RESPONSE OF NATURALLY REGENERATED AND UNDERPLANTED WHITE OAK (*QUERCUS ALBA* L.) SEEDLINGS 6 YEARS FOLLOWING MIDSTORY REMOVAL

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Abstract.—Historically, the abundance of red maple and shade-tolerant understory species was limited by fire and other disturbances. In the absence of periodic disturbance, regeneration of oaks with intermediate shade tolerance has been hindered due to inadequate light conditions created by shade-tolerant midstory trees. Research suggests that midstory removal in oak-dominated forests can create light conditions that enhance the growth of oak advance reproduction. The purpose of this study is to compare the competitive ability of underplanted versus naturally regenerated white oak seedlings under a midstory removal. In 2005, a 0.2-ha midstory removal and control were established at study sites. Seedling heights and basal diameters were measured at treatment establishment and after six growing seasons. Results showed seedling growth was higher under the midstory removal, and height growth of underplanted seedlings was greater than that of advance regeneration. It was also found that diameter growth was greater under the midstory removal; however, there was no difference between seedling types. Findings from this study provide further insight about the dynamics of oak response under a midstory removal and suggest regeneration methods for improving the competitive ability of white oak.

INTRODUCTION

Oak-dominated forests throughout the United States rely on periodic disturbances to regenerate successfully. One historic disturbance was fire. After the arrival of European settlers in the United States, fire was suppressed in most areas (Abrams 2003). Without regular disturbances, shade-tolerant species such as red maple (*Acer rubrum* L.), sugar maple (*A. saccharum* Marsh.), and American beech (*Fagus grandifolia* Ehrh.) became more prevalent (Abrams 1998, 2003). As shade-tolerant trees increase in number, they are able to form dense midstories that inhibit the growth of oaks with intermediate shade tolerance.

One of the challenges for successful oak regeneration is increasing light to favor oaks over shade-tolerant species while also limiting the light to shade-intolerant species such as yellow-poplar (*Liriodendron tulipifera* L.). In various studies conducted in forests dominated by white oak (*Quercus alba* L.), northern red oak (*Q. rubra* L.), and cherrybark oak (*Q. pagoda* Raf.), light levels in unaltered stands have been found to be 2 to 8 percent of full sunlight (Dillaway and Stringer 2006, Gottschalk 1994, Lhotka and Loewenstein 2009) and as low as 1 percent (Dey and Parker 1996). Several studies have suggested that 20 to 30 percent is the optimal light range for developing competitive oak seedlings (Dillaway and Stringer 2006, Gottschalk 1994, Guo et al. 2001, Jarvis 1964, Phares 1971).

The number of oak seedlings present at the time of release is also a major factor in the future success of a stand. Depending on stand condition, it has been suggested that 250 to 1,000 seedlings per ha should be present (Johnson and Jacobs 1981, Sander 1979, Spetich et al. 2004). Sander (1972)

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Table 1.—Absolute and relative density and basal area across all sites before and after midstory removal treatments

Species	Before treatment				After treatment			
	Trees* ha^{-1}	Relative abundance (%)	Basal area (m^2 ha^{-1})	Relative basal area (%)	Trees ha^{-1}	Relative abundance (%)	Basal area (m^2 ha^{-1})	Relative basal area (%)
White oak	109	5.5	21.5	27.4	92	30.6	20.7	32.8
Other oaks	61	3.1	18.2	23.2	54	18.1	18.0	28.7
Maples	1,138	57.5	14.8	18.9	49	16.4	5.9	9.4
American beech	308	15.6	4.8	6.1	8	2.7	3.7	5.9
Hickories	125	6.3	12.8	16.4	68	22.4	10.7	17.0
Black gum	69	3.5	1.9	2.5	13	4.4	1.6	2.6
Ash	38	1.9	1.7	2.2	7	2.2	1.1	1.7
Yellow-poplar	18	0.9	0.8	1.1	3	1.1	0.3	0.4
Other hardwoods	115	5.8	1.8	2.3	7	2.2	0.9	1.5
Total	1,981	100.0	78.3	100.0	301	100.0	62.9	100.0

*Greater than 2.5 cm diameter at breast height (d.b.h.)

also found that seedlings greater than 137 cm were likely in a better position to be recruited to the overstory after release. When forests are not able to attain adequate advance reproduction, underplanted seedlings can be utilized to increase oak abundance (Dey and Parker 1997b, Gardiner and Yeiser 2006, Johnson et al. 1986).

