

DISCUSSION PAPER

Changing Stand Structure and Regional Growth Reductions in Georgia's Natural Pine Stands

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ABSTRACT. Forest Inventory and Analysis (FIA) data indicate reductions in the growth of naturally regenerated pines in Georgia between the two latest measurement periods (1961-72 vs. 1972-82). Analysis of Covariance was used to adjust stand-level basal area growth rates for differences between periods in stand age, stand density, site index, mortality, and hardwood competition. The adjusted mean growth of pines during the later period declined by 19% for natural loblolly, 28% for natural shortleaf, and 28% for natural slash pine stands. The factor(s) causing the reductions remain unidentified, but differences in stand structure are not likely responsible. FOR. SCI. 37(2):703-717.

ADDITIONAL KEY WORDS. Forest inventory, basal area growth, forest growth decline.

THE FOREST INVENTORY AND ANALYSIS (FIA) WORK UNIT of the Southeastern Forest Experiment Station has reported declines in the average radial growth rates of naturally regenerated pines in Georgia, as well as in other areas of the Southeast (Sheffield et al. 1985). Results from this report have prematurely been portrayed by the popular media as evidence of acid deposition and air pollution. In response to the controversy surrounding the reductions, the national Forest Response Program has funded various studies to evaluate the effects of air pollution on Southeastern forests (Forest Response Program 1988). Coincident with this, several other investigators have examined the evidence presented by Sheffield et al. (1985) to determine if the subsequent emphasis on atmospheric pollutants is justified and to gain insight into other factors that might account for the reductions (Hyink and Zedaker 1987, Lucier 1988, Warren 1990). All of these authors emphasize the need for more rigorous analyses to establish the relationship between declining growth rates and changing stand structure (stand dynamics).

FIA data are observational rather than experimental—originally designed to monitor timber inventories, growth, and removals at the population level on a regional scale. They therefore reflect the net results of all factors influencing regional populations of trees and timber stands. These include shifting land-use patterns, timber harvesting and management practices, natural disturbances, stand dynamics, moisture stress, pollution, and a host of other forces. Interpretations must therefore be made cautiously. Although the data are observational, they are based on extensive, accurate, and repetitive measures of tree diameters.

As such, they provide an important record of forest growth at the regional level and merit the most rigorous and objective analyses possible.

The purpose of this paper is to re-analyze the FIA data set in an effort to clarify the influence of stand dynamics on the observed growth differences. This is accomplished by adjusting stand-level basal area growth estimates for small differences in stand age, stocking, site quality, and hardwood competition between the two latest measurement cycles using Analysis of Covariance. The adjusted mean growth rates are then tested for statistically significant differences between cycles. Analyses are conducted for naturally regenerated loblolly (*Pinus taeda* L.) and shortleaf (*P. echinata* Mill.) pine stands in the Piedmont and Mountain physiographic regions of Georgia, and natural slash pine (*P. elliottii* Engelm. var. *elliottii*) stands in the Coastal Plain area. Basal area growth rates between 1961 and 1972 are compared to growth rates between 1972 and 1982.

THE DATA

FIA SAMPLING PROCEDURES

In the Southeast, FIA data are periodically gathered from permanent nonforest and forest inventory plots. Sampling intensity across the region is approximately one forest plot per 3500 ac of timberland. This paper utilizes data collected from these plots during the third (1961), fourth (1972), and fifth (1982) statewide timber inventories of Georgia, where the network of plots was originally installed during the third survey. FIA has traditionally divided Georgia into five "Survey Units" for inventory purposes (Figure 1). For this analysis, data from the three northernmost Units were aggregated to form the Piedmont and Mountain study area. The two southernmost Units were grouped to form the Coastal Plain study area.

When the 1961 plots were installed, a basal area factor (BAF) 10 prism was used to tally all live trees 5.0 in. dbh and larger at each forest plot. This variable-radius plot was supplemented with a 1/115-ac circular fixed-radius plot to record trees from 1.0 to 4.9 in. dbh. Plot locations and tallied trees were inconspicuously monumented at the time of initial inventory. Estimates of 1961–72 growth used in this analysis were obtained from the remeasurement of samples that were still forested at the terminal inventory in 1972.

Also in 1972, a new initial inventory for the next measurement period was established, reflecting the changes in land use that had taken place since 1961. Some nonforest samples had reverted to timberland, and forest plots were installed accordingly. Conversely, some former forest samples had been diverted to nonforest uses and were reassigned to the pool of nonforest samples. Forest plots were retained at locations that were forested in both 1961 and 1972.

