# OAK REGENERATION FOLLOWING COMPLETE AND PARTIAL HARVESTING IN THE MISSISSIPPI BLUFF HILLS: PRELIMINARY RESULTS

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**Abstract**—The Bluff Hills subregion encompasses about 4.5 million acres along the eastern side of the Mississippi Valley Loess Plains province, primarily in MS and TN. Soils are silt loams and are considered some of the most productive hardwood sites in the United States. Efforts to regenerate these forests to oak (*Quercus* spp.) has met with limited success. Due to these difficulties in regenerating oak, we initiated a study to test several regeneration methods. Three treatments included clearcut harvesting, partial harvesting using a combination of even-aged and uneven-aged techniques, and partial harvesting followed by herbicide-injection of less-desirable species. We conducted pre-harvest measurements, followed by first (stocking only), fifth, and eleventh year post-harvest measurements on three sites in Warren County, MS. Results after 11 years showed that clearcut plots were dominated by yellow-poplar (*Liriodendron tulipifera* L.), despite the continued presence of oak reproduction. Partial harvesting increased oak reproduction stocking, but after 11 years this reproduction was competing with a shade-tolerant midstory canopy. Partial harvesting combined with midstory competition control greatly increased oak reproduction stocking, but also increased yellow-poplar reproduction. These results indicate that different approaches, including timing of treatments, are needed to regenerate oak successfully in the Bluff Hills.

## INTRODUCTION

The Bluff Hills, commonly referred to as Brown Loam Bluffs (Hodges 1995), constitute a sub-region of the Mississippi Valley Loess Plains province (Bailey 1980). They extend from Baton Rouge, LA, to Cairo, IL, adjacent the east side of the Lower Mississippi Alluvial Valley (Hodges 1995), encompassing about 4.5 million acres (Johnson 1991). Soils are of aeolian origin and highly productive. These soils are also erosive; therefore, the Bluff Hills are characterized as deeply gullied with narrow ridges and steep slopes due to past agricultural land use (Hodges 1995).

Johnson (1958, 1991) indicated the Bluff Hills are one of the most productive hardwood areas in the United States. Site index, base age 50 years, can be > 100 for several oak species on lower slopes (Broadfoot 1976). This sub-region is considered a disjunct remnant of the Appalachian mixed mesophytic forest (Braun 1950), and contains a high diversity of plant species (Johnson and Little 1967, Caplenor 1968, Miller and Neiswender 1987a, 1987b). Forests, especially oak-(*Quercus* spp.) dominated forests, became established on former agricultural land following abandonment in the early to mid-1900s. Interest in managing these forests has increased as the stands have matured. Unfortunately, many of the oak regeneration problems that have been encountered in other productive hardwood forests (Loftis and McGee 1993, Johnson and others 2002) also occur in the Bluff Hills. Therefore, we initiated a study to determine the effects that different harvesting practices, along with midstory canopy control, have on the density of oak reproduction.

## MATERIALS AND METHODS

Three study sites (Gooch-Dixon Tract, Logue Tract, and Swift Tract) were located in the Bluff Hills on Anderson-Tully Company lands in Warren County, MS. The average annual temperature in Warren County is 65.5 °F with a low of 47.2 °F in January and a high of 81.7 °F in July. Rainfall averages 58 in per year (Mississippi State Climate Office, http://www.msstate.edu/dept/geosciences/climate/normals.html). Soils are Memphis, Natchez, and Loring silt loams (USDA 1964). They are considered deep, well drained, and productive. Site index, base age 50 years, is estimated to be 100 to 120 feet for cherrybark oak (*Q. pagoda* Raf.). Past stand history includes agricultural abandonment in the early 1900s followed by forest succession. Periodic light harvests have been conducted since the mid 1900s.

