Low-Cost Forest Operation Systems that Minimize Environmental Impacts of Harvesting

F. Thomas Lloyd, Research Project Leader, USDA Forest Service, Southern Research Station

and

Thomas A. Waldrop, Research Forester, USDA Forest Service, Southern Research Station

Abstract: Forest operation systems have been developed for mixed pine and hardwood stands in the Piedmont region of the southeastern United States that reduce the cost and environmental impacts of forest operations. This has been done by studying the interrelations of forest operations with site edaphic properties and the biology of plant communities that reside on each site. In a region of highly erodible soils, forest operation systems are being examined for their effects on soil movement and stand dynamics of pine and hardwood mixtures. Timing of felling residual stems and post-harvest fire prescriptions affect subsequent fire intensity and severity. Soil and forest floor moisture strongly affect forest floor consumption by the fire, which in turn affects soil movement. Timing of the residual felling and the post-harvest fire also affect the competitive status of natural and artificial regeneration. Preliminary results are reported that show the potential of using a vegetation-derived ecological classification model to link harvesting prescriptions to physical characteristics of the site.

Keywords: pine-hardwood mixtures, growth and yield, ecosystem classification, prescribed fire.

INTRODUCTION

Seventy-five percent of the forest land base in the Piedmont region of the southern United States is controlled by non-industrial private forest (NIPF) landowners. The NIPF land base is large, but individual holdings are small; which means the number of landowners is large and that land use objectives vary widely. An additional complication is that incentives for these landowners to invest in forest management are not strong because of low unit value for stumpage (relative to long-term production costs). Harvesting under these economic conditions is usually done by either a commercial clearcut or the removal of a few of the best trees. Both of these forest operations leave behind large (relative to the regeneration), low quality residual trees which out-compete the higher-quality regeneration. This pattern creates a cycle of ever poorer-quality trees and reduced incentive for good timber management.

Industrial assistance programs for NIPF landowners and government-supported cost-share incentives have helped put some of these lands into productive pine plantations, but this effort is small relative to the need. Furthermore, the objectives of pine plantation management are too narrow for many NIPF landowners, and the public incentives dollars are becoming increasingly difficult for government to justify. It is also standard practice in pine plantation establishment to eliminate the hardwood root stocks. Hardwood eradication extracts a high cost in terms of energy used and productivity lost through soil disturbance. The end result of these limitations of pine plantation management is a high percentage of the 8.5 million-hectare NIPF land base being less than fully stocked with high-quality trees.

The guiding hypothesis for our overall research program has been that mixed-species stands, like those developing naturally on much of the NIPF land base, can be cost-effectively managed for good timber production as mixed conifer (southern pines) and hardwood stands. Naturally-regenerated mixtures of pines and hardwoods occur on about 1/4 of the Piedmont forest. Our research has focused on understanding the natural processes that occur in these pine-hardwood mixtures in order to develop forest operations that better ~~work with~~ nature. The result is operations that produce high-quality well-stocked pine-hardwood mixtures at less investment cost, with less impact to the site, and that meet a wider range of land management objectives than traditional plantation management.

The information in this paper integrates three lines of research. The first has been investigation of relative growth dynamics of mixtures of pines and hardwoods in naturally occurring, merchantable-sized stands. The second line of investigation has been to quantify the effects of several harvesting operations on pine-hardwood regeneration dynamics. The third emphasis has been on the development of landform/soil-based ecological classification systems, and how they can be used to relate vegetative responses from forest operations to spatial measures of landform and soil properties.

INTEGRATED STUDIES

Growth Dynamics of Commercial-Sized Pine-Hardwood Mixtures

Figure 1 captures a lot of information about relative height growth dynamics of pines and hardwoods on the dry to intermediate sites which comprise much of the Piedmont region. The oaks in these stands commonly originate as stump sprouts from existing root stocks, while the pines come from seed and/or planted seedlings. When the pines (largely loblolly pine (*Pinus taeda* L.)) are free-to-grow, they have three height-growth phases. The first phase is characterized by slow height growth (0 to 0.3 m/yr) for 1 to 3 years. The second phase has a burst of rapid height growth reaching 1.0 to 1.4 m/yr. Finally, height growth rates peak and begin to decline during the third phase. The decline is dramatic, dropping below 0.5 m/yr sometime during the third decade of stand life. In contrast, height growth of oaks is rapid immediately after cutting (0.7 to 1.0 m/yr for the first 2 to 3 yrs), followed by a fairly uniform growth rate (0.5 to 0.6 m/yr) for decades.

