DYNAMICS OF STAND GROWTH AND YIELD OVER 29 YEARS IN A LOBLOLLY PINE SOURCE TRIAL IN ARKANSAS

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Abstract. Stands representing 36 unselected, rangewide sources of loblolly pine in a 29-year-old geographic source trial in southwestern Arkansas were compared in terms of stem diameter, dominant height, mortality and stand basal area production trends over time. Significant geographic-source differences were maintained through age 29 for Dbh and dominant height, with eastern sources (particularly East Coast) maintaining an approximately constant percent superiority of 3-8% after age 11. By the study's conclusion the superiority of eastern-origin trees over western in volume per tree was 18%. Late mortality differed little between East Coast and local Arkansas stands through age 26, but subsequently diverged. Stand basal area production was superior in East Coast origin 'stands through age 26, but declined to no significant difference by age 29. The observed declines In yield superiority of East Coast over local stands after age 26 could not be shown to result from any difference in "competitive ability"; rather, It is hypothesized that the faster-growing East Coast stands reached a similar maximum size-density trajectory four years sooner. Given the value and cost advantages of larger piece size, these results favor use of East Coast material on moist sites In Arkansas. However, for the early growth benefits of source movement to be maintained through the long term, the fast-growing eastern-origin stands must be aggressively managed to minimize yield reductions associated with severe competitive stress.

INTRODUCTION

A very few organizations have begun to deploy and manage select Atlantic-coastal loblolly pine families on substantial plantation acreages in Arkansas and Oklahoma, on the basis of long-term seed source trials which have demonstrated a considerable superiority of Atlantic-coast material over local In individual-tree yield and form without major added mortality (Wells and Lambeth, 1979; Lambeth et al., 1984).

Strategic planning and forest management decisionmaking with respect to these non-local stands depend on an accurate assessment of expected stand-yield performance and response to competition through time. Stand yield data for trials near commercial rotation ages remains scarce. A scheduled thinning of a 29-year-old (from seed) loblolly pine source trial in southwestern Arkansas in early 1985 provided an opportunity to compare stand development for local and non-local stands grown together.

MATERIALS AND METHODS

The source trial discussed here was planted In 1957 in southwestern Arkansas In a cooperative effort between the Southern Forest Experiment Station, Potlatch Corporation and Georgia-Pacific Corporation. The portion of the study used In this analysis consists of 36 rangewide sources of loblolly pine, each planted In one 49-tree-square plot (with two borders) in each of four non-adjacent blocks In Hempstead County, Arkansas (Figure 1). These sites could be considered moist for Arkansas, with moisture-holding capacities of 20-23 cm. A "light thinning from below" (no other Information available) was performed just before the 17th growing season from seed. Individual-tree yield, survival, fusiform rust infection and stem form results were reported through field-age 10 by Grigsby (1973), for field-age 16 by Grigsby (1977), and for field-age 25 by Wells and Lambeth (1983).

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In early 1985, five trees were chosen from each source-plot to approximately represent the range of Dbh for that plot. Total height, Dbh, taper and wood specific gravity were measured on each stem. Total height, Dbh and taper were used in Smalian's formula to compute a 'true' total volume per tree. In addition, the two largest-Dbh stems per plot were sectioned longitudinally, and annual heights measured. Data collection was a cooperative effort, involving representatives from Potlatch Corporation, Weyerhaeuser Company, the U.S. Forest Service, Oklahoma State University and Texas A&M University. The 1985 data were then combined with historical data from ages 11, 17 and 26 (graciously provided by O. Wells and C. Lambeth) for this analysis.

The 36 sources were further delineated into seven geographic "regions" (Figure 1) for analysis, following the outlines used by Wells and Lambeth (1983). Analyses of variance were performed using the GLM procedure of SAS to assess the magnitude and pattern of region differences over time in individual tree and stand yield attributes. In addition, region differences in "competitive ability" were evaluated through a statistical test of heterogeneity in level and slope of region size-density trajectories between ages 26 and 29. Specific comparisons among regions and region groupings of interest were performed using single d.f. contrasts within the analyses of variance.

RESULTS AND DISCUSSION

Individual-Tree Yield

Region rankings and the significance of region differences for Dbh remained quite consistent from age 11 through age 29 (Table 1, Figure 2). Trees from regions east of the Mississippi River, and from the East Coast region in particular, were significantly larger in diameter than local and other western origin trees throughout this trial. Gulf Coast and Interior source trees did not differ significantly from East Coast source trees in Dbh after age 11, but trees from the Northeast showed a trend toward increasing slenderness relative to other eastern sources as the study progressed.

