TOPOGRAPHIC POSITION AND SITE INDEX: AN OAK REGENERATION RELATIONSHIP

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Abstract—In 1996, a 10-year study was initiated in an upland hardwood forest in northern Alabama to assess establishment success and stocking levels of oak reproduction following three regeneration treatments: block clearcutting, strip clearcutting, and deferment cutting. Each treatment was applied to two 4-acre stands. In addition, two 2-acre uncut controls were monitored. All treatments were established on a north aspect with slopes ranging from 5 to 60 percent. Oak site index (base age 50 years) ranged from 64 feet on the upper slope positions to 88 feet on the lower slope positions. Data on operational and environmental variables were collected pre- and postharvest and analyzed to determine whether relationships exist with stocking or success of oak reproduction. Four growing seasons after the harvest, a relationship between topographic position, site index, and oak reproduction success was evident. Nonovertopped oak reproduction was found to be most abundant on the upper slope positions and least abundant on the lower slope positions, regardless of harvesting treatment.

INTRODUCTION

Oak regeneration has been a topic of much debate and continued study. Relationships ranging from the size and amount of advance regeneration, as well as specific site conditions to survival and success, continue to be researched. The findings from various studies generally show that large numbers of adequate advance regeneration are needed to maintain oak as a major component of future forests. Additionally, and maybe more importantly, is the finding that a topographic trend for oak regeneration success exists. Oaks have been found to compete better on upper slope positions that exhibit low to moderate oak site indices. Much of this research has been accomplished in areas like the Southern Appalachians and the Missouri Ozarks (Johnson 1993, Loftis 1993).

Within Alabama, oak-hickory forests make up approximately 35 percent (7.7 million acres) of the timberland with 65 percent of the oak-hickory forests in the State found in north Alabama (McWilliams 1992). These upland sites exhibit the topographic trend of oak site indices with good-quality sites on the lower to middle slopes and poor- to moderate-quality sites on the upper slopes. These forested areas have long been viewed as valuable in economic and social terms. Unfortunately, the oaks in these stands are no longer self-replacing. Information on where to concentrate management efforts may be the only way to economically ensure the continued presence of oak in these forests. Additionally, confirming the generally accepted trends in oak silvics for the upland hardwood forests in northern Alabama allows for the legitimate application of research results between these locations.

In 1996, a 10-year study was initiated in an upland hardwood forest in the mountains of northern Alabama to assess establishment success and stocking levels of oak reproduction following three regeneration treatments: block clearcutting, strip clearcutting, and deferment cutting. The purpose of this study was to determine which ecological factors had an effect on fourth-year postharvest stand composition and to investigate whether the applied silvicultural methods developed adequate oak reproduction. The topographic trends based on data collected after the fourth full growing season (Fall 2000) are reported in this paper. The specific objectives of this assessment were to (1a) determine which potential environmental factors have affected successful fourth-year postharvest oak stocking, (1b) determine which potential environmental factors have affected fourth-year post-harvest oak stem success, and (2) investigate the contribution and competitiveness of oak stump sprouting 4 years after harvesting and compare the effect of the silvicultural treatments (block clearcutting, strip clearcutting, and deferment cutting) on oak reproduction.

METHODS

Study Site

The study was established on north-facing slopes in Alabama's Cumberland Mountain-Plateau Region. It is located on the Yeager Demonstration Forest presently owned and managed by International Paper Corp. This demonstration forest can be found in the southeast portion of Lawrence County, AL, adjacent to the William B. Bankhead National Forest.

Major ridges typically run east to west with slopes ranging from 5 to 60 percent. Oak site index (base age 50 years) was found to be 64 feet on the upper slope positions and 88 feet on the lower slope positions. Major hardwood species consisted of oaks (Q*uercus* spp.), hickories (C*arya* spp.), sugar maple (*Acer sacharum*), yellow-poplar (*Liriodendron tulipifera*), ash (*Draxinus* spp.), and sweetgum (*Liquidambar styraciflua*).