If pine density on these dry to intermediate sites is greater than 500 saplings/ha, then pines will form a closed canopy over the hardwoods during the rapid-growth period of the second phase. This pattern relegates hardwoods to the intermediate and suppressed crown classes, which suppresses their growth rates below those described above. Our research applies to mixed pine and hardwood stands that have pine densities below this 500/ha density threshold. In this type of stand, oaks (and other hardwoods) may fall behind in total height early in stand life, but they should receive some direct sunlight and become a commercially-valuable component of the stand.

Lloyd and Waldrop (1993) reported specifics about within-stand growth dynamics from a growth and yield study in merchantable-sized, naturally regenerated pine and hardwood mixtures. They analyzed relative height growth rates from 50 pairs of pines and oaks from stem analyses. Each pair was located on the same site near a 0.08 ha permanent growth plot. The maximum cumulative height advantage of the pines over the oaks was 6.1 m at an average age of 32 years. However, once the pines moved into their slow growth phase (less than 0.5 m/yr), the steady growth of the oaks began to catch up in cumulative height, so that by age 55 the oak height deficit was only 2.8 m. Also, pines in dominant and codominant crown classes began to experience disproportional mortality when stand age was in the late 30's and early 40's. These dry to intermediate Piedmont sites have traditionally been referred to as "pine sites" because of this early height growth dominance of pine; however, these growth patterns suggest that oaks are also a good species choice for sawtimber management.

Management of oak for sawtimber is also supported by basal area growth patterns. The pine and oak 10-year basal area "survivor" growth values in Table 1 are predicted from regression analyses using diameter data from the 0.08 ha permanent growth plots mentioned above. The term "survivor" growth is used because diameter growth was obtained from increment cores of all living, merchantable-sized trees at the time of initial plot installation. Initial basal area was calculated for surviving trees 10 years prior to plot establishment by subtracting increment core growth from present diameter. Initial age (another predictor variable used in the regression analyses for Table 1) was obtained by subtracting 10 years from stand age at plot establishment.

Separate regression analyses were done for pines, oaks, and other hardwoods. Basal area growth by species category was analyzed as a function of initial basal area of the species component, initial stand age, and the percentage of the total merchantable basal area in each species group. These predictor variables allowed making direct comparisons in Table 1 of basal area growth predictions of pines and oaks for the same initial basal area stocking for each projection period. All selected values of initial basal area used to make the predictions are within the ranges of the observed data used to fit the regression models.

Table 1 shows that the oaks begin to outgrow the pines in basal area at an earlier stand age than in total height. Oak basal area equals that of pine by age 15, and increasingly outgrows it beyond that age. We do not know relative oak and pine basal area growth below age 15, but the vigor of pine growth in that age range, reflected by the rapid height growth, suggests that pines probably outgrow the oaks for the early stage of stand development. By age 60 25 m^2 of oak basal area stocking produced 62 percent more 10-year basal area growth than an equivalent pine stocking.

Forest Operations to Establish Pine-Hardwood Mixtures

The rapid height growth of hardwood coppice (as compared to the height growth of planted pines) immediately following harvest has been a source of concern to managers and researchers interested in establishing pine-hardwood mixtures. Research emphasis has been on economic means of controlling hardwood growth long enough to allow the shade-intolerant pines to survive. McGee (1986, 1989) reported high survival and rapid growth of planted loblolly pines after harvesting low-quality hardwood stands by chainsaw to a 4-inch lower diameter limit (with and without herbicide injection of residuals) and by shearing to a 1-inch limit. Lloyd et al. (1991) showed that growth of planted shortleaf pines (*P. echinata* Mill.) in pine-hardwood mixtures improved after release at age four, but release was not necessary for survival. In a study by McMinn (1989), naturally-regenerated shortleaf, Virginia (*P. virginiana* Mill.) and loblolly pines were largely absent from areas harvested in the growing season and suppressed in dormant-season cuts where hardwoods were harvested to a 4-inch diameter limit instead of a 1-inch limit.

