INDIVIDUAL OAK TREE GROWTH IN SOUTHERN BOTTOMLAND HARDWOOD STANDS (PRELIMINARY RESULTS)

Luben D. Dimov, Brian Roy Lockhart, and Jim L. Chambers[1]

Abstract—Southern bottomland hardwood forests are an important natural resource. Silvicultural practices in them are often intended to provide suitable growing conditions to selected individual trees of valuable species by employing crop-tree management. Research on crop-tree management, however, has been considerably less than the research regarding stand-level management. In this study, trees from three bottomland hardwood sites were measured to perform regression analysis on d.b.h. growth and basal area growth of selected red oak group trees. The new variable score for direct sunlight from above and from the sides accounted for more variability in the growth models than other variables and indices from the literature. The new crown-class score is visually determined and requires only a simple calculation, which should make it useful for practitioners and researchers interested in predicting the growth of individual trees from the red oak group.

INTRODUCTION

Southern bottomland hardwood stands commonly occupy productive sites on major and minor stream bottoms (Hodges 1995). These forests are often naturally regenerated and characterized by a complex vertical structure combined with a diverse species composition. Their structural complexity and the presence of intricate interspecific and intraspecific relationships make research challenging. Therefore, to describe them quantitatively, very detailed data collection is needed. Necessary information includes individual tree dimensions and their spatial distribution.

Determining competition among trees is of considerable research interest, in part because competition is a common component of tree-growth models. Competition is assessed through variables describing the characteristics of neighboring trees or through competition indices, which are combinations of these variables. Independent variables used in the literature include crown-based variables (Cole and Lorimer 1994, Moore and others 1973, O'Neal and others 1994) and diameter-based variables (Faber 1991). In these and in other studies (Biging and Dobbertin 1992, Daniels and others 1986, Tome and Burkhart 1989), the two types of variables accounted for various amounts of the variability in d.b.h. and basal area growth, but neither of the two types of variables performed consistently better. Competition indices are usually divided into distance-dependent indices, when the intertree distances are taken into consideration, and distance-independent indices when the intertree distances are not taken into account (Munro 1974).

In this study, cherrybark oak (*Quercus pagoda* Raf.) was the species of main interest, although red oaks in general were also of consideration. Cherrybark oak was selected for its superior growth, economic value, and importance in the southern bottomland ecosystems (Burns and Honkala 1990). The objectives of this project were to find the factors that can best explain the variability in d.b.h. and basal area growth of selected trees by considering the characteristics of the individual trees and the other plot trees.

METHODS

Three 0.64-ha plots were established on each of three bottomland hardwood sites. One of the sites was on a major stream bottom (Mississippi River) and is located in St. Landry Parish, central Louisiana. The remaining two sites are on minor stream bottoms. One was located in Jackson Parish (Cypress Creek) in northern Louisiana and one in Drew County (Hungerrun Creek) in southeastern Arkansas. The stands were naturally regenerated, mature (more than 70 years old), relatively undisturbed (no cutting in approximately the previous 20 years) and dominated by red oaks. The soils on the St. Landry Parish site are Baldwin silty clay loam (fine montmorillonitic, thermic Vertic Epiaquals); on the Jackson Parish site, the soils are Guyton silt loam (fine-silty, siliceous, thermic Typic Glossaqualfs); and on the Drew County site, the soils are Ouacuta silt loam (fine-silty, siliceous, thermic Fluventic Dystrochrepts).

A dominant or codominant cherrybark oak that would be chosen as a crop tree during thinning was used for the central tree of each plot. For this study, a crop tree was considered a cherrybark oak tree that satisfied the objective of growing high-quality sawtimber. The spatial locations of all trees larger than 10.0 cm in diameter at breast height (d.b.h.) were recorded. Instruments used to map the tree locations included a ForestPro laser hypsometer-rangefinder, and a MapStar Angle Encoder (LaserTech, Inc.). Each tree's d.b.h. was measured and the species and crown class determined. Additional measurements collected for the overstory trees (dominant, codominant, and intermediate crown classes) included total height, height to the base of the crown, and vertically projected crown radius in each of the four cardinal directions. Tree heights were measured with the ForestPro, and the vertical projection of the crown edge was determined using a GRS Densitometer, whenever possible, to ensure vertical viewing. Additional data collected for the central crop tree and the two trees considered to be its main competitors included the vertically projected crown radius in four additional directions (total of eight directions). The two

[1]Graduate Research Assistant, Associate Professor, and Weaver Brothers Professor of Forestry, School of Renewable Natural Resources, Louisiana State University AgCenter, Baton Rouge, LA 70803, respectively.