Study Design

Each regeneration treatment was randomly assigned to two 4-acre stands (400 by 440 feet). Two 2-acre (200 by 440 feet) uncut controls were also established. The treat-

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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.

ment areas and the controls were oriented south to north along the gradient (slope). Three transects or plot lines were established within each treatment area, whereas one transect was established within each of the control areas. Each line of plots was comprised of approximately 67 one-half chain (33 feet) segments made up of 5-milacre plots (6.6 feet by 6.6 feet) running west to east. The odd numbered measurement plots along the central line were used to tag seedlings and complete an overall inventory including stems of all sizes. Stump sprouts and over-story data were collected in every plot in the one-half-chain-wide segment. This setup allowed for ease of relocation and tagging of seedlings, saplings, and residual overstory trees. Additionally, environmental data on each plot was collected consisting of various classes of vegetative competition cover, woody debris per plot, and topographic position. The approximate total number of milacre plots per transect is 334, with a total of 20 lines in the 8 blocks of this study.

Data Collection

Advance reproduction, overstory, and environmental data were collected during the summer of 1996 prior to harvesting. Immediately following the harvest in the fall of 1996, site and soil impacts were assessed and recorded for each measurement plot as well as a detailed regeneration and overstory survey. Additionally, 15 months after harvesting (Fall 1997), the stand was re-entered, plots relocated, and remeasured. The fifteen-month data is not reported in this paper. Finally, in the fall of 2000, after four full growing seasons, a regeneration and overstory survey was once again conducted. Postharvest germination was measured, tagged, and recorded. All reproduction was classified by competitive position: free to grow (FTG), crowded but not overtopped (CR), or overtopped (O). These classes were modified from Smith (1986).

Data Analysis

The variables examined for the fourth-year oak reproduction assessment fell into two categories, ecological factors and silvicultural factors. The ecological factors consisted of advance reproduction (numbers and sizes) topographic position, post- harvest establishment (numbers and sizes), postharvest seedling/sapling competitive position, percent cover of undesirable species and other nonoak tree species, percent cover of woody debris, and degree of disturbance. The silvicultural factors were: block clearcutting, strip clearcutting, and deferment cutting.

Most of the relationships found with the various ecological factors can be associated with their topographic position and related site index. Additionally, significant differences were found between regeneration treatments. However, the topographic trends were still evident across all treatments. Stepwise multiple logistic regressions were used to determine the models that best fit the data. All explanatory variables were entered into the model in various forms, combinations, and transformations. Multiple criteria for model fit were examined to determine the best models for plot stocking, individual stem success, and sprouting success.

Stepwise logistic regression using the Logistic Procedure in the Statistical Analysis System (SAS) for Windows, release 6.12 (SAS Institute Inc. 1990a, 1990b, 1997) was employed. The stepwise logistic regression procedure was used to explore a data set of explanatory variables thought to be related to the outcome variable. During the stepwise procedure, a statistical algorithm checked the importance of these variables and determined the addition or deletion of these variables into the model. The importance of an individual variable was defined as a measure of the statistical significance of the coefficient of the variable (Devore 1995, Hosmer and Lemeshow 1989). According to Hosmer and Lemeshow (1989) this procedure offers a useful and effective data analysis tool when the outcome being studied is relatively new, and those covariates and their associations with the outcome are not well understood. Stepwise logistic regression offers a fast and effective way to screen large numbers of variables and to simultaneously fit a number of logistic regression equations. One caution with logistic regression: As with any model-building technique, you are trying to find the best fitting and most parsimonious, yet biologically reasonable model to describe the relationship between an outcome and a set of independent variables (Hosmer and Lemeshow 1989). Although in most situations the stepwise method will identify a good model, there is no guarantee that the best model or a nearly best model will result. In certain situations where there appears to be a strong relationships among potential predictors, careful scrutiny is advised (Devore 1995).

Since the nature of this study is one of exploration, and the goal was to detect the influences affecting oak reproduction in a North Alabama upland hardwood forest, stepwise logistic regression seemed fitting. Furthermore, examining the site conditions and harvesting activities on such a site has previously not been well-documented. Using this type of exploratory analysis will bring about a better understanding of the natural processes. Logistic regression is also the preferred method when the outcome variable is a binary or dichotomous variable, such as success or milacre plot stocking (Hosmer and Lemeshow 1989).

When using stepwise regression for exploratory purposes it is important to choose an appropriate α level to judge the importance of variables. Hosmer and Lemeshow (1989) state that the use of an $\alpha = 0.05$ for entry into the model is too stringent and may often exclude important variables from the final model. Choosing an α level of 0.25 might be reasonable when the goal of the analysis is broad and the intent is to provide a more complete picture of the variables. For this study, a second α level of 0.15 was chosen, which indicated a minimal level for a variable to remain in the model. Essentially a variable will enter the model if it is deemed significant at an α of 0.25, and a variable will be deleted from the model if it is not significant at an α of 0.15 (Rao 1998).