Much of our research on hardwood control has centered on a set of operations described by Abercrombie and Sims (1986) which has proven successful in the Southern Appalachian Mountains (Phillips and Abercrombie 1987). The technique includes a commercial clearcut followed by spring felling of residual hardwood stems (> 2 m in height) and a summer broadcast burn. Felling and burning are designed to control hardwood sprout growth so pines can be established without eliminating hardwoods. Pines are planted the following winter at a wide spacing (4.5 m x 4.5 m or more) to reduce costs and allow some hardwoods to continue to receive some direct light from above.

Site preparation burning is an attractive operation for pine-hardwood regeneration in the mountains for several reasons. Burning is less expensive than mechanical site preparation and, if done properly, has less environmental impacts. By burning in July, as suggested by Abercrombie and Sims (1986), hardwood sprouts are top-killed and new sprouts that emerge after burning have a shortened growing season. These newer sprouts remain shorter than those in unburned areas for 4 years or more, allowing pines a better chance to survive (Waldrop 1995). Sprout quality is improved by burning because stump sprouts are replaced by well-anchored basal or root sprouts (Augspurger et al. 1989). Site preparation burning proved to be particularly attractive in areas with heavy coverage of mountain laurel (*Kalmia latifolia* L.) that would be too expensive to regenerate using mechanical control (Williams and Waldrop 1995).

Early trials of pine-hardwood regeneration in the Piedmont suggested that site preparation burning may be too risky (Waldrop et al. 1989). In this region, forest floor thickness varies by site, but remains substantially thinner than in the mountains (Ball et al. 1993). Therefore, the danger of exposing soil to erosion by burning is much greater in the Piedmont. For example, Van Lear and Kapeluck (1989) reported the loss of over 3.5 cm of topsoil during a 9-month period after burning a Piedmont site. The burning prescription used in that study was identical to one used in a previous study in the mountains (Van Lear and Danielovich 1988) where burning caused no increase in erosion. Van Lear and Kapeluck (1989) attributed the differences in the two studies to differences in forest floor thickness and droughty conditions prior to burning the Piedmont site. Another possible difference was the rainfall pattern after burning. The Piedmont site experienced heavy rainfall several days after burning.

Several studies are being conducted to learn how to use site preparation burning without causing erosion. Robichaud and Waldrop (1994) burned adjacent sites using different prescriptions which created conditions of low- and high-severity (soil exposure). Low-severity burns were conducted 6 days after a 4-day rainfall event totalling 37 mm. For this burn, the moisture content of the litter layer was 65.2 percent. High-severity burns were conducted 14 days after a rainfall of 44 mm and with the moisture content of the litter layer at only 5.9 percent. Sediment loss for one year after burning totalled 5.75 t/ha from the high-severity burns but only 0.14 t/ha from the low-severity burns (Stone et al. 1995). Site productivity was reduced by high-severity burning with biomass production being over two times greater in the low-severity sites (0.79 vs. 1.67 t/ha). Even though high-severity burning reduced site quality, pine survival was significantly lower in the low-severity burn areas (77 vs. 58 percent). This result was attributed to increased competition on the low-severity sites.

Fire severity is also related to another operation used to establish pine-hardwood mixtures, felling of residual hardwood stems. These stems are typically felled by chainsaw crews during the spring when new leaves are almost fully developed. Broadcast burns are conducted 4 to 6 weeks after residual stems are felled, generally in mid-July to early August. At that time, the felled stems have sufficiently dried to carry an intense fire. Waldrop (1995) found that fire behavior and fire severity could be controlled by varying the season of felling residual stems. By felling during winter, foliage was not present. Therefore, dry leaf litter was limited and fires did not carry between slash piles. In spring-felled areas, dry leaves carried the fire, producing uniform burns across the entire study area, while winter felling produced a patchy burn pattern. The patchy nature of these burns may help meet some objectives by increasing early-successional plant and animal species diversity (Evans et al. 1991) and contributing to stand structural diversity by leaving more woody debris. Also, winter felling may reduce erosion by decreasing burn severity and leaving more debris dams; however, this effect has not been studied.