Survey procedures were modified when the initial inventory of the 1972–82 period was established. Instead of a single BAF 10 prism point, three BAF 37.5 prism points (spaced 70 ft apart) were installed at each forested sample location to tally trees 5.0 in. dbh and larger. A series of three 1/300 ac plots were used to tally trees from 1.0 to 4.9 in. dbh. Where forest samples had been retained since 1961, the center of the first point was the same as the original BAF 10 plot center. Again, all tallied trees were referenced for subsequent remeasurement. Esti-

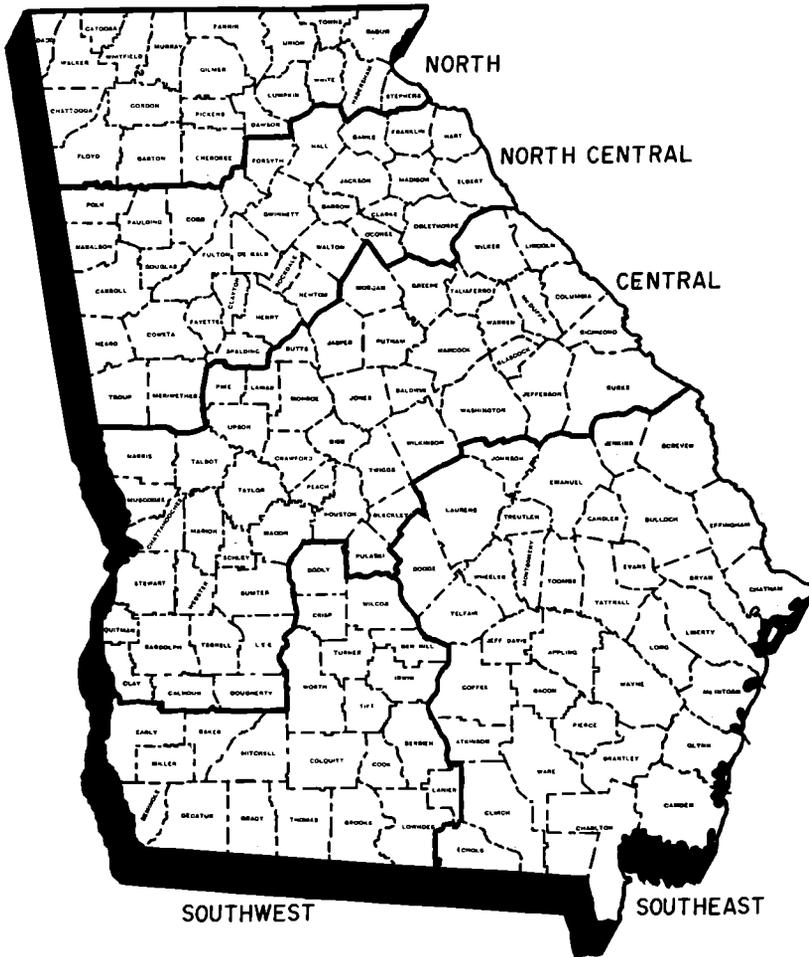


FIGURE 1. Forest Survey Units in Georgia

mates of growth between 1972 and 1982 were obtained from the remeasurement of plots that were still forested in 1982.

SAMPLE SCREENING CRITERIA

The data were screened to isolate similar sets of timber stands from each of the two measurement periods. The screening was applied separately to each survey cycle, and only samples that met the following criteria were retained:

1. Classified as timberland at both the initial and terminal inventories.
2. All sample points confined to a single forest condition.
3. No evidence of planting or artificial seeding.
4. No visual evidence of serious treatment or disturbance (such as timber cutting or insect, disease, or fire damage).
5. Classified as a loblolly or shortleaf forest type in the Georgia Piedmont or Mountain Survey Units, or a slash pine type in the Coastal Plain Units. To qualify as one of the three pine cover types, at least 50% of the initial basal area (trees 1.0 in. dbh and

larger) had to be pine species, with the plurality of the pine stocking in the cover-type species.

Most plots survived the screening for just one of the two periods and were used only for the period during which they qualified. Only 27 loblolly, 14 shortleaf, and 11 slash pine plots were common to both cycles. High disturbance rates were the primary reason for the small number of paired plots; it is somewhat unusual for southern pine stands to remain undisturbed for two contiguous decades.

Despite the presence of paired plots, samples representing the two cycles are best viewed as independent. Even on the paired plots, different sets of trees were measured as a result of the change in sampling procedures (1-point BAF 10 vs. 3-point BAF 37.5). Hence, no attempt was made to isolate the paired plots and track the same samples for the entire 21-year period.