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main competitors were determined by assessing crown proximity and overlap and the relative tree heights. Crown-class score as defined by Meadows and others (2001), was also determined for the central tree and the two competitors. This crown class numerical rating system assigns ratings for four criteria: (1) direct sunlight from above — values from 0 to 10; (2) direct sunlight from the sides — values from 0 to 10; only the upper half of the crown length was used for this criterion; (3) crown balance — values 1 to 4 were assigned according to the number of quadrants occupied by 20 percent or more of the total crown volume; and (4) relative crown size — values 1 to 4 were assigned for appropriate crown size and density as related to a tree of that diameter and species; one point was assigned if crown size and density were severely limiting to growth, two points if limiting to growth, three points if somewhat limiting to growth, and four points if not limiting to growth.

The point values for the criteria were summed, and crown class was assigned in the following manner: 24-28 points = dominant, 17-23 points = codominant, 10-16 points = intermediate, and 2-9 points = suppressed.

Following the measurements, the crop tree and the two trees considered to be its main competitors were cut. Cross-sections were obtained from 1.37 m (breast height) above the ground. The disks were sanded, and the radial growth for the previous 5 full years was measured in the four cardinal directions. This was not done for competitors that were not from the red oak group. The total number of red oak group trees cut from all 9 plots was 16 cherrybark oaks, 7 water oaks (*Q. nigra* L.), and 1 Nuttall oak (*Q. nuttallii* Palmer).

In this paper, the predicted variables are referred to as dependent variables, and the predictor variables (regressors) are referred to as independent variables. Three dependent variables were measured or calculated from the harvested trees: (1) 5-year d.b.h. growth, (2) 5-year basal area growth, and (3) percent basal area growth (ratio between the 5-year basal area growth and the basal area of the tree 5 years prior to cutting).

The independent variables considered in the analysis included: (1) d.b.h. of the tree 5 years prior to cutting, (2) basal area of the tree 5 years prior to cutting, (3) crown-class score (after Meadows and others 2001), (4) score for direct sunlight from above and from the sides (after Meadows and others 2001), (5) basal area of all plot trees, (6) basal area of all plot trees except the suppressed, (7) basal area of all oak trees on the plot, (8) basal area of all oak trees on the plot except the suppressed, (9) mean crown diameter of the overstory trees, (10) projected crown area, and (11) ratio between the projected crown area and the basal area of the tree 5 years prior to cutting.

The initial regression analysis included simple linear regression analysis. Each dependent variable was regressed against each of the independent variables to assess which independent variable accounted for the most variability in the dependent variable. This was followed by multiple linear regression analysis, where each of the three dependent variables was regressed against all independent variables. The selection of the independent variables to remain in the model was performed by the stepwise selection procedure (SAS 1991). The procedure required the variables to be included in the model if their significance level was less than 0.05 and to be excluded if their significance was over 0.10 after the inclusion of a new variable.

RESULTS

Among the simple linear regression models that used diameter growth as the dependent variable, there were three models whose independent variables were significant at the 0.05 level (table 1). Those three models included one of the following independent variables: score for direct sunlight from above and from the sides, crown-class score, and tree d.b.h. 5 years prior to cutting. The independent variables in the first two models accounted for 55 and 54 percent of the variability in the model, respectively, whereas the last model accounted for only 22 percent. The variability in the models was better accounted for by the crown-based variables than by the d.b.h.-based variable.

