

Growth Reductions in Naturally Regenerated Southern Pine Stands in Alabama and Georgia

G.A. Ruark, Southeastern Forest Experimental Station, P.O. Box 2680, Asheville, NC 28802, **C.E. Thomas**, Southern Forest Experiment Station, **W.A. Bechtold**, Southeastern Forest Experiment Station, and **D.M. May**, Southern Forest Experiment Station

ABSTRACT. Data from Forest Inventory and Analysis (FIA) units of the USDA Forest Service were used to compare average annual stand-level basal area accretion onto survivor pines in naturally regenerated pine stands throughout Alabama and Georgia. Growth rates measured between 1972–82 were compared to growth rates during the previous 10-year survey cycle in each state. Separate analyses were conducted for loblolly (*Pinus taeda*), longleaf (*P. palustris*), shortleaf (*P. echinata*), and slash (*P. elliotii*) pine cover types. The unadjusted average stand-level growth rates for survivor pines 1.0 in. diameter and greater at breast height were notably lower for all cover types during the latter survey in Georgia, while only the average unadjusted growth of shortleaf was substantially lower during this period in Alabama. However, when growth rates were adjusted with regression models to account for differences in initial stand structure (stand size class, stand density, site quality class, hardwood competition, and mortality) between the two survey periods, reductions in average adjusted basal area growth ranged from 3% to 31% during the later cycle in both states. The reductions were statistically significant in almost every case. The agents causing the growth differences were not identified, but it is unlikely that stand dynamics are responsible. The observational nature of the FIA dataset precludes further resolution of causal relationships.

South. J. Appl. For. 15(2):73–79.

Reductions in the average radial increment of naturally regenerated yellow pines over broad areas of the Southeastern United States

were reported by the Forest Inventory and Analysis (FIA) Unit of the Southeastern Forest Experiment Station (Sheffield et al. 1985). Sheffield and Cost (1987), and Lucier (1988) further interpreted these growth reductions and suggested possible explanations, but their results were inconclusive. All of these papers point to the fact that the observed reductions in tree-level growth rates were accompanied by simultaneous increases in the average age, density, and amount of hardwood competition in natural pine stands throughout the region. Hyink and Zedaker (1987) point out the need to adjust the analyses to account for these differences in stand structure.

Our main objective was to explore the relationship between temporal differences in stand structure and changing growth rates by taking a more rigorous look at FIA stand-level data from Georgia and Alabama. Through a covariate analysis, we adjusted average basal area growth rates from the two latest survey cycles for initial differences in stand size class, numbers of stems, site quality, hardwood competition, and mortality. A secondary objective was to determine if temporal patterns in the adjusted growth rates were consistent between the two States. Analyses were per-

formed on data from naturally regenerated stands of loblolly (*Pinus taeda*), longleaf (*P. palustris*), shortleaf (*P. echinata*), and slash (*P. elliotii*) pines. In addition to evaluating growth of the merchantable portions of these stands (trees 5.0 in. dbh and larger), we also compared the growth rates of trees 1.0 in. dbh and larger.

FIELD METHODS

Data for this analysis came from permanent inventory plots installed and remeasured by two separate FIA Units: Southern FIA for Alabama and Southeastern FIA for Georgia. Data are drawn from the fourth and fifth measurement cycles of each State. The fourth cycle spans the years 1962–72 in Alabama and 1961–72 in Georgia; the fifth cycle covers the years 1972–82 in both States.

Although FIA Units strive to retain consistency over time, new techniques designed to improve the efficiency of the surveys are occasionally implemented. There are also differences in sample design among FIA Units, as each Unit has evolved separately and tailors sampling procedures to the particular conditions encountered within its territory. Basic sampling procedures, changes over time, and differences between the two states are outlined below.

Alabama

All variables described in this analysis were obtained from permanent plots measured during the third, fourth, and fifth inventories of the state, conducted in 1962, 1972, and 1982.

The 1962 plots were established as 10-point clusters of horizontal point samples. All trees 1.0 in. dbh and larger were sampled with a prism having a basal area factor (BAF) of 37.5 at each of the 10 points. All plots, points, and tally trees were monumented for future remeasurement. Growth rates from 1962–72 were com-

puted from the remeasurement of sample trees in 1972.

Also in 1972, 1/300-ac fixed plots were installed at 3 of the 10 points to sample trees from 1.0 to 4.9 in. dbh. These serve as the initial inventory of small stems for calculation of growth from 1972 to 1982.

