Cercis canadensis* L.) were common understory species. Beneath mature stands oak reproduction was small and sparse, and competition by yellow-poplar and sugar maple was great.

Each site (block) comprised one replication of five treatments established along the slope contour. One replication, located on Miller Mountain (34°58'30"N., 86°12'30"W.), had a southwestern aspect and a mean elevation of 1,600 feet. Two replications, located at Jack Gap (34°56'30"N., 86°04'00"W.), both had northern aspects. One Jack Gap replication was located at 1,500 feet elevation and the other at 1,200 feet elevation. Treatments were randomly assigned to 10-acre areas within each replicated block. The treatments constituted five levels of overstory basal area retention: (1) 100 percent, untreated control; (2) 75 percent; (3) 50 percent; (4) 25 percent; and (5) 0 percent, clearcut. For the 50- and 25-percent retention, trees were marked to be retained using guidelines outlined by John Hodges, following those of Putnam and others (1960). Trees were chosen on the basis of species, favoring oak, ash, and persimmon (*Diospyros virginiana* L.), and class, favoring preferred and reserve growing stock. All leave trees had dominant or codominant crown positions and exhibited high vigor. Trees were harvested by conventional methods of chain saw felling and grapple skidding along predesignated trails. Roads were “daylighted” and trees harvested from fall 2001 through winter 2002.

For the 75-percent retention treatment, an herbicide (Arsenal®, active ingredient imazapyr) was used to deaden the midstory. Rates of application were within the range recommended by the manufacturer. Watered solutions were made in the laboratory, and then trees received application via waist-level hatchet wounds using a small, handheld sprayer. One incision was made per 3 inches of diameter, and each incision received approximately 0.15 fluid ounces of solution. Herbicide treatments were completed in fall 2001, prior to leaf fall. The goal was to minimize the creation of overstory canopy gaps while removing 25 percent of the basal area in the stand midstory. All injected trees were in lower canopy positions, reducing the creation of canopy gaps.

Prior to treatment, five measurement plots were systematically located in each treatment area. Plot centers were permanently marked with a 2-foot piece of reinforcing steel, and Global Positioning System (GPS) coordinates were recorded. Regeneration was sampled on 0.01-acre circular plots. Seedlings were tallied by species in each regeneration plot by 1-foot height classes, up to 1.5 feet diameter at breast height (d.b.h.), and then by diameter. Using the same plot center, a 0.025-acre plot was established, and all trees 1.6 inches d.b.h. and greater were monumented (distance and azimuth measured and recorded from plot center, each tree tagged with a numbered aluminum tag) and species and d.b.h. recorded. An additional 0.2-acre plot, located concentrically, was established, and all trees 5.6 inches d.b.h. were measured and monumented as described previously.

In mid- to late-summer 2002, all measurement plots were revisited. Regeneration was re-enumerated, and the status of all monumented trees was recorded. Wounds on trees 5.6 inches d.b.h. and greater were measured. A handheld spherical densitometer was used to measure canopy cover at two vertical levels, ground and 4.5 feet, at plot center and at 12 feet in each cardinal direction from plot center. An AccuPAR Linear Par Ceptometer, Model PAR-80, was used to measure photosynthetically active radiation at each plot center and along transects equally dissecting each plot.

All the data analyses were accomplished using the Statistical Analysis System (SAS Institute 1990). Analysis of variance was used to test for differences among treatments, and Duncan’s Multiple Range test was used for mean comparisons ($p < 0.05$).

RESULTS

Overstory Composition

The initial basal areas of the canopy trees (5.6 inches and larger d.b.h.) for each treatment are given in table 1. There were no significant differences among treatments for total basal area prior to treatment implementation. Oaks occupied most of the canopy in all pretreatment units, ranging from 41 percent in the 50-percent retention treatment to 51 percent in the 25-percent retention treatment. Across all treatment units, oaks comprised 46 percent of the total basal area, followed by 15 percent hickory, 13 percent sugar maple, and 9 percent yellow-poplar. The number of canopy trees averaged 115 stems per acre; oaks, with an average d.b.h. of 16 inches, averaged 35 stems per acre.