In order to determine the model that best fits the data, various criteria for assessing fit were examined. The Akaike Information Criterion (AIC) and the Schwartz Criterion (SC) were both used to compare different models fitted to the same data with lower values for each indicating a better model (Younger 1998). The adjusted R^2 was also examined to determine the amount of variation attributed to the model. To assess the contribution of individual independent variables to the model, an analysis of maximum likelihoods was used. To do this, standardized estimates and odds ratios were evaluated. Younger (1998) states that the true value in assessing standardized estimates in the relative affects of multiple independent variables on the response is when these independent variables have different units of measurement, whereas the odds ratio is a measure of association that approximates how much more likely or unlikely it is that an event will happen (Hosmer and Lemeshow 1989, Younger 1998).

The analysis of maximum likelihood estimates for individual oak stem success for topographic position were based on the upper slope positions being coded as the reference variable. So, all results demonstrate the relationship found between the middle slope and the reference variable as well as the lower slopes and the reference variable.

RESULTS

Prior to harvesting, the topographic trend was already evident among the advance reproduction of all species. Composition of nonoak commercial species or other commercial species was greatest on the lower slope positions, whereas oak composition was found to be greatest on the upper slope positions (table 1). This same trend was found 4 years after harvesting within in the seedling-sapling reproduction classes for overall and non overtopped reproduction (NOT; table 2). NOT reproduction was considered to be those stems in the FTG and CR classes. Oak reproduction maintained its higher numbers on the upper slope positions where competing commercial species were found to be at their lowest. Unexpectedly, other NOT commercial species followed the same pattern as oak reproduction. This inconsistency might be explained by a lower number of overall stems per acre on the upper slope positions, thus allowing greater numbers of all species to fall into the NOT category. Additionally, the greater presence of NOT commercial species other than oak was not of concern because they were still commercial species.

Milacre Oak Plot Stocking

The following model was chosen because it best represented the data and had the lowest AIC and SC as well as a high adjusted R^2.

$$\text{F4QSTK} = f\,(\text{TRTMT, TOPO, S1QALLLG, ARCRUSH, COMPLOG}). \tag{1}$$

where F4QSTK = fourth year nonovertopped oak milacre plot stocking, TRTMNT = regeneration treatment, TOPO = topographic position, S1QALLLG = preharvest oak stems per milacre plot greater than 12 inches in height, ARCRUSH

Table 1—Preharvest composition of advance reproduction (AR)[a] by topographic position

Species	Upper slope (121 plots)	Middle slope (190 plots)	Lower slope (177 plots)	Total
	stems per acre			
Oaks	5,752	1,874	1,011	8,637
Other commercial	7,860	10,547	17,333	35,740
Noncommercial	1,008	689	1,689	3,386
Overall	14,620	13,110	20,034	47,764

[a] AR includes stems of any size including the sprouting potential of cut trees.

Table 2—Total fourth-year reproduction and nonovertopped reproduction (NOT) by topographic position

Species	Upper slope (121 plots)		Middle slope (190 plots)		Lower slope (177 plots)		Total	
	Total	NOT	Total	NOT	Total	NOT	Total	NOT
	stems per acre							
Oaks	2,851	347	1,105	94	571	62	4,527	503
Other commercial	6,678	2,727	9,737	2,447	11,379	2,249	27,794	7,423
Noncommercial	1,165	612	900	374	1,672	780	3,737	1,766
Overall	10,694	3,686	11,742	2,821	13,621	3,091	36,057	9,604

NOT = nonovertopped reproduction.

= fourth year percent competition of *Rubus* spp. and shrubby vegetation per milacre plot with an arc-sin square root transformation, and COMPLOG = preharvest percent competition of nontree vegetation per milacre plot with a log transformation.

This final model was considered significant (p = 0.0773) for the chosen α levels. The Hosmer and Lemeshow (1989) goodness-of-fit statistic (10.44 with 8 DF; p = 0.2355) was determined to be nonsignificant; thus, the hypothesis of goodness-of-fit cannot be rejected. Additionally, an adjusted R^2 of 0.2116 indicated that approximately 21 percent of the variation was accounted for by the model.