All plots were revisited in 1982, but only 5 of the original 10 prism points were remeasured. The growth of trees between 1972–82 is thus based on a differencing of five remeasured prism points for trees 5.0 in. dbh and larger, and three remeasured fixed points for trees below 5.0 in. dbh. Consequently, the variance associated with prism estimates of the 1962–72 period can be considered similar to that of one 3.75 BAF prism point, while the variance for 1972–82 is similar to that obtained by one 7.5 BAF point.

Georgia

Permanent sample plots in Georgia were measured during the third (1961), fourth (1972), and fifth (1982) inventories of the state. While the 1962 data in Alabama were collected from a 10 point cluster, the 1961 Georgia data for trees 5.0 in. dbh and larger were sampled with a single point BAF 10 prism plot in each stand. Each plot was supplemented with one centrally located, 1/115-ac fixed plot to tally trees from 1.0 to 4.9 in. dbh. As in Alabama, all sample trees were referenced for subsequent remeasurement. The remeasurement plots were differenced to calculate fourth cycle (1961–72) growth.

After the BAF 10 prism points were remeasured in 1972, three new points were installed at each forest plot for future remeasurement. At each point, tally trees 5.0 in. dbh and larger were selected with a BAF 37.5 prism, yielding an effective plot-level BAF of 12.5. Three 1/300-ac fixed plots also were installed to sample trees from 1.0 to 4.9 in. dbh. The center of the first BAF 37.5 variable-radius point was the same as the original BAF 10 plot center. Estimates of basal area accretion were

obtained from the remeasurement of these 1972 forest plots in 1982.

SAMPLE SCREENING CRITERIA

The data from each state were screened to isolate similar sets of timber stands from the two survey cycles. Only samples that met the following criteria for a survey cycle were retained:

1. Sample points measured at exactly the same location at the initial and terminal inventories.
2. No evidence of planting or artificial seeding.
3. No evidence of cutting during the measurement period.
4. At least 50% of total initial basal area per acre (trees 1.0 in. dbh or larger) in pine species, with the plurality of the pine stocking in the cover type species.

The number of qualifying sample plots are listed in Table 1. Most sample locations survived the screening for only one of the two measurement periods and were used only for the period during which they qualified. As such, samples representing the two time periods are nearly independent. No attempt was made to track sample plots for 20 years, as this would necessarily produce samples of a population 10 years older during the second measurement period, and age was not one of the covariates in the model.

Detailed records were generated for each sample plot that met the screening criteria. On each plot and for each growth period, the initial inventory and subsequent growth of pines 1.0 in. dbh and larger (PSG1) were calculated. The growth of pines 5.0 in. dbh and larger (PSG5) also was calculated to represent the "merchantable" component of each stand.

Growth rates for each stand were provided in terms of "pine survivor growth," defined as the average annual basal area increment per acre onto pines tallied at the time of the initial inventory (by either fixed area or variable radius plots) that survived to the end of the measurement interval. The methods for computing survivor-tree basal area growth rates are described by Beers and Miller (1964).

The average values of the dependent and independent variables for each of the remeasurement cycles are listed in Table 2.

ANALYTICAL METHODS

To account for differences in initial stand conditions between the two time periods, we chose a linear regression model consisting of fixed and random components. The fixed components were survey cycle (C) and site class (S). Random components were quadratic mean diameter (QMD) of pines, number of pines 1.0 in. dbh and larger (N) or 5.0 in. dbh and larger (N5), pine basal area mortality (M), and the ratio of pine:total basal area (P), an indicator of hardwood encroachment. These measures were the best covariates consistently available for both survey cycles in both states for quantifying the influence of stand structure on growth.

