HICKORY REGENERATION UNDER FIVE SILVICULTURAL PRESCRIPTIONS IN AN OAK-HICKORY FOREST IN NORTHERN ALABAMA

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Abstract—Hickory (*Carya* spp.) regeneration in oak-hickory forests of the southern Cumberland Plateau has not been widely studied. I assessed hickory regeneration under five silviculture prescriptions, including clear-cut harvests, three levels of shelterwood harvests, and no harvest. Each stand-level treatment was replicated three times and treatments were implemented from fall 2001 through winter 2002. Overstory composition was dominated by white oaks (*Quercus alba* L. and Q. *prinus* L.) (37 percent of the total basal area per acre, and 15 percent of the total stems per acre) followed by hickory (17 percent of the total basal area per acre, and 18 percent of the total stems per acre). Hickory regeneration of all size classes averaged 405 stems per acre across all stands pretreatment and 285 stems per acre four years post-treatment; the majority tallied were 1-foot tall or less than. Light and canopy cover differed among treatments and with time. After four years, hickory regeneration did not differ among treatments. There were no differences in survival among the five treatments for tagged hickory seedlings, and in 2006, hickory seedlings in the 25 percent retention treatment had the greatest height growth.

INTRODUCTION

For a variety of reasons, interest in regenerating the upland hardwood forests of the southern Cumberland Plateau has increased, as has the challenge of doing so. Upland forests in this region are aging, the effects of harvesting practices are unknown, and land ownership changes have altered planning goals. Although much research in upland hardwood forests, including those described as oak-hickory forest types, has focused on regeneration methods for the oak species (*Quercus* spp.), few studies have examined the ecology and silviculture of hickory (*Carya* spp.) (Hannah 1987, Johnson and others 2002, Loftis 1983b, Roach and Gingrich 1968, Sander 1977). There are many reasons to focus on regenerating hickory along with the other species typically found in upland hardwood forests (Fralish 2004). Recent attention has considered hickories as a key component in wildlife habitat, particularly for bats. Some bat species prefer roosting in the loosely attached bark of species such as shagbark hickory (*C. ovata* K.). It has long been reported that hickory nuts are valued by wildlife. Additionally, utilization and cultural trends in wood products have supported a rise in the market price of hickory lumber for cabinets and flooring (Luppold and others 2001). Maintaining the high flora and fauna biodiversity in these systems is also important.

Ascertaining how millions of oaks, hickories, yellow-poplar (*Liriodendron tulipifera* L.), and maples (*Acer* spp.) became established on medium to high productive sites remains a standard question considered when regenerating upland hardwood forests. 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), Sander and others (1976). There has been much speculation on the conditions under which today's stands regenerated between 1820 and 1920 (Fralish 2004). Numerous studies have shown how site quality influences regeneration. Lower quality sites are found to be more easily regenerated to oak, and higher quality sites more difficult. Few studies have considered how site quality affects hickory regeneration.

Studies have shown that silviculture can be used to control factors such as light and spacing, which in turn greatly influence species response and stand composition. We also know some things about the probabilities for success using different types of regeneration on different sites. For example, for most species, stump sprouts are often more competitive than new seedlings. However, we know very little about the reproductive dynamics of hickory.

This study's main objective has been to quantify the sources and species composition of hickory regeneration resulting from a range of site disturbances. One goal is to help forest managers understand how stand manipulations will influence current stand dynamics and future composition and structure. Other ancillary goals are to help bring a positive financial return to the landowner and to maintain species diversity.

METHODS

Study Sites

To assess the shelterwood method of regenerating upland hardwood stands, I chose three sites on the mid-Cumberland Plateau in Jackson County, AL. The stands are located on strongly dissected margins and sides of the plateau (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 (*Quercus velutina* Lamarck, *Q. rubra* L., *Q. alba* L., *Q. prinus* L.), yellow-poplar, hickories, and sugar maple (*Acer saccharum* Marsh.), with a lesser proportion of ash (*Fraxnus* spp.) 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

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sparse, and competition by yellow-poplar and sugar maple was strong.