A replicated midstory removal study was established in 2005 to investigate what effect increased light would have on the height and diameter growth of white oak seedlings. The study is of particular interest because limited information is available on how the growth of white oaks is affected when understory light levels are enhanced using midstory removal. This paper reports on the effect of the midstory removal treatment on underplanted and naturally regenerated seedlings following six growing seasons.

STUDY AREAS

Three experimental sites (Water Plant, Pigg House, and Fentress Spur) were established in January 2005 in Berea College Forest. The forest is located in Madison County, Kentucky, which is on the western edge of the northern Cumberland Plateau physiographic region. Each site was dominated by Weikert channery silt loam, a well-drained soil common to the region. At the time of treatment implementation, basal areas of the site ranged from 24.5 to 27.9 m^2 ha^{-1}, and canopies were dominated by white oak, black oak (*Q. velutina* Lam.), chestnut oak (*Q. prinus* L.), and hickories (*Carya* spp. Nutt.). The understory was primarily composed of red maple, sugar maple, and American beech. Relative abundance and initial basal areas of major species before and after the treatment are presented in Table 1.

An analysis of site quality found the mean canopy height to be 27.9 m, and plots had an average site index of 19.5 m at age 50. Complete management data are unavailable, but tree cores taken from the sites suggest that there has been no major disturbance for 100 years.

METHODS

At each site, two areas with similar slope and aspect were chosen. One of these areas was randomly assigned a midstory removal treatment; the other was designated as the control. The midstory removal experimental unit consists of a 0.2-ha square surrounded by a 9.5-m buffer to minimize edge effects. In these areas, 20 percent of initial basal area was removed by chainsaw felling all trees greater than 2.5 cm in diameter at breast height (d.b.h.) and working upward until the target basal area was reached. No dominant or codominant trees were removed in this step. Felled trees were cut into small sections and stacked within the plots to decompose. Small stems and slash were carried outside of plot boundaries. During treatment, cut stumps were sprayed with 100 percent Roundup Pro® (Monsanto Company, St. Louis, MO) to prevent resprouting. The control experimental unit was created by delineating another 0.2-ha square plot in the predetermined area while leaving the midstory intact.

After treatments were established, each experimental unit was divided into 36 squares measuring approximately 7.6 m on each side. Six of these squares were randomly selected to be planted with twelve 1-0 bare-root white oak seedlings. Planting occurred in March 2005. Six more squares were also randomly selected as natural regeneration cells in which every white oak seedling present was measured. The remaining cells were part of another study and not pertinent to this paper. Each individual treatment plot ultimately received 72 underplanted seedlings, resulting in a total of 432 seedlings planted over all plots. There were 174 advance regeneration white oak seedlings over the three control sites and 178 seedlings in the removed treatments for a total sample size of 352 natural white oaks.

Initial measurements for all seedlings were taken before the 2005 growing season. These measurements consisted of total height as well as ground line diameter. In 2010, after six growing seasons, seedling heights and diameters were remeasured. Seedling height was determined by using a meter stick held vertically at the base of the plant and recording the height of the terminal leader. Diameter was recorded using digital calipers. Two perpendicular readings were taken to the nearest 0.1 millimeter at the intersection of the stem and soil. Final seedling diameter was the average of the two perpendicular readings. It should also be noted that when final measurements were taken, there was little to no evidence of damage from deer browsing or other damaging agents.

Growth data were analyzed as a randomized complete block analysis of variance (ANOVA) to test whether height and diameter growth after six growing seasons was significantly different between midstory removal treatments and seedling type (i.e., natural regeneration versus underplanted). The ANOVA model used mean height and diameter growth by experimental unit (i.e., 0.2-ha treatment plot) to avoid pseudoreplication. Site was used as the blocking factor in the ANOVA. The interaction between midstory removal treatment and seedling type was also tested for significance, but was found to have no effect. Percentage of seedling survival after six growing seasons was analyzed using logistic regression to test whether there were differences between treatments and seedling type. All data conformed to assumptions of normality and homogeneity of variance. Significance for tests was set at a value of $\alpha = 0.05$.

