Growth After Thinning a 35-Year-Old Natural Stand to Different Loblolly Pine and Hardwood Basal Areas

Michael G. Shelton *and* **Paul A. Murphy,** *USDA Forest Service, Southern Research Station, Monticello, AR 71656-3516.*

ABSTRACT. *Growth was monitored for 4 yr in a thinned stand in southern Arkansas with three pine basal areas (70, 85, and 100 ft^2/ac) and three hardwood basal areas (0, 15, and 30 ft^2/ac); pretreatment basal areas averaged 119 and 33 ft^2/ac for pines and hardwoods, respectively. Treatments were arranged in a 3 x 3 factorial randomized complete block design with three replicates, yielding 27 permanent 0.20 ac plots. Growth variables were regressed with residual pine and hardwood basal ureas. Pine basal area and volume growth increased with the pine stocking level after thinning and decreased with the level of retained hardwoods. For basal area and merchantable volume, hardwood growth largely compensated for losses in the pine component, und thus, hardwood retention had little net effect on the total growth of the stand. The greatest impact of hardwood retention was on the stand's sawtimber-growth, because hardwoods did not contribute to this product class. Each I ft^2/ac of retained hardwood basal area reduced pine sawtimber growth by 6 to IO bd ft Doyle/ac/yr, depending on the pine stocking. Because large differences existed in the value of timber-products, retaining 15 und 30 ft^2/ac of hardwoods reduced the value of timber production by 13 and 24%, respectively, at 4 yr after thinning. South. .I. Appl. For. 21(4):168–1 74.*

Pine–hardwood stands are an important resource in the South, occupying some 27 million ac (USDA Forest Service 1988). In addition, many of the 41 million ac in the natural pine type contain a significant hardwood component. Although pine-hardwood stands have occurred naturally for many years, their management and establishment has only been recently proposed (Waldrop 1989). Two major trends that are shaping the current interest in pine-hardwood stands are environmental issues and changing markets/processes (Lentz et al. 1989). Markets have been developed for the small-diameter hardwoods typically found on pine sites and are expected to increase in the future. Landowners now have the option to allow hardwoods to grow to merchantable size in established pine stands and harvesting them, rather than applying control treatments.

The competition between pines and hardwoods has long been the subject of southern forestry research. However, most of this information has focused on the critical establishment phase of even-aged stand development, because success or failure of pine regeneration often depends on controlling hardwood competition. The intensity of hardwood control during stand establishment is often directly related to the growth rates of the pines (Clover and Zutter 1993). However, less definitive results have been obtained for hardwood control in well-established pine stands. Some studies in natural stands have observed positive growth responses of overstory pines to hardwood removal (e.g., Grano 1970, Cain and Yaussy 1984), while others have not (e.g., Cain 1985). Boyer (1 986) proposed that a threshold exists for hardwoods, ranging between 10 and 30 ft^2/ac of basal area, below which there is no discernible effect on the growth of overstory pines. There appears to be little economic or biological justification for controlling hardwoods below this threshold.

One management alternative for pine-hardwood stands is to convert them to pure pine by removing hardwoods through harvesting or control treatments. However, many landowners find this option unacceptable, particularly if conversion requires high capital investments. Other landowners want to retain a hardwood component because they place a high priority on nontimber resources (Haymond 1988). Making wise choices among management alternatives requires quantitative information on resource trade-offs between pines and hardwoods. To better understand the growth relationships between pines and hardwoods, a thinning study was installed in a 35-yr-old natural loblolly pine (*Pinus taeda* L.) stand with a significant hardwood component located on a good site in southern Arkansas. In this paper, we report the growth relationships for the first 4 yr after thinning, which was completed in 1989.

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Methods

Study Area

The study was established in a natural, even-aged loblolly pine stand with a significant hardwood component located in the School Forest of the University of Arkansas at Monticello, Drew County, Arkansas. This area is in the West Gulf Coastal Plain. Soils were mapped as the Henry (Typic Fragiaqualfs) and Calloway (Glossaquic Fragiaqualfs) series. Both soils have silt loam surfaces and were formed on windblown silt. These poorly drained soils occur on broad upland flats and have a site index of 93 ft at 50 yr for loblolly pine. Normal annual precipitation for the study area is 53 in. with 25 in. occurring within the April-to-September growing season. During the monitoring period, growing-season precipitation was below normal for 1 yr and above normal for 3 yr; values were 28, 37, 29, and 19 in. for 1990, 1991, 1992, and 1993, respectively (USDC National Oceanic and Atmospheric Administration 1990-1 993).