The analysis of maximum likelihood estimates for the topographic position variable indicate that it was approximately 66 percent more likely for a milacre plot to be stocked with an oak 4 years after harvesting on the upper slope positions than either of the other topographic positions. This was represented by a negative standardized estimate for the middle slope (-0.111821) and lower slope (-0.097443) positions revealing a relatively weak effect of these variables to the model. Odds ratios were less than 1; the middle slopes were 0.659:1; and the lower slopes were 0.666:1. These ratios can also be stated as a percent likelihood by subtracting the odds from 1. Thus, milacre plot stocking would be 33.4 percent less likely on the lower slope positions and 34.1 percent less likely on the middle slope postions.

Given this greater likelihood for a plot to be stocked 4 years after harvesting on these upper slopes, it is important to look deeper into the dataset. Table 3 presents the plot-stocking data as well as changes in stocking from preharvest to year 4. Initially and at year 4, the upper slope positions had greater plot stocking. Additionally, milacre plot stocking on the upper-slope positions decreased by 15 percent less than the other positions.

Individual Oak Stem Success

This final model for oak stem success exhibited the lowest AIC and SC and had a relatively high adjusted R^2. It was also determined that this model best represented the data.

$$F4QSUC = f\ (INSZ, TRMT, TOPO, SHRBLOG). \qquad (2)$$

where F4QSUC = fourth year individual stem success, INSZ = initial stem size measurement categories, TRTMT = regeneration treatment, TOPO = topographic position, and SHRBLOG = fourth year percent competition of shrub species per milacre plot where a successful oak stem was found with a log transformation. This final model was significant at a chi-square probability of 0.7215 for the chosen levels. The Hosmer and Lemeshow (1989) goodness-of-fit statistic was 6.4317 with 8 DF (p = 0.5990), which was non-significant. Thus, the hypothesis of goodness-of-fit cannot be rejected. An adjusted R^2 of 0.0922 indicated that approximately 9 percent of the variation is accounted for by the model. Since the nature of this study is one of exploration, a low adjusted R^2 was acceptable. Furthermore, the high degree of variability in natural systems and the unpredictable nature of the parameters in this study allowed for a low adjusted R^2.

It was 80 percent less likely that an individual oak stem would be successful on the upper slope positions than the lower slope positions and 64.5 percent less likely that a stem would be successful on the upper slope than the middle slope positions, according to the analysis of maximum likelihood estimates. At first glance this seemd to go against conventional thinking as oaks generally do better on poorer quality upper slope positions. This issue will be addressed shortly. Standardized estimates of 0.037252 for the lower slope positions and 0.075621 revealed a relatively moderate effect of topographic position variable to the final model. Odds ratios were 1.2:1 for the lower slope positions and 1.355:1 for the middle slopes. Stated as percent likelihoods, it was 20 percent more likely that a stem would be successful on the lower slope, and 35.5 percent likely that a stem would be successful on the middle slope positions.

In order to understand the origin of the successful stems, these results were broken into advance reproduction and postharvest germination. Table 4 presents these results. Percent success of advance reproduction was higher on the middle slope and lower slope positions; however, actual

Table 3—Change in plot stocking of milacre plots for oaks from pre-harvest to fall 2000 by topographic position

Topographic position	Stocked preharvest[a]		Stocked Fall 2000[b]		Stocking change[c]	Change, as a percent of AR stocking[d]
	%	*no.*	*%*	*no.*	*%*	*%*
Upper slope	38	46	21	26	-7	-45
Middle slope	15	28	6	12	-9	-60
Lower slope	15	26	6	10	-9	-60
Overall	20	100	10	45	-10	-50

[a] Stocking of plots with at least one oak stem > 12 inches preharvest.
[b] Stocking of plots with at least one oak stem in a nonovertopped competitive position.
[c] As a proportion of total plots in the class.
[d] As a proportion of the plots that were stocked at preharvest.

Table 4—Success of oak advance reproduction and oak post harvest germination by topographic position 4 years after harvesting

Regeneration type	Topographic position							
	Upper slope		Middle slope		Lower slope		Overall	
	%	no./ac	%	no./ac	%	no./ac	%	no./ac
AR	3	165	4	74	4	40	3	84
PHG	8	182	2	21	4	23	5	61

AR = advance reproduction; PHG = post harvest germination.

successful stems per acre were highest on the upper slope positions, greater by more than 87 stems per acre than either of the other positions. In contrast, percent success of postharvest germination was greatest on the upper slope positions as were actual stems per acre—greater by more than 159 stems per acre.

