EFFECTS OF MIDSTORY REMOVAL ON UNDERPLANTED BLACK OAK AND WHITE OAK IN THE WESTERN CUMBERLAND PLATEAU

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Abstract.—Difficulties in successful oak regeneration have led to the examination of various techniques to increase oak recruitment. To ensure sufficient regeneration, oak seedlings can be underplanted and used in conjunction with intermediate treatments, such as midstory removal, that create a light environment favorable to oak advance reproduction. This study examines the 5-year response of underplanted white oak (*Quercus alba* L.) and black oak (*Quercus velutina* L.) seedlings to a midstory removal on intermediate sites within the western edge of the Cumberland Plateau. Three sites were established and split to provide an area where the midstory remained intact and an area where the midstory was removed. At each site, white and black oak 1-0 bareroot seedlings were underplanted. Midstory removal treatments removed 13 to 19 percent of the basal area in treated units. Seedling height, ground line diameter, and survival status were measured at the time of treatment implementation (spring 2004) and after five growing seasons. Fifth-year survival of white and black oaks under an intact midstory was 51 and 14 percent, respectively. Under removed midstories, white oak survival averaged 81 percent while black oak averaged 32 percent. Midstory removal increased diameter growth for both underplanted white and black oaks. Treatments did not affect seedling height growth of either species. The ground line diameter growth response is consistent with known patterns of oak carbon allocation favoring development of root systems prior to height growth, indicating increased aboveground growth potential.

INTRODUCTION

Periodic disturbances maintained oak-dominated forests of the eastern United States prior to European settlement (Abrams 1992, Brose and others 2001, Nowacki and Abrams 2008). Due to the alteration of historical disturbance regimes, dense midstory canopies of shade-tolerant species such as sugar maple (*Acer saccharum* Marsh.), red maple (*A. rubrum* L.), and American beech (*Fagus grandifolia* Ehrh.) have developed across the eastern hardwood region (Lorimer 1984, Goebel and Hix 1997, Fei and Steiner 2007, Oswalt and others 2008). Understory environmental conditions associated with dense midstory canopies has led to a decline in oak seedling development (Nowacki and others 1990, Lorimer and others 1994, Lockhart and others 2000).

Successful regeneration of oak in the eastern United States has been difficult due to the absence of large advance reproduction (Smith 1993, Lorimer and others 1994, Brose and others 1999). Underplanting can enhance the abundance of oak reproduction, but underplanted seedling development is fundamentally linked

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to the understory microenvironment. Lorimer and others (1994) found light intensities as low as 1 percent full light under developed midstory canopies. Although oaks have intermediate shade tolerance, extended periods without adequate light can result in mortality and loss of vigor (Dey and Parker 1997).

Light levels greater than 20 percent full light may increase growth under forest canopies for some oak species (Gottschalk 1994, Guo and others 2001, Dillaway and Stringer 2006). Midstory removal can create a favorable light environment and enhance recruitment of desired oaks into the overstory (Dey and others 2008). Underplanting and midstory removal have been suggested as an approach to increase advance reproduction in stands lacking sufficient natural seedling densities. Previous studies have focused on highly productive sites with cherrybark oak (*Quercus pagoda* Raf.) (Lockhart and others 2000, Lhotka and Lowenstein 2009) and northern red oak (*Q. rubra* L.) (Loftis 1990, Miller and others 2004). Understanding of how white (*Q. alba* L.) and black oaks (*Q. velutina* L.) respond to these treatments on intermediate-quality sites is limited.

Dillaway and others (2007) initiated a study to evaluate the effects of midstory removal on underplanted white and black oak in 2004. The objective of this paper is to quantify these effects five growing seasons following this treatment.

STUDY AREA

Study sites were located on Berea College Forest in Madison County, KY, and are part of the western rim of the Cumberland Plateau. Three stands of intermediate quality were used: Horse Cove, Water Plant, and Pigg House. Horse Cove is a southeast-facing site with a white oak site index (base age 50 yr) of 22 m, and, at the time of treatment, had a mean dominant tree age of 90 years and 28.0 m^2/ha basal area. The Water Plant site has an east aspect and site index of 23 m; it had a mean dominant tree age at time of treatment of 94 years and basal area of 23.7 m^2/ha. The third site, Pigg House, faces west, has a site index of 24 m, and had a basal area of 26.0 m^2/ha; dominant trees averaged 116 years old at the time of treatment. At all sites, mixed oaks and American beech dominated the overstories while red maple and sugar maple were primary components of the midstory.