The stand was regenerated from an existing hardwood-pine stand in the early 1950s. The hardwood component was killed, but no detail exists on how this was accomplished. The new pine stand was established from seeds produced by residual pines. A few pine seed trees still existed prior to study installation, but they were avoided in locating plots. Before treatment, the loblolly pine basal area averaged 119 ft^2/ac, and hardwood basal area averaged 33 ft^2/ac. Most hardwoods formed a uniform midcanopy with occasional individuals extending into the main canopy, which was dominated by loblolly pine. The hardwood component was principally willow and water oak (*Quercus phellos* L. and *Q. nigra* L., respectively), with lesser amounts of southern red oak (Q. *falcata* Michx.), and sweetgum (*Liquidambar styraciflua* L.). The red oak group accounted for 61% of the hardwood basal area, while the white oak group accounted for 6%. Stem quality of both pines and hardwoods was often poor because of past damage from ice storms and stem defects.

Study Design and Treatment Implementation

Twenty-seven circular, 0.20 ac measurement plots were established. Each had a 33 ft isolation strip creating a gross plot of 0.53 ac. The study used a 3 x 3 factorial randomized complete block design with three replicates. Treatments called for thinning the basal area of each plot to one of three pine levels (60, 75, and 90 ft^2/ac in trees ≥ 3.6 in. dbh) and one of three hardwood levels (0, 15, and 30 ft^2/ac). Measurement plots and isolation strips were thinned to the same assigned basal areas. Since this initial harvest was heavy, 10% of the cut basal area was retained on all plots to compensate for logging damage. Treatments were randomly assigned to plots, although a few were reassigned if existing basal area was below that randomly assigned.

Most of the harvested pines were below the mean stand dbh, but some low-quality dominant and codominant trees also were cut. Thinning the hardwood component favored retention of the larger and better quality oaks, but this goal was often compromised to meet basal area targets. The area outside the isolation strips was marked to leave about 75 ft^2/ac of pine basal area and a component of desirable hardwoods.

To minimize damage to the residual stand, all trees were harvested as pulpwood which was forwarded in 5 ft lengths. Pines and hardwoods were harvested separately. Logging began during fall of 1988 but was intermittently terminated because of wet soil conditions. The pine harvest was virtually completed by late spring of 1989. However, unusually wet weather during the summer prevented completion of the hardwood harvest until late summer of 1989. Thus, logging continued intermittently for about 1 yr, with the pine component being mostly harvested before the 1989 growing season and the hardwoods being harvested by the end of the 1989 growing season. To ensure that all plots had similar initial levels of understory vegetation, all submerchantable hardwoods at least 1 in. dbh were stem-injected with glyphosate during late winter and early spring of 1990. For most treatments, residual basal areas were higher than initially intended because of the low levels of logging damage and the 1 yr delay in treatment implementation.

Measurements

Before harvest, all woody vegetation was inventoried in the measurement plots and isolation strips by 1 in. dbh classes and species groups. After completion of logging in fall 1989. all trees in the measurement plots were assigned permanent numbers and measured for dbh, total height, and crown-base height. Age was determined on a subsample of about one-third of the residual trees. Tree sizes were remeasured during the fall of 1993. However, heights were measured on about one-third of the trees, which were selected to represent the range in dbh.

Data Analyses and Modeling

Loblolly pine site index was computed using the function of Farrar (1973) for trees sampled for age that showed no periods of past suppression. For the 1989 data, means were calculated for dbh, total height, and crown-base height for each plot, while basal area and volumes were summed. Pine volumes were calculated from taper curves for natural loblolly pine (Farrar and Murphy 1988). Inside bark, cubic-foot volume for merchantable trees (dbh ≥ 3.6 in.) was computed from a 1 ft stump to a 4.0 in. outside-bark top. Volumes for sawtimber trees (dbh ≥ 9.6 in.) were computed from a 1 ft stump to an 8 in. outside-bark top; cubic foot volume was inside bark. Hardwood volumes were calculated from the equations of Clark et al. (1986). Merchantability limits were the same as for pines except that stump heights varied as follows: 0.2 ft for trees with dbh of 3.6 to 4.9 in., 0.6 ft for trees with dbh of 5.0 to 10.9 in., and 1.0 ft for larger trees. Sawtimber volumes were not calculated for hardwood trees because of their small size and generally poor quality.