Oak Stump Sprouting Success

The model that best represented the oak sprouting success data was:

SPRSUC = f (TMT TOPO DBHCL). (3)

where SPRSCU = fourth year sprout success, TRTMT = regeneration treatment, TOPO = topographic position, and DBHCL = parent tree diameter at breast height by 2-inch diameter classes. Even though the chosen model did not exhibit the lowest AIC or SC, it did exhibit the highest adjusted R^2. Additionally, there were no noteworthy differences in the strength of the parameter estimates or odds ratios between models. Furthermore, the model that had the lowest AIC and SC values contained only one independent variable, DBHCL.

The chosen model was highly significant at a chi-square probability of 0.0001 and the Hosmer and Lemeshow (1989) goodness-of-fit statistic (9.3583 with 8 DF; p = 0.3130), which is nonsignificant. Thus, the hypothesis of goodness-of-fit cannot be rejected. An adjusted R^2 of 0.1614 indicated that approximately 16 percent of the variation was accounted for by the model and was considered acceptable.

The analysis of maximum likelihood estimates for this model indicated that it was approximately 80 percent more likely for a sprout to be successful on the upper slope than either of the other slopes. Standardized estimates for topographic position indicated a relatively high contribution from this variable -0.0368633 for the lower slope positions and -0.067484 for the middle slope positions. Odds ratios indicated that it was 20.1 percent (0.799:1) less likely for a sprout to be successful on the lower slope positions, and 22.0 percent (0.780:1) less likely for a sprout to be successful on the middle slope positions. Actual numbers per acre and percent success of oak stump sprouts by topographic position can be found in table 5.

DISCUSSION

Oak reproduction, including sprouts, normally follows a topographic trend with oak success decreasing as site quality increases and topographic position nears the lower slopes (Auten and Plair 1949, McNabb 1992, Roach and Gingrich 1968, Sander and others 1984). The results found on this site can be considered a confirmation that site index could be used as a measure of site quality. Essentially, drier poorer quality upper slope positions tend to favor the drought and shade tolerances of the oaks rather than the more mesic nature of competing species (Smith 1993). All topographic positions on this site were considered “better” quality sites with oak site indices (base age 50 years) greater than 60. Lorimer (1993) reported that sites exhibiting an oak site index (base age 50 years) greater than 60 are likely to convert to a more mesic species composition. Thus any NOT oak reproduction on this site should be considered acceptable.

On this same site in north Alabama, Stockman (2001) and Golden and others (1999) found this same relationship early on when studying apparent first-year oak seedling survival and 15-month oak stocking. It was also determined that a large yellow poplar and sugar maple component, which had greater success rates on the lower slope and middle slope positions, would negatively influence oak reproduction; our data confirm this speculation.

Table 5—Success of oak stump sprouts by topographic position 4 years after harvesting

Regeneration type	Topographic position							
	Upper slope		Middle slope		Lower slope		Overall	
	%	no./ac	%	no./ac	%	no./ac	%	no./ac
Sprouting	20	19	17	9	12	2	18	9

The unexpected positive relationship associated with oak stem success was noteworthy. The higher percent success on the middle and lower slope positions seemed to go against conventional thinking and research. This can be explained by reviewing tables 1 and 2. The upper slope positions had a greater number of stems present preharvest, and density at this topographic position decreased by the largest factor by year 4. This large decrease was for NOT stems as well as all oak stems. This larger decrease on the upper slope positions corresponded to the smallest percent success, as seen on table 4. Even though the upper slope positions had the smallest percent success values, they still exhibited the greatest number of successful stems per acre. Thus, on an absolute basis, the generally accepted topographic trend held true.

CONCLUSIONS

Our assessment of oak milacre plot stocking, individual stem success, and successful stump sprouting agrees with contemporary literature. It also confirmed that large numbers of well-developed advance reproduction are needed to successfully reproduce oaks as a major component of a future stand no matter where they may happen to be growing (Golden and others 1999; Loftis 1990, 1993; Roach and Gingrich 1968; Sander and others 1984).

Management Implications

When managing for natural oak reproduction it is important to focus efforts where they may be the most successful. In looking at the results from this study in North Alabama, we can see that oak regeneration does well on the upper slope positions. Thus, it may not be the best use of resources to manage on these positions. Additionally, it may be too hard to successfully manage for oaks on the lower slope positions. Focusing mainly on the middle slope positions and tending the upper slope positions seems to be the best management advice that can come from this study.

ACKNOWLEDGMENTS

I would like to thank those that cooperated on this project: International Paper Corp., the USDA Forest Service, Southern Research Station, Andrews Forest Service Lab in Auburn, Alabama, and Auburn University's School of Forestry and Wildlife Sciences.

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