Following treatment, the canopy tree basal area was not significantly different between the control and the 75-percent retention treatment, but these two retained significantly

Table 1—Average basal area (trees 5.6 inches d.b.h. and larger) for five retention treatments (pretreatment and posttreatment) and percent of total basal area retained 1 year posttreatment

Treatment	Pretreatment	Posttreatment	Total basal *area*
percent	- - - - - - - *ft*^{2} *per acre*	- - - - - - -	*percent*
100 retained (control)	106.2a	105.9a	99.7
75 retained (herbicide)	117.3a	82.1a	70.0
50 retained	106.3a	40.2b	37.7
25 retained	98.7a	27.3b	27.7
0 retained (clearcut)	109.7a	5.1c	4.7

Letters indicate significant difference among means within columns.

greater basal area than the other three treatments. On one of the measurement plots, a 12-inch d.b.h. sugar maple died, and it accounted for the only change in the control treatment basal area. Most of the herbicide-treated trees removed in the 75-percent retention treatment were in the midstory position. An average of 381 stems per acre was herbicide treated, and the average tree diameter of treated trees was 2.9 inches d.b.h. The basal area of trees 1.5 inches d.b.h. and larger for the 75-percent retention treatment was reduced from 115.9 square feet per acre to 86.1 square feet per acre, meeting the targeted 75-percent retention.

Thirty-eight percent of the canopy tree basal area was retained in the 50-percent retention treatment, and 28 percent was retained in the 25-percent retention treatment. The residual basal area on these treatments was not significantly different, but did differ significantly from the clearcut (5 percent retained), control (100 percent retained), and 75- percent retention (70 percent retained) treatments (table 1).

Because residual trees were chosen based on species, the residual-stand species composition varied from that of the original stands, except for the control treatment. For the –75-percent retention treatment, the proportion by species of the canopy tree basal area changed little. Prior to the herbicide treatment, red oaks were 14 percent and white oaks were 37 percent of the total canopy tree basal area, followed by 14 percent hickory, 14 percent yellow-poplar, and 8 percent sugar maple. One year posttreatment, these proportions were 13 percent for red oaks, 32 percent for white oaks, 14 percent for hickory, 12 percent for yellow-poplar, and 8 percent for sugar maple. For the 50-percent retention treatment, the major species proportions pretreatment were 19 percent red oaks, 27 percent white oaks, 20 percent hickory, 8 percent yellow-poplar, and 14 percent sugar maple. Following treatment (harvesting), the overstory tree basal area was composed of 28 percent red oaks, 36 percent white oaks, 13 percent hickory, 7 percent yellow-poplar, and 8 percent sugar maple. The 25-percent retention treatment species composition demonstrated a pattern similar to the 50-percent retention. Other tree species removed from these stands included red maple (*A. rubrum* L.), sourwood, sassafras (*Sassafras albidum* L.), blackgum, black locust (*Robinia pseudoacacia* L.), and American beech (*Fagus grandifolia* Ehrh.).

Residual Tree Damage

Damage to the residual trees was evaluated for the 25- and 50-percent retention treatments by crown observations and by measuring wounds on the lower bole. Less than 1 percent of the residuals in the 50-percent retention treatment and 6 percent of the residuals in the 25-percent retention treatment suffered any type of noticeable crown damage. Most of the damage was to the boles, and this damage was concentrated on the lower bole area; only one wound was noted 10 feet or higher on any bole. For the 50-percent retention treatment, 25 percent of the residual trees had wounds on the lower bole, and these averaged 131 square inches. The amount of bole damage for the 25-percent retention was 15 percent, and the average wound size was 70 square inches. No immediate response of epicormic branching was noted on the residuals during the first growing season after treatment.

