VOLUME GROWTH OF PINE AND HARDWOOD IN UNEVEN-AGED LOBLOLLY PINE - UPLAND HARDWOOD MIXTURES

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Abstract. – Results are reported from an exploratory investigation of stand-level periodic volume growth of uneven-aged mixed loblolly pine (*Pinus taeda* L.) - upland hardwood stands on good sites in southeastern Arkansas. A restricted set of replicated observations was extracted from an extensive CFI database involving varying pine-hardwood mixtures to form an array of plots with different levels of pines and hardwoods. Analysis was conducted of the 5-year periodic annual increment of the pine, the hardwood, and the total (pine plus hardwood) in relation to the stand density of the pine and hardwood components. Results show that at low to moderate pine basal area levels, an added hardwood component increases total stand growth but decreases total growth at higher pine levels. There seems to be little or no economic justification for mixed stands based on these growth predictions and current stumpage prices. The implications of these results and other factors regarding mixed stand management are also discussed.

INTRODUCTION

The information base on the growth of mixed southern pine - hardwood stands is quite limited and that for uneven-aged stands is particularly restricted. Most of the information deals with even-aged stands. Although the principles of species interactions in mixed stands are probably fundamentally similar in both even- and uneven-aged stands, the degree of the effect of one species upon another will probably be somewhat different in the two situations.

The general successional trend in the dominant woody vegetation on the southern uplands is toward hardwoods ultimately replacing pine unless the trend is interrupted or arrested by disturbances such as windstorms, fire, or forest management. Our southern pineries existed in the past essentially because catastrophes, principally wildfire, occurred at varying intervals and intensites over time and favored the light-seeded pioneering pines. Since we no longer allow fires to burn unchecked, the successional trend under these conditions is for hardwoods to generally invade pine stands at some stage of development and to eventually dominate without intervening treatment to favor pines. If our major economic interest is in pines, then the hardwoods must be kept at some tolerable level.

Most investigations on the effects of hardwoods on pine growth have dealt with the impacts of hardwoods overtopping or threatening to overtop pine regeneration in even-aged stands (Russel 1963, Clason 1978, Michael 1980, Hebb 1981) and early growth rates of pine stands are directly related to the intensity of hardwood control during stand establishment. Little information exists on the effects of hardwoods on pines in older stands. Some studies have shown a positive response of overstory pines to hardwood removal (Grano 1970, Pienaar and others 1983, Cain and Yaussy 1984). Burkhart and Sprinz (1984) show that as the percentage of hardwoods in the total stand increases in loblolly pine plantations, the survival, growth, and yield of the pine decreases. In even-aged shortleaf pine (Pinus echinata Mill.) stands, hardwood control increased growth rates of pines, particularly in dry years (Rogers and Brinkman 1965, Bower 1968). Grano (1970) has shown in uneven-aged loblolly-shortleaf pine stands that hardwoods can reduce the radial increment of pines by 30 to 40 percent in dry years. Other studies have not shown such responses (Russel 1961, Cain 1985, Boyer 1987). There may be a site-dependent threshold for hardwood density below which there is no appreciable effect of the hardwoods on the pine overstory and, from limited observations, the level appears to vary between about 10 to 30 square feet of basal area per acre (Boyer 1986). The level is probably toward the lower end for dry years and sites. Once a satisfactory pine sapling stand is established, there may be no strong economic reason to reduce hardwoods below this threshold during a rotation. However, it might be beneficial in reducing site preparation costs when the regeneration period is again reached. In uneven-aged pine stands the need to periodically secure regeneration and the restricted stand density range suitable for selection management are likely to call for a different strategy.

This paper deals with the periodic annual increment (p.a.i.) in merchantable cubic feet observed on a set of continuous forest inventory plots in natural stands in southeastern Arkansas. The stands are uneven-aged and composed principally of loblolly pine with varying admixtures of upland hardwoods

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composed mostly of oaks (Quercus sp.). The purpose is to present information on the contribution of the pine and hardwood components to the total stand growth and to foster some appreciation of the contribution of the hardwoods in uneven-aged pine stands.

