DEVELOPMENT OF GROWTH AND YIELD MODELS FOR SOUTHERN HARDWOODS: SITE INDEX DETERMINATIONS

John Paul McTague, Daniel J. Robison, David O'Loughlin, Joseph Roise, and Robert Kellison[1]

Abstract—Growth and yield data from across 13 southern States, collected from 1967 to 2004 from fully-stocked even-aged southern hardwood forests on a variety of site types, was used to calculate site index curves. These derived curves provide an efficient means to evaluate the productivity-age relation which varies across many sites. These curves were derived for mixed-species and represent a substantial improvement over previously available curves of this nature. These site index curves will be used as a "productivity driver" in the development of growth and yield models for these forest types.

INTRODUCTION

Growth and yield information are reasonably well-documented for species that occupy pure natural stands and plantations. Such is the case with the southern pines (*Pinus* spp.), especially loblolly (*P. taeda* L.) and slash (*P. elliottii* Engelm.) pines for which multiple growth and yield tables have been developed (Burkhart and Strub 1974, Clutter 1963, Clutter and Jones 1980, Hafley and Buford 1985). Species that occur in mixed stands are much more difficult to model unless they have similar growth rates and quality attributes. The southern hardwoods are difficult to quantify for growth and yield parameters because of the diversity of species within and among site types. Of the 214 million acres of forest land in the South, hardwoods occupy about 120 million (FIA 2002). Rauscher and others (2000) performed an accuracy test on 10 publicly available hardwood growth and yield models and found some models performed well while others were lacking. In this paper, we report the development of site index curves for a variety of stand and species types typical of even-aged southern hardwoods. These curves, representing the influence of site type = productivity on tree growth rates, will be used as drivers in the development of growth and yield models.

PROCEDURE

In 1967, the Hardwood Research Cooperative at North Carolina State University initiated a project to develop growth and yield tables for southern hardwoods. The first effort was to recognize the forest site types that were of sufficient size to be identified as separate operating units. Nine such units were identified, six in the Coastal Plain (red river bottoms, black river bottoms, branch bottoms, muck swamps, peat swamps, wet flats) and three in the Piedmont/mountains (bottomlands; coves, gulfs and lower slopes; upland slopes and ridges).

Plots, totaling 641, were established by members of the Hardwood Research Cooperative from Delaware to Florida and Texas. The stands selected for plot establishment were relatively even-aged, fully stocked, and otherwise unmanaged. Thus results from this study cannot be extrapolated with accuracy to stands that have been abused, thinned, or subjected to various intermediate stand treatments. Selecting a uniform distribution of age classes was a challenge, because prolonged selective cutting from above in many southern hardwood forests has created stands with two or more age classes. Such stands were avoided in plot establishment to the extent possible. Plots were established in stands ranging from 20 to 60 (± 10 years) years old.

Circular 0.2-acre plots were used, in which all trees > 5.5 inches d.b.h. were measured by species and age for total height, merchantable height, d.b.h., and stand density. Merchantable height to the nearest foot was measured to a 4-inch top (outside bark). A subplot of 0.01-acre was installed within the 0.2-acre plot for the measurement of number of stems by species, by 1-inch diameter class, from 1.6 to 5.5 inches d.b.h. Seedlings and sprouts smaller than 1.6 inches d.b.h. were recorded by species without regard to diameter or height class. Of the 641 plots installed, 187 were maintained for repeated measurements on a 5-year cycle, and 146 were observed more than once (13,008 trees were used in the data analysis).

RESULTS AND DISCUSSION

Some southern hardwood site types are much more productive than others, and in addition, within a single site type, productivity will vary. In the Southern United States forests, the most commonly used method to quantify stand productivity is site index (the expected tree height at a given base age). Site index curves are almost always species specific. In Carmean and others' (1989) inventory of site index curves for the Eastern United States, 127 individual curves were presented representing a wide range of species and conditions. Most were for a single species. The best example of a mixed species curve is for upland oaks, where Olsen (1959) combined data for white, northern red, scarlet, black, and chestnut oaks (*Quercus* spp.). As noted by Avery and Burkhart (2002), the concept of single species site index is not generally well-suited for mixed-species stands. Hardwood stands are commonly mixed species.

