MODELING 9-YEAR SURVIVAL OF OAK ADVANCE REGENERATION UNDER SHELTERWOOD OVERSTORIES

Martin A. Spetich and David L. Graney[1]

Abstract—Survival of white oak (*Quercus alba* L.), northern red oak (*Q. rubra* L.), and black oak (*Q. velutina* Lam.) on upland oak stands was modeled 9 years after shelterwood treatment. Stands represented a range of site quality, overstory stocking, and understory treatments. There were three levels of understory treatment and two levels of shelterwood treatment for a total of six overstory-understory treatment combinations. Understory treatment consisted of (1) removal of all competing woody stems < 1.6 inches diameter at breast height, (2) removal of this diameter range of stems but only those that were ≥ 5 feet tall, and (3) no understory treatment. Overstory shelterwood treatments were 40 and 60 percent residual stocking. We used logistic regression to model survival of advance regeneration 9 years after understory and overstory treatments. Results were expressed as survival probabilities. Significant predictors of survival included initial seedling basal diameter, percent residual stocking of the shelterwood treatment, site index, and the number of terminal bud scale scars of the seedling prior to treatment.

INTRODUCTION

Upland hardwood stands in the Boston Mountains of northern Arkansas can have more than 1,000 stems per acre of oak advance reproduction (Graney 1989), but most stems are < 1 foot tall. Many of these stands are mature and fully stocked and have well-developed understories of shade-tolerant species. Given the size and status of existing reproduction, new stands that develop after a harvest often contain a low proportion of oaks. To help restore oak to this ecosystem, stimulating the survival and growth of this small advance reproduction is often a priority of forest management plans in the Ozark Highlands.

Oaks are important to wildlife and, in turn, to forest energetics. Wildlife species that utilize oak mast include white-tailed deer (*Odocoileus virginianus*); black bear (*Ursus americanus*); turkey (*Meleagris gallopavo*); blue jays (*Cyanocitta cristata*); squirrels (*Tamiasciurus* spp., *Sciurus* spp., and others); and mice (*Peromyscus* spp.). For instance, a study by Harlow (1975) found that acorns made up an average of 76 percent of the diet of white-tailed deer during November and early December. Fluctuations in wildlife populations often follow fluctuations in oak mast production (McShea and Schwede 1993, Nixon and others 1975, Wentworth and others 1990). Major declines in oak populations could also lead to declines in the populations of associated wildlife species where alternative resources are not available.

In this study, we introduce the use of the number of terminal bud scale scars as one predictor of survival of oak advance reproduction. Terminal bud scale scars are formed during a shoot resting phase that occurs after the first flush of shoot growth. Under good growing conditions, such as direct sunlight and frequent rainfall, a second flush of growth would begin from this bud (Johnson and others 2002). However, under the typically dense forest canopies and normally hot and dry summers of the Boston Mountains, there is rarely more than one flush each year.

Understanding how to predict successful survival of oak advance regeneration will allow managers to more effectively restore this valuable resource to the landscape. The objectives of this paper are to (1) identify predictors of survival of oak advance reproduction during the first 9 years under shelterwood conditions, and (2) provide survival models based on this information.

STUDY SITES

The study sites were located in the Boston Mountains of Arkansas, part of the southern lobe of the central hardwood region (Merritt 1980). The Boston Mountains are the highest and most southern feature of the Ozark Plateau Physiographic Province. They form a band 30 to 40 miles wide and 200 miles long from north-central Arkansas westward into eastern Oklahoma. Elevations range from about 900 feet in the valley bottoms to 2,500 feet at the highest point. The plateau is sharply dissected. Most ridges are flat to gently rolling and generally < 0.5 mile wide. Mountainsides consist of alternating steep simple slopes and gently sloping benches. Vegetation across the landscape is a forest matrix with inclusions of nonforest. Soils on mountaintops and slopes usually have shallow to medium depth and are represented by medium-textured members of the Hartsells, Linker, and Enders series (Typic Hapludults) derived from sandstone or shale residuum. Their productivity is medium to low. In contrast, soils on mountain benches are deep, well-drained members of the Nella and Leesburg series (Typic Paleudults). They developed from sandstone and shale colluvium, and their productivity is medium to high. Rocks in the area are alternating horizontal beds of Pennsylvanian shales and sandstones. Annual precipitation averages 46 to 48 inches, and March, April, and May are the wettest months. Extended summer dry periods are common, and autumn is usually dry. The frost-free period is normally 180 to 200 days long.