Canopy Cover and Understory Light Conditions

One goal of these stand manipulations was to evaluate vegetation responses under various light levels. Canopy cover percentages and the percent of full sunlight measured 4.5 feet above the ground are given in table 2. Percent canopy cover did not differ significantly between the control and the 75-percent retention treatment, but the amount of light reaching the understory was significantly greater in the 75-percent treatment than the control (table 2). Canopy cover and light levels were similar for the 50- and 25-percent retention treatments, and these differed significantly from the other three treatments. At the end of the first growing season after treatment, a gradient of light was recorded across four treatments, following the basal area reductions.

Regeneration

Across all treatments, large advance reproduction, > 1 foot tall but < 1.5 inches d.b.h., averaged 3,313 stems per acre (table 3). The oak component was low, making up 2 percent (71 stems per acre) of the total large advance reproduction. Small advance reproduction, < 1 foot tall, averaged 6,671 stems per acre, and small oaks were 13 percent of this total. Across all treatments, large advance reproduction was dominated by sugar maple (389 stems per acre) and ash (206 stems per acre).

After the 75-percent retention treatment, total seedling counts and the number of oak seedlings were below pretreatment counts (table 3). There was a slight increase in both small and large advance reproduction of sugar maple.

Table 2—Comparisons among five basal area retention treatments for percent canopy cover at two understory positions; and percent full sunlight measured at 4.5 vertical feet in the understory, 1 year posttreatment

Treatment	Canopy cover at ground level	Canopy cover at 4.5 feet	Full sunlight at 4.5 feet
	percent		
100 retained (control)	100a	100a	8a
75 retained (herbicide)	98a	98a	16b
50 retained	79b	75b	38c
25 retained	79b	76b	32c
0 retained (clearcut)	51c	32c	60d

Letters indicate significant difference among means within columns.

Table 3—Number of stems per acre by size class for select species and total of all species, by basal area retention treatment, for pretreatment (pre) and year 1 posttreatment (post) counts

	Treatment retention (percent)									
Size class and species	100 Control		75 Herbicide		50		25		0 Clearcut	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
	number of stems per acre									
≤1 all	4,982	4,186	7,798	6,573	4,581	6,180	5,342	5,186	10,653	5,453
>1 all	2,615	2,480	2,579	2,586	3,995	3,674	4,075	4,213	3,299	2,960
≤1 oaks	699	780	1,652	1,520	400	480	713	673	746	340
>1 oaks	200	193	40	20	26	46	40	140	47	107
≤1 sugar maple	959	867	1,538	1,593	1,185	687	833	613	1,312	533
>1 sugar maple	147	133	500	553	353	360	366	400	573	373
≤1 yellow-poplar	0	0	73	33	33	820	13	647	13	1,540
>1 yellow-poplar	7	7	20	33	0	160	13	93	20	160
≤1 ash	173	127	212	160	226	707	127	413	539	760
>1 ash	113	87	53	67	433	407	206	260	226	393

< 1 = to 1 foot in height; > 1 = greater than 1 foot tall but less than 1.5 inches d.b.h.

In the clearcut treatment, total oak seedling stems per acre declined for the smallest size class and increased for the largest. The number of oak stems per acre increased in the 50-percent retention treatment, from 400 to 480 stems per acre for small seedlings, and from 26 to 46 stems per acre for large seedlings. Large oaks also increased in the 25-percent retention treatment, from 40 to 140 stems per acre.

In three harvest treatments (25- and 50-percent retention and clearcut), both large and small advance sugar maple reproduction declined in numbers, from an average of 1,110 stems per acre to 611 stems per acre for the smallest sugar maple seedlings, and from 431 stems per acre to 378 stems per acre for the largest. For both size classes, the number of stems per acre of yellow-poplar increased in all three of these treatments. The number of ash seedlings per acre also increased, except for large advance ash in the 50-percent retention treatment, which declined slightly.