DESCRIPTIONS OF MEASURED VARIABLES

FIA field crews generally measure a few tree heights on each plot and then estimate the rest. Although ocular height estimates produce acceptable results for broad-scale inventory purposes, they were judged too imprecise to allow modeling of growth in terms of volume. Since all tree diameters were measured, basal area accretion was chosen as the most appropriate dependent variable for this analysis. More specifically, two measures of basal area growth were evaluated—that of pines alone, as well as the combined growth of all tree species encountered in the sampled pine stands.

FIA computes net basal area growth between two inventories from three separate components: survivor growth + ingrowth - mortality. Survivor growth is defined as the periodic basal area increment on trees 1.0 in. dbh and larger that are present at the time of initial inventory and survive to the time of terminal inventory. Ingrowth is the terminal inventory of all trees that grow above 1.0 in. dbh on the fixed-radius plot during the measurement cycle. Mortality is the initial inventory of trees 1.0 in. dbh and larger that die from natural causes prior to the terminal inventory. Survivor growth, ingrowth, and mortality were calculated for each plot as prescribed by Beers and Miller (1964). Length of measurement period varied slightly from plot to plot, so all components of growth were divided by the plot measurement interval and converted to an average annual basis. Length of measurement interval ranged from 9.7 to 11.6 years.

Stand age represents the average chronological age (at the initial inventory) of all trees identified as part of a manageable stand. In pine stands, the manageable stand is almost always synonymous with the primary overstory. Since these are natural stands, many of which became established over a period of several years, the age data were placed into 10-year classes.

Measures of stand density (numbers of trees per acre and basal area per acre) were computed from all trees alive at the initial inventory of each sample. Stand density data were summarized for all species combined, as well as separately for the yellow pines.

Trees sampled for estimation of site index were selected from the dominant and codominant pines in each stand. Height and age data from the site trees were used to assign site indices based on the natural loblolly, shortleaf, and slash pine site index curves developed by Schumacher and Coile (1960).

ANALYTICAL METHODS

MODEL SELECTION

Trials of various growth formulations yielded model (1) as the best predictor of basal area growth (in terms of parameter consistency and interpretation, residuals analysis, and R-square):

$$\ln(G) = b_0 + b_1*S + b_2*\ln(A) + b_3*\ln(N) + b_4*(P) + b_5*\ln(M + 1) \quad (1)$$

where

A = stand age (midpoint of 10-year class)

G = gross annual basal area growth per acre (survivor growth + ingrowth)

P = ratio of yellow pine basal area per acre to basal area of all species

M = annual basal area mortality per acre

N = number of stems per acre

S = site index (base 50 years).

Note that survivor growth and ingrowth were summed to gross growth and modeled as the dependent variable. Mortality was not subtracted but rather used as an independent variable. Relegation of mortality to the right side of the equation removed a substantial source of variation from the response variable.

ANALYSIS OF COVARIANCE

Sample sizes, unadjusted growth rates, and the untransformed means of model covariates are summarized in Table 1. Two versions of model (1), each with dummy variables to distinguish between the two measurement periods (T_1 and T_2), were fitted to these data. The first, model (2), describes the growth of the pine component only. The second, model (3), describes the growth of all tree species. Models (2) and (3) were applied to each of the three cover types, yielding a total of six growth comparisons.

$$\ln(G_p) = b_0*T_1 + b_1*T_2 + b_2*S + b_3*\ln(A) + b_4*\ln(N_p) + b_5*(P) + b_6*\ln(M_p + 1) \quad (2)$$

$$\ln(G_t) = b_0*T_1 + b_1*T_2 + b_2*S + b_3*\ln(A) + b_4*\ln(N_t) + b_5*(P) + b_6*\ln(M_t + 1) \quad (3)$$

where

G_p = yellow pine gross annual basal area growth per acre

G_t = all species gross annual basal area growth per acre

M_p = yellow pine annual basal area mortality per acre

M_t = all species annual basal area mortality per acre

N_p = number of yellow pines per acre

N_t = number of all species per acre

TABLE 1.
Sample sizes, means, and standard errors of unadjusted Georgia growth data by forest type and measurement period.

