PREDICTING OAK DENSITY WITH ECOLOGICAL, PHYSICAL, AND SOIL INDICATORS

Callie Jo Schweitzer, Adrian A. Lesak, and Yong Wang[1]

Abstract—We predicted density of oak species in the mid-Cumberland Plateau region of northeastern Alabama on the basis of basal area of tree associations based on light tolerances, physical site characteristics, and soil type. Tree basal area was determined for four species groups: oaks (*Quercus* spp.), hickories (*Carya* spp.), yellow-poplar (*Liriodendron tulipifera* L.), and other species. Basal area of all species was also divided into three categories based on shade tolerance (shade tolerant, intermediate tolerance, and shade intolerant). Principal components analysis was used to explore the communalities among the measured site characteristics and the species and shade tolerance groups. Stepwise multiple linear regression modeled the extent to which the forest composition factors and physical and soil indicators predicted the density of oaks. Oak basal area responded negatively to basal area of all shade tolerance groups and the species groups that correlated with them. Elevation was related positively to oak density. Our results support the premise that oaks are weak competitors with species of various shade tolerance strategies.

INTRODUCTION

The ecological and economic importance of oaks has resulted in an interest in their ecology, competitive capacity, and management. The oak-dominated forests of the mid-Cumberland Plateau are an excellent laboratory in which to study oak ecology under conditions of high physiographic and arboreal diversity. Many questions remain about the biology of oaks and the mechanisms by which their widespread dominance in forested landscapes throughout the Eastern United States is achieved and maintained. In few places is the importance of oaks to forest ecology greater than in the Cumberland Plateau region and its southern fringes.

The mechanisms that influence the composition of oak-dominated forests and the competitive interactions within these systems have been described for many regions and many stages of forest development. This study clarifies basic relationships between oak density and the density of coexisting species and ecological species groups in addition to characteristics of the physical environment in the oak-hickory forests in northeastern Alabama.

Exploratory predictive models focusing on ecologically important species and their ecological strategies in relation to potentially important abiotic factors could be used to gain an understanding of the complex dynamics of oak forests. Multivariate statistics can be used both to evaluate the influence of several environmental factors simultaneously and to identify interactions and correlations among those factors. The objective of this study was to determine whether differences in oak density can be predicted accurately on the basis of species composition, physical site attributes, and soil type.

METHODS

Study Area

The study area is located in northern Jackson County, AL, on property managed by Stevenson Land Company and the Alabama Department of Conservation and Natural Resources, State Lands Division. Situated in the mid-Cumberland Plateau, the region is characterized by narrow, flat plateaus dissected by numerous deep valleys. In this study, data were collected at two sites, one located at Jack Gap (34°56′ 30″ N, 86°04′00″ W) and one at Miller Mountain (34°58′30″ N, 86°12′30″ W). The Jack Gap and Miller Mountain sites cover approximately 40 and 20 ha, respectively, for a total study area of 60 ha. The study sites are at upper- or mid-slope positions on the side of the plateau, and their elevation ranges from 260 to 520 m. Jack Gap has a predominately north slope aspect, while Miller Mountain has a south to southwesterly slope aspect. Mature upland hardwood forest is the dominant land cover in the northern half of Jackson County, where many large continuous tracts are present. The forest cover of the sites and much of the surrounding area is of the oak-hickory type (*Quercus* spp. and *Carya* spp.) with yellow-poplar (*Liriodendron tulipifera* L.), sugar maple (*Acer saccharum* Marsh.), red maple (*Acer rubrum* L.), and American beech (*Fagus grandifolia* Ehrh.) as associates (Hartsell and Vissage 2001). Stand age ranges from about 80 to about 110 years.

Tree Measurements

Seventy-five 0.08-ha circular plots were randomly selected from 150 systematically arranged points located throughout the study area (50 plots at Jack Gap and 25 at Miller Mountain). Diameter at breast height (d.b.h.) and species were recorded for every tree ≥ 14 cm in diameter on each plot. Basal area [BA = cross-sectional area (m^2)] for all trees in this d.b.h. class was calculated for each plot using d.b.h. measurements. Basal area totals for the individual species were summed for species groups (oak species, hickory species, yellow-poplar, and other species) and for shade tolerance groups (shade tolerant, intermediate tolerance, and shade intolerant). Species were assigned to tolerance groups based on classifications by a majority of four sources (Burns and Honkala 1990, Harrar and Harrar 1962, Johnson and others 2002, Loftis 1991).

[1] Research Forester, USDA Forest Service, Southern Research Station, Ecology and Management of Southern Appalachian Hardwood Forests, Normal, AL 35762; former student and Associate Professor, respectively, Alabama Agricultural and Mechanical University, Normal, AL 35762.