Sixty sample plots were systematically located in each study site in 1989 (180 plots total). These circular plots were 0.01 acre. This plot size was chosen to use Johnson's (1980) evaluation technique for determining oak reproduction stocking. Sample plots were located along transects 264 feet (4 chains) apart with individual plots 132 feet (2 chains) along each transect. Exceptions were made if sample plots were likely to be destroyed in skid trials, log dumps, or creek beds. Landform position was noted for each sample plot: ridge, slope, or bottom. All stems were measured prior to harvest in height (inches) or diameter at breast height (d.b.h., inches) if d.b.h. was > 0.5 inch. Post-treatment measurements involved stem counts by size classes. Pretreatment basal area was determined using a 10-factor prism and summed for sample plot basal area per acre. Pretreatment tree composition was determined using importance values (sum of relative frequency, relative density and relative dominance; Krebs 1985).

Hart and others (1995) modification of Johnson's (1980) evaluation technique was used to determine oak reproduction stocking on each sample plot. Points are assigned to stems based on height or d.b.h. (see Hart and others (1995) for

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more information about size classes). If points total 12 or more, then the sample plot is considered stocked with desirable reproduction (Johnson 1980). If 60 percent of the sample plots in a stand are stocked, then the stand is considered adequately stocked for a clearcut harvest to successfully regenerate the stand to oak (Johnson and Deen 1993).

Each study site (90 acres) was harvested in the late summer/early fall 1989. Three harvest treatments were conducted on about 1/3 of each study site. These treatments were: (1) a commercial clearcut followed by a herbicide injection using Tordon 101R® of all remaining stems ≥ 1-inch d.b.h.; (2) a partial harvest following Anderson-Tully Company's marking guidelines involving a tree classification system (see Putnam and others 1960 and Lockhart and others 2005 for examples); and (3) a similar partial harvest followed by herbicide injection of all remaining less-desirable stems ≥ 1 inch d.b.h. Sample plot remeasurements were conducted 1 (1990; oak stems only), 6 (1995), and 11 (2000) years following harvesting. We analyzed data using each study site as a replicate in a randomized complete block design, although the clearcut treatment was designated as the middle treatment in each study site to facilitate harvesting. The remaining treatments were randomized. Seedling densities from each sample plot were pooled by treatment within each study site, then converted to per acre values. We analyzed the data using log transformations. Percent data were analyzed using arcsine transformations. Repeated measures analysis was conducted using PROC GLM (SAS 1985), with significance determined at $p \leq 0.05$ and means separation using Duncan's Multiple Range Test.

## RESULTS AND DISCUSSION

A total of 44 tree species > 4.5 inches d.b.h. were identified across all study sites prior to treatment (Wishard 1991). Dominant species included cherrybark oak, sweetgum (*Liquidambar styraciflua* L.), yellow-poplar (*Liriodendron tulipifera* L.), white oak (*Q. alba* L.), and American beech (*Fagus grandifolia* Ehrh.) (table 1). The ten most important species comprised 79 percent of total importance values (table 1). Oaks comprised 43 percent of total importance values. Preharvest basal area averaged 106 square feet per acre with no difference between designated treatments (p=0.4212, fig. 1). Following harvesting, the partial harvest treatments had greater residual basal area than the clearcut treatment (p=0.0153, fig. 1). These basal area values were obtained prior to the injection treatment.

Total reproduction density of all species prior to harvest was 7,070 seedlings per acre. No difference existed between designated treatments in 1989 (p=0.0975, fig. 2). Six years after treatment reproduction density had declined 41 percent across all treatments (p=0.0049 for the time and treatment interaction). A higher density was found in the clearcut treatment compared to the partial harvest treatments (p=0.0126, fig. 2). Eleven years after treatment, reproduction density had declined another nine percent compared to pre-harvest density. No differences were found between treatments (p=0.6086).

**Table 1—Importance values (sum of relative density, relative dominance, and relative frequency) for trees > 5.5 in d.b.h. across three study sites in Warren County, MS**

| Species | Importance value |
|---|---|
| Cherrybark oak (*Quercus pagoda* Raf.) | 69.6 |
| Sweetgum (*Liquidambar styraciflua* L.) | 36.0 |
| Yellow-poplar (*Liriodendron tulipifera* L.) | 25.2 |
| White oak (*Q. alba* L.) | 21.2 |
| American beech (*Fagus grandifolia* Ehrh.) | 20.5 |
| Shumard oak (*Q. shumardii* Buckl.) | 16.2 |
| Bitternut hickory (*Carya cordiformis* (Wangenh.) K. Koch) | 14.5 |
| Water oak (*Q. nigra* L.) | 13.0 |
| White ash (*Fraxinus americana* L.) | 12.2 |
| Sassafras (*Sassafras albidum* (Nutt.) Nees) | 7.2 |

