A WHOLE STAND GROWTH AND YIELD SYSTEM FOR YOUNG LONGLEAF PINE PLANTATIONS IN SOUTHWEST GEORGIA

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Abstract—A whole stand growth and yield system for planted longleaf pine (*Pinus palustris* Mill.) was developed from permanent plot data collected annually over an 8 year period. The dataset consists of 12 intensively-managed longleaf pine plantations that are located in Lee, Worth, Mitchell, and Baker counties in southwest Georgia. Stand survival, dominant height, basal area, and cubic foot volume yield models were developed and incorporated in a computer growth and yield simulator. Model prediction error remained low across a variety of planting densities.

INTRODUCTION

A whole stand growth and yield system was developed for young (< age 20) longleaf pine (*Pinus palustris* Mill.) plantations based on a permanent plot system from 15 plantations located in the Flint River Basin of southwest Georgia. A system of equations was developed for stand survival, dominant height, basal area per acre, and cubic foot volume outside bark (ob) per acre. Initial testing using a west gulf system developed by Lohrey and Bailey (1976) provided less than acceptable results, especially for the dominant height prediction model.

STUDY DESCRIPTION

The longleaf pine data is part of a growth and yield study from 15 stands located in Lee, Worth, Mitchell, and Baker counties in southwest Georgia. Sample plots are approximately 0.1 (mean 0.10585) acre in size with stands ranging from 2 to 19 years old. Stand density ranges from 273 to 940 trees per acre and from 5 to 136 square feet of basal area per acre. Rectangular fixed area plots were established at different dates and have been remeasured annually; thus the number of measurements available per plot ranges from 2 to 10. A total of 105 plot measurement and remeasurement observations are available providing 49 unique growth intervals.

At each measurement date, diameter at breast height (d.b.h.) was measured with a diameter tape and recorded for every tree to the nearest 0.1 inch. Total tree height was measured with a height pole or an Impulse laser (depending upon tree size) and recorded to the nearest 0.1 foot. Trees < 15 feet were measured with a height pole while taller trees were measured with an Impulse 200 laser. Initially, crown class was recorded for just the older stands (> 12 years) except for the most recent measurement period, where crown class was assigned to all trees, regardless of age. The traditional definition of crown class was slightly modified in order to assign crown class to the younger aged stands. The younger plantations generally have wider initial planting spacing, and thus all trees receive full sunlight. The codominant crown class was defined as those trees that make up the main crown canopy, while intermediate and suppressed classes were assigned to those trees visually shorter (and usually less vigorous) than the trees that constitute the average crown height. Cubic foot volumes are based on a taper function developed by Brooks and others (2002) based on trees sampled from the same plantations.

SURVIVAL PROJECTION

A survival projection model commonly employed for loblolly (*Pinus taeda* L.) and slash pine (*Pinus elliottii* Engelm. var. *elliottii*) plantations (Pienaar and others 1988) was used to model stand level survival. Since mortality in these young stands was negligible, this model was fit independently from the other stand level models, and initial planting density was included as an initial condition. The model is of the form:

$$N_2 = N_1 * Exp\left\{\alpha_1\left(\left(\frac{A_2}{10}\right)^{\alpha_2} - \left(\frac{A_1}{10}\right)^{\alpha_2}\right)\right\} \qquad (1)$$

where

N_2 = projected survival in trees per acre at age A_2,

N_1 = current trees per acre at age A_1, and

α_1, α_2 = parameters to be estimated from the data.

DOMINANT HEIGHT PROJECTION

The algebraic difference equation form of a modified Chapman-Richards height/age projection function was selected as the model form:

$$DHT_2 = DHT_1\left[\frac{1 - Exp(\beta_1 * A_2)}{1 - Exp(\beta_1 * A_1)}\right]^{\beta_2} \qquad (2)$$

where

DHT_2 = projected dominant height at age A_2,

DHT_1 = current dominant height at age A_1, and

β_1, β_2 = parameters to be estimated from the data.

This equation form has been used successfully in both loblolly (Pienaar and Shiver 1980) and slash (Pienaar and Shiver 1984) pine plantations. All possible non-overlapping growth intervals were used to fit this nonlinear, two parameter model. This model was fitted as part of a system of equations which also included a basal area projection model, a volume prediction model, and a volume projection model.