Citation for proceedings: Connor, Kristina F., ed. 2006. Proceedings of the 13th biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–92. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 640 p.

Physical Data

Elevation for each measurement plot was derived from U.S. Geological Survey 1:24,000 Digital Elevation Model (DEM) data for the Estill Fork and Hytop quadrangles. The DEM data were converted to a three-dimensional triangulated irregular network (TIN) format to obtain the slope (°) and aspect (°) of each plot. Elevation extraction and conversion of DEM data to TIN was done with Arc geographical information system software (ESRI, Redlands, CA). Because the aspect measurements were based on circular values, each value was converted to a northness [cos(aspect)] and eastness [sin(aspect)] component for analysis purposes. For the northness component, 1 equals due north, and -1 due south. For eastness, 1 equals due east, and -1 due west. For ease of interpretation, either component may be multiplied by the inverse of its trigonometric function to be reconverted to the original value in degrees.

Soil Data

Natural Resources Conservation Service personnel surveyed the soil profiles at several locations at each study site and outlined the major soil series on topographical maps that could be used to match soil types to the vegetation plots (Personal communication. Doug Clendendon. 2002. Soil Survey Project Leader, USDA Natural Resources Conservation Service, P.O. Box 1208, Normal, AL). In addition to individual samples and observations, 6 soil transects (4 at Jack Gap, 2 at Miller Mountain), each with 10 sample points, were used to delineate soil series boundaries on a finer scale than is available from conventional county soil maps. Transects were placed so that the range of representative land forms in the study area could be sampled. The soil characteristics of these physiographic features were then extrapolated to similar features (in appropriate topographic context) throughout the entire study area and boundaries drawn. Our study area was composed of three soil series: Bouldin stony loam, Enders gravelly loam, and Limrock gravelly loam.

Statistical Analysis

Principal components analysis—Because of the potential correlation among the primary species groups, shade tolerance groups, and the site characteristics, we employed principal components analysis (PCA) to explore communalities among the dependent variables. Prior to PCA, we examined descriptive statistics to identify violations of the assumptions required for linear multivariate analyses. We used a matrix of all partial regression plots to assess the linear relationships among the variables. Large departures from linearity were not detected. Normality plots, histograms, and the Kolmogorov-Smirnov normality test all showed that elevation and BA of oak species had uneven but normal distributions. The BA values of shade tolerant species, intermediate tolerance species, shade intolerant species, hickory species, yellow-poplar, and other species were all non-normal with positive skewness as a result of many low and zero values. Square-root transformation brought all of these variables within normal parameters. None of the transformations (square-root, logarithmic, inverse, or reflection) that we applied to slope, northness, and eastness remedied their departures from normality, and the value of these variables were left unchanged.

Correlation analysis (excluding oak species BA) showed that a large number of variables were correlated, and this suggested that PCA could be used to group them. To solidify this decision to proceed with PCA, measures of sampling adequacy (relating to the degree of intercorrelation with the other variables) for each variable were examined, and other species BA was excluded from the variable set to increase the overall Kaiser-Meyer-Olkin measure of sampling adequacy to 0.581. The Bartlett's Test of Sphericity was highly significant (X^2 = 251.048, df = 36, $p < 0.0005$), further establishing the appropriateness of PCA. Factor extraction was limited to components with Eigenvalues > 1, and examination of a scree plot of Eigenvalues across the components was used to confirm inclusion. VARIMAX rotation was used to differentiate important variable loadings on each component, and factor scores based on the extracted component coefficients were calculated for later analysis. All analysis was conducted using SPSS version 10.0 (SPSS, Inc. 1999).

Multiple linear regression—The stepwise method of multiple linear regression, the principal component scores for each plot, and the three dummy-coded soil series were used to predict BA of oak species.

RESULTS

On all 75 measurement plots combined, 1,703 trees of 33 species were recorded. Elevation of the plots ranged from 320 to 514 m, and the average slope was 39°. Aspects were primarily north and southwest with slightly more variation on the east-west axis than the north-south axis. Our plots overlaid three soil types (table 1).

Principal components analysis identified four factors that accounted for 75.59 percent of the total variance within the variable set (table 2). Principal component (PC) 1 explained 32.24 of this variance and had an Eigenvalue of 2.901. This component had high positive loadings for both BA of intermediate tolerance species and BA of hickory species (table 3). PC 2 (19.53 percent variance explained, Eigenvalue = 1.758) was highly associated with BA of yellow-poplar and BA of shade intolerant species. PC 3 (12.65 percent variance explained, Eigenvalue = 1.139) had high positive loadings for slope and eastness and high negative loading for northness. PC 4 (11.17 percent variance explained, Eigenvalue = 1.006) had positive loading for the elevation variable and negative loading for BA of shade tolerant species.