Calculation methods for the 1993 data were identical to those of 1989, except for the total height and crown-base height of unmeasured trees. Prediction equations relating total height and crown-base height to dbh were developed for the pine component of each plot. In about one-quarter of the cases, equations were not significant at $P = 0.10$. These were generally the low-basal area plots where the range in dbh was narrow. Plot means were used for the total height and crown-base height of the unmeasured trees in those plots.

Developing suitable prediction equations for hardwoods was complicated by the multiple species involved and the low rates of height growth. The height growth of oaks and other hardwoods measured both in 1989 and 1993 was calculated. Plot values were analyzed using analysis of variance, which revealed no significant differences among treatments. The total height and crown-base height of unmeasured trees in 1993 were calculated from their 1989 measurement using the mean growth rates of species groups observed for the entire study.

Annual growth for the 4 yr period was calculated as the difference between plot values in 1989 and 1993, divided by the length of the monitoring period. This is net growth, as it included the effects of mortality and ingrowth (for pine sawtimber only). Ingrowth for pine sawtimber was the volume of trees growing past the 9.5 in. merchantability threshold for dbh. For trees dying during the monitoring period, mortality losses were calculated from tree values in 1989.

The basal area of individual plots varied within a designated treatment because of: (1) tree mortality from logging damage and natural causes, (2) growth that occurred during study installation, and (3) the inability to precisely control basal areas on small plots. Basal areas at the beginning of growth monitoring ranged by a **mean** of 6.4 ft^2/ac within both pine and hardwood treatment classes. Because of this variation, growth data were analyzed using regression, which allowed using the actual basal area of each plot rather than its class designation. After evaluating several candidate functions, the following form was selected for predicting annual pine growth:

$$PG = b_0 PBA \exp(b_1 PBA + b_2 HBA) \quad (1)$$

where *PG* is the annual pine growth for dbh, basal area, and volume; *PBA* and *HBA* are the pine and hardwood basal areas, respectively, at the beginning of monitoring; and the b_i's are the coefficients to be determined. The equation for hardwood growth was:

$$HG = b_0 HBA \exp(b_1 PBA + b_2 HBA) \quad (2)$$

where *HG* is the annual hardwood growth for dbh, basal area, and volume, and other symbols are as previously defined. Data for equation (2) excluded the pine-only plots. The equation for total growth was:

$$TG = b_0 TBA \exp(b_1 TBA + b_2 HBA / TBA) \quad (3)$$

where *TG* is the total annual growth (pines plus hardwoods) for basal area and volume, *TBA* is the sum of the pine and hardwood basal area, and other symbols are as previously defined. The motivating reason for fitting Equation (3) was to test if differing pine-hardwood compositions affected total growth; no additivity is implied between Equations (1) and (2) and Equation (3). Equations were fitted by nonlinear least squares regression using the SAS procedure MODEL (SAS Institute 1988). Coefficients were dropped from the full models if they did not differ from zero at *P* I0.0.5.

Results and Discussion

Stand Conditions After Thinning

Loblolly pine trees averaged 14 in. dbh and were 7.5 ft tall with a live crown ratio of 41% (Table 1). Dbh, total height, and crown-base height tended to be slightly greater for the lower stocking levels because the smaller trees within the stand were generally removed in thinning. By contrast, stand-level values, such as the number of trees, basal area, and volume, were substantially greater for the higher stocking levels. The age of loblolly pine averaged 35 yr.

Hardwoods averaged 7 in. dbh and were 56 ft tall with a live crown ratio of 53% (Table 1). After thinning, the hardwood component was mostly oaks, which accounted for 74 and 82% of the number and basal area of hardwood trees, respectively. Willow and water oaks were the two most common species. Sweetgum was the most common nonoak species, accounting for 13% of the hardwood number and 9% of the hardwood basal area. Age for the red oak group averaged 36 yr. Although both pine and hardwoods were about the same age, the pines were twice as large as hardwoods in dbh and about one-third greater in total height. Such differences in size are typical and reflect the relative growth rates of the respective species groups. Most of the pines in this stand were in dominant and codominant crown classes, while the hardwoods were mostly in subordinate classes. On most Coastal Plain sites, the height growth of loblolly pine will greatly exceed that of neighboring hardwoods, especially if the pines are free to grow (Wahlenberg 1960). Because of the vertical stratification in this stand, hardwoods compete with pines for soil moisture and nutrients but not for sunlight.

Table 1. Descriptive statistics for the pine and hardwood components in 35-yr-old loblolly pine and pine-hardwood stands by residual basal areas at the beginning of growth monitoring.