Preliminary structural specification of the model was achieved by working with the loblolly data. Models were then refitted and reevaluated for the other cover types. Trials of numerous candidate regression models resulted in the choice of the following models when both structural and empirical considerations were balanced:

Table 1. Numbers of plots qualifying for analysis by state, cover type, and survey cycle.

| State | Cycle | Loblolly | Longleaf | Shortleaf | Slash |
|---------|---------|----------------------------|----------|-----------|-------|
| | | (no. of plots) | | | |
| Alabama | 1962–72 | 190 | 62 | 116 | 15 |
| | 1972–82 | 292 | 80 | 139 | 28 |
| Georgia | 1961–72 | 439 | 148 | 238 | 288 |
| | 1972–82 | 361 | 93 | 122 | 210 |

Table 2. Unadjusted average values of dependent and independent variables by forest type, survey cycle, and state.

| Forest type | Survey cycle | Alabama | | | | | | | Georgia | | | | | | | | | | |
|-------------|--------------|--------------------------------------|------|-------|-----|-----|-----|---------|---------|--------------------------------------|------|-------|-----|-----|----|---------|--|--------------------------------------|--|
| | | PSG1 | PSG5 | M | QMD | N | S | P | PSG1 | PSG5 | M | QMD | N | S | P | | | | |
| | | (ft ² /ac/yr) | | (in.) | | (#) | | (class) | | (ft ² /ac/yr) | | (in.) | | (#) | | (class) | | (ft ² /ac/yr) | |
| Loblolly | 4 | 3.06 | 1.89 | 0.41 | 7.3 | 350 | 3.2 | 78 | 4.06 | 2.45 | 0.73 | 5.9 | 592 | 3.6 | 87 | | | | |
| | 5 | 3.02 | 2.18 | 0.86 | 6.8 | 416 | 2.8 | 78 | 2.92 | 2.27 | 1.16 | 6.4 | 524 | 3.4 | 82 | | | | |
| Longleaf | 4 | 2.03 | 1.33 | 0.11 | 7.6 | 180 | 4.0 | 87 | 2.24 | 1.57 | 0.15 | 7.5 | 176 | 4.1 | 95 | | | | |
| | 5 | 1.93 | 1.28 | 0.23 | 6.9 | 268 | 3.9 | 83 | 2.08 | 1.59 | 0.17 | 8.0 | 205 | 3.9 | 93 | | | | |
| Shortleaf | 4 | 2.50 | 1.43 | 0.51 | 6.4 | 462 | 3.5 | 76 | 2.97 | 1.76 | 0.51 | 5.3 | 498 | 3.8 | 83 | | | | |
| | 5 | 2.28 | 1.46 | 1.41 | 5.3 | 572 | 3.2 | 79 | 2.23 | 1.68 | 1.08 | 5.4 | 561 | 3.6 | 79 | | | | |
| Slash | 4 | | | | | | | | 3.02 | 1.95 | 0.36 | 6.7 | 422 | 3.7 | 91 | | | | |
| | 5 | | | | | | | | 2.76 | 1.99 | 0.57 | 5.7 | 481 | 3.6 | 88 | | | | |

$$\ln(PSG1) = b_0 * C1 + b_1 * C2 + b_2 * \ln(QMD) + b_3 * \ln(N) + b_4 * S + b_5 * P + b_6 * \ln(M + 1) \quad (1)$$

$$\ln(PSG5) = b_0 * C1 + b_1 * C2 + b_2 * \ln(QMD) + b_3 * \ln(N5) + b_4 * S + b_5 * P + b_6 * \ln(M + 1) \quad (2)$$

where variables are described in Table 3.

The dependent variables *PSG1* and *PSG5* were transformed by natural log to satisfy the least-squares assumption of homogeneous variance. The independent variables *QMD*, *M*, *N*, and *N5* were also expressed in logarithmic form to linearize their relationship with

the logarithm of pine survivor growth. Since several of the stands had no pine mortality, 1 ft² of basal area was added to *M* for all samples prior to log transformation to eliminate the need to delete samples (Damon and Harvey 1987).

The SAS General Linear Models (GLM) procedure (Freund et al. 1986) was used to fit the models and test hypotheses concerning the significance of the coefficients on the survey period dummy variables (*C1* and *C2*). Models (1) and (2) were parameterized separately by forest type within their respective State. Model predictions and root mean square errors were corrected for log bias upon conversion to arithmetic units (Baskerville 1972).

RESULTS

A general reduction in the growth of naturally regenerated pine stands was seen in both states, regardless of pine cover type. The specific results of all solutions of models (1) and (2) are listed in Table 4. The sample of naturally regenerated slash pine stands in Alabama was prohibitively small and precluded analysis for this cover type in that state.

No violations of regression assumptions were apparent in any of the models. Error variances appeared stable across the range of observations, and residual plots of *PSG1* and *PSG5* against each independent variable revealed no evidence of curvilinear trends.