Among oak reproduction, 1,281 seedlings per acre were tallied prior to treatment, or 18 percent of total reproduction. A difference was found between designated treatments with the partial harvest/inject treatment having 41 percent less oak reproduction compared to the other treatments (p=0.0431, fig. 3). Six years after harvesting, oak reproduction density had declined 65 percent (p=0.0001 for time effect) to 443 stems per acre (p=0.9597). A 15 percent increase in oak reproduction was noted 11 years after treatment (p=0.8470, fig. 3).

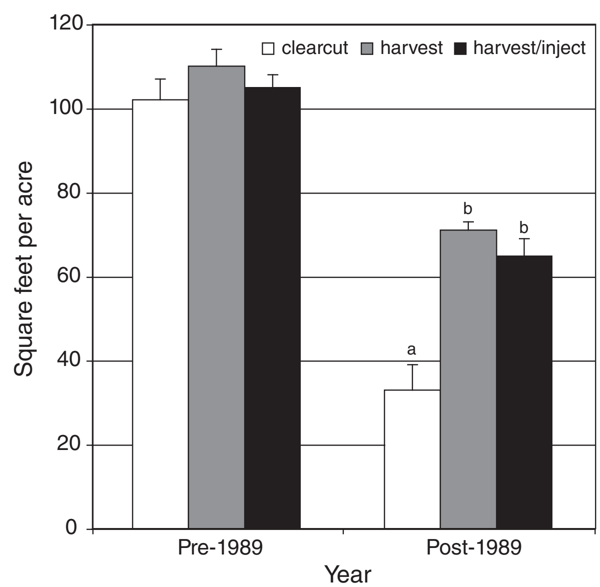


Figure 1—Pre- and post-harvest basal area per acre by treatment in the Bluff Hills, Warren County, MS. Bars represent one standard error. Columns followed by different letters within a year are significantly different at $p \leq 0.05$.

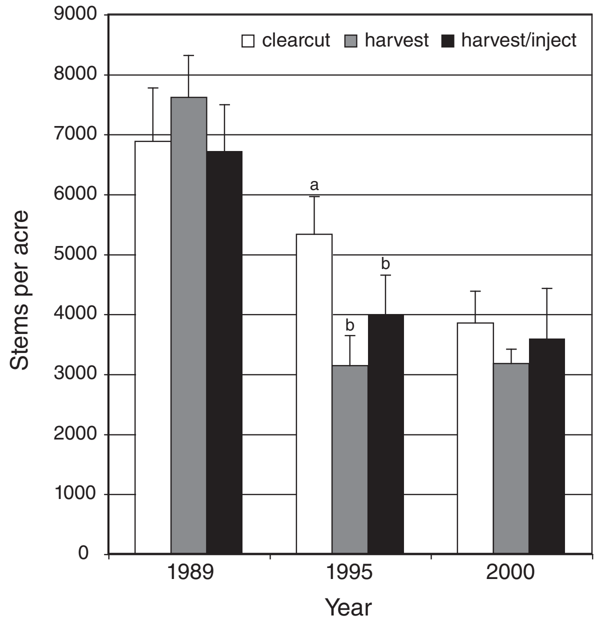


Figure 2—Hardwood reproduction per acre by treatment in the Bluff Hills, Warren County, MS. Bars represent one standard error. Columns followed by different letters within a year are significantly different at p ≤ 0.05.