Table 2.—Average heights and basal diameters (± SE) of white oak seedlings before and after treatment

	2005		2010	
Dependent variable	Natural regeneration	Underplanted	Natural regeneration	Underplanted
Height (cm)				
Control	9.9 ± 0.42	10.9 ± 0.42	25.5 ± 2.3	40.2 ± 2.0
Removal	9.8 ± 0.43	11.1 ± 0.27	34.1 ± 4.2	53.1 ± 3.3
Diameter (mm)				
Control	2.96 ± 0.11	5.17 ± 0.10	3.10 ± 0.22	5.27 ± 0.33
Removal	3.14 ± 0.13	5.43 ± 0.14	4.56 ± 0.42	6.78 ± 0.30

RESULTS

At the time of establishment, there were no height differences between treatment ($p = 0.88$) or seedling type ($p = 0.23$). Diameters were found to be the same within individual seedling types ($p = 0.42$); however, a difference was noticed between natural versus underplanted seedlings ($p < 0.0001$). Average initial height was found to be 9.9 cm for advance reproduction white oaks and 11.0 cm for underplanted seedlings. Average diameters in 2005 were 3.05 mm and 5.30 mm for advance reproduction and underplanted seedlings, respectively (Table 2).

After six growing seasons, underplanted seedlings in the removal treatment were found to have the highest total height on average (53.1 cm), followed by underplanted white oaks in the control (40.2 cm). Advance regeneration oaks in the removal treatment had an average total height of 34.1 cm, and advance regeneration seedlings in the control had the smallest average height (25.5 cm) (Table 2).

Underplanted seedlings were found to have greater height growth versus advance reproduction seedlings ($p < 0.0001$) six growing seasons following midstory removal. Seedlings in the midstory removals were also found to have grown more, on average, than those in the controls ($p = 0.0002$). Average height growth was found to be greatest for underplanted seedlings under the midstory removal (42.0 cm). Conversely, the least growth was seen among advance reproduction seedlings in the control (15.6 cm) (Table 3).

Diameter growth was found to be significantly different between treatments ($p < 0.0001$), but not between different seedling types in the same treatment ($p = 0.5297$) (Table 3). Among advance reproduction seedlings, average diameter growth was 1.41 mm in the removed treatment versus 0.09 mm in the control. Underplanted seedling diameters in the midstory removal increased an average of 1.65 mm, whereas those in the control increased an average of only 0.10 mm over the six growing seasons.

Analysis of seedling survival found that both treatment ($p < 0.0001$) and seedling type ($p < 0.0001$) were significant predictors of seedling survival; however, there was no significant interaction between factors. Naturally regenerated seedlings had better survival than underplanted seedlings. After six growing seasons, highest overall survival was 93 percent as seen among advance reproduction in the removal treatment. The survival rate of underplanted seedlings in the removal treatment was second highest at 75 percent. A similar pattern was observed within the controls with naturally regenerated seedlings and underplanted seedlings having overall survival rates of 69 and 50 percent, respectively (Table 4).

Table 3.—Average white oak seedling height and diameter growth (± SE) after six growing seasons

Dependent variable	Natural regeneration	Underplanted
Height (cm)		
Control	15.6 ± 2.0 A*	29.2 ± 3.9C
Removal	24.3 ± 1.9 B	42.0 ± 3.4D
Diameter (mm)		
Control	0.09 ± 0.23A	0.10 ± 0.33A
Removal	1.41 ± 0.37B	1.65 ± 0.27B

*Same letters indicate no significant difference between treatments and seedling types at $\alpha = 0.05$.

Table 4.—White oak seedling survival (%) after six growing seasons

	Treatment	
Seedling type	Control	Removal
Natural regeneration	69 A*	93 B
Underplanted	50 C	75 A

*Same letters indicate no significant difference between treatments and seedling types at $\alpha = 0.05$.

DISCUSSION

Studies examining cherrybark oak have found significant yearly height increases of 16 cm for underplanted seedlings (Lhotka and Loewenstein 2009) and 5.5 cm for naturally regenerated seedlings (Lockhart et al. 2000) following a midstory removal. Lhotka and Loewenstein (2009) also found significant diameter growth of 1.9 mm after two growing seasons. Dey and Parker (1997b) found height growth of 13.1 cm for underplanted red oak seedlings 2 years following a shelterwood treatment. This same study also found negligible growth for seedlings planted under intact midstories. Another northern red oak study in Wisconsin found underplanted seedlings were nearly twice as tall 5 years following an understory removal when compared to seedlings in the control (Lorimer et al. 1994). In the same study, seedling height was nearly doubled for naturally grown oaks under a midstory removal.