[1] Research Forester, USDA Forest Service, Southern Research Station, Hot Springs, AR 71902; and Research Forester, Retired, USDA Forest Service, Southern Research Station, respectively.

Citation for proceedings: Connor, Kristina F., ed. 2004. Proceedings of the 12th biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–71. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 594 p.

METHODS
Treatments
Six mature upland hardwood stands were selected for study at three locations in the Ozark National Forest. Three stands are on upper north- or east-facing slopes with site indices of 57 to 63 feet (mean = 60 feet) for northern red oak (*Quercus rubra* L.), base age 50 years. The other three stands are on north- or east-facing mountain benches with northern red oak site indices of 72 to 80 feet (mean = 75 feet). Mean age for upper slope stands was 74 years (range = 72 to 84 years), while stands on mountain benches averaged 78 years (range = 70 to 84). Six plots (approximately 1 acre in area) were established in each stand. Overstory [stems ≥ 1.6 inches in diameter at breast height (d.b.h.)] densities were reduced to either 40 or 60 percent relative stocking density (Gingrich 1967). There were three levels of understory (stems < 1.6 inches d.b.h.) treatment: (1) removal of all competing woody stems < 1.6 inches d.b.h (intensive), (2) removal of this diameter range of stems but only those ≥ 5 feet tall (partial), and (3) no understory treatment. The six overstory-understory treatment combinations were randomly assigned to each plot.

Pretreatment overstory stocking for all plots averaged 106 percent, and basal area averaged 118 square feet per acre. The shelterwood was created by a low thinning (thinning from below). After all subcanopy stems < 1.6 inches d.b.h. were removed, the overstory canopy was harvested to the prescribed stocking level. Stumps of all slow-growing or noncommercial overstory stems were sprayed with 2,4-D plus picloram to reduce sprouting. Overstories on all plots were predominantly oak. Northern red, black (*Q. velutina* Lam.), and white oak (*Q. alba* L.) accounted for 80 percent of the overstory stocking before treatment and > 90 percent after treatment. White ash (*Fraxinus americana* L.) and black cherry (*Prunus serotina* Ehrh.) represented < 1 percent of the stocking on all plots.

Understory control treatments were imposed by cutting target stems near ground level and spraying stumps with the 2,4-D plus picloram herbicide immediately after cutting. Understory treatments were completed in May 1980, and overstories were cut May through July 1980. Understories on upper slope sites (site index 60 feet at 50 years) were dense mixtures of tolerant species such as red maple (*Acer rubrum* L.), serviceberry [*Amelanchier arborea* (Michx. F.) Fern], redbud (*Cercis canadensis* L.), and blackgum (*Nyssa sylvatica* Marsh.). Dogwood (*Cornus florida* L.), hophornbeam [*Ostrya virginiana* (Mill.) K. Koch.], pawpaw [*Asimina triloba* (L.) Dunal], and sugar maple (*A. saccharum* Marsh.) were common on bench sites (site index 75 at 50 years).

Reproduction Measurement
Reproduction was measured on a series of sixteen 1/735-acre subplots systematically distributed across the interior 0.25 acre of each plot. On each subplot, all reproduction < 1.5 inches d.b.h. was tallied by species and 1-foot height classes. In addition, all oak stems were identified and mapped for remeasurement. For these stems, basal diameter (1 inch above groundline) and height were measured to the nearest 0.1 inch and 0.1 foot, respectively. Reproduction was measured before treatment and 9 years after treatment. During the initial pretreatment measurement, the total number of terminal bud scale scars was counted for each stem of advance oak reproduction.