METHODS

Data

The inventory data come from 1/5-acre permanent plots located in uneven-aged loblolly-shortleaf pine stands with varying densities of pine and hardwoods on the lands of the Potlatch Corporation in southeastern Arkansas. The stands containing the plots have been periodically cut under a selection system. The site index is generally 80 to 90 feet for loblolly (base age 50 years). However, no age data are available. These plots were inventoried in 1966, 1971, and 1976 affording information on two 5-year growth periods. Each plot tree in the 5-inch class and larger was positively identified and the records included species, dbh to the nearest 0.1-inch, and tree history.

Merchantable cubic-foot volume and basal area were calculated for each tree. Tree volumes were calculated using local volume functions fitted to local tables for pine and hardwoods which contained average volumes per 2-inch dbh class. All volumes are in terms of merchantable cubic feet, outside bark (o.b.), for trees with dbh 4.5 inches, to a 4-inch, o.b., top. Stump heights were 1/2-foot for sub-sawtimber (dbh 9.5 inches) and 1-foot for sawtimber (dbh 9.5 inches). The tree volume functions fitted by least squares are:

$$PVol = -11.59 + 3.789(D) - .3912(D^2) + .03204(D^3) - .000502(D^4) \quad (1)$$

$n = 11$, $R^2 = .9997$, $RMSE = 1.113$

$$HVol = 8.554 - 2.910(D) + .3327(D^2) - .00213(D^3) \quad (2)$$

$n = 11$, $R^2 = .9997$, $RMSE = .869$

where

PVol = pine cubic-foot volume per tree
HVol = hardwood cubic-foot volume per tree
D = tree dbh in inches
n = number of 2-inch dbh classes
R^2 = coefficient of determination
RMSE = root mean square error

Volumes and basal areas were summed for each plot on an acre basis and the p.a.i. in volume was calculated for each plot for each of the two growth periods. The plots were then screened with the following restrictions to obtain a homogenous data set for analysis that contained a minimum amount of extraneous variation:

1. Initial pine basal area is >0.

2. Initial hardwood basal area is ≤ 50 percent of the total basal area.

3. Basal area of pines other than loblolly is ≤ 10 percent of the initial total basal area.

4. Basal area of oaks is ≥ 50 percent of the initial hardwood basal area.

5. Mortality during a period is ≤ 10 percent of the initial total basal area.

6. Ingrowth of pine or hardwood during a period is ≤ 10 percent of the initial basal area for pine or hardwood, respectively.

7. Periodic annual increment of pine or hardwood during a period is ≥ 0.

Although the growth values are actually net, we are essentially dealing with survivor cubic-foot volume p.a.i. of pine-hardwood stands with up to 50 percent of the density in hardwoods. Further, the hardwood density is at least 50 percent oak. This screening of several hundred plot observations resulted in selecting 58 observations on p.a.i. distributed by basal area of pine and basal area of hardwood as shown in table 1. No more than four replications per cell were chosen in an effort to extract a controlled experiment from uncontrolled data. The mean, minimum value, and maximum value for the variables and restrictions are shown in table 2. In this analysis data set, the following proportions by numbers of trees occur in the stands at the start of the 5-year growth periods:

1. 99 percent of the pines were loblolly and only 1 percent were shortleaf.

2. 67 percent of the pines were poletimber (≤ 9.5 inches dbh) and 33 percent were sawtimber (> 9.5 inches dbh).

3. 72 percent of the hardwoods were oaks composed of 44 percent red oaks and 28 percent white oaks.

4. The red oaks were principally southern red oak (Q. falcata Michx.), willow oak (Q. phellos L.), and water oak (Q. nigra L.) while the white oaks were principally post oak (Q. stellata Wangenh.) and white oak (Q. alba L.).

5. 18 percent of the hardwoods were gums, principally sweetgum (Liquidambar styraciflua L.), and the remaining 10 percent were miscellaneous hardwoods.