	Basal area		
Variable	Low	Medium	High
Loblolly pine			
Quadratic mean dbh (in.)	14.9	13.7	14.1
Crown-base height (ft)	45	44	44
Total height (ft)	76	74	74
Trees/ac	59	84	96
Basal area (ft ‘lac)	68	83	98
Sawtimber basal area (ft^2/ac)	65	80	94
Merchantable volume (ft^3/ac)	2,140	2,500	2,980
Sawtimber volume (ft^3/ac)	1,920	2,140	2,590
Sawtimber volume (bd ft Doyle/ac)	7,620	7.770	9,640
Hardwoods			
Quadratic mean dbh (in.)	—	7.2	6.9
Crown-base height (ft)		26	26
Total height (ft)		57	54
Trees/ac		71	118
Basal area (ft^2/ac)		18	30
Merchantable volume (ft^3/ac)		380	620

Table 2. Equations and associated statistics for predicting the annual growth rates in a 35-yr-old natural stand thinned to different pine and hardwood basal areas.

Equation [1]	Fit index	Root MSE	Mean value
Loblolly pine			
$DBH = 0.01660\ PBA \exp(-0.01809\ PBA - 0.008835\ HBA)$	0.49	0.04	0.27
$BA = 0.06970\ PBA \exp(-0.005696\ PBA - 0.009416\ HBA)$	0.62	0.36	3.09
$MCF = 2.069\ PBA \exp(-0.007727\ HBA)$	0.52	21.2	153
$SCF = 2.167\ PBA \exp(-0.008794\ HBA)$	0.59	21.2	158
$DOY = 10.96\ PBA \exp(-0.009726\ HBA)$	0.49	121	788
Hardwoods			
$DBH = 0.02605\ HBA \exp(-0.05696\ HBA)$	0.20	0.03	0.15
$BA = 0.1040\ HBA \exp(-0.01272\ PBA)$	0.42	0.22	0.92
$MCF = 2.366\ HBA \exp(-0.01002\ PBA)$	0.64	4.23	25.7
Total stand			
$BA = 0.08257\ TBA \exp(-0.007844\ TBA)$	0.18	0.41	3.70
$MCF = 3.012\ TBA \exp(-0.004338\ TBA - 0.7873\ HBA/TBA)$	0.37	20.5	170

[1] Abbreviations for annual growth are: DBH = quadratic mean dbh (in.); BA = basal area (ft^2/ac); MCF = merchantable volume (ft^3/ac); SCF = sawtimber volume (ft^3/ac); DOV = sawtimber volume (bd ft Doyle/ac). Abbreviations for basal areas at the beginning of the monitoring period are: PBA = pine basal area (ft^2/ac); HBA = hardwood basal area (ft^2/ac); TBA = total basal area (ft^2/ac). Degrees of freedom were either 24 or 25 for pine and stand total equations and 16 for the hardwood equations. All regression coefficients significantly differed from zero at $P \leq 0.01$.

Pine Growth

Equations and associated statistics for predicting annual growth rates of loblolly pine are presented in Table 2. Fit indices (equivalent to R^2 for linear equations) ranged from 0.49 to 0.62. Both pine and hardwood basal areas were significant for all growth variables, and all regression coefficients significantly differed from zero at $P \leq 0.001$.

Pine growth variables were calculated for a representative range in residual basal areas and are plotted in Figure 1. Pine dbh growth was negatively affected by increases in the basal area of both pines and hardwoods. By contrast, pine basal area and volume growth increased when the pine stocking level increased but decreased when the stocking of hardwoods increased. Such relationships are consistent with our