The absolute variability in growth was found to be greater for smaller diameter stems, as reflected by a larger root mean square error (RMSE) for the *PSG1* regressions than for the *PSG5* models. Even so, both models had similar coefficients of determination for a given species.

Alabama

The least-squares adjusted means (LSMEANS) for natural loblolly stands in Alabama exhibit a 10% reduction for the *PSG1* model, and a 3% reduction for the *PSG5* component (Table 4). While the *PSG1* growth difference was statistically significant, the *PSG5* difference was not. This is the only case tested in either state that did not yield a significant reduction. Loblolly comprises approxi-

Table 3. Description of variables used in models.

| Dependent variables: | | |
|------------------------|------------|----------------------------------------------------------------------------------------------------------------------------|
| <i>ln(PSG1)</i> | | = ln (average annual basal area growth onto 1+ in. dbh survivor pine) (ft ² /ac/yr) |
| <i>ln(PSG5)</i> | | = ln (average annual basal area growth onto 5+ in. dbh survivor pine) (ft ² /ac/yr) |
| Independent variables: | | |
| Name | Type | Description |
| <i>C1</i> | Dummy | = Alabama 1, for 1962-1972; 0, otherwise Georgia 1, for 1961-1972; 0, otherwise |
| <i>C2</i> | Dummy | = Both states 1, for 1972-1982; 0, otherwise |
| <i>ln(QMD)</i> | Continuous | = ln (initial quadratic mean diameter of 1+ in. dbh pine (in.)) |
| <i>ln(N)</i> | Continuous | = ln (initial stems/ac of 1+ in. dbh pine) |
| <i>ln(N5)</i> | Continuous | = ln (initial stems/ac of 5+ in. dbh pine) |
| <i>S</i> | Class | = Site class, volume growth potential (ft ³ /ac/yr); 1 = >165; 2 = 120-165; 3 = 85-120; 4 = 50-85; and 5 = <50. |
| <i>P</i> | Continuous | = initial pine basal area proportion: (basal area (1+ in. dbh pine))/(basal area (1+ in. dbh all species)) |
| <i>ln(M + 1)</i> | Continuous | = ln (basal area of 1+ in. dbh pine mortality plus 1) (ft ² /ac/yr) |

Table 4. Least-squares adjusted pine survivor basal area growth and associated statistics, by forest type, survey cycle, and state.

| Forest type | Survey cycle | Alabama | | | | | Georgia | | | | | |
|-------------|--------------|---------------------------------------------|---------------|----------------------|----------------|------|---------------------------------------------|---------------|----------------------|----------------|------|------|
| | | Adjusted growth (ft ² /ac/yr) | Change (%) | Prob.>t ^a | R ² | RMSE | Adjusted growth (ft ² /ac/yr) | Change (%) | Prob.>t ^a | R ² | RMSE | |
| Loblolly | PSG1 | 4 | 2.65 | -10 | 0.04 | 0.40 | 2.00 | 3.61 | -23 | 0.01 | 0.42 | 1.86 |
| | | 5 | 2.37 | | | | | 2.78 | | | | |
| | PSG5 | 4 | 1.71 | -3 | 0.57 | 0.53 | 0.93 | 2.39 | -18 | 0.01 | 0.51 | 1.10 |
| | | 5 | 1.66 | | | | | 1.95 | | | | |
| Longleaf | PSG1 | 4 | 2.27 | -29 | 0.01 | 0.54 | 1.05 | 1.82 | -13 | 0.03 | 0.54 | 1.07 |
| | | 5 | 1.62 | | | | | 1.58 | | | | |
| | PSG5 | 4 | 1.40 | -18 | 0.01 | 0.50 | 0.53 | 1.23 | -11 | 0.05 | 0.66 | 0.66 |
| | | 5 | 1.14 | | | | | 1.09 | | | | |
| Shortleaf | PSG1 | 4 | 2.22 | -16 | 0.02 | 0.43 | 1.67 | 3.10 | -31 | 0.01 | 0.52 | 1.35 |
| | | 5 | 1.87 | | | | | 2.13 | | | | |
| | PSG5 | 4 | 1.49 | -14 | 0.04 | 0.45 | 0.69 | 1.82 | -26 | 0.01 | 0.40 | 0.84 |
| | | 5 | 1.28 | | | | | 1.34 | | | | |
| Slash | PSG1 | 4 | — | — | — | — | — | 2.45 | -23 | 0.01 | 0.36 | 1.73 |
| | | 5 | — | | | | | 1.90 | | | | |
| | PSG5 | 4 | — | — | — | — | — | 1.56 | -15 | 0.01 | 0.43 | 1.02 |
| | | 5 | — | | | | | 1.33 | | | | |

^a The probability that the least-squares-adjusted means are equal. The probability of obtaining a larger t-value under the null hypothesis that least-square adjusted mean growth during the fourth cycle equals adjusted growth during the fifth cycle.

mately half of the natural pine stands in the state.