6. 71 percent of the hardwoods were poletimber and 29 percent were sawtimber.

Table 1.--Distribution of growth observations by pine and hardwood basal area classes.

Pine Basal Area Class sq. ft./ac.	Hardwood Basal Area Class (sq. ft./ac.) 0	10	20	30	40	All
	no. of obs.					
20	3	2	1	-	-	6
30	4	1	2	-	-	7
40	4	2	-	4	-	10
50	4	-	1	-	3	8
60	2	1	-	-	-	3
70	4	1	1	1	-	7
80	1	2	-	-	1	4
90	4	2	-	-	-	6
100	2	1	-	-	-	3
110	2	-	-	-	-	2
120	2	-	-	-	-	2
Totals	32	12	5	5	4	58

Table 2.--Means and limits for variables and restrictions.

Item	n	Mean	Minimum	Maximum
Pine p.a.i.	58	107.3	25.1	242.7
Hardwood p.a.i.	58	11.9	0	47.0
Total p.a.i.	58	119.1	25.1	242.7
Pine basal area	58	59.4	15.6	121.3
Hardwood basal area	58	8.9	0	39.8
Percent of total basal area in shortleaf pine	58	0.7	0	9.6
Percent of total basal area in hardwood	58	13.1	0	48.9
Percent of hardwood basal area not oaks	32[a]	13.9	0	47.6
Mortality as percent of total basal area	58	1.6	0	8.6
Pine ingrowth as percent of pine basal area	58	2.4	0	9.7
Hardwood ingrowth as pct. of hardwood basal area	32[a]	2.6	0	10.5

[a]Twenty-six observations had no initial hardwood basal area.

Table 3.--Fit statistics[a] for prediction equations.

Equation	n	Mean	Bias	FI	RMSd	MABSd
6 (PPAI)	58	107.3	.3652	.6696	30.26	22.78
7 (HPAI)	58	11.9	-.1688	.8725	5.13	3.24
8 (TPAI)	58	119.1	.1964	.6028	31.15	23.62

[a] n = number of values

p = predicted value

o = observed value

Mean = $\Sigma(o)/n$

Bias = $\Sigma(p-o)/n$

FI = $1 - [\Sigma(p-o)^2/\Sigma(o-\Sigma(o)/n)^2]$

RMSd = $[(\Sigma(p-o)^2)/n]^{1/2}$

MABSd = $\Sigma|p-o|/n$

Analysis

The analysis consisted of regression analysis to relate the pine, hardwood, and total (combined pine + hardwood) p.a.i. to the pine and hardwood basal area at the start of the growth period. We investigated and evaluated several systems of linear equations in which pine, hardwood, and total p.a.i. are each predicted. We also tried non-linear systems in which the total p.a.i. is predicted, pine p.a.i. is predicted as a proportion of the total p.a.i., and hardwood p.a.i. is obtained by subtraction. We finally converged on the following system of nonlinear models due to reasonable trends and goodness of fit:

$$PPAI = f1(PBA, HBA) \quad (3)$$

$$HPAI = f2(PBA, HBA) \quad (4)$$

$$TPAI = PPAI + HPAI \quad (5)$$

where

PPAI = 5-year pine p.a.i., cu. ft./ac./yr.

f1, f2 = functions of similar form

PBA = pine basal area, sq. ft./ac.

HBA = hardwood basal area, sq. ft./ac.

HPAI = 5-year hardwood p.a.i., cu. ft./ac./yr.

TPAI = total p.a.i. = (PPAI + HPAI)

Equations 3 and 4 in this model set were formulated and fitted via non-linear least-squares utilizing "seemingly unrelated regression" procedures (SAS 1984). Solution of equation 5 is obtained by summing fitted equations 3 and 4. All three equations were then evaluated regarding goodness-of-fit.