Extracted variables for the top four principal components and their loading direction (+ or -) are given below:

PC 1 = (+) BA intermediate tolerance species and (+) BA hickory species

PC 2 = (+) BA yellow-poplar and (+) BA intolerant species

PC 3 = (+) slope and (-) northness and (+) eastness

PC 4 = (+) elevation and (-) BA tolerant species

Stepwise multiple regression using the four principal component scores and three soil types resulted in a highly significant model with a relatively low predictive capacity (F = 13.231, df = 3,71, $p < 0.0005$, $R^2 = 0.359$). Low variance among the residuals, rather than the large sample size, probably explains the high significance level of this model, and this suggests that the model is a good fit despite its low predictive power. Examination of standardized residual and normality plots showed that this model fit the assumptions of normality, homoscedasticity, and linearity very well.

Table 1—Descriptive statistics for primary species groups, shade tolerance groups, and site physical data used in predictive modeling; data from 75 plots sampled in Jackson County, AL

Variable	N	Minimum	Maximum	Mean	Standard deviation	Variance
BA all oak species	75	0.00	33.43	10.05	6.81	46.43
Slope	75	28.04	43.45	38.70	4.89	23.91
Northness	75	-0.99	1.00	0.40	0.57	0.33
Eastness	75	-0.96	1.00	-0.16	0.71	0.50
Elevation	75	320.6	514.45	427.05	53.84	2,898.91
BA tolerant species[a]	75	0.00	3.55	1.70	0.88	0.77
BA intermediate[a] tolerance species	75	0.00	4.47	1.96	0.89	0.79
BA intolerant species[a]	75	0.00	4.22	1.60	1.07	1.16
BA hickory species[a]	75	0.00	3.59	1.55	0.88	0.78
BA yellow-poplar [a]	75	0.00	3.61	1.00	1.03	1.06
Other species[a]	75	0.00	5.22	2.37	0.81	0.65

BA = basal area.
[a] The square root of the basal area of the dependent variable and variable groups. Tolerant species included basswood (*Tilia heterophylla* Vent.), beech (*Fagus grandifolia* Ehrh.), and sugar maple *(Acer saccharum* Marsh.); intermediate tolerance species included ash (*Fraxinus* spp.), cucumber tree *(Magnolia acuminata* L.), red maple (*A. rubrum* L.), and elm (*Ulmus* spp.); intolerant species included black cherry (*Prunus serotina* Ehrh.), black locust (*Robinia pseudoacacia* L.), and sassafras [*Sassafras albidum* (Nutt.) Nees.]; hickory species included mockernut (*Carya tomentosa* Nutt.), pignut (*C. glabra* Sweet), red *(C. ovalis* Sarg.), and shagbark (*C. ovata* K. Koch.).

Table 2—Principal components derived from the 9 dependent variables for 75 plots located in Jackson County, AL

Principal component	Eigenvalue	Percent of variance explained	Cumulative percent
1	2.901	32.239	32.239
2	1.758	19.529	51.768
3	1.139	12.652	64.420
4	1.006	11.174	75.593
5	0.781	8.678	84.271
6	0.600	6.670	90.941
7	0.539	5.992	96.933
8	0.149	1.659	98.592
9	0.127	1.408	100.000

The resulting model included three of the principal components:

$$\text{BA of oak species} = 10.052 - 2.744(\text{PC } 1) - 2.690(\text{PC } 2) + 1.371(\text{PC } 4)$$

The negative value of PC 1 suggests that oak BA increases as BA of competitors with similar tolerance characteristics, such as hickories, decreases. The negative values of PC 2 suggest that oak BA increases as BA of yellow-poplar and other intolerant species decreases. The positive coefficient of PC 4 means that oak BA increases as elevation increases and BA of tolerant species decreases.

DISCUSSION

The loading of variables in the different principal components provides some insight into correlations between vegetation and site characteristics. Not only did hickories and yellow-poplar correlate with their respective shade tolerance groups, but elevation and BA of shade tolerant species showed a negative relationship. Slope and aspect were also grouped together.

Multiple regression showed the selected variables combined into three components that modeled oak BA significantly but had low predictive power. Nevertheless, the model supports certain inferences. Oak BA tends to increase in importance in our study areas as elevation increases. This relationship has been confirmed in other studies of Alabama upland hardwoods. Oaks predominated mainly in upper slope positions (Golden and others 1999, Shostak and others 2004). This may reflect the drought tolerance of some oak species such as black (*Q. velutina* Lamark), scarlet (*Q. coccinea* Marsh.), chinkapin (*Q. muehlenbergii* Englem.), and to a lesser extent chestnut oak (*Q. montana* L.).

The soils on the top of the plateau are often thin and well-drained, while on the escarpment or side of the plateau, soil thickness and moisture increase (Smalley 1982). The underlying soil type appeared to have little influence on the density and composition of these stands.

