SURVIVAL AND GROWTH OF UNDERPLANTED NORTHERN RED OAK ON MESIC SITES IN EASTERN TENNESSEE: TWO-YEAR RESULTS

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Abstract—As part of a replicated oak regeneration study initiated at the University of Tennessee's Oak Ridge Forestry Experiment Station, 180 northern red oak (*Quercus rubra* L.) seedlings were allocated equally among three no-cut control stands, which provided an opportunity to chart the survival and growth of understory planted oak seedlings across several growing seasons (2002 and 2003). Seedling survival decreased from 58 percent in 2002 to 43 percent in 2003, while average seedling growth dropped from 15.42 cm in 2002 to –8.52 cm in 2003. Logistic regression found that first-year survival was related to three initial seedling attributes: shoot length, root collar diameter, and number of first-order lateral roots. Two-year survival was significantly related to shoot length ($p<0.05$). The only significant relationship found for growth was between first-year growth and shoot length with $R^2=0.29$ and a $p<0.0001$. An exploratory analysis on a subset of seedlings (n=30) relating survival and growth to neighborhood structure found overstory and understory structure to have significant effects on first-year survival, while only overstory structure had an effect on first-year growth and 2-year survival.

INTRODUCTION

Regenerating oak on mesic sites may require foresters to adopt a more pluralistic approach. The success of traditional prescriptions for regenerating oak, like the shelterwood method, are contingent on the presence of large advance reproduction prior to harvest. This assumption is often violated on mesic sites, where oak saplings are conspicuously absent from the understory. Artificial regeneration can partially offset the problem of regenerating oak on mesic sites by bolstering oak density in the understory but may require other silvicultural treatments in order to be successful. Planting oak in conjunction with cutting is a promising composite method that simultaneously increases the abundance of oak reproduction while creating a more favorable light environment for new oak development.

A critical decision is whether to plant before or after harvest. There are advantages and disadvantages associated with pre-harvest and post-harvest planting that should be considered. The pre-harvest option avoids planting in and around logging residue; however, seedlings are likely to experience logging-related damage during harvest (Olson and others 2004). Although seedlings start in a high light environment when planted after harvest, environmental fluctuations associated with open conditions can stress seedlings during acclimation from nursery to field conditions. Another issue with planting is the timing between planting and cutting. In the case of pre-harvest planting, waiting too long to harvest can lead to low survivorship, eliminating seedlings before they have a chance to restock the new stand.

The primary objective of this study was to document 2 years of survival and growth of planted northern red oak in the understories of mesic, closed canopy stands. A second objective was to relate planted seedling survival and growth to neighborhood structure.

STUDY SITES

Study sites are located at the University of Tennessee's Forestry Experiment Station in Oak Ridge, TN. The experiment station is in the Ridge and Valley Physiographic Province. Soils underlying the study sites are classified as variants of the Fullerton series, which are Typic Paleudults derived in cherty, dolomitic limestone residuum (Moneymaker 1981). This area supports a mixed-species assemblage typical of the southern portion of the Central Hardwood Region, composed primarily of upland oak species (*Quercus* spp.), yellow poplar (*Liriodendron tulipifera* L.), red and sugar maple (*Acer rubrum* L. and *A. saccahrum* Marsh., respectively), hickory species (*Carya* spp.), and miscellaneous hardwoods.

METHODS

Study Background and Design

This research is based on a larger harvest/regeneration study evaluating natural and artificial regeneration. The original experiment was a randomized block design, because of inherent topographic and edaphic variability of the study site. The harvest treatment consisted of five levels of overstory removal and a no-cut control, which were replicated three times.

Seedlings used were 1-0 bare-root northern red oak grown in 2001 at the Flint River Nursery, GA. In April, 2002, a total of 1,080 seedlings were planted with shovels. Sixty seedlings were planted in each overstory treatment unit on a spacing of 20 feet by 20 feet. This study focuses on the survival and growth of underplanted northern red oak in the three control units.

Data Collection

All 180 seedlings in control units were visited at the end of the 2002 and 2003 growing seasons to determine survival and measure height growth. Survival was determined by identifying new twigs with fresh buds and leaf scars. Growth was derived by measuring shoot length and subtracting this value from the initial shoot length measure made prior to planting in 2002.