Analysis
Logistic regression was used to model survival of advance regeneration 9 years after understory and overstory treatments. Results are expressed as the probability of survival of advance regeneration. The full power and versatility of logistic regression to analyze dichotomous data first gained recognition in the 1960s (Hosmer and Lemeshow 1989). Since then researchers have utilized this method to examine everything from human health issues to the growth and survival of naturally regenerated trees (Lowell and others 1987). Here we use logistic regression to examine survival of advance oak regeneration.

To evaluate logistic regression model performance, we selected predictors with a *P* value of 0.05 or less based on the chi-square distribution with one degree of freedom. We used the Hosmer-Lemeshow goodness-of-fit statistic (Hosmer and Lemeshow 1989 to test the null hypothesis that the equation described the data. For Hosmer-Lemeshow goodness-of-fit, the null hypothesis was rejected for *P* values of 0.05 or less (indicating a poor fit of the equation to our data). It is therefore important to note that predictor *P* values of 0.05 or less have a different interpretation than the Hosmer-Lemeshow goodness-of-fit *P* values of 0.05 or less.

RESULTS AND DISCUSSION
Overall, significant predictors of survival included initial seedling basal diameter, percent residual stocking of the shelterwood treatment, site index, and the number of terminal bud scale scars of the seedling prior to treatment. Initial seedling height class was not a significant predictor. This was likely due to > 93 percent of seedlings being < 1 foot tall (the shortest height class in this study) at the beginning of the study (table 1). Only 69.4 percent of the reproduction was in the smallest (1-inch) basal diameter class (table 1).

We identified predictors of survival of advance reproduction for northern red oak, white oak, and black oak. For northern red oak, both number of terminal bud scale scars prior to treatment and site index were significant predictors

Table 1—Percent of advance regeneration by height and basal diameter class in upland hardwood stands of the Boston Mountains prior to treatment

Height		Diameter	
class		*class*	
feet	*percent*	*inches*	*percent*
< 1	93.3	0.1	69.4
2	4.9	0.2	14.8
3	0.9	0.3	8.7
4	0.6	0.4	3.1
5	0.3	0.5	1.7
> 5	0.0	> 0.5	2.4

of survival (tables 2 and 3). Survival probability of northern red oak increased as the number of terminal bud scale scars increased and as site index decreased (fig. 1). Similar relationships of increasing regeneration success with decreasing site index have been observed (Loftis 1990, Spetich and others 2002). To our knowledge, this is the first time that terminal bud scale scars have been used as an indicator of regeneration survival in oaks. However, number of terminal bud scale scars may not be a useful indicator on sites where deer browsing, frequent fire, or mechanical damage would result in frequent top-stem loss and resprouting.

One reason for the greater survival with increasing number of terminal bud scale scars may be related to its relationship to an ever-increasing root system. After each growth flush, photosynthates are translocated to the root system (Johnson and others 2002). Because each terminal bud scale scar represents one flush of growth, a larger number of terminal bud scale scars likely represents a relatively greater accumulation of photosynthate in that root system.

In dense stands of northern Arkansas, top dieback from fire was likely a rare occurrence over most of the past century. For instance, Guyette and Spetich (2003) found a mean fire-return interval (average fire-free interval) of > 80

Table 2—Survival probability logistic regression models for northern red, white, and black oaks[a]

Species	N	Model[b]	Figure
			no.
NRO	1,288	P_{REO}=1/(1+EXP(-(-1.22 + (0.203 * no. bud scale scars) + (3184.11 * (1/SI)^2))))	1
BO			
Model 1	550	P_{BLO1} = 1/(1+EXP(-(-0.669 + (0.264 * no. bud scale scars) - (0.056 * D))))	2
Model 2	550	P_{BLO2} = 1/(1+EXP(- (-1.284 + (16.359 * stem diameter) - (0.599 * D))))	3
WO	625	P_{WHO} =1/(1+EXP(-(-1.285 + (0.199 * no. bud scale scars) + (0.507 * D)))	4

NRO = northern red oaks; BO = black oaks; WO = white oaks.

[a] This is the probability of advance regeneration surviving 9 years under a shelterwood. See table 3 for associated *p*-values and parameter estimates.

[b] Model parameter definitions: no. bud scale scars = number of terminal bud scale scars on a seedling prior to treatments; SI = site index in feet at base age 50 years; D = parameter estimate for stocking density (see table 3); stem diameter = stem diameter prior to treatments.