METHODS

Within each site, a 0.2-ha area was divided into two 0.1-ha experimental units. Experimental units were randomly assigned one of two treatments: midstory removal or undisturbed control. The midstory removal treatment targeted removal of approximately 20 percent of the total stand basal area. Removals using cut stump treatment with glyphosate started with trees 2.5 cm diameter at breast height (d.b.h.) and progressively moved through increasing size classes until the targeted 20 percent of total basal area was removed or until midstory was completely removed. Treatment retained all dominant and co-dominant trees.

Removed basal area and diameter distribution of removed stems varied among sites due to different stand structures. Removed stems were classified as small (d.b.h. 2.5 to 12.7 cm) and large (d.b.h. 12.7 to 25.4 cm). At Horse Cove, removal of 1.3 m^2/ha basal area of small stems and 4.1 m^2/ha of large stems amounted to a 19-percent removal of the total basal area. Pigg House had 2.2 m^2/ha of small stems and 1.0 m^2/ha of large stems removed, resulting in a removal of 17 percent of the total basal area. The Water Plant site had 14 percent of the total basal area removed; small stems accounted for 1.3 m^2/ha and large stems accounted for 4.1 m^2/ha.

Within each experimental unit, black and white oak 1-0 bareroot seedlings were planted in March 2004. Black and white oak seedling sample sizes varied among experimental units, ranging from 50 to 65 per unit. Initial seedling ground line diameters (gld) and heights were recorded at planting and seedlings were tagged to facilitate long-term monitoring (Dillaway and Stringer 2007).

Seedling height, gld, and survival were reevaluated following five growing seasons (August 2008). Seedling heights were measured with a meter stick held perpendicular to the ground. Tallest shoot height was rounded to the nearest 0.1 cm. Glds were measured at the convergence of the stem and ground using the average of two perpendicular measurements made with digital calipers. Seedlings possessing visible living tissue were considered alive. Average height, gld, and percent survival were calculated for each experimental unit by species. Two-way ANOVA (SAS Institute Inc., Cary, NC) was used to assess the effects of midstory removal treatment and species on 5-year height and diameter growth using site as a blocking variable and an alpha = 0.05. Residual analysis confirmed statistical assumptions of normality and homogeneity of variance were met. Survival data were analyzed using a generalized linear model assuming binomial distribution with a logit link function (SAS Institute Inc.).

RESULTS

Initial seedling gld and height were similar between treatments for both black and white oaks ($p > 0.05$) (Table 1). Black oak seedlings averaged 31.3 cm in height and mean gld was 6.2 mm. White oak heights averaged 24.6 cm, and gld averaged 5.9 mm.

Midstory treatment increased gld growth of black oak ($p = 0.0005$) and white oak ($p = 0.0041$). After five growing seasons, black oak gld growth averaged 0.4 mm in the control and 2.2 mm in the midstory removal treatment while white oak gld growth was 0.6 mm in the control and 1.9 mm under midstory removal. Gld growth was not different between species within treatments ($p < 0.05$). Midstory removal had no effect on height growth of black oaks ($p = 0.1287$) or white oaks ($p = 0.5855$). Height growth for black oaks averaged 1.8 cm in the control and 13.2 cm in the removal treatment (Table 2). White oaks had an average height growth of 7.4 cm in the control and 11.1 cm in the removal treatment. Height growth did not differ between species.

Table 1.—Initial seedling height and diameter (mean ± standard error) of black and white oak underplanted in the western Cumberland Plateau.

Dependent variable	Black oak	White oak
Seedling diameter (mm)		
Control	6.1 ± 0.1 ^{a*}	6.1 ± 0.5 ^{a}
Removal	6.2 ± 0.1 ^{a}	5.7 ± 0.2 ^{a}
Seedling height (mm)		
Control	30.8 ± 1.6 ^{a}	24.9 ± 1.0 ^{b}
Removal	31.8 ± 0.8 ^{a}	24.3 ± 0.4 ^{b}

* Numbers followed by the same superscript letters indicate no significant difference (α = 0.05) between treatments and species.