Forest type and remeasurement period	Stand variables									
	Sample size	Pine gross growth (G_p)	Total gross growth (G_t)	Pine mortality (M_p)	Total mortality (M_t)	Pine initial number (N_p)	Total initial number (N_t)	Stand age (A)	Base 50 site index (S)	Pine basal area ratio (P)
	Number	.....	.....	.....	.....	.....	.....	(yr)	(ft)	(ratio)
Loblolly pine										
1961-1972										
\bar{X}	235	4.47	5.40	0.75	0.84	619.1	918.9	21.5	72.0	0.87
S_x		0.18	0.18	0.07	0.08	43.5	50.1	0.8	0.7	0.01
1972-1982										
\bar{X}	104	3.18	4.21	0.71	0.88	555.3	923.3	22.9	71.5	0.79
S_x		0.16	0.18	0.10	0.10	50.5	61.2	1.1	1.1	0.02
Shortleaf pine										
1961-1972										
\bar{X}	127	3.44	4.43	0.45	0.57	531.9	789.4	20.9	64.7	0.83
S_x		0.18	0.19	0.07	0.08	52.0	57.2	1.1	0.9	0.02
1972-1982										
\bar{X}	45	2.62	3.64	0.69	0.96	533.4	996.7	25.4	69.6	0.75
S_x		0.27	0.33	0.12	0.14	75.2	78.7	1.6	2.0	0.02
Slash pine										
1961-1972										
\bar{X}	84	3.74	4.45	0.23	0.29	385.7	535.4	21.8	71.7	0.91
S_x		0.30	0.30	0.08	0.08	59.1	65.1	1.3	1.0	0.02
1972-1982										
\bar{X}	83	2.94	3.88	0.43	0.53	471.4	786.3	24.8	71.1	0.83
S_x		0.23	0.26	0.08	0.08	45.5	66.0	1.4	1.2	0.02

T_1 = time period 1 dummy variable (1 for 1961–72, 0 for 1972–82)

T_2 = time period 2 dummy variable (0 for 1961–72, 1 for 1972–82) and A , P , and S are as defined for model (1).

Prior to final solution, Cooks D influence values (Cook 1979) were computed to identify data points wielding unusual leverage in the models. High leverage observations, along with conventional outliers, were verified and eliminated if measurement error was detected. All such observations with no apparent error were retained in the final solutions. Seven plots were deleted, leaving a total of 678.

RESULTS

PINE GROWTH MODELS

Regression coefficients and selected statistics of fit for the three pine growth models [model (2)] are given in Table 2A. Model R-squares ranged from 0.50 and 0.52 for loblolly and shortleaf, to 0.21 for slash pine. Model residuals revealed no violations of regression assumptions in any of the models and contained no evidence of curvilinear trends.

Significant interaction was detected between pine number (N_p) and measurement period (T_1 and T_2) in the shortleaf model. To allow for separate regression slopes between time periods for this variable, an interaction term was substituted for N_p in the shortleaf model as depicted in Table 2A. The adjusted growth of shortleaf pine was therefore compared at a common density equal to number of trees averaged over both periods (rather than the intercept). No significant interactions involving measurement period were observed in the loblolly or slash pine models.

Using the least-squares-adjusted mean growth of pine species in pine stands as the basis for comparison (Table 3A), gross basal area growth during the more recent period was 19% less in natural loblolly stands ($P < 0.001$), 28% less in natural shortleaf stands ($P < 0.001$), and 28% less in natural slash pine stands ($P < 0.002$). These percentages are based on the untransformed (arithmetic) means, which have been corrected for the bias that results from logarithmic transformation (Baskerville 1972).

Predicted growth values (curves) from model (2) are plotted against observed basal area growth and stand age in Figure 2. The observed data are offset to either side of each 10-year age class to aid viewing.

TOTAL GROWTH MODELS

Analogous results from solutions of model (3) are displayed in Tables 2B, 3B, and Figure 3. Variation introduced by pooling both hardwood and pine growth resulted in lower R-squares relative to the "pine-only" models. As with the pine models, all assumptions required for valid linear regressions were satisfied. Tests for interactions between measurement period and other variables uncovered none in the loblolly and slash pine total growth models, but a significant interaction between density (N_p) and period (T_1 , T_2) was substituted for the main effect of density in the shortleaf model (Table 2B).

Results from the total growth models were consistent with those from the pine

TABLE 2.

Solutions of models [2] and [3] by forest type, with selected statistics of fit.

A. Model [2], pine growth models solved for $\ln(G_p)$											
Forest type	R-square ^a	RMSE ^b	Independent variables ^c								
			T ₁	T ₂	ln(A)	ln(N _p)	ln(N _p) * T ₁	ln(N _p) * T ₂	S	P	ln(M _p + 1)
Loblolly	0.504	0.464	-1.258 0.001	-1.468 0.001	-0.259 0.001	0.399 0.001	—	—	0.005	0.834	-0.379 0.001
Shortleaf	0.519	0.442	-1.653 0.001	-3.633 0.001	-0.207 0.001	—	0.378 0.001	0.664 0.001	0.012	0.601	-0.565 0.001
Slash	0.208	0.619	-1.356 0.020	-1.681 0.004	-0.283 0.001	0.404 0.001	—	—	0.015	0.135	-0.446 0.005
B. Model [3], total growth models solved for $\ln(G_t)$											
Forest type	R-square ^a	RMSE ^b	Independent variables ^c								
			T ₁	T ₂	ln(A)	ln(N _t)	ln(N _t) * T ₁	ln(N _t) * T ₂	S	P	ln(M _t + 1)
Loblolly	0.382	0.441	-0.610 0.067	-0.785 0.018	-0.276 0.001	0.347 0.001	—	—	0.003	0.698	-0.230 0.001
Shortleaf	0.373	0.401	-0.645 0.093	-3.039 0.001	-0.166 0.001	—	0.304 0.001	0.617 0.001	0.008	0.218	-0.401 0.001
Slash	0.118	0.561	-0.794 0.180	-1.066 0.073	-0.233 0.001	0.347 0.001	—	—	0.010	0.137	-0.200 0.134