Table 3—*P*-values and parameter estimates for survival models in table 2

Species	Goodness of-fit[a] *p*-value	Percent stocking parameter estimates[b] 40	60	Logistic regression predictor *p*-values[c] Bud scale scars	D[d]	*(1/SI)^2*[e]	Stem diameter[f]
NRO	0.418			< 0.001		0.033	
BO							
Model 1	0.311	0	1	< 0.001	0.019		
Model 2	0.579	0	1		0.004		< 0.001
WO	0.685	0	1	< 0.001	0.006		

NRO = northern red oaks; BO = black oaks; WO = white oaks.

[a] Based on the Hosmer-Lemeshow goodness-of-fit statistic, differences between estimated probabilities and observed responses are not significant (Hosmer and Lemshow 1989). Small *p*-values designate a poor fit of the equation to the data while large values (> 0.2) indicate a good fit.

[b] 40 = 40 percent residual shelterwood stocking; 60 = 60 percent residual shelterwood stocking.

[c] Based on the chi-square distribution with one degree of freedom.

[d] D = parameter estimate for stocking density.

[e] SI = site index, base age 50.

[f] Basal stem diameter prior to treatment measured at 1 inch above groundline.

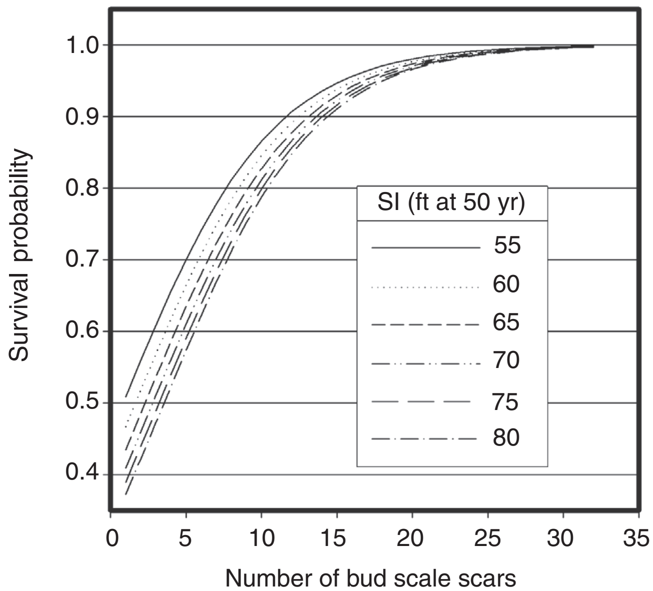

Figure 1—Northern red oak survival probability of advance regeneration by number of terminal bud scale scars prior to treatment and site index.

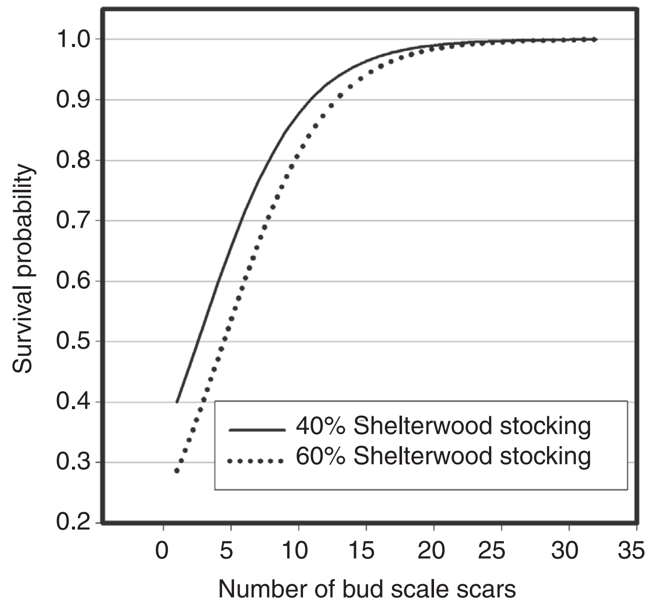

Figure 2—Black oak survival probability of advance regeneration by number of terminal bud scale scars prior to treatment and percent residual shelterwood stocking.