RESULTS AND DISCUSSION

The fitted equations for the system are as follows:

$$PPAI = 2.70100(PBA)e^{\{A\}}, \quad (6)$$

where: $\{A\} = -0.0046892(PBA) - 0.0085694(HBA)$

$$HPAI = 4.24869(HBA)e^{\{B\}}, \quad (7)$$

where: $\{B\} = -0.0087526(PBA) - 0.0313041(HBA)$

$$TPAI = PPAI + HPAI \quad (8)$$

The goodness of fit statistics for this set are shown in table 3. The amount of variation in the dependent variables accounted for by the system is not outstanding but is probably about as much as could be expected from such a database not controlled for research purposes. The unusually good fit index (FI) for HPAI is partly due to 18 of the 58 observations being zero and thus having zero deviations from the predicted value. The lower RMSD for HPAI reflects the lower p.a.i. of the hardwood component compared to the pine.

The predicted response of pine and hardwood for typical selection stand densities is shown in table 4. We see that increasing hardwood basal area decreases pine p.a.i. at any pine density level. This is similar to the response found by Burkhart and Sprinz (1984) in loblolly pine plantations. In a like manner, hardwood p.a.i. declines with increasing pine basal area at any hardwood density level. Both responses are also illustrated in figures 1 and 2.

Except at the lowest HBA levels, the effect of the pine basal area on pine p.a.i. is somewhat more than directly proportional. For example, in table 5 a total basal area of 60 square feet per acre is partitioned into varying proportions of pine and hardwood basal area. Here, we see that where PBA is 90 percent of TBA, the PPAI is 89 percent of TPAI. But, where PBA is 70 percent of TBA, the PPAI is 73 percent of TPAI. As the PBA decreases to 50 percent, its contribution to TPAI increases to 58 percent. Also, the effect of hardwood basal area on hardwood p.a.i. peaks at about 30 square feet (figure 2) at any pine basal area level and does not vary much above 20 square feet of HBA.

The effect of pine and hardwood basal area on total p.a.i. is shown graphically in figure 3. At low pine densities the hardwood density contributes to total growth. But, as PBA increases above about 50 to 80 square feet, HBA reduces the total growth. At the upper pine densities total growth reduction increases as HBA increases. These responses imply that, at lower pine densities, the pine component does not fully utilize the site's resources and the additional hardwood component makes a net contribution to total growth but pine growth alone decreases (table 4). In contrast, at the upper pine density levels, adding hardwood density results in a net competitive effect and the total growth is reduced. The reduction in total growth here is directly related to the hardwood density level.

An interesting aspect of these relationships is the implied growth/density efficiencies. If we define efficiency as the ratio of p.a.i. to basal area and plot it on the ratio of pine basal area to total basal area, we get the efficiency trends depicted for pine, hardwood, and total in figures 4 through 6. Each figure shows the calculated efficiency as plotted for three levels of total basal area normally encountered in selection stands - 45, 60, and 75 square feet. In all cases the lowest total basal area

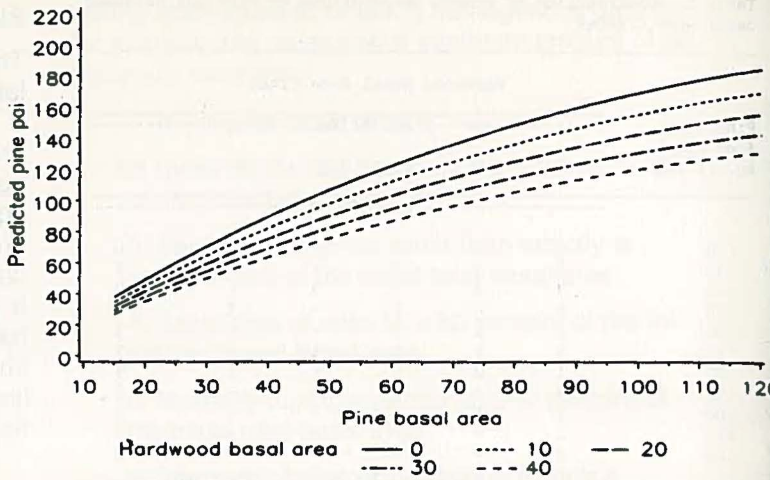

Figure 1.--Pine p.a.i. in relation to pine basal area, by hardwood basal area level (HARDBA).