Table 1—Simple linear regression models for the three dependent variables. Shown are the independent variables significant at the 0.05 level

Dependent variable	Independent variable	r^2	*P*-value
5-year d.b.h. growth	Score for direct sunlight from above and from the sides[a]	0.55	< 0.001
	Crown-class score[a]	0.54	< 0.001
	D.b.h. of the tree 5 years prior to cutting	0.22	0.022
5-year basal area growth	Basal area of the tree 5 years prior to cutting	0.63	< 0.001
	D.b.h. of the tree 5 years prior to cutting	0.62	< 0.001
	Projected crown area	0.44	< 0.001
	Crown-class score[a]	0.39	0.001
	Score for direct sunlight from above and from the sides[a]	0.39	0.001
	Mean crown diameter of the overstory trees	0.36	0.002
	Basal area of all plot trees except the suppressed	0.27	0.010
Percent basal area growth	Score for direct sunlight from above and from the sides[a]	0.32	0.004
	Crown-class score[a]	0.30	0.006

[a] For definitions of score for direct sunlight from above and from the sides and crown-class score, see the crown-class system by Meadows and others (2001) in the Methods section.

For the simple linear regression models with five-year basal area growth as the dependent variable, there were more models with significant independent variables at the 0.05 level. Each of these models included one of the seven variables: basal area of the tree 5 years prior to cutting, d.b.h. of the tree 5 years prior to cutting, projected crown area, crown-class score, score for direct sunlight from above and from the sides, mean crown diameter of the overstory trees, and basal area of all plot trees except the suppressed (table 1). In general, these variables accounted for a larger amount of the variability in the models compared to the previous case, where the dependent variable was the 5-year d.b.h. growth. The variables basal area of the tree 5 years prior to cutting and d.b.h. of the tree five years prior to cutting had r^2 values of 0.63 and 0.62, respectively. The projected crown area had an r^2 of 0.44, and the latter four variables had r^2 of 0.39, 0.39, 0.36, and 0.27, respectively.

When percent basal area growth was the dependent variable, there were two highly significant variables - score for direct sunlight from above and from the sides, and crown-class score (table 1). However, all variables accounted for only a small part of the variability in the model – 32 and 30 percent, respectively.

Multiple linear regression analysis was then performed on the same three dependent variables; results are presented in table 2. The standardized coefficients demonstrate the relative importance of each variable for the model. For example, for the first dependent variable, the standardized coefficient of 0.73 for the variable score for direct sunlight from above and the sides means that: a one-standard deviation change in the independent variable will lead to a 0.73-standard deviation change in the dependent variable. Thus, it is clear that in this case, the particular variable is more "important" for the model than the second variable—basal area of all oak plot trees except the suppressed, whose standardized coefficient is only 0.29. For the model for 5-year basal area growth, the standardized coefficients differ less from each other. This indicates that the two selected independent variables contribute similarly to the model. In the third multiple linear regression model, where the percent basal area growth is the dependent variable, the standardized coefficients suggest that the variable score for direct sunlight from above and from the sides is more "important" for the model than the mean crown diameter of the overstory trees and basal area of all plot trees.

DISCUSSION

Five-year basal area growth was the factor with the most variability accounted for by the individual independent variables assessed (table 1). When multiple linear regression was performed, the 5-year basal area growth was again the dependent variable with the most variance accounted for (table 2). Unlike the simple linear regression models, the multiple linear regression model for the percent basal area growth accounted for slightly more variation than the model for 5-year d.b.h. growth. The variables crown-class score and score for direct sunlight from above and from the sides appeared to be significant in the simple linear models for all three dependent variables. Additionally, the score for direct sunlight from above and from the sides was selected by the stepwise selection method in each of the three multiple linear regression models. Moreover, the standardized coefficients suggested that this crown-based variable was substantially more "important" than the other

Table 2—Multiple linear regression models for tree growth[a]