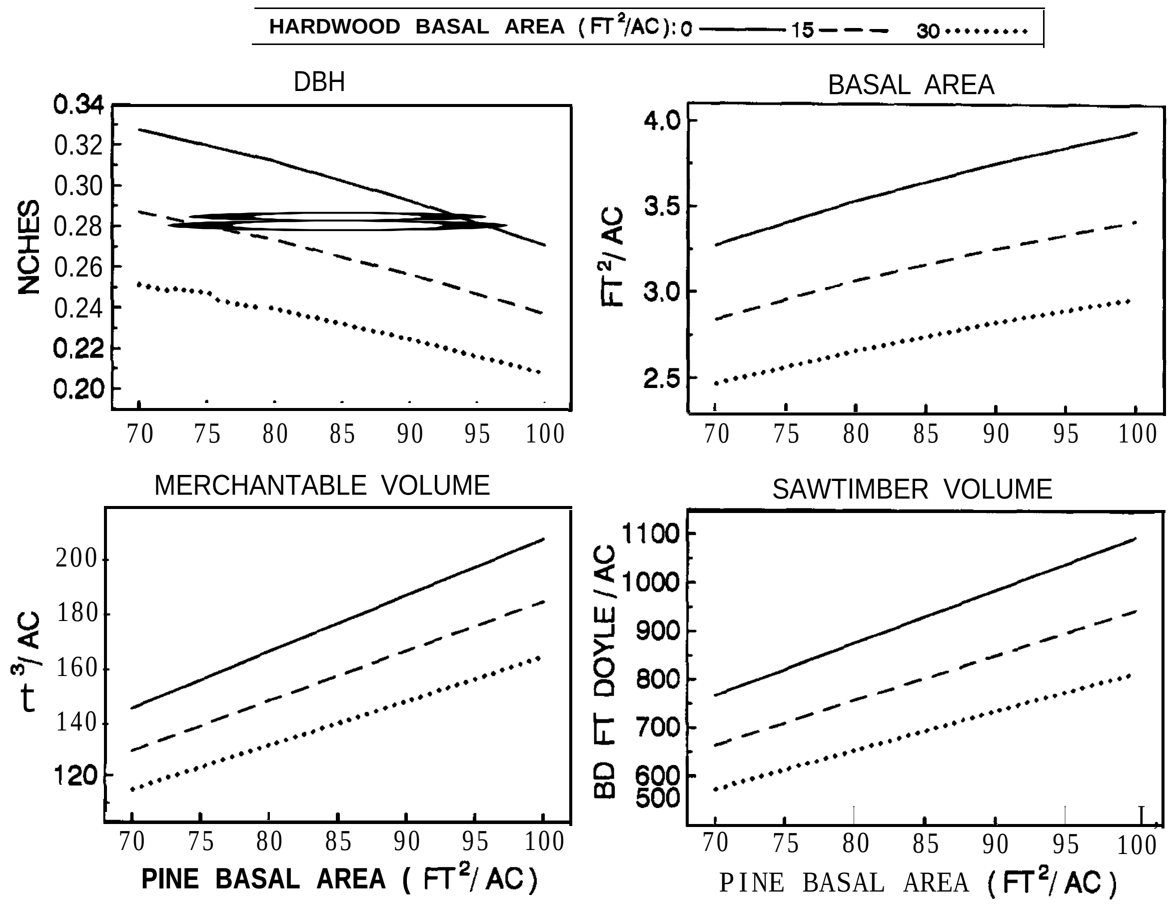

Figure 1. Effects of residual pine and hardwood basal areas on mean annual growth of the pine component at 4 yr after thinning a 35-yr-old natural stand. Values were calculated from the pine equations presented in Table 2.

understanding of competition and the difference in the growth of the individual versus the population. Increasing stand basal area suppresses the growth of individual trees by increasing competition for limited resources, but the growth of the population increases because there are more trees occupying the site. Retaining 15 ft^2/ac of hardwoods reduced pine growth by 11 to 14% depending on the specific growth variable; retaining 30 ft^2/ac of hardwoods resulted in reductions of 21 to 25%.

Pine mortality losses were very low after thinning, averaging only 0.14 trees/ac/yr. Losses occurred in scattered individual trees and included lightning, insects, and unknown causes. Ingrowth to sawtimber size classes averaged only 0.46 trees/ac/yr, because most of the trees were already in this class at the beginning of the study. Ingrowth only accounted for 1 to 2% of the sawtimber volume growth.

The growth rates observed for the pine-only treatment of this study were similar to those reported for thinned 45-yr-old natural pine stands on medium-to-good sites in southern Arkansas and northern Louisiana (Murphy and Farrar 1985). Annual basal area growth maximized at 3.5 ft^2/ac/yr for a residual basal area of 130 ft^2/ac, while sawtimber volume growth maximized at values of 180 ft^3/ac/yr for a residual basal area of 100 ft^2/ac. Comparable values for the basal area and sawtimber volume growth of our study are 3.9 ft^2/ac/yr and 217 ft^3/ac/yr, respectively, for a residual pine basal area of 100 ft^2/ac.

Hardwood Growth

Fit indices for the hardwood growth equations ranged from 0.20 to 0.64 (Table 2). Pine basal area did not significantly affect hardwood dbh growth (P = 0.14) and was dropped from the full model. All remaining regression coefficients significantly differed from zero at $P \leq 0.01$.