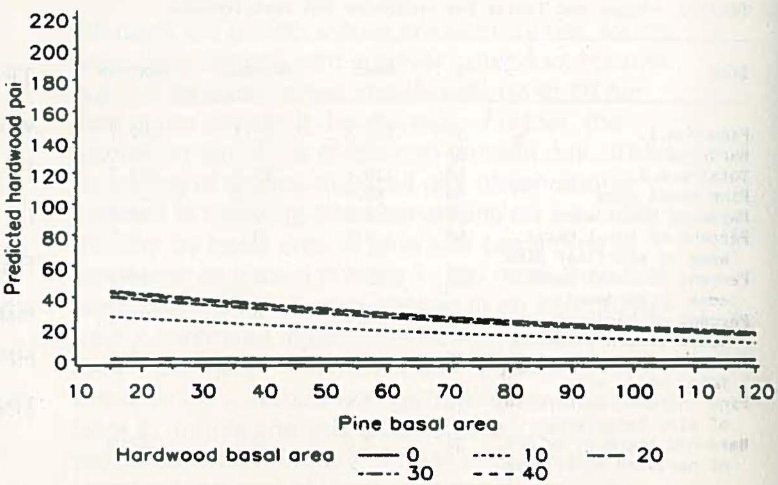

Figure 2.--Hardwood p.a.i. in relation to pine basal area, by hardwood basal area level (HARDBA).

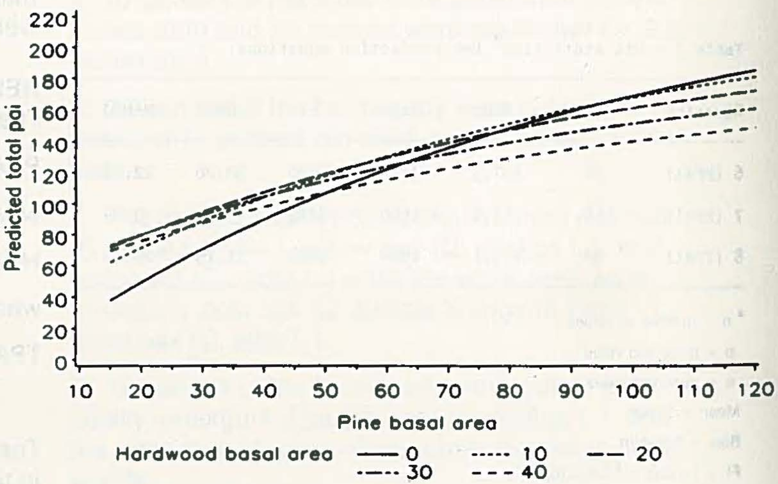

Figure 3.--Total p.a.i. in relation to pine basal area, by hardwood basal area level (HARDBA).

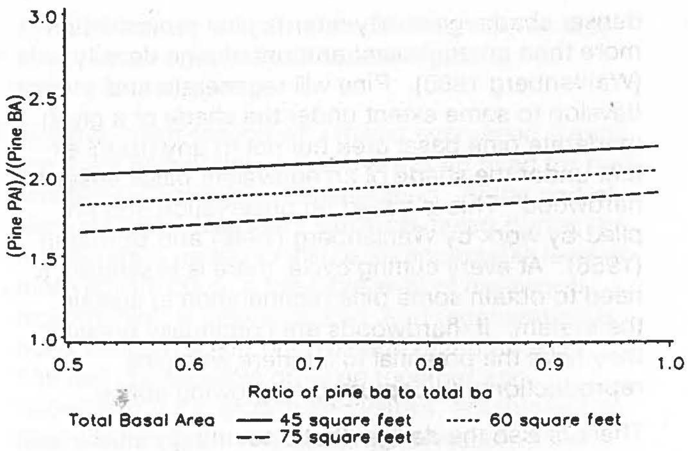

Figure 4.--Pine growth efficiency in relation to the proportion of pine in the total basal area, by three total basal area levels.