^a Untransformed statistic defined as: TSS-ESS/TSS; where TSS = total sums of squares in arithmetic units, and ESS = error sums of squares in arithmetic units.
^b Root mean square error in logarithmic units.
^c Significant interactions between $\ln(N_p)$ and remeasurement period, and between $\ln(N_t)$ and period were substituted for main effects in the shortleaf models.
^d The probability that the coefficient is equal to zero. The probability of obtaining a larger F-value under the null hypothesis that the coefficient equals zero. Coefficients were evaluated with respect to their contributions to reduction of error sums of squares when entered last in the model.

TABLE 3.

Comparisons of least-squares adjusted mean growth from solutions of models [2] and [3], by forest type and measurement period.

A. Model [2], pine growth models solved for $\ln(G_p)$						
Forest type	Measurement period	..... Basal area growth ($\text{ft}^2/\text{acre}/\text{year}$) .....			..... Logarithmic units Arithmetic units ..	
		\bar{Y}	$S_{\bar{Y}}$	Prob. > T^a	\bar{Y}	Change
Loblolly	1961-1972	1.268	0.031	0.001	3.957	-19%
	1972-1982	1.057	0.046		3.205	
Shortleaf	1961-1972	1.031	0.040	0.001	3.093	-28%
	1972-1982	0.704	0.072		2.230	
Slash	1961-1972	1.106	0.070	0.002	3.661	-28%
	1972-1982	0.781	0.071		2.646	

B. Model [3], total growth models solved for $\ln(G_t)$						
Forest type	Measurement period	..... Basal area growth ($\text{ft}^2/\text{acre}/\text{year}$) .....			..... Logarithmic units Arithmetic units ..	
		\bar{Y}	$S_{\bar{Y}}$	Prob. > T^a	\bar{Y}	Change
Loblolly	1961-1972	1.529	0.029	0.001	5.084	-16%
	1972-1982	1.354	0.044		4.269	
Shortleaf	1961-1972	1.380	0.036	0.001	4.310	-32%
	1972-1982	0.996	0.073		2.935	
Slash	1961-1972	1.365	0.063	0.004	4.582	-24%
	1972-1982	1.093	0.064		3.491	

^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-squares adjusted mean growth between 1961-1972 equals least-squares adjusted growth between 1972-1982.

models. Gross basal area growth of all species in these same stands was significantly less for all three cover types—down by 16%, 32%, and 24% in natural stands of loblolly ($P < 0.001$), shortleaf ($P < 0.001$), and slash pine ($P < 0.004$), respectively (Table 3B).

DISCUSSION

THE DATA

Data screening was used to isolate the most useful subsets of FIA data available for detecting unusual changes in regional growth rates. Analyses were confined to natural pine stands because pine stand dynamics are simpler to model than hardwood dynamics. Disturbed stands were rejected because their structure was altered during the measurement period. Pine plantations were bypassed because two important cultural measures critical to evaluation of plantation growth, fertilization and genetic improvement, are not collected by FIA.