Treatments

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), had northern aspects. One Jack Gap replication was located at 1,500 feet elevation and the other at 1,200 feet. 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 using chainsaw felling and grapple skidding along predesignated trails. Roads were "daylighted" (trees on or adjacent to roads removed to allow sunlight in and surfaces to dry) 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 and a small, handheld sprayer. One incision was made per 3 inches 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 basal area in the stand midstory. All injected trees were in lower canopy positions, reducing the creation of canopy gaps.

Measurements and Statistics

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 GPS coordinates were recorded. Regeneration was sampled on 0.01-acre circular plots. I tallied all vegetation in the regeneration plot. Seedlings were tallied by species by 1-foot height classes up to 4.5 feet tall; large seedlings were recorded as those greater than 4.5 feet tall up to 1.5 inches diameter at breast height (d.b.h.). Trees larger than 1.5 inches d.b.h. were tallied 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, 2003, 2004, 2005, and 2006, all measurement plots were revisited. Regeneration was re-enumerated, and the status of all monumented trees recorded. A hand-held spherical densitometer was used to measure canopy cover above 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 (Decagon Devices, Inc, Pullman, WA, U.S.A.), was used to measure photosynthetically active radiation at each plot center and along transects equally dissecting each plot.

All 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 ($p < 0.05$). Logistic regression was used to test the relationship among hickory sprouting probabilities and initial tree diameters.

RESULTS

Overstory Tree Conditions

Treatments resulted in a gradient of residual stand conditions, following 105.9 square feet per acre for the control, 82.1 square feet per acre for the 75 percent treatment, 40.2 square feet per acre for the 50 percent treatment, 27.3 square feet per acre for the 25 percent treatment and 5.1 square feet per acre for the clearcut. The 50 and 25 percent treatments were not significantly different from one another. Hickory species tallied in all stands included pignut, red, shagbark, and mockernut (*Carya glabra* Sweet, *C. ovalis* Sarg., *C. ovata* K. Koch, and *C. tomentosa* Nutt.). Hickory species were combined for all analysis. Following treatment, hickory basal area was 4, 15, 11, 2, and 1 percent of the total basal for control, 75 percent, 50 percent, 25 percent and clearcut stands. Overstory hickory stems per acre remained unchanged from pretreatment values through 2006 for the control (15 stems per acre (SPA)) and the 75 percent retention treatment (24 SPA). There was less than one SPA of hickory remaining after clearcutting. In the 50 percent retention treatment, hickory SPA in the overstory went from 24 to 3, and in the 25 percent treatment they declined from 16 to 1 SPA.

Canopy Cover

Densiometer data were significantly different among treatments for each post-treatment year measured (table 1). The control and 75 percent retention treatments did not differ in their percent cover. The 75-percent retention treatment was aimed at reducing the midstory, without altering the main canopy, so this result was expected. Both of these treatments had significantly greater canopy cover compared to the other three treatments for years 2002, 2003, and 2004; in those same years, the 50 and 25 percent retention treatments were not significantly different from one another but were from the other three treatments, and the clearcut was significantly different from the other four treatments. In 2005 and 2006, the 50 percent retention treatment had similar canopy cover as the 75 percent treatment. The high productive nature of these systems caused the vegetation to respond quickly to increased space and light. By 2006, percent canopy cover of

Table 1—Canopy cover percentages for each treatment by year

	2002	2003	2004	2005	2006
Control	99.7a	96.8a	98.9a	96.2a	95.8a
Seventy-five	98.3a	94.6a	92.6a	92.3ab	91.9ab
Fifty	76.0b	48.0b	71.9b	87.8bc	84.2bc
Twenty-five	74.9b	44.7b	65.1b	82.0c	85.2c
Clearcut	31.0c	25.4c	47.6c	80.4c	83.7c

Values in columns with the same letters are not significantly different.

the three harvested treatments (50, 25, and clearcut) were not significantly different from one another.

Understory Light Levels

There were significant differences in the reduction of full sunlight reaching the understory each year post-treatment (table 2). In all five measurements post-treatment, the control plots had significantly greater reductions in full sunlight reaching the forest floor than did the other five treatments. In 2004, the control and 75 percent retention treatments did not differ from one another, but were significantly different from the other three treatments. After five growing seasons, four distinct light regimes were measured below the canopy, and the greatest reduction in light was under the control treatments, followed by the 75 percent retention treatment and then the 50 percent retention treatment. In 2006 there was no difference in light reduction under the 25 percent retention treatment and the clearcut, although these treatments both differed from the other three.