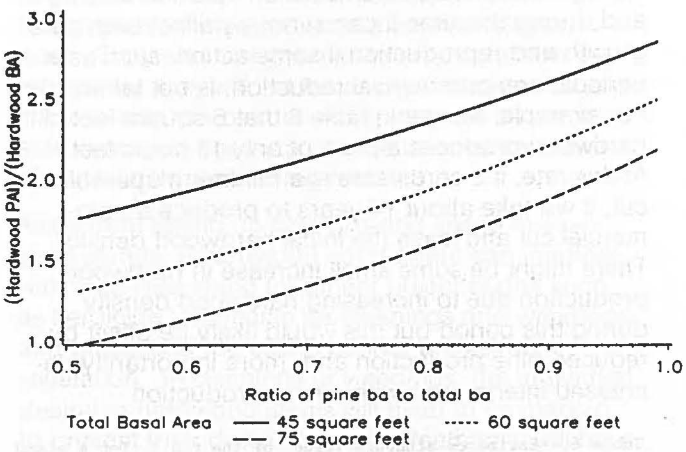

Figure 5.--Hardwood growth efficiency in relation to the proportion of pine in the total basal area, by three total basal area levels.

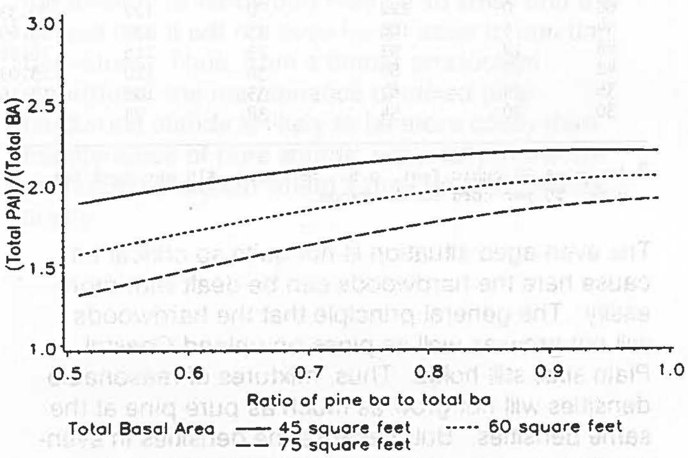

Figure 6.--Total growth efficiency in relation to the proportion of pine in the total basal area, by three total basal area levels.

class has the highest efficiency and all efficiencies increase as the proportion of pine basal area increases. For pine and the total stand the increase in efficiency is gradual as the proportion of pine basal area increases but for hardwood the increase is relatively steep. Efficiencies range from about 1.6 to 2.2 cubic feet per square foot for pine, from about 1.0 to 2.9 for hardwood and from about 1.3 to 2.2 for total. At higher proportions of pine basal area, hardwood efficiency greatly exceeds that of pine, indicating that the hardwoods are much more tolerant in this situation. Although hardwood efficiency is greatest at higher proportions of pine density, this does not result in greatly increasing total efficiency (figure 6). Hardwood levels are so low at higher pine proportions that total efficiency tends to become asymptotic when the pine basal area proportion is above 80 to 90 percent.

Table 4.--Predicted p.a.i. by pine and hardwood density levels.