Increasing pine basal area resulted in a reduction in hardwood growth for all expressions except dbh (Figure 2). Increasing pine basal area from 70 to 85 ft^2/ac decreased hardwood basal area and volume growth by 14 to 17%; comparable decreases in growth were 26 to 32% when pine basal area increases from 70 to 100 ft^2/ac. Hardwood mortality losses averaged 0.69 trees/ac/yr.

Total Stand Growth

Equations for the total stand growth (pines plus hardwoods) were developed for basal area and merchantable volume (Table 2). The ratio of hardwood and total basal area [the HBA/TBA term in equation (3)] did not significantly affect the total basal area growth (P = 0.48) and was dropped from the full model. All remaining regression coefficients significantly differed from zero at $P \leq 0.001$, but the fit index was only 0.18. The lack of significance for the proportion of

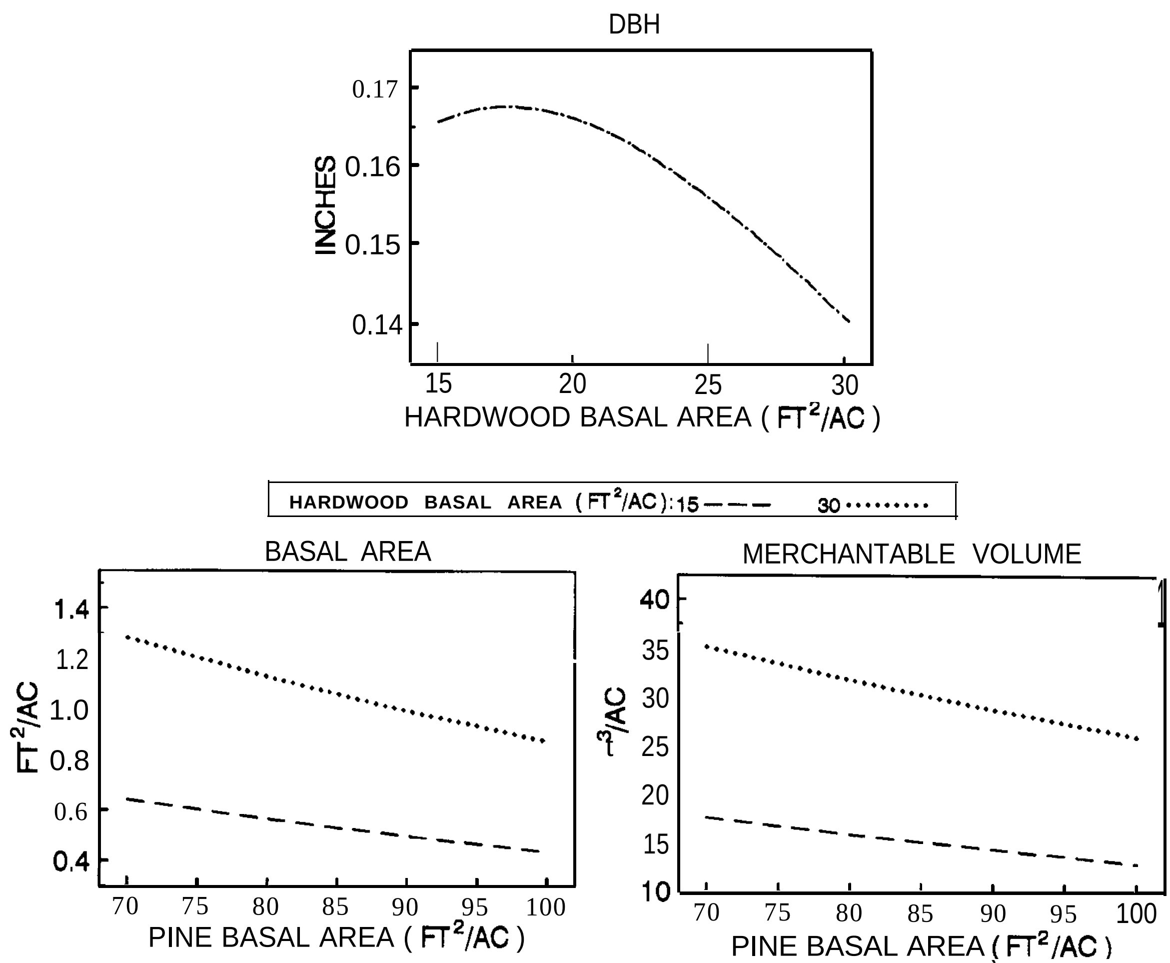

Figure 2. Effects of residual pine and hardwood basal areas on mean annual growth of the hardwood component at 4 yr after thinning a 35-yr-old natural stand. Values were calculated from the hardwood equations presented in Table 2.

total basal area in hardwoods indicated that the pine-hardwood composition of this stand did not substantially affect total basal area growth. This observation was also supported by equations for each species group, which showed that hardwoods were growing at 3.5% annually compared to 3.7% for the pines when basal areas were 85 and 15 ft^2/ac for pines and hardwoods, respectively. For the residual basal areas evaluated in this study, total basal area growth only varied between 3.3 and 3.9 ft^2/ac/yr (Figure 3).