Southern hardwood stands have a wide range of species with a mix often confounded by past management practices.

[1] Timberland Investment Resources, LLC, Atlanta, GA 30326 and Adjunct Professor, Department of Forestry and Environmental Resources, North Carolina State University, Raleigh, NC 27695; and Associate Professor, Research Assistant, Professor, and Professor Emeritus, respectively, Department of Forestry and Environmental Resources, North Carolina State University, Raleigh, NC 27695.

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.

Quantifying site productivity is difficult, in part because site quality changes between species for the same parcel of land. To standardize the measurement of site quality, height/age curves for mixed species stands needed to be developed. This is an extension of the concept of site quality being the integration of genetic quality, fertility, water, and climate over time.

In the development of a height over age relation, we went through many iterations. We ultimately selected polymorphic site index curves for our purpose and used the equation form and two-step procedure discussed by Bailey and Clutter (1974). The equation has the form:

$$\ln H = a_i + b(1/A)^k \tag{1}$$

where

a_i = the site specific intercept

b = the common slope

k = the linearization parameter.

Following the methodology outlined by Bailey and Clutter (1974), we first developed an estimate for k, where

$$\hat{k} = 0.38509 \tag{2}$$

Once k was predetermined, the equation was linear, and a linear model could be used to estimate parameters a and b. This is where we deviated in a subtle way from Bailey and Clutter (1974). We continued to model $(1/A)^k$ as the covariate; however, instead of treating the plots as fixed effects of the intercept, we felt that it was more logical to treat the plots as a random effect and that the repeated height observations within each plot were correlated. The remeasurements, which were 5 years apart, led inevitably to a positive autocorrelation, implying that an above-average value on a plot was likely to be followed by another above-average value. Failing to recognize the within-plot correlation is not especially serious, since it is likely that the estimated parameters are unbiased. In the presence of autocorrelation, the precision of the estimators is usually overstated, resulting in *p*-values that are too small (Schabenberger and Pierce 2001). Recognizing that many forestry studies have either missing measurements or a remeasurement schedule that varies from study to study, it was decided to model covariance structure of the error using exponential spatial covariance structure. We employed SAS PROC MIXED to estimate the coefficients. The resulting height age model was:

$$\ln H = 5.5253 - 4.2858\left(\frac{1}{A^{0.38509}}\right) \tag{3}$$

where

5.5253 = the average intercept value. A family of site index curves was derived by isolating the $\hat{b}$ term and imposing the condition that at base age 25, height = S; then

$$-4.2858 = (\ln S - 5.5253)25^{0.38509} \tag{4}$$

Substituting this last equation (4) into the previous one (3) and solving for H we get:

$$H = 251(\frac{S}{251})^{\left(\frac{25}{A}\right)^{0.38509}} \tag{5}$$

where

S = site index (base age 25)

H = predominant mean height (40 tallest trees per acre)

A = total stand age.

The fit index (F.I.) is:

$$(1\text{-}2.707805/32.19649) = 0.9159 \tag{6}$$

where F.I. is defined as 1-SSE/SS_y. ANOVA was used to estimate SS_y, and the SAS means procedure was used to estimate the SSE. The residual is computed after including both random and fixed terms in equation (3). REML rather than ordinary least squares was used to estimate the parameters. The site index curves expressed in equation (5) are shown in figure 1.

These site index curves represent a substantial advance in our ability to model productivity across a range of site types for even-aged southern hardwoods. The data from the plots were then used to calculate and model southern even-aged hardwood merchantable stand survival, basal area projection, total number of merchantable trees including ingrowth, ingrowth basal area, stand-level and individual tree-level equations, individual tree mortality and growth, individual tree height prediction and diameter projection, submerchantable tree estimations, and volume estimation (inside and outside bark for total volume, merchantable volume, and volume ratio).