Seedlings Counts

Seedling counts for natural regeneration in the 75 percent retention treatment showed that for all species, the total number of seedlings in all height classes changed from 9,439 SPA in 2001 (pretreatment) to 7,768 SPA in 2006 (post-treatment) (table 3). However, it is noteworthy that these

Table 2—Light reduction percentages for each treatment by year

	2002	2003	2004	2005	2006
Control	92a	94a	97a	96a	98a
	(10.3)	(7.7)	(4.9)	(6.6)	(1.6)
Seventy-five	83b	83b	94a	92b	91b
	(13.9)	(16.1)	(7.2)	(11.8)	(4.1)
Fifty	66c	68c	73b	82d	83c
	(32.0)	(21.7)	(20.7)	(22.4)	(7.3)
Twenty-five	69c	47d	75b	86c	67d
	(25.5)	(29.8)	(19.2)	(16.4)	(22.1)
Clearcut	41d	41e	41c	63e	67d
	(21.4)	(21.4)	(23.4)	(27.2)	(18.1)

Values in columns with the same letters are not significantly different; numbers in parentheses are one standard deviation.

Table 3—Seedling counts per acre for natural regeneration of all species encountered and for all hickory species

	< 1 ft		1 to 4.5 ft		> 4.5 ft		Total	
	All	Hic	All	Hic	All	Hic	All	Hic
Control 2001	5284	365	2771	50	185	15	8240	430
Control 2006	2271	350	2698	39	286	34	5255	423
Seventy-five 2001	7040	333	2171	29	228	22	9439	384
Seventy-five 2006	3584	295	4084	29	100	24	7768	348
Fifty 2001	4670	253	3498	82	300	18	8468	353
Fifty 2006	857	78	5941	266	243	0	7041	344
Twenty-five 2001	5426	326	4370	136	243	16	10039	478
Twenty-five 2006	1428	78	6040	339	215	0	7683	417
Clearcut 2001	5998	287	3270	38	257	19	9525	344
Clearcut 2006	828	107	5469	189	144	0	6441	296

totals are not absolute because counts in the 0.01-acre plot of more than 25 for a given species in a given height class were recorded as 25, and not truly enumerated. Hickory seedling tallies in this treatment were 384 SPA in 2001, and 348 SPA in 2006. Control SPA for all species decreased from 8,240 to 5,255 SPA, and the hickory component remained relatively unchanged, with 430 SPA in 2001 and 423 in 2006. Totals by height classes did not differ between years for the control and 75 percent retention treatments. In the 50, 25, and clearcut treatments, the number of hickory stems that were 1.0 to 4.5 feet tall increased from 2001 to 2006: 82 to 266, 136 to 339, and 38 to 189 SPA, respectively. The number of SPA greater than 4.5 feet tall decreased to zero in all three of these treatments.

Tagged Hickory Seedling Survival and Growth

There were no significant differences in percent survival among the five treatments for the hickory seedlings that were tagged and followed, for each year measurements were made (fig. 1).

There were 20 tagged hickory seedlings in the 50, 75 percent, and clearcut treatments, 28 tagged seedlings in the control, and 16 in the 25 percent retention treatment. Relative height and basal diameter growth of the tagged hickory seedlings differed among treatments only for relative height growth in 2006. In 2006, relative height growth of the seedlings in the 25 percent retention treatment was significantly greater than height growth in the control. In 2006, the relative height growth of seedlings in each treatment was 1.6 inches for the control, 5.1 inches for seedlings in the 75 percent retention, 8.7 inches for the clearcut treatment, 11.4 inches for 50 percent retention, and 18.9 inches for the 25 percent retention treatment (fig. 2). Relative diameter growth was negligible and not significantly different among the treatments.