years for the time period from 1911 to 2000 in the lower Boston Mountains of Arkansas. Additionally, we rarely observed oak-specific mechanical damage from deer in this forest matrix. This was probably due to the preponderance of other species preferred by deer, such as poison ivy (*Toxicodendron radicans* L.); greenbrier (*Smilax Bona-nox* L., *S. glauca* Walt., *S. rotundifolia* L.); huckleberry (*Vaccinium vacillans* var. *crinitum* Fern.); red maple (*A. rubrum* L.); and Virginia creeper (*Parthenocissus quinquefolia* L. Planch.).

We produced two survival models for black oak advance reproduction. In model 1, significant predictors of survival included number of terminal bud scale scars and shelterwood percent stocking (tables 2 and 3). Survival probability increased with increasing number of terminal bud scale scars and as residual shelterwood stocking percent decreased (fig. 2). In model 2, significant predictors included initial basal stem diameter and percent shelterwood stocking (tables 2 and 3). In this case, survival probability increased as initial basal stem diameter increased but increased only slightly as percent shelterwood stocking decreased (fig. 3). Survival probability was nearly 100 percent for regeneration with an initial basal stem diameter of 0.4 inch for both the 40 and 60 percent stocking treatments. The importance of stem diameter and percent stocking were also noted in a recent paper examining the success of underplanted northern red oak (Spetich and others 2002).

For white oak advance reproduction, significant predictors of survival included number of terminal bud scale scars and shelterwood percent stocking (tables 2 and 3). Probability of survival increased with increasing number of bud scale scars and with increasing percent residual stocking (fig. 4). Survival increased with greater percent stocking and was the opposite of what we observed for black oak in this study. This is also contrary to findings of a study examining planted northern red oak (Spetich and others 2002).

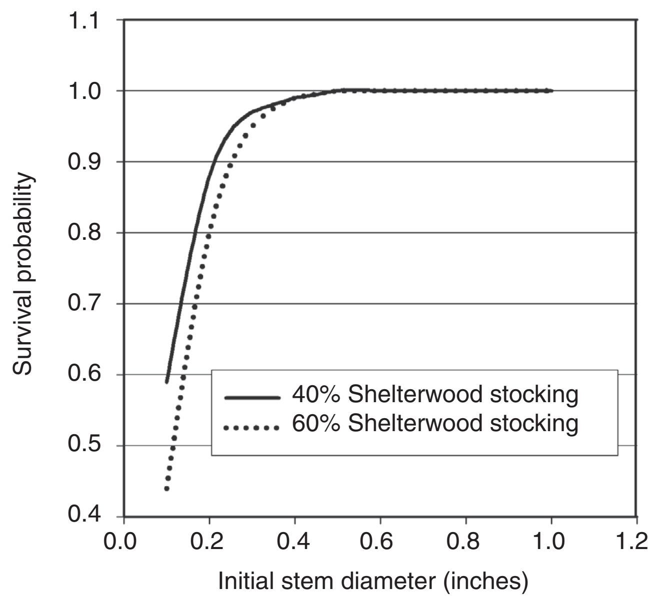

Figure 3—Black oak survival probability of advance regeneration by initial stem diameter prior to treatment and percent residual shelterwood stocking.

This increasing survival with greater stocking might indicate greater sensitivity of white oak to logging disturbance. For instance, as residual stocking level was decreased, relatively more trees were removed in the harvest, likely resulting in greater mechanical disturbance to the site.

When managing for both black oak and white oak, it may be useful to use an intermediate residual stocking level. Our models indicated somewhat higher survival for northern red oak at 40 percent residual stocking, while for white oak