The equation for total growth in merchantable volume had a fit index of 0.37. The regression coefficient for the proportion of total basal area in hardwoods was significant (P = 0.004) and negative, indicating that the hardwood volume growth was lower than that of the pines. This largely reflects the shorter merchantable heights of hardwoods. Plotting values calculated from this equation also shows that pine-hardwood composition has a pronounced effect on volume growth when gaged by total basal area (Figure 3). For example, a total basal area of 100 ft^2/ac was predicted to grow 19.5 ft^3/ac/yr when composed of pines only, but growth was

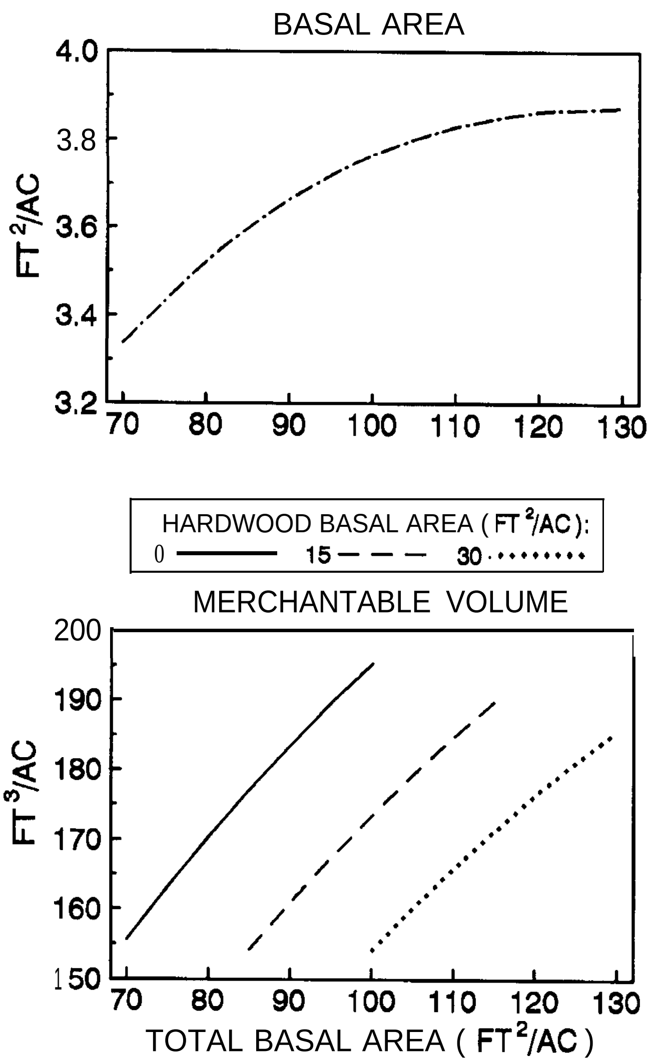

Figure 3. Effects of residual total basal area on mean annual growth rates for total basal area and merchantable volume (pines plus hardwoods) at 4 yr after thinning a 35-yr-old natural stand. Values were calculated from equations for stand totals presented in Table 2.

reduced to 154 ft^3/ac/yr when hardwoods made up 30% of the total basal area. It is important to note, however, that this reduced growth is mostly attributable to the reduced pine stocking rather than the increase in hardwoods. When the pine stocking is held constant, hardwood retention appears to have very little effect on total merchantable volume growth, although there is a compensatory shift from pine to hardwood growth. For example, total volume growth in a stand with 70 ft^2/ac of pines was predicted to be 1.56, 154, and 154 ft^3/ac/yr when hardwood basal area was 0, 15, and 30 ft^2/ac, respectively; comparable growth rates for a stand with 100 ft^2/ac of pines was predicted to be 195, 190, and 186 ft^3/ac/yr when hardwood basal area was 0, 15, and 30 ft^2/ac, respectively. However, hardwood retention most ‘strongly affected the stand’s sawtimber growth, because hardwoods did not contribute to the growth of this product class. Shiver and Brister (1996) also noted that hardwoods reduced sawtimber yields in natural pine stands.