Hickory Sprouting Probabilities

Across the three harvest treatments (50 and 25 percent retentions and clearcut), 158 total sample hickory trees were tallied (1.5 inches d.b.h. and greater). From each cut hickory

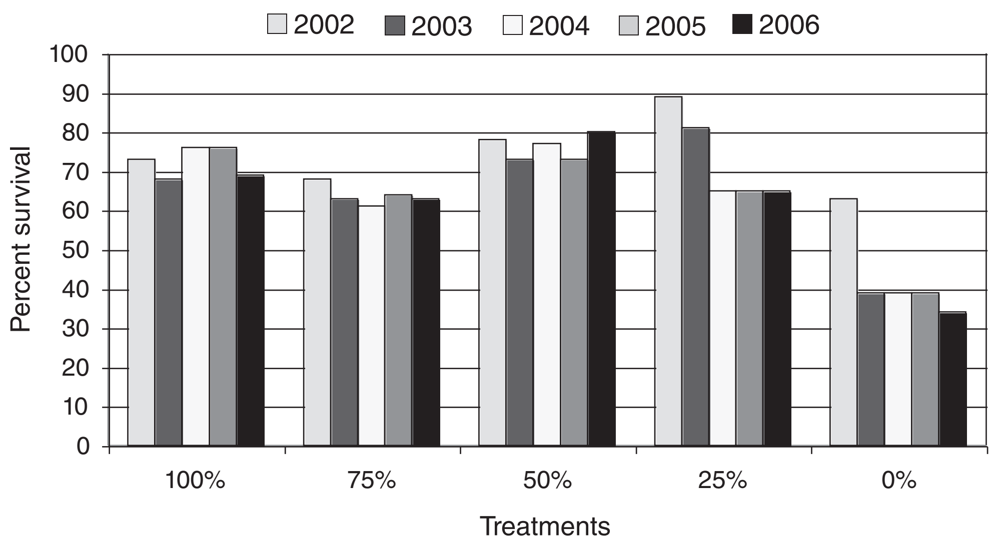

Figure 1—Tagged hickory seedling survival percentages compared among treatments by year. No significant differences were found.

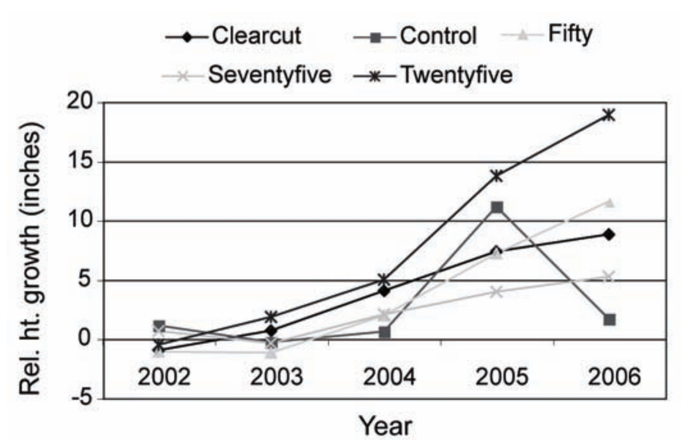

Figure 2—Relative height growth of tagged hickory seedlings in all treatments over 5 years.

tree, I recorded whether each had sprouted or not, and I used these data in logistic regression analysis to estimate the probability of sprouting as related to initial tree d.b.h. For cut trees, hickory sprouting probability decreased with increasing initial tree diameter (fig. 3). Logistic regression (binary outcome, sprout or no sprout) likelihood ratio indicated significance at $p<0.0025$.

DISCUSSION

For analysis of this study I combined the four hickory species tallied into one group; there was no dominant hickory species. Prior to stand manipulations, hickories on these sites averaged 13 SPA and comprised 11 percent of the total basal area. Overstory hickory species were not favored as residual trees, and very few remained after harvesting.

Treatments created a gradient of light levels. Species that adapt rapidly to their environment may have a competitive advantage in habitats with changing light intensities. Little is known about how hickory regenerates or how it may respond to changing light, although in this study, hickory showed minimal response to increased light. However, because these systems respond rapidly to disturbance, residual trees may be influencing reproduction within a few years following disturbance. The difference in light levels dissipated with time; the greater-cut treatments reduced light by almost 70 percent after five growing seasons. Miller and others (2006) found that reserve trees in a two-aged system rapidly expanded their crowns and influenced the composition of reproduction.