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BASAL AREA PROJECTION

The following algebraic difference model was selected from several model forms tested. Once non-significant parameters were removed, the final model was of the form:

$$BA_2 = Exp\left\{Ln\left(BA_1\right) + \delta_1\left(Ln\left(DHT_2\right) - Ln\left(DHT_1\right)\right) + \delta_2\left(Ln\left(N_2\right) - Ln\left(N_1\right)\right)\right\} \quad (3)$$

where

BA_2 = projected basal area at age A_2,

BA_1 = current basal area at age A_1,

δ_1, δ_2 = parameters to be estimated from the data, and other variables as previously defined.

VOLUME PREDICTION AND PROJECTION

In order to make the system more flexible, both a volume prediction and projection model were fitted to the data. The final form of the volume prediction model was:

$$V_1 = Exp\left\{\lambda_1 + \lambda_2 * Ln\left(DHT_1\right) + \lambda_3 * Ln\left(N_1\right) + \lambda_4 * Ln\left(BA_1\right)\right\} \quad (4)$$

where

V_1 = current cubic foot volume (ob) at age A_1,

λ_i = parameters to be estimated from the data,

i = 1..4, and other variables as previously defined.

The projection model is an algebraic difference form of equation (4):

$$V_2 = Exp\left\{Ln\left(V_1\right) + \theta_1 * \left(Ln\left(DHT_2\right) - Ln\left(DHT_1\right)\right) + \theta_2 * \left(Ln\left(BA_2\right) - Ln\left(BA_1\right)\right)\right\} \quad (5)$$

where

V_2 = projected cubic foot volume (ob) at age A_2,

θ_i = parameters to be estimated from the data,

i = 1,2, and other variables as previously defined.

All equations except the survival prediction model were fitted as a system of seemingly unrelated regressions (SUR) using SAS SYSNLIN (SAS 1993).

RESULTS AND CONCLUSIONS

Parameter estimates for each model are displayed in table 1. In addition, the fit statistics of average bias $\left(\frac{\sum_{i=1}^{n}\left(\hat{Y}_i - Y_i\right)}{n}\right)$ and root mean squared error $\left(\sqrt{\frac{\sum_{i=1}^{n}\left(\hat{Y}_i - Y_i\right)^2}{n}}\right)$ were computed for each model form and are displayed in table 2. Residual analysis for each model did not indicate any unusual trends in the data even though the stands cover a wide range of planting densities and site types. The technique employed provides an accurate whole stand growth and yield system for the longleaf pine plantations that comprise this dataset. Due to the limited size of the dataset, no independent verification of this prediction system was tested. In addition, the effects of potential correlation from the use of plot remeasurement data have not been investigated. This dataset does include a variety of densities and also includes cutover as well as oldfield sites. Extrapolation to other datasets should be conducted with caution due to the limited age distribution. In addition, caution must be employed when projecting stands beyond the upper age limits of the existing data; the older stands are just reaching the point of self thinning, so the existing survival model may not accurately account for this mortality. However, it does provide a system that should be applicable to plantations in this region whose ages are consistent with those currently in the Conservation Reserve Program. A computer simulation system incorporating these models can be obtained from the primary author.

Table 1—Parameter estimates for the planted longleaf pine growth and yield system

Parameter	Estimate	Approximate Pr > |t|
α_1	-0.206745	< 0.0001
α_2	0.360652	< 0.0001
β_1	-0.07576	< 0.0001
β_2	2.099041	< 0.0001
δ_1	1.817699	< 0.0001
δ_2	7.398342	0.0227
λ_1	-0.70743	< 0.0001
λ_2	1.004848	< 0.0001
λ_3	0.025178	0.0239
λ_4	0.97592	< 0.0001
θ_1	1.458852	0.0010
θ_2	0.642513	0.0276

Table 2—Fit statistics for the system of growth and yield models by model type

Model	n	Average bias	RMSE
N_2	49	1.706	10.076
DHT_2	49	-0.002	0.622
BA_2	49	0.317	3.483
V_1	49	-2.970	18.235
V_2	49	8.080	77.374

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