In the clearcut, prior to treatment, sugar maple and red maple accounted for 12 and 48 percent of the total seedling count in the small reproduction class, and yellow-poplar was < 1 percent (13 stems per acre). Posttreatment small sugar maple and red maple seedlings comprised 10 and 2 percent of the total stems per acre, respectively, and yellow-poplar increased to 28 percent (1,540 stems per acre). This trend was similar for both the 50- and 25-percent retention treatments.

DISCUSSION

Upland hardwood forests on escarpment sites in north Alabama have unique species composition. Site quality is good, and the dominant species include white and red oaks, ash, yellow-poplar, hickory, red maple, and sugar maple. The range of shade tolerance exhibited by these species contributes to the challenge of regenerating timber stands. Oaks, which had low advance reproduction numbers, and which were small in stature, are key species in the stand's desired future condition. The challenge of this study was to manipulate the stand to foster the growth and development of small oaks, while simultaneously discouraging the proliferation of yellow-poplar. Under the varying canopy cover and light levels, the response of the small but numerous sugar maple seedlings on these sites was uncertain.

The gradient in overstory canopy cover and understory light levels was accomplished by removing varying amounts of the overstory and midstory basal area. By selecting leave trees prior to harvest, the residual stand composition in the 25- and 50-percent retention treatments was changed. High-value species were favored. After one growing season, a few trends in the regeneration response were noted.

The increase in yellow-poplar seedlings following harvesting (25- and 50-percent retention treatments and clearcut) supports the findings of others (Kuers and Kuthe 1998, Loftis 1983b, McGee and Hooper 1970). An increase in early successional species was measured on all harvested areas. The contribution of stem sprouts to the reproduction in these treatments will influence the stands' future composition. Modeling of sprouting potential will aid in evaluating the contribution of stem sprouts to the new stand, and the competitiveness of oak and other species. The growth rate of early successional species (yellow-poplar, black cherry, black locust, red maple) coupled with sprouting competition potentially will influence the future eminence of oak.

Golden and others (1999) assessed oak regeneration in a north Alabama stand following clearcutting and a deferment cut that retained approximately 25 percent of the original basal area. They found the most influential factor related to postharvest stocking of oak was the presence of advance reproduction taller than 6 inches, contrasting with others' findings (Loftis 1983a, 1983b, 1990; Sander 1971, 1972). One goal of establishing a gradient of basal area retentions and light levels was to determine what degree of harvest would allow adequate development of advance oak regeneration, based on the size-class status of reproduction present.

Shelterwood cutting successfully altered stand structure and species composition. Stand density was reduced and species composition altered to promote the growth and development of residual trees. Growth and vigor of a residual stand will help meet future timber and wildlife needs, as well as contribute to the next age class through sprouting. Logging damage to residual stems was confined to lower boles and occurred on 15 to 25 percent of residual stems > 5.6 inches d.b.h. These values were considerably lower than those reported by Meadows (1993) in a bottomland hardwood stand (62 percent residual damage) and fell within the range of 18 to 42 percent residual damage reported by Lamson and others (1984) in an upland hardwood stand. Directional felling and preplanned roads and skid trails contributed to mitigating unnecessary residual damage. Wounds to residual trees and epicormic branching will be monitored.

CONCLUSIONS

A large-scale stand manipulation study was implemented, resulting in four treatments that had significantly different residual basal areas. Prior to harvest, advance reproduction was dominated by sugar and red maples, and there were few oaks. Since the harvests, small (< 1 foot in height) sugar maple and oak seedling numbers have declined, and there have been more large oak seedlings. However, competition is increasing with the pervasion of yellow-poplar seedlings. Reduction of the midstory altered light levels on the ground differently than the other harvest treatments. The response of both the advance oak reproduction and the more shade-tolerant sugar maple seedlings will be monitored closely under these treatments.

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