Region differences in dominant height[1], particularly between eastern and western sources and between East Coast and local sources, also were statistically significant at all four ages examined in this analysis (Table 1, Figure 3). The percentage difference between East Coast and local sources was greatest in the early years of the study (through age 17), although the absolute difference increased through age 26 and was essentially constant thereafter. This result supports the observation of Sprinz et al. (1987a), from the same study, that region height-age curves differed in shape, with the eastern sources growing more rapidly early on, but the western sources showing a "growth spurt" later, leading to essentially parallel height-age curves by the end of the study. The four "eastern" sources (Northeast, East Coast, Gulf Coast and Interior) did not differ significantly from one another in dominant height at any of the ages examined.

The observed region rankings for Dbh and height were reflected in similar rankings for "true" volume per tree at age 29 (Table 1). Again, eastern sources averaged much larger than western sources (0.33 m^3 vs. 0.28 m^3), and East Coast origin trees averaged larger than local-origin trees (0.32 m^3 vs. 0.27 m^3). Northeast origin trees ranked with the top sources for volume per tree, despite their small average diameter, not only because of their height but also because of excellent stem form - trees from the Northeast were significantly more cylindrical than trees from any other region (Sprinz et al., 1987b).

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[1] Dominant height is defined here as the average height of the two largest-diameter trees on a 49-tree plot.

FIGURE 1. Location of geographic sources and boundaries of geographic regions used in the analysis (after Lambeth et al.).

Stand Yield

Mortality behavior for the different regions after age 11 tended to follow an inverse trend with average stem diameter, with some notable exceptions (Table 2). Between ages 17 and 26, Gulf Coast and Interior stands (two of the largest in Dbh during that period) suffered considerably more mortality than most of the other regions. However, the Lost Pines source, which ranked near the bottom for Dbh at ages 17 and 26, showed the second-greatest percent mortality during that period, while East Coast origin stands, which ranked near the top for Dbh, exhibited very little mortality during that period (no significant difference from local stands). During the period from ages 26 to 29, Gulf Coast, Interior and Lost Pine stands continued to exhibit relatively high mortality percentages, and East Coast stands also began to show added mortality relative to local stands. Stands of Northeast origin, despite an Improving rank for Dbh from age 26 to 29, actually exhibited less mortality than local Northwest origin stands between those ages.

Table 3 and Figure 4 combine Individual-tree yield and mortality performance for the seven regions In terms of stand basal area and volume yield. Two trends are most apparent in these data. The first is the poor stand yield performance of Gulf Coast and Interior stands after the age-17 thinning, a reflection of the high mortality observed in stands from these regions. The second Is the changing stand-yield superiority of East Coast origin material during the study period. The statistically significant 8.5% stand basal area superiority of East Coast stands over local stands observed at age 17 declined to 6.6% (ns) by age 26 and -1% (ns) by age 29. Total volume per hectare was slightly greater for East Coast stands than for local stands (1.6%, ns) at age 29, due to the height and stem form superiority of East Coast material at that age.

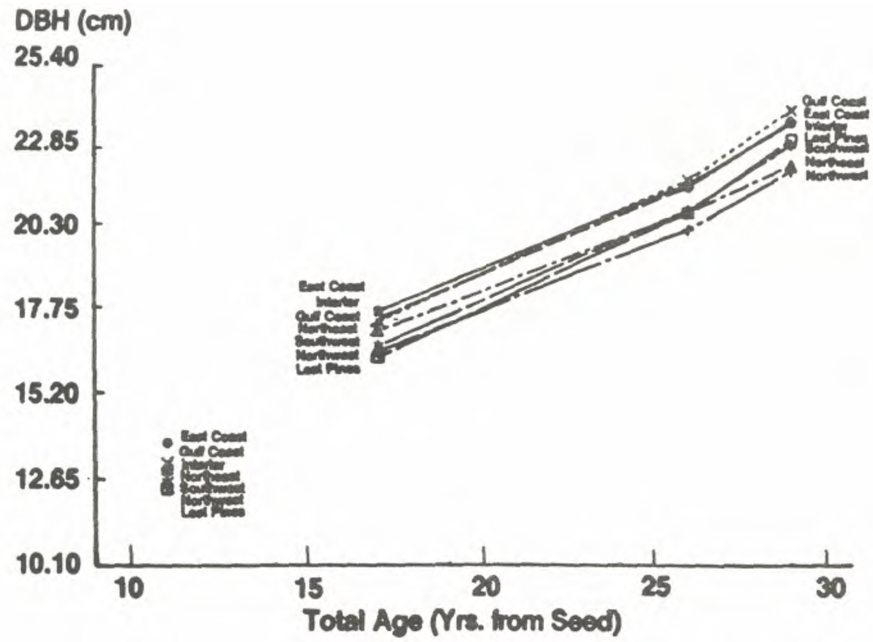

FIGURE 2. Time-trend in plot-average Dbh for 7 geographic regions of loblolly pine in an Arkansas provenance trial.

