INFLUENCE OF WEATHER AND CLIMATE VARIABLES ON THE BASAL AREA GROWTH OF INDIVIDUAL SHORTLEAF PINE TREES

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An individual-tree basal area growth model previously developed for even-aged naturally occurring shortleaf pine trees (*Pinus echinata* Mill.*)* in western Arkansas and southeastern Oklahoma did not include weather variables. Individual-tree growth and yield modeling of shortleaf pine has been carried out using the re-measurements of over 200 plots permanently established on the Ozark and Ouachita National Forests during the period 1985-1987. Different basal area growth models for shortleaf pine have been proposed previously, such as a model that was part of a distance-independent individual-tree simulator (Lynch and others 1999) and a model that utilized nonlinear mixed modeling of basal area growth (Budhathoki and others 2008). However, none of the previous studies incorporated the influence of the weather and climate variables in the individual-tree growth prediction models.

Change in forest productivity is the response of trees subject to varying temperature and precipitation over long time scales (Boisvenue and Running 2006). Monitoring of tree performance and response to changes in weather and climate is useful in understanding the limiting factors for forest growth on particular sites (Miller and others 2004). We used the geographic coordinates of the plots to obtain weather and climate variables in an attempt understand the influence of those climatic variables in a shortleaf pine individual-tree basal area growth model.

The GPS location of the plot was used to select the nearest weather station for each of the 129 permanent 0.2-acre fixed-radius plots that we used in this study. Maximum air temperature, average air temperature, and precipitation recorded for the weather station nearest to each plot were used as periodic climate variables. Four periodic measurements of individual trees on each plot were used to develop data for three growth periods on each plot. Lynch and others (1999) and Budhathoki and others (2008) estimated parameters in nonlinear model 1 (base model) using ordinary least squares. In this base model, average annual individual-tree basal area growth was predicted using explanatory variables, including midpoint individual-tree basal area, maximum expected individual-tree basal area for shortleaf pine trees, stand age for the plot, and the ratio of individual-tree diameter to the quadratic mean plot diameter. Weather variables including periodic average daily maximum temperature, periodic average daily mean temperature, and periodic average daily precipitation were added in the base model to construct model 2. Daily averages were for a growing season extending from March 1 to September 30.

We used nonlinear modeling methods to estimate parameters in an individual-tree basal area growth model for shortleaf pine using the Proc NLIN procedure with SAS 9.3, and nls2 package with R 2.15.2. The equation used in model 2 showed some potential for weather variables to improve predictions for the annual basal area growth of individual shortleaf pine trees. Parameter estimates for both models were significant ($\alpha = 0.05$). The estimates of parameters associated with tree measurement variables were similar in both models 1 and 2. Table 1 presents means and standard

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Citation for proceedings: Holley, A. Gordon; Connor, Kristina F.; Haywood, James D., eds. 2015. Proceedings of the 17th biennial southern silvicultural research conference. e–Gen. Tech. Rep. SRS–203. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 551 p.

Table 1--Summary of the data used to fit parameters to an individual-tree basal area growth model 1 and model 2 for Growth Period 1 (GP1), Growth Period 2 (GP2), and Growth Period 3 (GP3)

	----------GP1----------		---------GP2----------		----------GP3----------	
Variables	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.
Average BA[a] growth per tree (*ft²/year*)	0.0123	0.0105	0.0138	0.0123	0.0147	0.0125
Mid-point BA for tree in period (*ft²*)	0.3540	0.3646	0.4168	0.4013	0.5771	0.4529
Stand age (*years*)	41.681	18.724	46.677	18.726	50.777	18.221
Midpoint value of stand BA (*ft²/acre*)	107.318	29.017	127.033	33.895	108.693	35.481
Quadratic mean diameter (*inches*)	7.451	3.230	8.223	3.203	9.426	2.935
Avg. daily max. temperature (*°F*)[b]	81.657	2.684	80.187	2.818	81.947	3.465
Avg. daily mean temperature (*°F*)[b]	69.865	1.915	69.041	2.117	70.378	2.343
Avg. daily precipitation (*inches*)[b]	0.1619	0.0163	0.1515	0.0153	0.1315	0.0149

[a]BA = basal area.
[b]Average over growing season (1st March to 30th September).