PBA	HBA	PPAI	HPAI	TPAI
-sq. ft./ac.-		--------	cu. ft./ac./yr.	---------
45	0	98	0	98
45	10	90	21	111
45	20	83	31	114
45	30	76	34	110
60	0	122	0	122
60	10	112	18	131
60	20	103	27	130
60	30	95	29	124
75	0	143	0	143
75	10	131	16	147
75	20	120	24	144
75	30	110	26	136

These growth predictors can be used to obtain crude estimates of the monetary impact of pine-hardwood mixtures. For example, look at the situation in table 4 where a stand has 60 square feet of TBA with PBA varying from 100% to 50%. Assume that a cord contains 90 cubic feet (o.b.) and that stumpage is $15 per cord for pine and $5 per cord for hardwood. The resulting scenario illustrated in table 5 shows that 10 percent hardwood decreases the total stumpage only by a dollar or two, but 50 percent hardwood decreases stumpage by nearly half. Even if stumpage prices were equal for pine and hardwood, the mixed stand value growth will be less than that for pure pine. However, in some cases (table 4) equal stumpage prices could result in a slight monetary advantage if total basal areas are in the sustainable range under selection management.

Table 5.--Predicted p.a.i. for 60 square feet of total basal area composed of varying percentages of pine and hardwood basal area.

PBA	HBA	PPAI	HPAI	TPAI
----------	pct	----------	----------	cu. ft./ac./yr.
100	0	100	0	122
90	10	89	11	121
80	20	80	20	116
70	30	73	27	110
60	40	66	34	102
50	50	58	41	93

OTHER CONSIDERATIONS

Aside from the growth and stumpage aspects, a number of other considerations must be dealt with in managing mixed pine-hardwood stands. It is probably true that if we wish to expend sufficient energy and ignore costs we could manage almost any conceivable mixture of pines and hardwoods. But, we also think that where economical timber production is the primary goal, on suitable uplands it will be best to manage pine in pure stands and any desired hardwood component will best be managed separately as inclusions of whatever size is deemed suitable. These could be patches of a few tenths to an acre or so, the borders of drainages, and/or the stream bottoms. This allocation may complicate inventory and record-keeping but will largely prevent long-term management problems. In general, hardwoods should be grown on the sites best suited to them, which will usually be the minor to major stream bottoms in the Southern Coastal Plain. Whether pine or hardwood is to be managed, we think that both will be most efficiently managed as essentially pure stands due to the silvical nature of these species groups, management considerations, and general successional trends.

In selection or uneven-aged pine management, it seems imperative that stands be kept as "pure" as feasible. The basal area "window" for pine selection management is fairly narrow - about 45 to 75 square feet - and all needs to be in pine for adequate production. The addition of a hardwood component to the pine component may push the density above the level where development of pine regeneration and recruitment into the stand can be sustained. This level has not been well quantified but observations strongly suggest that it is no higher than 80 square feet at the end of a cutting cycle for uneven-aged loblolly pine stands in southeastern Arkansas. Until this level is better defined, the safest option is to allow practically no hardwoods in uneven-aged pine stands.

If the hardwood component is added in place of pine, the pine growing stock is reduced, which generally lowers total production and profits. Furthermore, hardwood density, due to its much denser shade, generally retards pine reproduction more than an equivalent amount of pine density (Wahlenberg 1960). Pine will regenerate and develop to some extent under the shade of a given moderate pine basal area but not to any useful extent under the shade of an equivalent basal area of hardwood. This is based on observation and implied by work by Wahlenberg (1948) and Bormann (1956). At every cutting cycle, there is essentially a need to obtain some pine regeneration to sustain the system. If hardwoods are continually present they have the potential to interfere with pine reproduction and capture pine growing space.

There is also the danger that a seemingly small amount of hardwood in a selection stand may, by default, increase to a major proportion simply because the volume and growth is not sufficient for it to be operationally reduced at each cutting cycle. It may take two or three cutting cycles to build enough hardwood volume for an operational cut and during this time it can seriously affect both pine growth and reproduction if some action, such as a periodic non-commercial reduction, is not taken. For example, we see in table 6 that 6 square feet of hardwood produces a p.a.i. of only 13 cubic feet. At this rate, if 2 cords/acre is a minimum operable cut, it will take about 14 years to produce a commercial cut and leave the initial hardwood density. There might be some small increase in hardwood production due to increasing hardwood density during this period but this would likely be offset by reduced pine production and, more importantly, increased interference with pine reproduction.