The observational nature of the data, combined with the screening necessary to

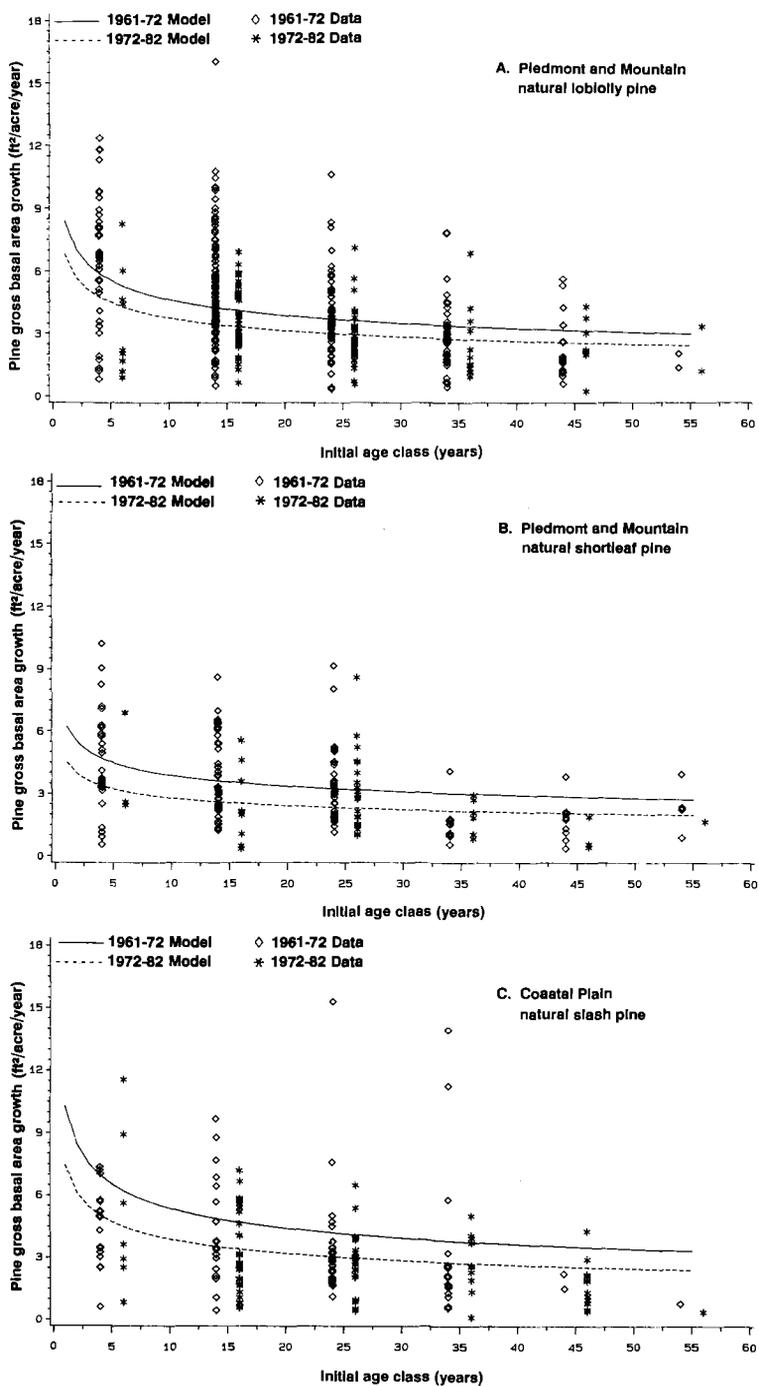


FIGURE 2. Pine annual basal area growth by initial age class, Georgia 1961-72 vs. 1972-82

accomplish this analysis, raises some important issues. First, the results presented here pertain only to a subset of the population. It is not known if the reductions observed for natural pines are relevant to other segments of the population. Similar analyses of FIA plantation data do *not* indicate significant