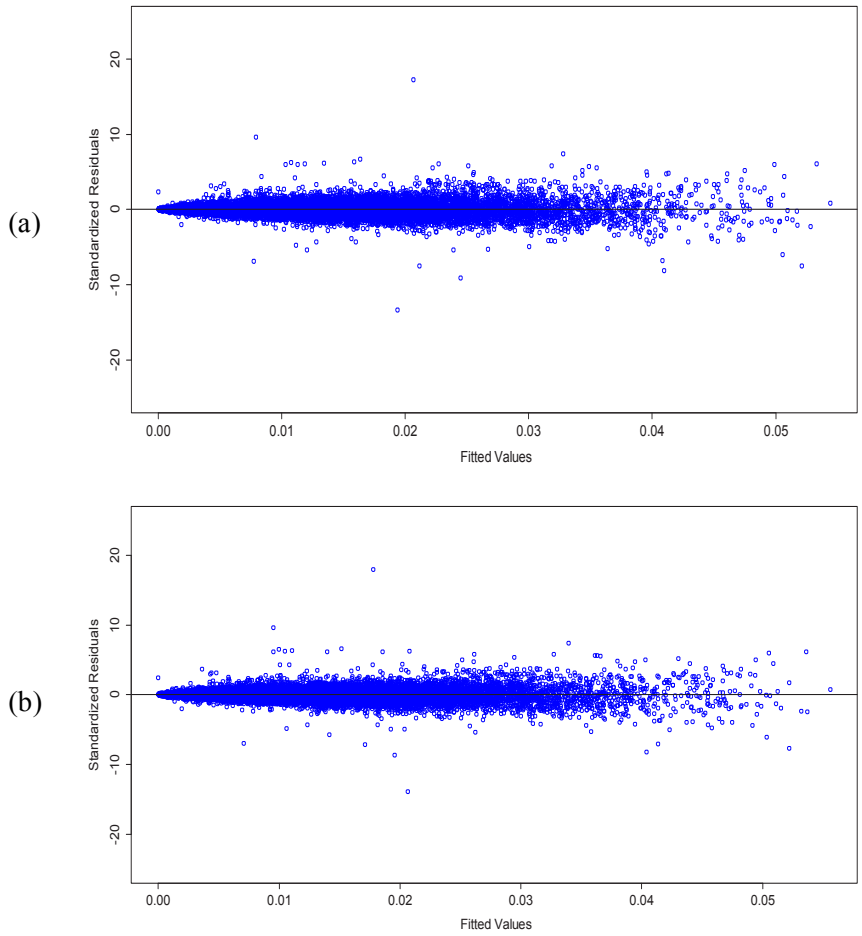


Figure 1—Standardized residuals versus fitted values of a basal area growth model for shortleaf pine using: (a) model 1 and (b) model 2.

deviations for variables used in the model by growth period for three periods. The mean square error of model 1 was 0.000058 and of model 2 was 0.000055, indicating that addition of weather and climate variables reduced the mean square error. When compared using the corrected total sum of squares, we found that the fit index (proportion of total variation explained by the model) of model 2 (0.6169) was slightly better than model 1 (0.5964). The summary of fit statistics for the models were as follows: (a)Akaike's information criterion (AIC) of model 1 was -100540.1 and of the model 2 was -101381; (b) Bayesian information criterion (BIC) of model 1 was -100479.6 and of model 2 was -101297.8; and (c) the residual standard error of model 1 was 0.007144 and of model 2 was 0.006935.

We found that non-linear least squares modeling methods with weather variables used to estimate parameters in an individual-tree basal area growth model for naturally occurring shortleaf pine indicated better fit than a model without weather variables. A small but significant influence of weather variables including precipitation and average air temperature was observed in the modified individual-tree basal area growth model of shortleaf pine.

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