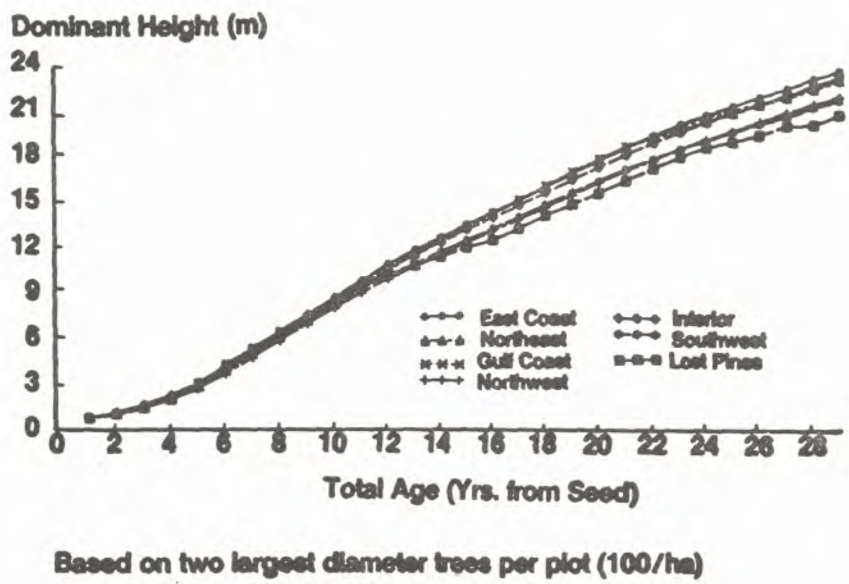

FIGURE 3. Time-trend in dominant height for 7 geographic regions of loblolly pine in an Arkansas provenance trial.

Source variability within a region was large and statistically significant for percent mortality and for stand basal area during the entire study period. In fact, source-in-region variability was actually greater than region-to-region variability for these traits. This result indicates that, even within a poor-performing region, sources (families?) can be found which perform well, and conversely, that care should be taken to test a number of sources, even from a high-ranking region, to screen out poor sources prior to large-scale deployment.

Response to Competition

Why a decline in the stand production advantage of East Coast stock after age 26? Is this a reflection of some kind of late-onset adaptability problem which is causing greater-than-expected mortality or less-than-expected growth in East Coast stands grown in Arkansas?

TABLE 2. Percent mortality[a] for seven geographic regions of loblolly pine in an Arkansas provenance trial.

Source	DF	TIME INTERVAL (Age from Seed) 17 to 26 P>F	26 to 29 P>F
BLOCK	3	***	****
REGION	6	***	ns
East vs. West		ns	ns
East Coast vs. Northwest		ns	ns
Gulf Coast vs. East Coast		**	ns
Interior vs. coastal		ns	ns
Northeast vs. East Coast		ns	ns
SOURCE (reg)	29	*	**
ERROR	103	4.21[c]	2.48

TIME INTERVAL (Age from Seed)

Region	17 to 26 $\bar{x}$ (%)	Region	26 to 29 $\bar{x}$ (%)
GC	23.6	GC	14.2
LOST	18.9	LOST	12.4
INT	16.0	EC	12.2
SW	10.3	INT	11.2
NE	8.4	SW	11.2
EC	8.41	NW	6.6
NW	7.1	NE	5.4

[a] Percentage variable was transformed to arsine (sqrt (%)) for analysis of variance.

[b] ****: Significant at α = 0.0001; ***: Significant at α = 0.01; **: Significant at α = 0.05; *: Significant at α = 0.10; ns: Not Significant

[c] Sum of squares is listed for ERROR

TABLE 3. Stand basal area and volume yield for seven geographic regions of loblolly pine at ages 11, 26 and 29 from seed, in an Arkansas provenance trial.