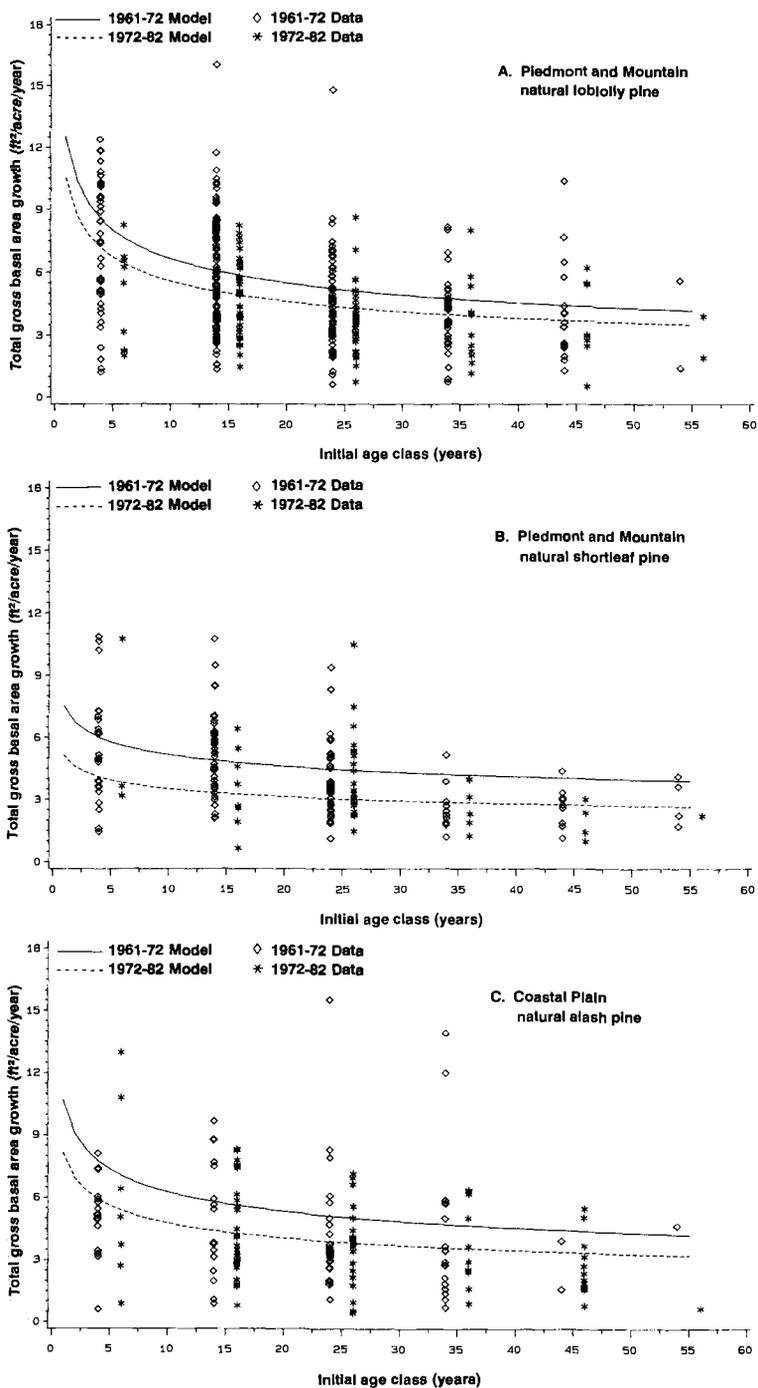


FIGURE 3. Total annual basal area growth by initial age class, Georgia 1961-72 vs. 1972-82

growth differences between the two latest measurement cycles, but plantation management practices could be offsetting the factors responsible for lower growth rates in natural stands. Stand-level growth rates of hardwoods have not been evaluated.

Secondly, the data were drawn from populations existing at two different points in time, so any population shifts not associated with the model covariates are not controlled in this analysis. For example, it is likely that a higher proportion of natural pine stands during the earlier cycle originated on abandoned agricultural fields, possibly benefitting from residual fertilizer and lack of hardwood competition. A shift such as this would be covered only to the extent that tree site index (S) and pine basal area proportion (P) can be considered valid and comprehensive measures of site quality and hardwood competition. Even though site index is the most direct and probably the best tool now available for evaluating forest productivity, it could be argued that traditional site indices based on tree height/age relationships may not be sufficient to capture the effect of relevant population changes such as a difference in the proportion of old field sites or a potential difference in genetic substrate (Monserud 1987).

Another issue with regard to the data is the change in sampling procedures between the two cycles. In effect, the variable plot-level BAF increased from 10 to 12.5, and the fixed-area plot size for saplings changed from 1/115 to 1/100 ac. While slightly different plot sizes altered the variance associated with parameter estimates obtained from one cycle relative to the other, the estimates themselves remained unbiased by the procedural shift. As such, the change in protocol does not compromise the use of these data for the purposes described herein.

THE MODELS

Statistics of fit and model performance

The model solutions in Tables 2A and 2B support the suitability of the covariate structures specified by models (2) and (3), as illustrated by the consistency of the estimated coefficients (in both magnitude and sign) for all cover types analyzed. The signs are positive in every case for $\ln(N_p)$ and $\ln(N_t)$, and negative in all cases for $\ln(A)$, $\ln(M_p + 1)$ and $\ln(M_t + 1)$. When untransformed, these three terms reduce to the ratio of density divided by age and mortality. This configuration results in a biologically sensible model not unlike the one Nelson (1963) used to describe loblolly basal area growth. Growth drops off rapidly with increasing age, but for a fixed age increases along with density until excessive competition causes it to peak and turn downward. Nelson (1963) captures this relationship between growth and density by specifying a quadratic term for density. Our model accomplishes the same thing by using the interplay between density and mortality. Density builds to a threshold level at which competition-related mortality begins to increase, eventually causing growth to turn down.

The performance of our covariate structure was further tested on natural loblolly growth and yield data collected during an independent study of permanent 1/4-ac fixed plots. Again, the magnitude and algebraic signs of coefficients were consistent with those obtained from FIA data. When fit to growth and yield data, the model produced an R-square of 0.82, which approaches the maximum explanatory power that can be expected from forest growth models. The lower R-squares obtained from FIA data are due to the greater variation associated with prism samples, as well as the wide range of stand conditions encountered when plots are selected from the inventory or an extensive geographic area.