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The exploratory analysis relating neighborhood structure to survival and growth was based on 10 seedlings selected in each of the 3 control units (n=30). The neighborhood of each seedling was delineated and quantified using the point-quarter method with the planted seedling acting as plot center. Neighboring vegetation was tallied separately into overstory ($\geq$ 5 cm d.b.h.) and understory (> 1.4 m tall, < 5 cm d.b.h.) categories according to size. The distance from plot center and d.b.h. of neighboring vegetation were recorded, which were used to derive basal area and stem density values.

Statistical Analysis

Methods—All analyses relating planted seedling survival and growth to initial seedling attributes and neighborhood structure were performed using logistic and simple linear regression, respectively, with SAS software. All testing was performed at the 5 percent level.

Variables—The variables used to represent initial seedling attributes were shoot length (SL), root-collar diameter (RCD), and number of first-order lateral roots (FOLR), which were measured prior to planting in 2002. Total basal area (BA), density (Den), and basal area of nearest neighbor (BA-NN) were calculated for both understory and overstory neighborhood components. The basal area and density of overstory and understory were combined to get a total basal area (TBA) and density (TDen).

RESULTS

Overall Survival and Growth

First-year and 2-year survival of planted oak seedlings was 58 percent and 43 percent, respectively. Shoot growth averaged 15.42 cm in the first year and -8.52 cm after 2 years.

Seedling Attributes and Survival and Growth

Significant relationships between first-year survival and all seedling attributes were detected according to logistic regression (table 1). In all three models, slopes were positive, suggesting positive relationships between seedling attributes and first-year survival. The only significant explanatory variable of 2-year survival was shoot length. Once again, the relationship between survival and shoot length after 2 years was positive. The low R^2-values make interpretability more tenuous; however, a pattern of low R^2-values is typical of logistic regression (Saxton 2002). After the second growing season (2003), the only significant attribute-related growth trend was a negative relationship with shoot length yielding an R^2 of 0.29 (table 1).

Neighborhood Effects

The average total density and basal area of seedling neighborhoods were 1,892.8 stems/ha and 0.49 m^2, respectively. For overstory neighborhood (stems $\geq$ 5 cm d.b.h.), average density, basal area, and basal area of nearest neighbor were 428.7 stems/ha, 0.45 m^2, and 0.15 m^2, respectively. For the understory (stems < 5 cm d.b.h.), neighborhood structure consisted of an average density of 1,464.1 stems/ha, average basal area of 0.03 m^2, and an average nearest neighbor basal area of 0.005 m^2.

First-year survival was significantly related to overstory density, understory density, total density, and basal area of overstory nearest neighbor (table 2). In all cases, first-year survival response to these factors was negative. Only basal area of nearest neighbor in the overstory was a significant predictor of 2-year survival, which also yielded a negative relationship.

The only significant growth responses detected were between first-year growth and overstory basal area (R^2 = 0.43) and total basal area (R^2 = 0.35).

DISCUSSION

Overall, the pattern of survival and growth after 2 years indicated that seedling condition was on the decline. The drop in survival from 58 percent after the first growing season to 43 percent after 2 years suggests that conditions in the understory are likely having a negative effect on planted oak seedlings. Further evidence of poor understory response is the shift from growth in the first season (15.42 cm) to dieback (-8.52 cm) during the second. Although Dey and Parker (1997) observed 90 percent survival in a similar study, they found growth of underplanted red oak after 2 years was negligible to negative. The observation of shoot growth during the first year is deceiving without any indication of shoot vigor, since many of the seedlings exhibited etiolated growth. Etiolated growth is a compensatory response to a limiting light environment and,

Table 1—Regression results of 1-year and 2-year survival and growth of underplanted northern red oak predicted by 3 initial seedling attributes: shoot length (SL), root-collar diameter (RCD), and number of first-order lateral roots (FOLR). The values shown from left to right are: R-square, p-value in parentheses, and slope sign for significant relationships only

	Initial seedling attribute		
Response	SL	RCD	FOLR
Survival			
1-year	0.09 (0.001) +	0.03 (0.04) +	0.12 (<0.0001) +
2-year	0.11 (0.005) +	0.02 (0.35)	0.09 (0.06)
Growth			
1-year	0.29 (<0.0001) -	0.003 (0.63)	0.035 (0.1)
2-year	0.05 (0.07)	0.017 (0.25)	0.04 (0.09)