This study explored ways to regenerate these stands and maintain a known hickory component by manipulating overstory and midstory stand structure to alter light and growing conditions. In a previous study, Schweitzer and others (2004) used a multispecies regeneration model to compare predicted species composition with regeneration goals. The predictions from this model are for stand composition following an extensive regeneration cut. Model predictions for these stands enumerated 462 SPA at crown closure following treatment, with 27 percent black cherry (*Prunus serotina* Ehrh.), 21 percent black locust (*Robinia pseudoacacia* L.), 15 percent sugar maple, and 12 percent yellow-poplar. Hickory was predicted to comprise only 2 percent of the total SPA. The model does not predict how species compete under shelterwood conditions, such as those created in this study. However, study data will contribute to calibrate the model to predict species composition under different regeneration regimes.

In my seedling tallies, there was little recruitment of hickory into the largest size class following disturbance. Reducing just the midstory did not appear to favor hickory recruitment of any size class, nor hickory seedling growth. The three treatments that altered the light environment the most, the clearcut, 50 and 25 percent retention treatments, all had an increase in the number of seedlings tallied in the 'greater than 1 foot tall but less than 4.5 feet tall' class. These three treatments also produced no seedlings in the largest seedling size class. The disturbance was, in fact, detrimental to these larger seedlings. Mann (1984) reported that mechanical damage to stumps and soil incurred during harvesting treatments influenced seedling abundance. After five growing seasons, tagged hickory seedlings changed little in their relative growth; only seedlings in the 25 percent retention treatment were significantly taller than those in the controls. Although the vegetation has responded quickly under favorable site conditions, more time will be needed to make a definitive assessment of the response of hickory regeneration.

Stump sprouts may provide for some hickory recruitment into the next stand. At 10 inches d.b.h., there was approximately a 50 percent chance of the hickory sprouting from the stump after harvest. On average there were 13 SPA of hickory less than or equal to 10 inches d.b.h. Additional analysis incorporating the vigor of the sprouts, as well as edaphic and topographic features of the sites to strengthen the probability predictions is warranted.

CONCLUSIONS

Naturally regenerating the suite of hardwood species on any given site can be complicated. Much research has focused on regenerating oak on better quality sites, and little attention has been given to species such as hickory.

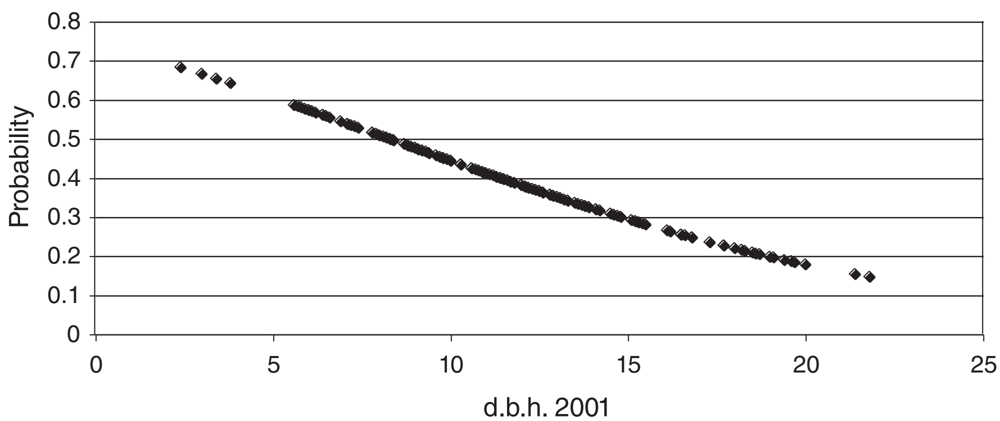

Figure 3—Hickory sprouting probabilities for cut trees on the 25- and 50-percent retention treatments and clearcuts.

Some have suggested that hickory is playing a major role in the replacement of American chestnut (*Castanea dentata* Mill.) and could be considered a inter-generational species (Johnson and Ware 1982). With the recent increased interest in biodiversity and conservation in the forested systems of the Cumberland Plateau, we need to direct our attention to manipulating stands, in order to obtain and retain myriad species composition. Our knowledge base for doing so is limited, but we can use methods for similar species and incorporate the response of all species. Thus far, regenerating hickory using silvicultural prescriptions successful in regenerating oak, such as the midstory reduction treatments, has not resulted in the recruitment or growth of hickory seedlings.

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