The Alabama longleaf models indicate significant reductions of 29 and 18% in their *PSG1* and *PSG5* components, respectively. Results from the shortleaf models are similar, revealing a 16% reduction for *PSG1*, and a 14% decrease for *PSG5*.

Georgia

The growth of natural pine stands in Georgia was substantially less during the fifth cycle for all cover types. Loblolly growth rates declined by 23% for *PSG1*, and 18% for *PSG5* (Table 4). Longleaf growth was down 13% and 11% in the *PSG1* and *PSG5* models, respectively. Shortleaf *PSG1* and *PSG5* components were significantly reduced by 31% and 26%. The growth of natural slash pine stands in Georgia fell by 23% for *PSG1*, and 15% for *PSG5*.

DISCUSSION

Sampling Procedures

Southeastern FIA installs more plots, but of smaller size, while the Southern FIA plots in Alabama are about twice the size of the

Southeastern plots in Georgia. The smaller plots result in less within-plot variation, while the larger plots capture more of the forest diversity. The major difference between the two data sets is that during the earliest survey estimates of the 1.0 to 4.9 in. component were derived from fixed plots in Georgia, but were calculated from prism plots in Alabama. Although differences in protocol resulted in dissimilar estimation variances between the two states during the earlier survey, the sampling methods nonetheless produced unbiased estimates of stand parameters.

Plots were screened to isolate the best data for detecting changes in growth rates at the state level. Analyses were confined to pine because pine stand dynamics are much simpler to model than hardwood stand dynamics. Pine plantations were bypassed because information on cultural measures such as fertilization and genetic improvement, critical to proper partitioning of plantation data, are not collected by FIA. Stands that experienced cutting were eliminated because the exact timing and extent of the cutting, as well as its effect on the residual stand,

could not be determined. To the extent that unthinned stands were not cut for a reason (i.e., management is often concentrated in better growing stands), the possibility that sample selection during one or both cycles was biased toward slower growing stands remains. However, the models would still adjust for any structural differences.

Models and Variables

Tests of the hypothesis that basal area growth differs between the two measurement periods hinge on having a properly specified linear model. Omission of a pertinent variable biases estimates of the cycle coefficients to the extent that the omitted variable is collinear with the survey period (Belsley et al. 1980). All variables in models (1) and (2), therefore, were retained, even in cases where some failed to contribute significantly to the model. This strategy reduced the chance of bias resulting from model specification error, but may have inflated the variance estimates associated with the measurement cycle coefficients, especially if serious collinearity existed between survey pe-

riod and any of the variables. Retaining complete model specification reduces the likelihood of finding statistically significant differences between survey cycles. Thus, our tests for the significance of differences between cycles were potentially conservative (Pindyck and Rubinfeld 1981).

All variables were evaluated for potential interaction with the cycle variables to ensure that the cycle coefficients were properly parameterized and stable for both time periods. Significant interactions were observed between survey cycle and quadratic mean diameter in the Georgia loblolly *PSG1* and Alabama shortleaf *PSG5* models; between cycle and $\ln(M + 1)$ in the Georgia shortleaf *PSG1*, and Alabama loblolly *PSG1* models; and between cycle and pine ratio (*P*) in the Alabama shortleaf *PSG1* model. The appropriate interaction terms were subsequently added to models (1) and (2), producing the results posted in Table 4. However, all decisions to include interaction terms were empirical. To ensure that statistical decisions were not unduly influencing the outcome of the analysis, these models were also fitted without interaction terms. Solutions without the interactions yielded LSMEAN estimates that were essentially the same as those from models including the interactions.