Collinearity

Tests of the hypothesis that basal area growth differs between the two cycles depend on a properly specified model. Omission of a pertinent variable will bias the measurement period coefficients to the extent that the omitted variable is collinear with measurement period (Belsley et al. 1980). We retained all model covariates in models (2) and (3), even where some failed to contribute significantly. While this strategy reduces the chance of bias resulting from specification error, it can inflate the variance estimates associated with the measurement period coefficients, especially if serious collinearity exists between period and any of the other variables. By retaining complete model specification, the models are less likely to show statistically significant differences between survey cycles, thus rendering our tests conservative (Pindyck and Rubinfeld 1981).

Interactions

Decisions to include interaction terms involving measurement period were strictly empirical. Significant interactions between period (T_1 and T_2) and density (N_p , N_t) in the two shortleaf models indicated a need to fit separate slopes by cycle for these particular variables. To ensure that statistical decisions were not unduly influencing the outcome of the analysis, the shortleaf models were also fitted without the interaction terms. Solutions without the interactions yielded adjusted mean differences that were approximately the same as models with the interactions.

In addition to interactions involving measurement period, interactions between other variables were also evaluated. Statistically significant interactions were found between mortality and density in the two shortleaf models ($M_p * N_p$, $M_t * N_t$) and between mortality and site index in the slash pine models ($M_p * S$, $M_t * S$). These were judged to be spurious and not entered into the final solutions. Again, the adjusted mean differences remained nearly the same regardless of their inclusion or exclusion.

Hardwood competition

Although (P) was incorporated into the model as a measure of competition from non-yellow-pine tree species, the limited ways of expressing this variable from the available data prompted us to explore the influence of hardwood competition further. This was accomplished by deleting all samples with less than 85% of their initial basal area in yellow pine species. When the models were rerun against these smaller data sets, statistically significant growth reductions of similar magnitude were still evident in every case, further suggesting that competition from other tree species is not the principal cause of the pine growth reductions. The role of competition from shrubs and other understory vegetation is not known.

THE RESULTS

Basal area growth rates of natural pines in Georgia were significantly less during the later period after adjusting for differences in stand structure. Results from the total growth models further indicate that the overall growth of pine stands was less during the later period, inferring that pine growth reductions have not been offset by increased growth of other species.

The significance of serious growth reductions during the latest survey cycle

must be qualified by the absence of "normal" regional growth standards. Since the comparisons presented here involve only two periods in time, it is not clear if growth between 1972–82 was abnormally low, or if growth between 1961–72 was abnormally high. Data from the survey prior to 1961 were collected under a radically different set of protocol, thereby precluding statistical comparison with the two subsequent measurement periods. 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. However, average tree-level growth rates (unadjusted for stand structure) prior to 1961 were even higher than those recorded between 1961 and 1972 (Sheffield et al. 1985), suggesting the latest reductions may be the continuation of a longer downward trend.

At least three other studies of growth covering approximately the same time span corroborate allegations of extensive reductions involving naturally regenerated southern pines. Ruark et al. (1990) have found that similar analyses of FIA data from the two latest survey cycles of Alabama show the growth of naturally regenerated pine stands in that state have declined by magnitudes comparable to Georgia. Zahner et al. (1988) analyzed tree ring data from natural loblolly stands in Georgia, North Carolina, and South Carolina. After factoring the influences of tree age, stand structure *and* drought from the ring chronologies, they reported a steady decline of 36% in ring-area growth between 1949 and 1984. Lloyd and Waldrop (personal communication)¹ are analyzing growth measurements collected at 5-year intervals since 1955 from natural loblolly growth and yield plots in Virginia and South Carolina. After adjusting for differences in stand structure, they have found a reduction of 23% when stand-level basal area growth between 1955–59 is compared to growth between 1977–81.

CONCLUSIONS

After adjusting for differences in average site indices, initial stand ages, initial stand densities, mortality, and hardwood competition, gross annual basal area growth rates of natural pine stands in Georgia were significantly less between 1972 and 1982 than between 1961 and 1972 in every case tested. Mean annual growth rates of the pine component in natural pine stands were down by 19% in Piedmont and Mountain loblolly stands, 28% in Piedmont and Mountain shortleaf pine stands, and 28% in Coastal Plain slash pine stands. Mean annual growth rates of all tree species in these stands fell by 16%, 32%, and 24%, respectively.

The growth of naturally regenerated pines in Georgia has changed by more than can be attributed to any obvious stand structural factors. Identification of potential causal agents beyond the endogenous stand variables employed in this analysis is probably not feasible with these data. The roles of exogenous factors such as climate or pollution, or of possible population shifts not controlled by the structural variables in the model, have not been resolved by this analysis. The broad geographic areas associated with regional growth rates increase the likelihood that several factors are contributing to the reductions, probably varying in importance with species, location, and time.

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