ACKNOWLEDGMENTS

NC State Hardwood Research Cooperative members 1967 to 2004: North Carolina Forest Service, South Carolina Forestry Commission, Union Camp Corporation, Champion Corporation, Federal Paper Board Company, Hammermill Company, International Paper Company, Tennessee Valley Authority, Scott Paper Company, Kimberly-Clark Company, The Timber Company, Georgia-Pacific Corporation, Westvaco Company, Weyerhaeuser Company, Sunoco Forest Products Company, T&S Hardwoods, Inc., Alabama River Woodlands Company, Rayonier Corporation, Chesapeake Company, Temple-Inland Forest Products Corporation, Jefferson-Smurfit Company, American Cyanamid Corporation, and BASF Corporation.

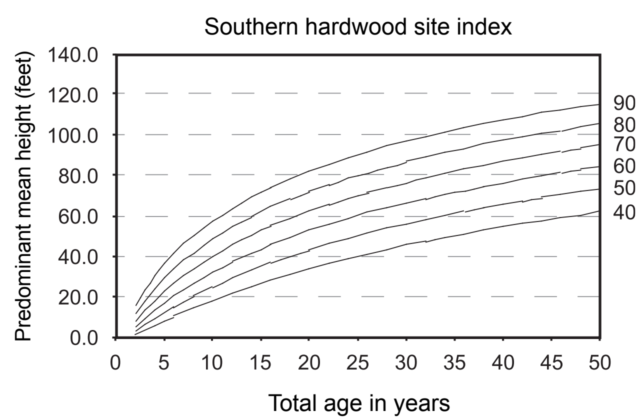

Figure 1—Site index curves for mixed species southern hardwood stands. These are from the polymorphic Bailey-Clutter approach modeled with a mixed model analysis of covariance with plot location as a random effect. Site index base age is 25 years.

LITERATURE CITED

Avery, T.E.; Burkhart, H.E. 2002. Forest measurements. Fifth edition. New York, New York: McGraw Hill. 455 p.

Bailey, R.L.; Clutter, J.L. 1974. Base-age invariant polymorphic site curves. Forest Science. 20: 155-159.

Burkhart, H.E.; Strub, M.R. 1974. A model for simulation of planted loblolly pine stands. In: Fries, J., ed. Growth models for tree and stand simulation. Research Notes No. 30. Stockholm, Sweden: Royal College Forestry: 128-135.

Carmean, W.H.; Hahn, J.T.; Jacobs, R.D. 1989. Site index curves for forest tree species of the Eastern United States. Gen. Tech. Rep. NC-128. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 148 p.

Clutter, J.L. 1963. Compatible growth and yield models for loblolly pine. Forest Science. 9: 354-371.

Clutter, J.L.; Jones, E.P. 1980. Prediction of growth after thinning in old-field slash pine plantation. Res. Pap. SE-217. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. 14 p.

Forest Inventory and Analysis – Southern Region (FIA). 2002. Draft RPA 2002. Forest resource of the United States. http://ncrs2.fs.fed.us/4801/fiadb/rpa_tabler/Draft_RPA_2002_Forest_Resource_Tables.pdf.

Hafley, W.L.; Buford, M.A. 1985. A bivariate model for growth and yield prediction. Forest Science. 31: 237-247.

Olsen, D.F. 1959. Site index curves for upland oak in the Southeast. Res. Note SE-125. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. 2 p.

Rauscher, H.M.; Young, M.J.; Webb, C.D.; Robison, D.J. 2000. Testing the accuracy of growth and yield models for Southern hardwood forests. Southern Journal of Applied Forestry. 24: 176-185.

Schabenberger, O.; Pierce, F.J. 2001. Contemporary statistical models for the plant and soil sciences. Boca Raton, FL: CRC Press. 738 p.