	Age from Seed						
	11		26		29		
Source	DF	Basal Area (m^2/ha) PR>F[a]	DF	Basal Area (m^2/ha) PR>F	DF	Basal Area (m^2/ha) PR>F	Volume/Tree (m^3/ha) PR>F
BLOCK	3	****	3	****	3	****	***
REGION	6	ns	6	***	6	**	**
East vs West	1	ns	1	ns	1	ns	ns
EC vs NW	1	ns	1	ns	1	ns	ns
GC vs EC	1	ns	1	***	1	***	***
INT vs Coast	1	ns	1	ns	1	ns	ns
NE vs EC	1	ns	1	ns	1	ns	ns
SOURCE (REG)	29	**	29	**	29	***	ns
ERROR	103	122.9[b]	103	4199.0	103	5681.5	1238084.8

Region	Basal Area (m^2/ha) $\bar{x}$	Region	Basal Area (m^2/ha) $\bar{x}$	Region	Basal Area (m^2/ha) $\bar{x}$	Region	Volume (m^3/ha) $\bar{x}$
EC	30.3	EC	44.3	NW	46.1	NE	394.2
INT	29.4	NE	42.0	EC	45.7	EC	337.5
NE	29.2	SW	41.6	NE	45.5	NW	332.2
SW	28.9	NW	41.6	SW	45.5	INT	326.2
LOST	28.9	INT	40.2	INT	42.2	SW	300.3
NW	28.7	LOST	37.0	LOST	40.0	GC	275.8
GC	27.6	GC	34.7	GC	35.8	LOST	254.8

a ****: Significant at α = 0.001; ***: Significant at α = 0.01; **: Significant at α = 0.05; *: Significant at α = 0.10; ns: Not significant

b Sum of squares is listed for ERROR

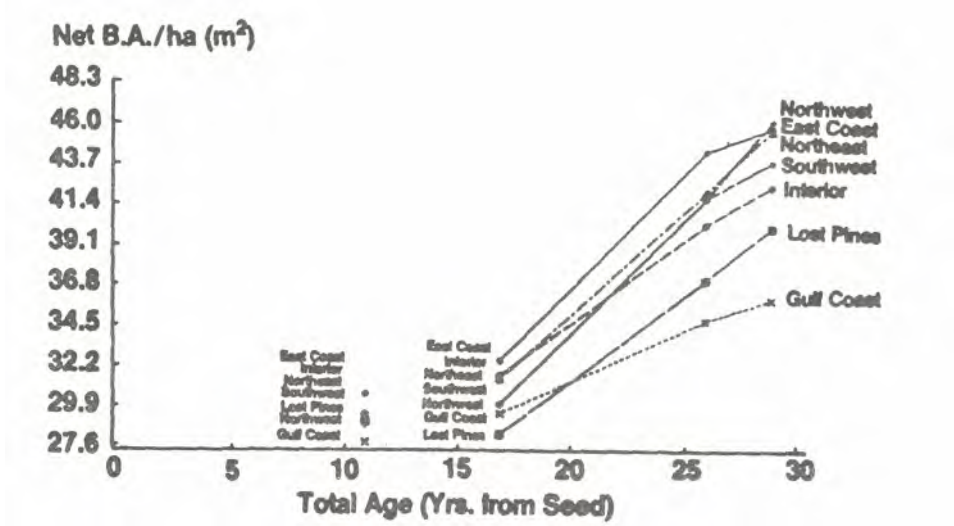

FIGURE 4. Time-trend in stand basal area per hectare for seven geographic regions of loblolly pine in an Arkansas provenance trial.

The basis for evaluating these possibilities lies in the fundamental concept of maximum size-density. The relationship of average plant volume or weight with stocking in log-log space is remarkably consistent - a linear trend with a slope of -3/2 - across a wide variety of species, from weeds to forest trees (Yoda et al., 1963; Kira et al., 1953; Drew and Flewelling, 1979; Reineke, 1933). [2] Once a given stand has reached full site occupancy, it progresses through time by moving along a size-density "trajectory," with increases in stem size (growth) accompanied by decreases in stand density (mortality). Although the slope of the size-density relationship appears to be consistent across species, the level of the relationship varies widely.

The slope and level of the size-density relationship for local source stock could be viewed as a benchmark for the amount of mortality which "adapted" material would experience per unit increase in average tree size, and for the maximum average tree size which could be expected in an "adapted" stand at a given stand density. Non-local stands exhibiting a flatter slope would be showing more mortality than local stands per unit of size growth. Non-local stands showing a lower level would be demonstrating an inability to carry the same average size as local stands were their stocking levels the same.