Hardwood competition, which we expressed as the percent pine stocking ($1 - \text{hardwood stocking}$), could only be examined in a limited number of ways from the available data. Thus, we do not know whether the effects of hardwoods on pine survivor growth were adequately captured by the models. To explore this further, all samples with less than 85% of the total stand basal area in yellow pine species were deleted to minimize the impact of hardwoods. When Equations (1) and (2) were refitted to these smaller data sets (approximately two-thirds of the plots were retained), growth reductions of similar magnitude were still evident in every case. This further suggests that hard-

wood competition is not the principal cause of pine growth reductions. However, more useful competition measures may still be of value, especially since current measures do not account for competition from shrubs and herbaceous vegetation.

The growth of all survivor trees, regardless of species, also was evaluated. The growth decline exhibited by the pine survivor trees persisted for the whole stand in both states and for all cover types. This implies that reductions in pine growth are not being compensated by increased growth of the hardwood component.

Site class was estimated from the heights and ages of dominant trees on or near each plot. FIA site class is analogous to site index, but is expressed in cubic feet of growth per acre per year at the culmination of mean annual increment. The possibility that a disproportionate number of natural pine stands on superior sites have been converted to plantations, thereby reducing the average site quality in the later survey cycle, was not borne out by the data. The mean site class and its distribution did not change between measurement cycles, suggesting that an adverse migration in average site quality due to land management practices is not a likely explanation for the growth reductions. The inclusion of site class in the model, as well as the large sample size, should adequately capture the effect of site. Still, the wide range in productivity covered by each site class allows for the remote possibility that site quality has depreciated over time. For example, if the average production potential on site class 3 lands fell from 115 to 90 ($\text{ft}^3/\text{ac}/\text{yr}$), a drop of 22%, our measure of site quality would be insensitive to the change.

The Results

The implications of serious growth reductions during the fifth cycle must be qualified by the absence of a definition of "normal." Since the comparisons presented here involve only two periods in time, it is unclear whether growth

during the fifth cycle was abnormally high, or growth during the fourth cycle abnormally low. It was not possible to compare recent stand-level growth rates with growth during earlier time periods. The methods for estimating growth during the third survey cycle (conducted during the 1950s) were radically different from later methods, so comparisons with the fourth and fifth cycles were not possible. It is therefore not known if the latest reductions represent the continuation of a downward trend, the bottom of a long-term cycle, or simply a return to normal.

Because of the lack of precise height growth data, it was not possible to evaluate stand-level volume growth. Although volume growth is highly correlated with basal area growth, the two are not necessarily linear functions of each other. This phenomenon has given pause to more than a few growth and yield modelers, who were unable to obtain significant coefficients for site index models designed to predict basal area growth (Brender and Clutter 1970, Farrar 1985). If tree height growth has accelerated and average tree taper has changed, it is conceivable for basal area growth to decline while volume growth remains constant or even increases.

Due to the relatively high *PSG1* growth rates of loblolly and shortleaf pine stands during Georgia's fourth cycle, subsequent growth reductions involving these two cover types were approximately twice as large in Georgia as in Alabama (Table 4). However, the relationship was reversed for longleaf pine stands. Fourth cycle longleaf growth rates for *PSG1* in Alabama are noticeably high, and declined by more than twice the magnitude observed for Georgia.

In general, fourth-cycle estimates of growth vary widely between states for all cover types, but fifth-cycle estimates for both states are more similar in all cases (Tables 3 and 4). The differences are puzzling. They may be connected with the wholesale reversion of abandoned farmland to

forest in the Piedmont of Georgia following World War II. Roughly two-thirds of these stands were naturally regenerated. Conversion of farmland in Alabama, where most of the land resides on the Coastal Plain, was less extensive during this same period. The relative brevity of this reversion suggests that there was a large component of young old-field pine stands in the 1961 Georgia forest, possibly benefitting from the effects of residual fertilizer and/or absence of competition from other species. Growth on these synchronously reforested acres might have boosted average growth rates during the fourth measurement cycle in Georgia. However, this argument is difficult to reconcile with the notably high longleaf growth rates during Alabama's fourth survey.

The relatively large growth reductions apparent on stems smaller than 5 in. dbh in both Alabama and Georgia suggests that if exogenous factors are involved, they may be exerting most influence on the submerchantable portion of the stand. If this is true, the impact of the growth reductions may be moderated by long rotations, where many of the small stems in a young stand would die due to competition. Reduced growth onto these small stems would be lost through normal attrition anyway. However, in short rotation management, where stems are harvested at small diameters, the impact of reduced *PSG1* growth is more pronounced.