No differences were found in oak reproduction within each size class between treatments in 1989, 1995, or 2000, due primarily to large variation between treatment means. Therefore, oak reproduction density was pooled among treatments. A majority of oak reproduction existed in the < 1 foot height class (fig. 4, table 2). Eighty-six percent of all oak reproduction was < 1 foot in height in 1989. This percentage decreased to 21 percent by 1995, but increased to 53 percent following the 2000 growing season (p=0.0001 for time effect; table 2). The 269 seedlings per acre < 1 foot in height in 2000 were distributed among the treatments as follows: 8, 54, and 38 percent among the clearcut, partial harvest, and partial harvest/inject treatments, respectively (p=0.0705, fig. 4). Observations in the field indicated that the 1999 growing season produced a bumper acorn crop, resulting in the recruitment of new seedlings into the < 1 foot height class. Higher percentages among the partial harvest/inject and partial harvest treatments was expected, because these treatments maintained a mature oak canopy that provided acorns.

In general, oak density declined with increasing size class and time (table 2). An exception occurred with reproduction > 3 feet tall but < 0.5 inch d.b.h. in 1995 and the largest size class in 2000 (table 2). The increase in oak reproduction in these size classes reflects ingrowth from seedlings in the smaller size classes. The 257 stems per acre in 1995 was also the result of the two larger size classes tallied together (table 2). Noteworthy is the largest percentage of stems for these two densities were found in the clearcuts. Fifty-two percent of the stems >3 feet tall but < 0.5 inch d.b.h. in 1995 were found in the clearcut treatment compared to 29 and 19 percent in the partial harvest/inject and partial harvest treatments, respectively. Likewise, 71 percent of the stems in the largest size class in 2000 were found in the clearcut treatment.

While a larger percentage of oak stems in the 0.5 to 5.5 inch d.b.h. class in 2000 appeared in the clearcut treatment, many of these stems were suppressed. We made an assessment in each clearcut plot as to which tree would likely dominate the plot over time. In most cases, the choice of species was clear. Yellow-poplar dominated in the clearcuts, i.e., it was the dominant species in 81 percent of the plots (table 3). Yellow-poplar was a major component of the stands prior to treatment, although stem numbers were considerably less than were the oaks (table 1). Previous experience with

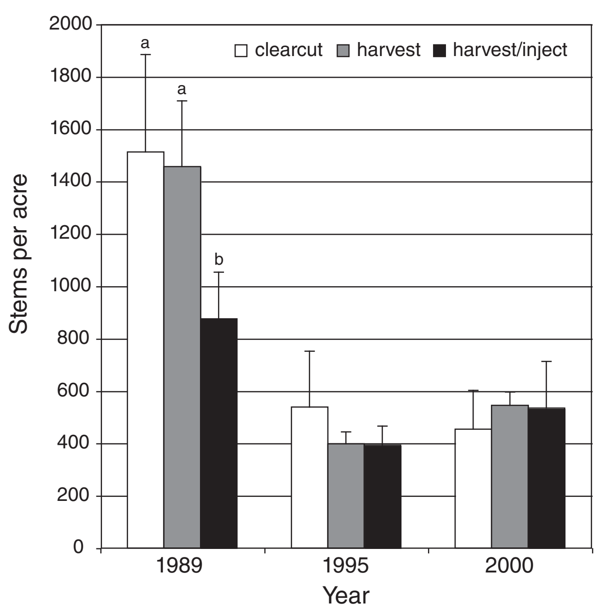


Figure 3—Oak reproduction per acre by treatment in the Bluff Hills, Warren County, MS. Bars represent one standard error. Columns followed by different letters within a year are significantly different at p ≤ 0.05.

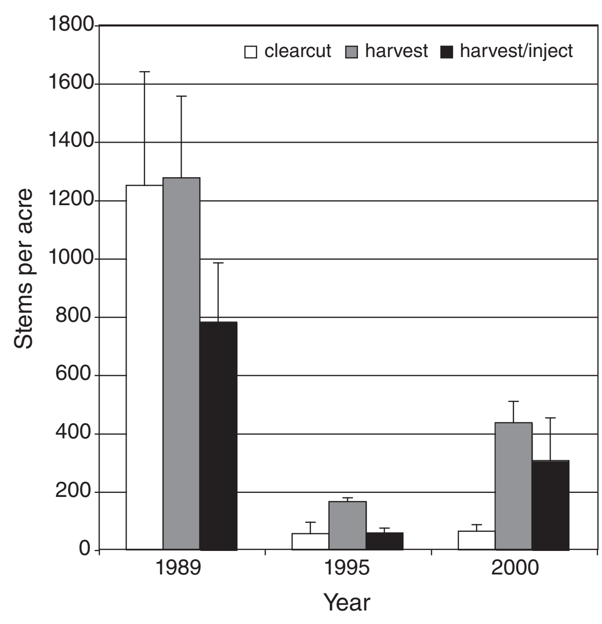


Figure 4—Oak reproduction per acre < 1 foot in height by treatment in the Bluff Hills, Warren County, MS. Bars represent one standard error.