In this study, when only age-26 and age-29 data were Included, all region stands with two exceptions followed size-density trajectories which were consistent with Reineke's (1933) -1.605 slope. Local and Northeast stands exhibited size-density slopes which were significantly steeper (less mortality per unit of size-growth) than the others (Figure 5). It Is a distinct possibility, however, that the size-density slopes for the local and Northeast stands would have "flattened" to near -1.605 had the study continued past age 29. Certainly the amount of competitive stress (as indicated by stand basal area) being experienced by stands from these regions at age 26 was considerably less than the amount being experienced by East Coast stands at the same age. It is not possible to

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2 When Dbh is used as the dependent variable rather than volume, Reineke (1933) showed that a -1.605 slope applied, across several tree species.

draw a definitive conclusion on size-density slope differences from these data. However, it is clear than Gulf Coast and Interior stands exhibit size-density trends which are considerably lower in level than the size-density trends exhibited by the other regions in the study. Stands of these two regions appear unable to maintain the same average tree size for a given stocking level that stands of the other regions carried.

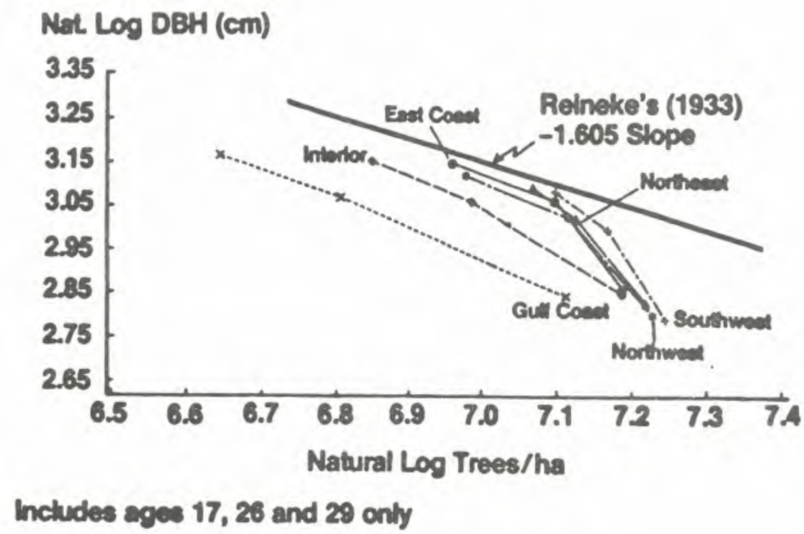

FIGURE 5. Size-density trajectories for six geographic regions (Lost Pines not included) of loblolly pine in an Arkansas provenance trial.

CONCLUSIONS

The use of East Coast material on moist sites like these in Arkansas appears to offer substantial benefits over use of local material, both in individual-tree and stand yield, through stand densities which could be considered quite high for loblolly pine. There does, however, appear to be a point in stand development at which severe competitive stress results in a decline in the stand-yield superiority of East Coast material (after age 26 or 44.3 m^2/ha of stand basal area in this study), and the earlier yield advantages thereafter are reduced.

It cannot be demonstrated conclusively from these results that East Coast stands exhibit an Intrinsically lower "carrying capacity" or exhibit more mortality per unit of growth than local-origin stands grown on the same sites. Instead, It is very likely that the decline In the stand-yield superiority of East Coast stands after age 26 only reflects a "normal" response to the much higher levels of growing stock In the East Coast stands relative to local origin stands of the same age. Of course, this conjecture should be restricted to the types of moist sites represented by the study blocks - drier sites could well lead to very different relative responses.

The strong relationship of piece-size to net stand value should also be considered here. As the average Dbh of a stand increases, harvesting and handling costs per unit of volume tend to decrease sharply, while product value per unit volume tends to Increase with average diameter for solidwood uses. Therefore, there would appear to be a stand-value benefit to use of East Coast stock over the smaller diameter local stock even for the same stand-volume yield.

The Gulf Coast sources used in this trial exhibited excessive mortality when grown this far offsite, even though the study sites were moist. Any decision to use Gulf Coast stock in Arkansas should be carefully considered in light of this evidence. Also, Interior sources of loblolly pine do not appear to offer significant long-term advantages in survival or growth rate over East Coast sources for planting on moist sites in Arkansas on the basis of this study. Diameter growth consistently averaged less, and mortality the same or greater, throughout the study period. On the other hand, Northeast-origin stands actually outyielded both local and East Coast origin stands in total volume by the conclusion of this study, and were superior in stem form. Further testing of stands from this region is warranted.

The results of this study underscore the critical interdependence of forest management and genetic improvement. For the early yield advantages of source movement to be realized, faster-growing non-local stands clearly must be thinned or harvested before they reach severe levels of competitive stress, and such treatments may be required sooner in the faster-growing stands than in slower-growing local stands.

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