Farrar et al. (1989) developed equations for the growth of pine-hardwood stands in southern Arkansas. Although these stands were somewhat uneven-aged in structure, growth relationships were quite similar to those reported here. For a pine basal area of 70 ft^2/ac, equations of Farrar et al. predicted the total merchantable growth to be 136, 142, and 132 ft^3/ac/yr, respectively, when 0, 15, and 30 ft^2/ac, respectively, of hardwoods are present. Values from our study are about 12% higher than those of Farrar et al.

Pine-Hardwood Trade-Offs

Although hardwood retention did not strongly affect the total growth in the stand conditions evaluated here, there was a substantial difference in product value between pines and hardwoods. Thus, stand composition strongly affected timber-production values. Although product values vary greatly both locally and temporally, the outcome of any substitution of growth from pine sawtimber to hardwood pulpwood is obvious. Stumpage prices during the middle of the 4 yr growth period averaged $259/mbf Doyle for pine sawtimber and $8/cord for hardwood pulpwood in southern Arkansas (Arkansas Cooperative Extension Service, Little Rock, AR). Thus, the value of the total annual growth for a pine basal area of 85 ft^2/ac is $25 1/ac, but is reduced to $218 and $190/ac when 15 and 30 ft^2/ac of hardwoods, respectively, were retained. The more difficult and perhaps unanswerable question is whether the retention of 15 or 30 ft^2/ac of hardwoods provides nontimber benefits that are worth $33 and $61/ac/yr, respectively. This answer, of course, depends on the landowner.

The decision to retain or remove hardwoods in pine-hardwood stands ultimately depends on landowner objectives, local timber markets, and various economic considerations. One of the greatest current challenges to the forestry profession is to integrate multiple resources into a framework of timber management activities that will satisfy landowner, societal, and environmental goals. Accomplishing this complex task is far beyond the scope of this paper, but some simple considerations can be brought out. In the stand conditions evaluated here, hardwood removal had some distinctive benefits. Growth rates for pine sawtimber, the most valuable timber product, were clearly increased through at least the during first 4 yr after treatment. Although stumpage prices for hardwood pulpwood were low, their harvest generated income that would be welcomed by many landowners. Removing hardwoods increased forage production and provided understory cover, which enhanced wildlife-habitat quality for some species (Tappe et al. 1993). The visual properties of pine stands with no midcanopy hardwoods is also pleasing to some viewers; such stands have a park-like appearance with good visibility.

By contrast, hardwood retention was also beneficial in these stand conditions. A hardwood midstory may promote more rapid pruning of the lower branches of the pines, which may increase stem quality and lumber yields. A hardwood midstory may also be favorable to certain wildlife species that are dependent on vertical stratification (Myers and Johnson 1978). As hardwood size and vigor increases after thinning, increased mast production in the future will be an important resource to some animals. Retaining a hardwood component may improve the visual quality of the stand to some people. especially if a component of flowering trees is retained. Hardwoods provide a sharp contrast with neighboring pines in terms of texture, shape, color, and seasonality. A hardwood component clearly suppresses the development of understory vegetation. which facilitates stand regeneration when the time comes for reproduction cutting (Cain 1991) and makes walking and working more pleasant.

Conclusions

There has long been an interest in the rates of timber production in natural stands, and short-term results of this study contribute to this body of information. In this study, pine growth rates increased with pine stocking levels and decreased with the level of retained hardwoods. All expressions of stand-level pine growth were greatest for the highest pine basal area tested (100 ft^2/ac) with no hardwoods. At least through the first 4 yr after thinning, the impacts of hardwoods on pine growth appear to be progressive rather than having a minimum threshold. Hardwoods contributed to the total merchantable volume growth of the stand, and the growth of retained hardwoods largely offset losses in pine merchantable volume growth. Thus, retained hardwoods had little net effect on the total stand growth. However, hardwood retention strongly affected the value of timber products because of the large price differential between pine sawtimber and hardwood pulpwood. The greatest negative effects of retaining a hardwood component in this stand was the reduction in pine sawtimber growth-each 1 ft^2/ac of retained hardwood basal area reduced pine sawtimber growth by 6 to 10 bd ft Doyle/ac/yr during the first 4 yr after thinning. The growth relationships described in this study contribute to information needed by landowners and foresters in making silvicultural decisions regarding stand composition and in making the complicated choices between timber and nontimber resources, but additional inventories will be needed to confirm long-term relationships.

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