Dependent variable and R^2	Independent variable	Unstandardized coefficient	Standardized coefficient	*P*-value
Model 1	Intercept	-13.49	—	0.052
5-year d.b.h. growth				
$R^2 = 0.63$	Score for direct sunlight from above and from the sides[b]	1.89	0.73	< 0.001
	Basal area of all oak plot trees except the suppressed	0.46	0.29	0.038
Model 2	Intercept	-133.60	—	0.013
5-year basal area				
growth$R^2 = 0.78$	Basal area of the tree 5 years prior to cutting	0.08	0.66	< 0.001
	Score for direct sunlight from above and from the sides[b]	11.71	0.40	0.001
Model 3	Intercept	15.35	—	0.004
Percent basal area				
growth $R^2 = 0.77$	Score for direct sunlight from above and from the sides[b]	1.01	0.86	< 0.001
	Mean crown diameter of the overstory trees	-0.01	-0.50	0.001
	Basal area of all plot trees	-0.48	-0.36	0.008

[a] The independent variables were selected by the stepwise procedure (SAS 1991).

[b] For definitions of score for direct sunlight from above and from the sides and crown-class score, see the crown-class system by Meadows and others (2001) in the Methods section.

predictor variables in the models with 5-year d.b.h. growth and percent basal area growth and almost as "important" in the basal area growth model (table 2). Therefore, it appears that the amount of direct sunlight from above and the direct sunlight reaching the upper 50 percent of the crown accounted for most of the variability in diameter and basal area growth. The inclusion of the crown characteristics balance and relative crown size in the crown-class score did not provide a better fit. It is possible that the first two criteria of the crown-class system by Meadows and others (2001) have the most impact on the growth in diameter and basal area. However, thinning may alter these relationships and the growth of other trees remaining after a thinning operation.

Although this study does not have the same design as studies by O'Neal and others (1994) and Cole and Lorimer (1994), some comparisons can be made. This study's multiple regression model for diameter growth accounted for a larger amount of the variability than the model of O'Neal and others (1994): an R^2 of 0.63 for this study's species from the red oak group versus O'Neal and others' (1994) 0.30 and 0.39 for white oak (*Quercus alba* L.) and southern red oak (*Quercus falcate* Michx.), respectively. A new crown-based variable, crown position index (CPI), was tested by O'Neal and others (1994). This variable was based on the relative crown position and crown size as expressed by crown projections and relative heights of the crop trees and their competitors and was calculated by a formula. Calculating the index required the collection of numerous measurements on the crop tree and the competitors. In contrast, determining the score for the criteria direct sunlight from above and from the sides from the rating system by Meadows and others (2001) does not require direct measurements and is easily determined visually. Moreover, as seen by the coefficients of determination above, it appeared to have a higher correlation to the d.b.h. growth than the CPI.

The results for basal area growth models were similar to those of Cole and Lorimer (1994). This study achieved R^2 of 0.78, whereas the models of Cole and Lorimer (1994), who worked with sugar maple (*Acer saccharum* Marsh.), white ash (*Fraxinus americana* L.), and basswood (*Tilia americana* L.), accounted for 0.79, 0.88, and 0.81 of the variability, respectively. They also found the percent-exposed crown area (ECA) to be a variable of specific interest, so it was included in the basal area growth models for all three tree species they worked with. The authors indicated that percent ECA can be used as a crown competition variable to estimate the competitive effects without direct measurement of any of the competitors, which would save field measurement time. However, some measurements on the crop tree are still necessary. Unlike the procedure for measuring and calculating the percent ECA, the procedure for determining the score for direct sunlight from above and from the sides requires neither measurements on any tree, including the crop tree itself, nor calculations (other than a simple summation of two numbers between 0 and 10), which should make it more appealing for use by practitioners in the field. In addition, all variables in the basal area growth models in the study by Cole and Lorimer (1994) are log-transformed. The interpretation for the basal area growth model in this study is straightforward; the results from table 2 clearly indicate that a one-point increase in the score for direct sunlight from above and from the sides will correspond to an 11.71 cm^2 increase in the basal area growth of the tree over the following 5-year period. Nevertheless, some transformation of the model variables in this study and the addition of more data may further improve the performance of the models. The comparisons indicate that the performance of the models in this study is comparable to others reported in the literature

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