**Table 2–Mean oak reproduction density (stems per acre) by size class for three measurement periods across three study sites in Warren County, MS**

| Size class | 1989 | 1995 | 2000 | p-value for time effect |
|---|---|---|---|---|
| < 1 foot | 1,102 (87) | 93 (22) | 269 (50) | 0.0001 |
| 1 to 3 feet | 120 (9) | 93 (22) | 66 (13) | 0.0845 |
| > 3 feet, < 0.5 in d.b.h. | 49 (4) | 257 (56) | 47 (9) | 0.0001 |
| 0.5 to 5.5 in d.b.h. | 10 (1) | --- | 131 (27) | 0.0009 |
| Total | 1,281 (18) | 443 (11) | 511 (15) | 0.0001 |

Numbers in parentheses represent one standard error of the mean.

yellow-poplar in the southern Appalachians indicates that a few trees in the overstory canopy will provide enough seed to dominate the regeneration pool following clearcut harvest, because its seed remain viable in the seed bank for eight years, and it has the ability to grow rapidly in conditions of high light (Clark and Boyce 1964, Beck and Hooper 1986). Yellow-poplar densities in 1995 were 940, 549, and 117 stems per acre in the clearcut, partial harvest/inject, and partial harvest treatments, respectively—a gradient of decreasing sunlight (fig. 5). Yellow-poplar densities were still > 500 stems per acre after 11 years in the clearcut treatments (fig. 5). Oaks and elms (*Ulmus* spp.) each dominated seven percent of the plots in the clearcuts while white ash (*Fraxinus americana* L.) and sweetgum combined dominated the remaining five percent (table 3). The oak-dominated plots were located on ridge sites. These sites have lower site index compared to slopes and bottoms due to greater erosion, lower soil moisture holding capacity, and greater disturbance from logging equipment.

Using Hart and others (1995) modification of Johnson's (1980) reproduction evaluation technique, 25 percent of the plots in the present study were stocked with oak reproduction prior to harvesting. 41 percent of the clearcut plots were adequately stocked, which is 19 percent less than the recommended 60 percent before a clearcut harvest should be conducted (Johnson and Deen 1993). Adequate stocking increased to 57 percent in the clearcut plots one year following harvesting and remained around 55 percent throughout the study period (fig. 6). While the number of stocked plots remained relatively high, much of this reproduction was suppressed by yellow-poplar.

**Table 3—Dominant tree on clearcut plots 11 years after harvesting across three study sites in Warren County, MS**

| Species | No. plots | Percent | Ridge | Slope | Bottom |
|---|---|---|---|---|---|
| Yellow-poplar | 35 | 81.4 | 5 | 29 | 1 |
| Oaks | 3 | 7.0 | 3 | 0 | 0 |
| American elm | 3 | 7.0 | 0 | 2 | 1 |
| White ash | 1 | 2.3 | 0 | 1 | 0 |
| Sweetgum | 1 | 2.3 | 1 | 0 | 0 |

Partial harvesting nearly doubled the number of stocked plots one year following treatment (25 percent in 1988 to 49 percent in 1990). Stocking remained near 50 percent six years after treatment then fell to 33 percent 11 years after treatment (fig. 6). Stocking was greatly increased by partial harvesting and injection of the shade-tolerant midstory. Initial stocking was only 8 percent, but increased to 38 percent one year after treatment. Stocking then increased to 45 percent six years after treatment before falling to 36 percent in 2000 (fig. 6).