In both Georgia and Alabama, numbers of pine stems per acre accounted for more variation than all the other covariates combined. A positive coefficient for the variable confirms the large impact that successful regeneration has on pine production at the stand level. Although substantial growth reductions persisted after accounting for differences in initial pine stocking, factors that affect pine regeneration in natural stands merit further attention.

Any differences in initial stand condition beyond the stand structural covariates examined in the

models were uncontrolled in these analyses. Other expressions of stand conditions that were not used may further explain the disparity in growth. Notably absent is an accounting for exogenous stand factors, such as temperature and precipitation. Data on these factors are difficult to obtain at the localized plot level across large regions. The extent to which natural variations in climate could further explain the reduction in growth in natural pine stands is not known.

There remain some significant and somewhat perplexing differences between the growth patterns in these two neighboring states. In Alabama, but not in Georgia, the unadjusted mean basal area growth per acre has increased for the merchantable (*PSG5*) component of loblolly natural stand (Table 2). What has declined is the adjusted growth (i.e., the growth expected if the model specification is correct for both periods). Our efforts to test the validity of the model indicate that it is indeed specified correctly. The only remaining caveat is that, with the models exhibiting coefficients of determinations in the ranges reported, it remains possible that unspecified covariates correlated with period, but not identified in the model, could account for the apparent decline. However, these unresolved differences between the two states do not compromise the significance of the results reported here.

In a study of "Simpson's Paradox" in Alabama's natural and planted loblolly pine stands, Thomas and Parresol (1989) showed that mean basal area growth rates were high even though basal area growth by diameter class for all diameter classes was lower for 1982 vs. 1972. Simpson's paradox can occur when a population is broken down into classes (stratified). Every class mean for the first population (A) may exceed those of a second population (B) even though the grand mean for B is greater than that for A. Consequently, the appearance of a 10% growth decline in Alabama's natural loblolly stands due

to lower growth of the *PSG1* component is tempered by only a modest 3% decrease in the growth of the merchantable (*PSG5*) stand component. However, in Georgia significantly large reductions in both total stand and merchantable stand components persist for all cover types.

Another study involving a different data set and analytical techniques corroborates the results presented here. Zahner et al. (1989) analyzed tree-ring data from natural loblolly stands in Georgia, North Carolina, and South Carolina. After factoring the influences of both stand dynamics and drought from the ring chronologies, they reported a 20% reduction in ring widths during the same time span.

CONCLUSIONS

In both Alabama and Georgia, a consistent pattern of declining growth in naturally regenerated stands is manifested across all pine forest types after adjusting for differences in initial stand structure. The magnitude of the reductions ranged from 10% to 31% for the growth of all pines with initial dbh 1.0 in. and larger. Reductions for pines with initial dbh 5.0 in. and larger ranged from 3% to 26%.

The agents responsible for the growth differences observed in these two states were not identified. Any further resolution of potential causal relationships using FIA data would require the acceptance of untested assumptions and considerable speculation, especially since they are observational rather than experimental, are statistically unbalanced with respect to influential variables, and do not account for any exogenous factors such as climate or pollution. This analysis does, however, minimize the chance that any obvious stand structural factors are responsible for the growth differences. It also identifies situations where growth differences are occurring, thereby serving as a guide for future research into causal relationships. □