Table 2.—Seedling measurements (mean ± standard error) of white and black oaks underplanted in the western Cumberland Plateau after five growing seasons.

Dependent variable	Black oak	White oak
Survival (%)		
Control	14 ± 1 ^{a*}	51 ± 15 ^{c}
Removal	32 ± 1 ^{b}	81 ± 6 ^{d}
Diameter growth (mm)		
Control	0.4 ± 0.3 ^{a}	0.6 ± 0.2 ^{a}
Removal	2.2 ± 0.2 ^{b}	1.9 ± 0.2 ^{b}
Height growth (cm)		
Control	1.8 ± 4.7 ^{a}	7.4 ± 3.3 ^{a}
Removal	13.2 ± 8.9 ^{a}	11.1 ± 3.1 ^{a}

* Numbers followed by the same superscript letters indicate no significant difference (α = 0.05) between treatments and species.

Black oak survival was increased by treatments ($p < .001$); survival averaged 32 percent under midstory removal treatments and 14 percent in the control. Survival of white oak was also higher in the midstory treatments ($p < .001$), averaging 81-percent survival compared to 51 percent in the control. White oak survival was greater ($p < 0.05$) than black oak in both treatments.

DISCUSSION

The midstory removal treatment applied in this study increased gld growth and survival of underplanted white oak and black oak seedlings. Seedling gld growth was 450 and 217 percent higher in the midstory removal treatment than the controls for black oak and white oak, respectively. White and black oak survival in the midstory removal treatment was approximately 30 and 18 percent higher, respectively. These results follow the trend seen in previous studies that focused on northern red oak (Loftis 1990, Miller and others 2004) and cherrybark oak (Lockhart and others 2000, Lhotka and Loewenstein 2009) seedlings under midstory and shelterwood treatments. It is reasonable to suggest that the improved gld under the midstory removal is resulting in increased root biomass and potentially improved carbohydrate stores in these seedlings (Dillaway and others 2007). Diameter is also a key indicator of seedling ability to support growth after release (Sander and others 1984).

Increased height growth has been observed under shelterwood and midstory removal treatments in previous studies that looked at artificial and natural regeneration of northern red oak (Loftis 1990, Miller and others 2004) and cherrybark oak (Lockhart and others 2000, Lhotka and Loewenstein 2009). In our study, 5-year height growth of white and black oak was not increased by midstory treatment. This outcome could be attributed to factors such as transplant shock generally associated with post-planting moisture and/or nutrient stress (Pope 1993) or a lag time in seedling response to midstory removal as seen by Lockhart and others (2000). Observed growth rates for white and black oak may also reflect carbon allocation patterns associated with oak species, which possess a more conservative growth strategy (Johnson and others 2002), or favored root growth over height growth on intermediate-quality sites where soil moisture may be limiting (Kolb and others 1990).

Research involving northern red oak (Loftis 1990) and cherrybark oak (Lockhart and others 2000) on highly productive sites suggests that midstory removal should precede overstory removal by 7 to 10 years so that oak reproduction can reach a competitive size prior to release. The minimum height for successful release of oak is generally considered to be 1.37 m (Sander 1972). If our observed growth rates continue, average seedling height after 10 growing seasons would be approximately 58 cm for black oaks and 46 cm for white oaks. These data suggest that underplanted white and black oak seedlings on intermediate- quality sites similar to our experimental area may require more time to reach competitive heights following midstory removal than other oak species found on more productive sites. Perhaps seedling height growth rates in our study may have improved if a small percent of the overstory basal area were removed in conjunction with the midstory removal to increase light availability (Loftis 1990).

Increases in seedling gld growth and survival for black oak and white oak indicate that the midstory removal treatment had a positive effect on the underplanted seedlings through five growing seasons. Increased seedling diameter under midstory removal treatment suggests seedlings will have a greater height growth potential in future growing seasons. Continued monitoring of seedlings will help provide insight into the long-term effectiveness of this treatment in improving underplanted black and white oak growth and survival on intermediate-quality sites.

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