Previous work indicates that disturbance is necessary to sustain oak in southern mixed-species upland hardwood forests (Johnson and others 2002, Loftis 2004). Examples include the Bluff Hills (Goelz and Meadows 1995), Ozarks (Spetich and Graney 2004), Appalachians (Loftis 1985, 1990), and the Cumberland Plateau (Schweitzer 2004). Unfortunately, disturbance alone does not guarantee successful oak regeneration. The degree of disturbance, source of oak reproduction, and the influence of competing

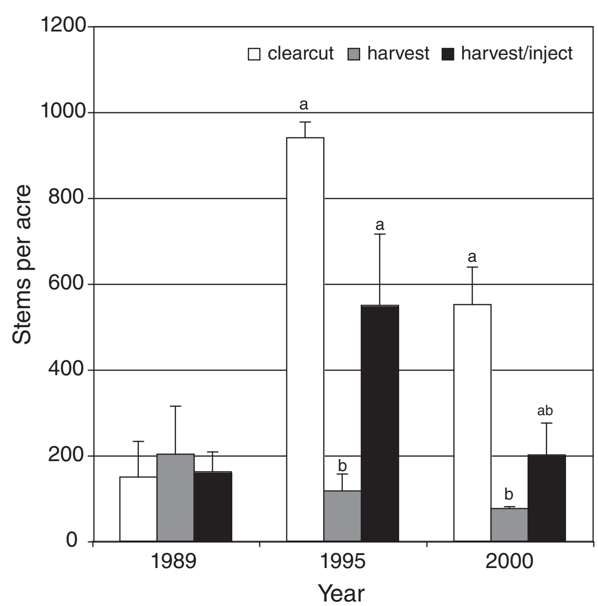


Figure 5—Yellow-poplar reproduction per acre by treatment in the Bluff Hills, Warren County, MS. Bars represent one standard error. Columns followed by different letters within a year are significantly different at p ≤ 0.05.

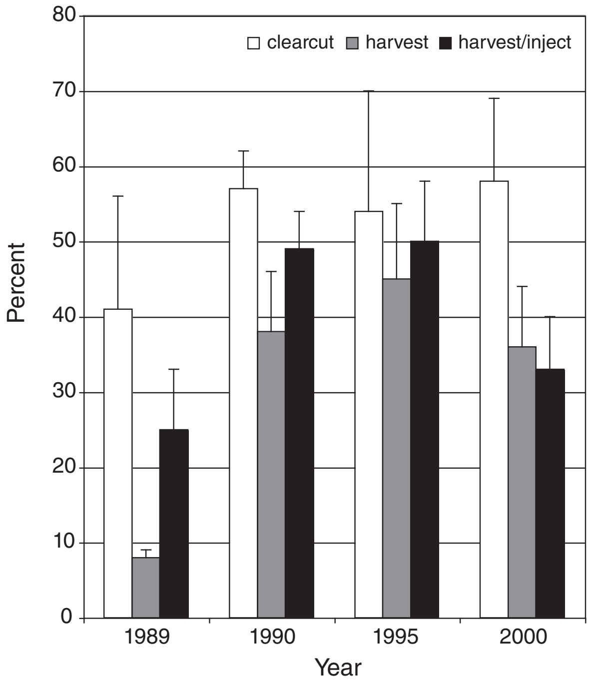


Figure 6—Percent of oak reproduction stocked 0.01-acre plots by treatment in the Bluff Hills, Warren County, MS. Bars represent one standard error.

species are also important factors in successful oak regeneration (Loftis 2004).

In our study, a heavy disturbance, such as clearcutting, in a mixed-species stand with a yellow-poplar component resulted in yellow-poplar dominated stands 11 years after harvesting. The oak composition in these stands after 11 years was significantly reduced relative to their dominance in the previous stand. Similar results were found following clearcutting in southern Appalachian hardwood stands (Beck and Hooper 1986). In the Bluff Hills, yellow-poplar is considered a desirable timber species; therefore, if the management objective includes yellow-poplar and the species is present in the stand, then a heavy disturbance is all that is needed to sustain or even increase the yellow-poplar component. Oak reproduction stocking in the clearcut areas was still relatively high at 58 percent (fig. 6), but much of this reproduction was suppressed by yellow-poplar. Release treatments have been proposed as one way to increase oak seedling or sapling competitiveness when overtopped by competing species, but these treatments have had mixed results (Trimble 1973, 1974, Smith 1983).