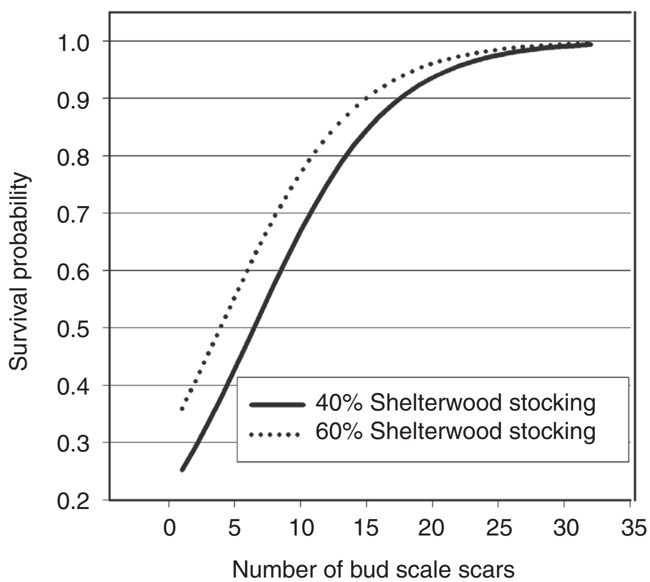

Figure 4—White oak survival probability of advance regeneration by number of terminal bud scale scars prior to treatment and percent residual shelterwood stocking.

the 60 percent stocking level indicated somewhat higher survival. On sites where advance regeneration of both black and white oak are equal, a residual stocking level of 50 percent may give better combined results for these two species. However, if the management objective is to increase the survival of one of the two species due to adequate regeneration of the other, then we suggest applying the residual stocking level that best suits that species.

ACKNOWLEDGMENTS

We extend our appreciation to the field technicians who installed and measured this study: Richard Chaney, Jim Whiteside, Greg Polus, Arvie Heydenriech, Jesse Swaford, and Kenny King. We thank Ozark National Forest personnel for assistance with stand selection and study installation. Thanks to Michael Shelton and Eric Heitzman for reviewing this manuscript and to Betsy Spetich for editorial guidance.

LITERATURE CITED

Gingrich, S.F. 1967. Measuring and evaluating stocking and stand density in upland hardwood forests in the Central States. Forest Science. 13(1): 38-53.

Graney, D.L. 1989. Growth of oak, ash and cherry reproduction following overstory thinning and understory control in upland hardwood stands of northern Arkansas. In: Miller, J.H., ed. Proceedings of the fifth biennial southern silvicultural research conference. Gen. Tech. Rep. SO-74. New Orleans: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station: 245-252.

Guyette, R.P.; Spetich, M.A. 2003. Fire history of oak-pine forests in the lower Boston Mountains, Arkansas, USA. Forest Ecology and Management. 180: 463-474.

Harlow, R.F. 1975. Deer foods during years of oak mast abundance and scarcity. Journal of Wildlife Management. 3: 330-336.

Hosmer, D.W.; Lemeshow, S. 1989. Applied logistic regression. New York: John Wiley. 307 p.

Johnson, P.S.; Shifley, S.R.; Rogers, R. 2002. The ecology and silviculture of oaks. New York: CABI Publishing. 503 p.

Loftis, D.L. 1990. Predicting post-harvest performance of advance red oak reproduction in the Southern Appalachians. Forest Science. 36: 908-916.

Lowell, K.E.; Mitchell, R.J.; Johnson, P.S. [and others]. 1987. Predicting growth and “success” of coppice-regenerated oak stems. Forest Science. 33: 740-749.

McShea, W.J.; Schwede, G. 1993. Variable acorn crops: responses of white-tailed deer and other mast consumers. Journal of Mammalogy. 74: 999-1006.

Merritt, C. 1980. The central region. In: Barrett, J.W., ed. Regional silviculture of the United States. 2d ed. New York: John Wiley: 107-143.

Nixon, C.M.; McClain, M.W.; Donohoe, R.W. 1975. Effects of hunting and mast crops on a squirrel population. Journal Wildlife Management. 39: 1-25.

Spetich, M.A.; Dey, D.C.; Johnson, P.S.; Graney, D.L. 2002. Competitive capacity of *Quercus rubra* L. planted in Arkansas' Boston Mountains. Forest Science. 48: 504-517.

Wentworth, J.M.; Johnson, A.S.; Hale, P.E. 1990. Influence of acorn use on nutritional status and reproduction of deer in the Southern Appalachians. Proceedings of the annual conference of the southeastern association of fish and wildlife agencies. 44: 142-154.