In these mature forests, oaks compete with species in all three shade tolerance classes. There are different theories about mechanisms of succession from stand establishment to canopy dominance. The initial floristic model (Egler 1954) takes initial species composition as the starting point and details how species dominance changes as species grow at different rates. Relay floristics (Egler 1954) suggests that

Table 3—Final principal component loadings using the rotation method Varimax with Kaiser normalization correlating the principal component and each original variable; data from 75 plots sampled in Jackson County, AL

Variable	Component 1	2	3	4
Slope			0.789	
Northness			-0.689	
Eastness			0.671	
Elevation				0.833
BA tolerant species [a]				-0.758
BA intermediate[a] tolerance species	0.948			
BA intolerant species[a]		0.921		
BA hickory species[a]	0.923			
BA yellow-poplar[a]		0.937		

BA = basal area.
[a] The square root of the basal area of the dependent variable and variable groups. Tolerant species included basswood (*Tilia heterophylla* Vent.), beech (*Fagus grandifolia* Ehrh.), and sugar maple (*Acer saccharum* Marsh.); intermediate tolerance species included ash (*Fraxinus* spp.), cucumber tree (*Magnolia acuminata* L.), red maple (*Acer rubrum* L.), and elm (*Ulmus* spp.); intolerant species included black cherry (*Prunus serotina* Ehrh.), black locust (*Robinia pseudoacacia* L.), and sassafras [*Sassafras albidum* (Nutt.) Nees.]; hickory species included mockernut (*Carya tomentosa* Nutt.), pignut (*C. glabra* Sweet), red (*C. ovalis* Sarg.), and shagbark (*C. ovata* K. Koch.).

species composition changes as later successional species disperse and grow into stands, taking advantage of the conditions created by earlier ones. Our findings are consistent with both of these models. Nevertheless, our results do show that differences in shade tolerance strategies among the species studied do not appear to alleviate competition in these forests.

Future Considerations

To improve the predictive ability of our model, an expanded set of variables measured at a greater sample size would be helpful. Inclusion of more sample plots with a wider range of aspects, slopes, and elevations may clarify the influence of these factors. Other models constructed from our data may predict the change in BA of other important species.

CONCLUSIONS

Our efforts to model the dominance of oak using topographical and ecological factors confirm the reputation of oaks as poor competitors. Many of our stands in north Alabama are at or near rotation, and it may be desirable to regenerate them to oak. As this study shows, successful regeneration to oak will require careful consideration of competing vegetation.

ACKNOWLEDGMENTS

The authors wish to thank the following people for their assistance with this study: Greg Janzen, Adrian Johnson, Jennifer Rice, Ryan Sisk, Zach Felix, Lysbeth Hol, and David Loftis. The authors are grateful to Stacy Clark (USDA Forest Service) and Wubishet Tadesse (Alabama Agricultural and Mechanical University) for their reviews of this manuscript.

LITERATURE CITED

Burns, R.M.; Honkala, B.H., tech. coords. 1990. Silvics of North America: Hardwoods. Agric. Handb. 654. Washington, DC: U.S. Department of Agriculture, Forest Service. 877 p. Vol. 2.

Egler, F.E. 1954. Vegetation science concepts. 1. Initial floristic composition: a factor in old-field vegetation development. Vegetatio. 4: 412-417.

Golden, M.S.; Dubois, M.R.; Stockman, J.L. 1999. Oak regeneration following three cutting treatments on mountain slopes in north Alabama. In: Haywood, J.D., ed. Proceedings of the 10th biennial southern silviculture research conference. Gen. Tech. Rep. SRS-30. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 8-14.

Harrar, E.S.; Harrar, J.G. 1962. Guide to southern trees. New York: Dover Publications. 709 p.

Hartsell, A.J; Vissage, J.S. 2001. Forest statistics for North Alabama, 2000. Resour. Bull. SRS-64. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 50 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. 1991. Regeneration of southern hardwoods: some ecological considerations. In: Silvicultural challenges and opportunities in the 1990s: proceedings of the national silviculture workshop. Washington, DC: U.S. Department of Agriculture, Forest Service, Timber Management: 139-143.

Shostak, D.I.; Lowenstein, E.F.; Dubois, M.R. 2004. Topographic position and site index: an oak regeneration relationship. In: Connor, K.F., ed. Proceedings of the 12th biennial southern silviculture research conference. Gen. Tech. Rep. SRS-71. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 243-248.

Smalley, G.W. 1982. Classification and evaluation of forest sites on the Mid-Cumberland Plateau. Gen. Tech. Rep. SO-38. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 123 p.

SPSS, Inc. 1999. SPSS Base 10.0 applications guide. Chicago, IL: SPSS, Inc. 426 p.