The partial harvesting in this study, conducted using Anderson-Tully Company guidelines, does not follow classical regeneration methods. It can probably best be described as an irregular shelterwood with components of single-tree and group selection combined with low and crown thinning. About 1/3 of the basal area was removed during partial harvesting operations. Trees with quality boles and relatively large crowns were maintained in the overstory. Past observations have indicated that desirable reproduction, especially oak, was inconsistent following these partial harvests. Oak reproduction stocking improved following the partial harvest, but still did not reach the minimum 60 percent recommendation before a final removal harvest (Johnson and Deen 1993). Further, the proportion of oak stems compared to total reproduction remained constant, 19 percent prior to harvest and 17 percent 11 years after harvest, but about 1/2 of this reproduction was seedlings < 1 foot in height. We observed in both the partial harvest and partial harvest/inject treatments the presence of many one year old seedlings indicating a recent bumper acorn crop. Many of these seedlings will perish without a follow-up treatment to increase light levels (Crow 1988, 1992). Yellow-poplar reproduction density decreased from 203 stems per acre prior to harvest to 76 stems per acre 11 years after harvest. The shade-tolerant midstory canopy, which was left intact, had a positive effect in reducing the yellow-poplar reproduction density, but concurrently was keeping the oak reproduction from growing into larger height classes.

Partial harvesting combined with injection of midstory stems was designed to further increase light levels reaching advance oak reproduction and the forest floor by removing less-desirable, shade-tolerant species. This treatment is similar to one proposed by Loftis (1990), except partial harvesting was conducted in the overstory canopy. Loftis (1990) proposed a shelterwood method for regenerating red oak in the southern Appalachians that involved reducing basal area by about one-third, but the trees were removed from below using herbicides, leaving the main canopy intact. Loftis (1990) stated this treatment would prevent yellow-poplar from becoming established and growing prior to the final removal cut. In addition, the shade-tolerant midstory would be removed, increasing the light levels reaching advance oak reproduction and may allow for the establishment of new oak reproduction if the treatment coincided with a bumper acorn crop. Lockhart and others (2000) showed that removal of the midstory canopy alone would increase light levels reaching the forest floor from 5 to 10 percent to 40 percent. Loftis (1990) further stated that a final removal harvest could be conducted about 10 years after the initial herbicide treatment.

Oak reproduction stocking apparently improved following the partial harvest treatment. Stocking increased 375 percent one year following treatment, and reached 45 percent stocking six years after treatment before declining to 33 percent stocking 11 years after treatment (fig. 6). Yellow-poplar density also increased following treatment from 162 stems per acre prior to treatment to 549 stems per acre six years after treatment. Yellow-poplar density declined to 201 stems per acre 11 years after treatment ($p=0.0004$ for time effect). Based on Loftis's (1990) findings, the partial harvesting in the overstory, while benefiting oak reproduction, also allowed for the establishment and growth of excessive yellow-poplar. We further observed that a new shade-tolerant midstory canopy was developing 11 years after treatment. These stems came primarily from advance reproduction that was too small to inject at the time of midstory competition control in 1989.

Little research has been conducted regarding silvicultural practices in the Bluff Hills sub-region. This is surprising given the rich soils and high quality hardwoods that can be grown there (Fickle 2001). Much of this land was cleared for agriculture during the late 1800s and early 1900s, before being abandoned due to boll weevil infestations (Fickle 2001).

Forests have succeeded abandoned agricultural land and pastures and, as these forests mature, landowners need information on management options. This is particularly true for regenerating desirable species such as the oaks. The Bluff Hills probably can be considered similar to the higher quality sites found in the southern Appalachians. Results from hardwood research in this region, such as the shelterwood method (Loftis 1990) and prescribed fire (Barnes and Van Lear 1998, Brose and others 1999), may have use in the Bluff Hills, but research is needed to confirm the applicability of these recommendations to the Bluff Hills.


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