Table 2—Regression results of 1-year and 2-year survival and growth of underplanted northern red oak predicted from 3 overstory, understory and combined overstory and understory structural attributes. For overstory and understory, basal area (BA), density (Den), and basal area of the nearest neighbor (BA-NN) were used. The combined analysis used total basal area (TBA) and total density (Tden). The values shown from left to right are: R-square, p-value in parentheses, and slope sign for significant relationships only

		Neighborhood attribute		
	Response	BA	Den	BA-NN
Overstory	Survival			
	1-year	0.037 (0.31)	0.1 (0.03) -	0.13 (0.02) -
	2-year	0.018 (0.43)	0.032 (0.085)	0.11 (0.034) -
	Growth			
	1-year	0.43 (0.002) -	0.09 (0.26)	0.0007 (0.9)
	2-year	0.009 (0.72)	0.0004 (0.94)	0.02 (0.6)
Understory	Survival			
	1-year	0.08 (0.056)	0.18 (0.02) -	0.05 (0.15)
	2-year	0.032 (0.32)	0.09 (0.054)	0.01 (0.47)
	Growth			
	1-year	0.1 (0.17)	0.022 (0.53)	0.07 (0.27)
	2-year	0.03 (0.54)	0.003 (0.85)	0.002 (0.86)
		TBA	TDen	
Total	Survival			
	1-year	0.004 (0.23)	0.14 (0.026) -	
	2-year	0.02 (0.38)	0.043 (0.07)	
	Growth			
	1-year	0.35 (0.007) -	0.07 (0.3)	
	2-year	0.005 (0.78)	0.002 (0.9)	

therefore, is symptomatic of poor light conditions (Taiz and Zeiger 1998). This suggests that planted oaks were light-limited. However, the effect of light on oak seedling survival and growth in this study is speculative without any measure of light to test these relationships.

The positive relationships between all seedling attributes and first-year survival represents a pattern of improved survival for the larger outplanted seedlings. If this survivorship pattern holds true, then one way to increase the success of planting northern red oak would be to select only the largest seedlings. However, the negative relationship between first-year growth and shoot length suggests that larger seedlings grew less than smaller seedlings during the first year. A combination of increasing survival and diminishing growth with increasing seedling size during the first growing season represents a survival-growth trade-off. According to the survival-growth trade-off, underplanting smaller seedlings will lead to increased growth but lower survival. Conversely, a higher proportion of large seedlings are expected to survive to year 2, yet will add less growth during the first growing season.

Neighborhood analysis revealed that both overstory and understory factors had a significant impact on survival of planted northern red oak in the first year. The literature on oak recruitment failure is replete with examples suggesting understory competition is a primary limiting factor (Abrams 1992, Lorimer 1994). This study illustrates that the understory environment is partly a product of overstory structure and, therefore, overstory attributes affect the performance of plants in the understory. Canham and Burbank (1994) found resource availability varied spatially beneath multi-species canopies and that resource heterogeneity corresponded with variation in overstory structure and composition. Although only neighborhood structure was evaluated in this study, it is plausible that planted oak performance was influenced by neighborhood composition in the diverse mixed-species stands sampled.

A consistent trend across all analyses of survival and growth was deterioration of relationships by the end of 2 years. This observation, along with the result of low survival and seedling dieback, suggests that underplanted northern red oak seedlings are declining irrespective of seedling attributes and stand conditions. If current trends continue, there will not be a reliable component of planted oak to restock larger size classes in the future.

SILVICULTURAL IMPLICATIONS

If enrichment planting is to be used to establish and develop oak reproduction in stands similar to those included in this study, then underplanting without further treatment may not be the best option. A cutting restricted to the smaller diameter classes in a manner reminiscent of a thinning-from-below or low thinning may admit adequate light for understory oak growth, while retaining enough overwood to prevent the development of shade-intolerant competition, such as yellow poplar (Loftis 1990). Harvesting after underplanting, however, is not a perfect remedy. Olson and others (2004) found that harvest-induced damage to seedlings, whether complete or partial cutting, was severe enough to diminish or decimate oak planting stock. Therefore, the viability of pre-harvest planting needs to be weighed against the post-harvest option in order to determine the planting strategy best suited for a particular situation.

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