Although this study examined white oak, results are consistent with previous findings from other species which indicate that underplanted seedlings perform better when under a midstory removal. As with Lorimer et al. (1994), underplanted seedlings exhibited increased growth compared to naturally regenerated oaks. These results suggest that, for white oak-dominated sites of the Appalachian Mountains, underplanting may be a viable option for increasing the number of vigorous seedlings prior to release.

The success of the underplanted seedlings over natural seedlings may be a result of initial stem diameter. Although heights of both seedling types were not significantly different at inception, the diameters of underplanted seedlings were larger. Dey and Parker (1997a) found initial stem diameter to be the best indicator of the success of underplanted red oak seedlings as this relates to root size and carbohydrate stores. It has been suggested that, for northern red oaks, seedling stock should be no less than 9.5 mm (Johnson et al. 1986). Initial diameters for planted oaks in this study averaged 5.2 mm, but no information is available for white oaks on the relationship between initial basal diameter and long-term success.

Diameter growth after 6 years illustrates the ability of the intact midstory to limit growth. Minimal diameter increase under a midstory was also seen by Dey and Parker (1997b). In the control treatment of our study, both underplanted and natural seedlings experienced an average yearly increase of only 0.02 mm. Significant diameter growth was seen in the removal treatment, where white oak diameters showed more than a tenfold increase. This result underscores the importance of maintaining adequate light levels during seedling development. Because initial diameters of naturally regenerated seedlings in this study were generally small, future studies should attempt to assess the response of advance regeneration white oak seedlings that have larger diameters at the time of treatment.

In terms of height growth, oaks planted in the midstory removal grew an average of 7.0 cm each year, which is similar to that seen with northern red oak (Lorimer et al. 1994). To reach the height of 137 cm as suggested by Sander (1972) for competitive seedlings at the time of final release, the oaks from this study would require 13 more growing seasons at the current growth rate. Planting more developed seedlings and increasing initial light levels may be the best approach for effectively regenerating similar stands.

One option for increasing growth rates would be to use older seedling stock such as 2-0 bare-root or containerized seedlings. These plants should have larger initial root systems that are more vigorous and could speed early growth (Dey and Parker 1997a, Jacobs et al. 2005). Increasing the initial light levels through the removal of more basal area may also speed the growth of white oak seedlings. Given the site index of the experimental units, Loftis (1990) and Spetich et al. (2004) would suggest a 40- to 60-percent reduction in initial basal area, whereas this study eliminated only 20 percent of basal area. Achieving the suggested reduction in basal area would mean potentially removing trees occupying a dominant or codominant canopy position.

Proper timing of the initial midstory removal and final release should not be overlooked (Loftis 1990). Tolerant species also respond favorably to increased understory light levels (Clinton et al. 1994), so the final harvest should be performed when enough oak seedlings have reached a competitive size, but before oak seedlings become overtopped by shade-tolerant species. Loftis (1990) suggests that the final harvest should be completed approximately 10 years following midstory removal; however, exact timing for a final release is dependent upon site conditions, species silvics, and other environmental factors.

CONCLUSIONS

Few studies have looked at the effect of a midstory removal on the growth and vigor of white oak seedlings. Results after six growing seasons show that the midstory removal significantly increased the height and diameter growth of seedlings. Greatest height and diameter growth was observed among oak seedlings planted under a midstory removal, suggesting that artificial regeneration is a worthwhile practice for increasing the number of vigorous seedlings before a final harvest. The minimal diameter growth exhibited by seedlings under an intact midstory also suggests that, for best growth in both height and diameter, forest managers should plant seedlings immediately after the midstory removal.

When underplanted seedlings are used, survival should also be considered. Although underplanted seedlings were shown to grow faster than natural seedlings, they had a lower survival rate. This result suggests that underplanted seedlings should be used along with natural regeneration to achieve necessary seedling densities.

Despite the significantly higher height and diameter growth of underplanted seedlings under the midstory removal, seedlings have not reached the recommended height for release. Additional research on whether larger bare-root or containerized seedlings can improve early growth and survival of white oak underplanted after midstory removal is warranted.

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