Literature Cited

- BASKERVILLE, G.L. 1972. Use of logarithmic regression in the estimation of plant biomass. *Can. J. For. Res.* 2:49–53.
- BEERS, T.W., AND C.I. MILLER. 1964. Point sampling: Research results, theory, and applications. *Purdue Univ. Agric. Exp. Stn. Bull.* 786. 56 p.
- BELSLEY, D.A., E. KUH, AND R.E. WELSCH. 1980. *Regression diagnostics: Identifying influential data and sources of collinearity.* Wiley, New York. 292 p.
- BRENDER, E.V., AND J.L. CLUTTER. 1970. Yield of even-aged natural stands of natural loblolly pine. *Ga. For. Res. Council Rep.* 23. 7 p.
- DAMON, R.A., AND W.R. HARVEY. 1987. Experimental design, ANOVA, and regression. Harper and Row, New York. 508 p.
- FARRAR, R.M., JR. 1985. Volume and growth predictions of thinned even aged natural longleaf pine stands in the east Gulf area. *USDA For. Serv. Res. Pap. SO-220.* 171 p.
- FREUND, R.J., R.C. LITTELL, AND P.C. SPECTOR. 1986. SAS system for linear models. SAS Institute, Cary, NC. 210 p.
- HYINK, D.M., AND S.M. ZEDAKER. 1987. Stand dynamics and the evaluation of forest decline. *Tree Physiol.* 3:17–26.
- LUCIER, A.A. 1988. Pine growth-rate changes in the Southeast: A summary of key issues for forest managers. *South. J. Appl. For.* 12:84–89.
- PINDYCK, R.S., AND D.L. RUBINFELD. 1981. *Econometric models and economic forecasts.* McGraw-Hill, New York. 630 p.
- SHEFFIELD, R.M., AND N.D. COST. 1987. Behind the decline. *J. For.* 85(1):29–33.
- SHEFFIELD, R.M., ET AL. 1985. Pine growth reductions in the Southeast. *USDA For. Serv. Res. Bull. SE-83.* 112 p.
- THOMAS, C.E., AND B.R. PARRESOL. 1989. Comparing basal area growth rates in repeated inventories: Simpson's paradox in forestry. *For. Sci.* 35:1029–1039.
- ZAHNER, R., J.R. SAUCIER, R.K. MEYERS. 1989. Tree-ring model interprets growth declines in the Southeastern United States. *Can. J. For. Res.* 19:612–621.

Fusiform Rust Incidence in Loblolly and Slash Pine Plantations in East Texas

Alexandros A. Arabatzis and Timothy G. Gregoire,
Department of Forestry, Virginia Polytechnic Institute and State University, Blacksburg, VA 24061-0324 and J. David Lenhart,
School of Forestry, Stephen F. Austin State University,
Nacogdoches, TX 75962-6109.

ABSTRACT. A method to predict the incidence of fusiform rust (*Cronartium quercuum* [Berk.] Miyabe ex Shirai f. sp. fusiforme) in unthinned loblolly (*Pinus taeda* L.) and slash pine (*Pinus elliotti* Englem.) plantations located on non-old-fields in East Texas is presented. In addition, procedures are described to estimate changes in rust incidence over time as:

1. A rust-free tree remains rust free, develops stem or branch galls, or dies.
2. A tree with branch galls remains with branch galls only, develops stem galls, or dies.
3. A tree with stem galls remains with stem galls, or dies.

Multinomial logistic regression models utilizing basic plantation parameters as predictors were fit to estimate current rust incidence and, then, the change in rust condition over time.

South. J. Appl. For. 15(2):79–84.

Fusiform rust, caused by the fungus *Cronartium quercuum* (Berk.) Miyabe ex Shirai f. sp. fusiforme, is the most damaging disease of loblolly and slash pines, the

two major pine species in the southern United States. Annual losses in the order of \$130 million (Anderson and Mistretta 1982) underscore the need for assessing the incidence of this disease so that detection, control, and prevention practices can be efficiently deployed.

The purpose of this study was to predict the incidence of fusiform rust in planted stands of loblolly and slash pine in East Texas. By incidence we mean the proportion of trees in a stand in each infection-level category; and the change in these proportions over time, henceforth called the *transition proportions*. Shoulders and Nance (1987) compiled statewide summaries of similarly defined transition proportions and observed that transition proportions may vary widely among stands. Our modeling effort was intended to provide more precise estimators of stand-level transition propor-

tions by including stand attributes as explanatory factors.

Within a timber stand, rust proportions follow a multinomial distribution. Accordingly, multinomial logistic regression (MLR) models were fit. The MLR model estimates the probability of an event. When applied to a stand of trees, this probability is interpreted as the estimated proportion of trees in a certain class. MLR models can accommodate an arbitrary number of classes; when only two classes are recognized, the MLR reduces to the binary logistic model, which has been widely used in forestry to model mortality (see, for example, the work by Monserud 1976, Hamilton 1974 and 1986, and Hamilton and Edwards 1976).

DATA

Data from the East Texas Pine Plantation Research Project (ETPPRP) were available for analysis. The ETPPRP is a long-range project initiated in 1982 by the School of Forestry at Stephen F. Austin State University and participating forest industries¹ (Lenhart et al. 1985). Each of the 252 ETPPRP permanent plots (173 in loblolly and 79 in slash) is located

¹ The continuing support from the participating companies—Champion International Corporation, International Paper Company, Louisiana-Pacific Corp. and Temple-Inland Forest Products Inc.—is appreciated.