Table 6.--Estimated stumpage value[a] of the p.a.i. for a stand with 60 square feet of total basal area composed of varying proportions of pine and hardwood basal area.

PBA	HBA	PPAI	HPAI	TPAI	VALUE
-sq. ft./ac.-		------	cu. ft./ac./yr	-----	dollars
60	0	122	0	122	20.33
54	6	108	13	121	18.69
48	12	93	23	116	16.76
42	18	80	30	110	15.03
36	24	67	35	102	13.15
30	30	54	38	93	11.11

[a] Assuming 90 cubic feet, o.b., per cord, $15 per cord for pine, $5 per cord for hardwood.

The even-aged situation is not quite so critical because here the hardwoods can be dealt with more easily. The general principle that the hardwoods will not grow as well as pines on upland Coastal Plain sites still holds. Thus, mixtures of reasonable densities will not grow as much as pure pine at the same densities. But, because the densities in even-aged stands are usually maintained at higher levels than in uneven-aged stands, one can tolerate a certain amount of hardwood and still maintain satisfactory pine densities and production. For example, 10 to 20 square feet of hardwood might be acceptable in even-aged stands containing 60 to 100 square feet of pine.

Another major reason why mixed even-aged stands are more acceptable is that there is no need for periodically recurring pine regeneration. At the end of each rotation, necessary steps are taken during the regeneration period to insure an acceptable level of pine reproduction, a tolerable level of hardwood reproduction is also accepted, and regeneration is not a concern again until the end of the rotation. The two components grow up together and, depending upon growth and values, are thinned as desired during the rotation and harvested at the end. Some hardwoods may actually act as valuable trainers to the pines and improve their pruning and form (Paul 1933) although at a cost of reduced pine production. Also, some landowners may accept even-aged mixed stands containing a relatively large hardwood component because they cannot afford expensive site preparation or pine release work. They may not get maximum production or returns but they will not have large investments and can exercise this option, which may not be available in uneven-aged stands due to adverse effects of hardwoods on pine regeneration.

Aside from taking up pine growing space in even-aged stands, a hardwood component can interfere with area-wise stand treatment prescriptions such as herbicide treatments for cleanings and weedings and prescribed fire use to control undesirable vegetation. In cleanings or weedings, the individual desirable hardwood stems will need to be marked to prevent their destruction and treatments will have to be stem-wise. It will be difficult to burn and discriminate between desirable hardwoods and undesirable brush. Fires are likely to be irregular in intensity and coverage and they may promote decay in the desired hardwood component. Also, the amount of hardwood may be so small and dispersed that it will not even be an asset to non-timber values. Thus, from a timber production standpoint, the maintenance of mixed pine-hardwood stands is likely to be more costly than maintenance of pure stands, especially in the uneven-aged situation where it may be prohibitively costly.

CONCLUSION

There are conditions in uneven-aged stands where a hardwood component in addition to the pine component can increase the total growth of the stand. These conditions are usually where pine basal area is less than about 60 square feet per acre. Above this level the addition of hardwoods decreases the total growth. Although the density is within the range suitable for selection management, the added growth due to the hardwoods usually does not appreciably increase the total stumpage value. A hardwood component usually decreases total stumpage because its growth and value are generally much less than that for pine. For these and other reasons, it is suggested that a hardwood component is best accomodated as separate pure aggregations or stands rather than dispersed throughout the pine stand.

The stand-level models developed here provide some useful insight into the function of mixed stands. However, they are limited in their ability to explain mixed stand growth and constitute little more than a primer. They do not take into account the impact of a number of additional possible factors such as differential rates of growth, ingrowth, and mortality among species; the distribution of species and stems vertically in the understory, midstory, and overstory; distribution of species and stems laterally over area; and inter-tree influences. Evaluation of these effects is largely beyond the capability of stand-level growth prediction systems and individual-tree systems will be required to quantify these effects.

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Thirty-four papers are presented in four categories: Silviculture and Ecology; Wildlife; Growth and Yield; and Management. In addition, eight poster presentations are summarized and three papers from a general session are included.

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