Even though winter felling may reduce erosion, it may not control hardwood competition as well as felling in spring. Phillips and Abercrombie (1987) suggested that spring felling would better control hardwood sprout growth than winter felling because felling occurred when carbohydrate reserves in root systems are typically low. Geisinger et al. (1989) found that hardwood sprouts were shorter in spring-felled areas than in winter-felled areas after one growing season. By the end of six growing seasons, however, winter felling of residual stems, followed by summer burning had produced nearly identical stands to those regenerated by spring felling and summer burning (Waldrop, manuscript under review). Growth reductions from spring felling lasted only one growing season and had no apparent effect on stand development. This result suggests that the precise timing of felling as described by Phillips and Abercrombie (1987) is not as critical for the Piedmont ecosystem.

Several studies of regeneration techniques in the Piedmont suggest that little or no site preparation is needed to establish pine-hardwood mixtures on dry sites. Waldrop (1991) and Perry and Waldrop (1993) harvested hardwoods in small openings (0.04 and 0.13 ha) to create pine-hardwood groups. Competition with edge trees reduced hardwood height growth more than that of planted loblolly pines. This pattern allowed the pines to overtop hardwoods within 2 years with no site preparation. In another study using clearcutting, Waldrop (under review) found that site preparation burning did not improve the survival or growth of planted loblolly pines. Pines overtopped hardwoods in burned areas by age 4 and in unburned areas by age 6 (fig 2).

Our studies contradict the findings of other studies which show that burning, herbicide application, or release are needed to prevent hardwoods from overtopping pines. However, those studies may have been conducted on better-quality sites or under different weather conditions than ours. Also, conclusions of previous studies may have been drawn before pines had adequate time to catch hardwoods. In our work, pines were shorter than hardwoods for several years. However, pine heights either equalled or exceeded the heights of hardwoods in all treatment areas within six years (fig 2) and before crown closure occurred. On better quality sites, hardwoods would grow faster and crown closure could occur before the pines reached the upper canopy. Additional research is needed to identify the types of sites where pine-hardwood regeneration is possible. Research is also needed to determine the level or intensity of site preparation required to successfully establish mixtures of pines and hardwoods on each site type.

Linking Prescriptions to Ecological Land Units

The research described above for dry to intermediate Piedmont sites suggests that little more is needed than to fell the non-merchantable residuals and plant pine at a wide spacing to get a productive pine-hardwood mixture. However, general silvicultural knowledge about eastern hardwoods suggests that this prescription might need modification as the site becomes more moist and site quality improves. More specifically, hardwood stem density and growth rates increase as moisture availability increases. If we had a practical way to model moisture gradients, we could tailor harvesting prescriptions to land units. A promising model of site units has been developed for the Piedmont region by Jones (1989).

Jones (1991) identified 5 ecological site units that present a moisture gradient for the Piedmont. His approach is to separate, as much as possible, the effects of forest disturbance from the biological effects of plant suitability to site conditions. This is done by first identifying relations between vegetation and landform/edaphic variables on sites showing minimal evidence of disturbance. Finding suitable stands for this first phase has a measure of subjectivity, but from a forest management perspective, it works well. Once land units are delimited by landform and soil variables (derived from the "undisturbed" plant community vegetation patterns found on these reference sites), the investigation can began to examine community development patterns in disturbed environments, such as the pine-hardwood communities our forest operations create. The land units from this ecological classification modeling process provide a tool to begin to make some order out of the complex array of community development patterns that disturbance can create.

Jones (1991) identified five ecological land units that he calls xeric, subxeric, intermediate, submesic, and mesic. One stand, in which the regeneration study discussed above (Waldrop 1995) is located, is made up mostly of subxeric land units but the treatment area also contains two xeric ridges, some "intermediate" northerly facing slopes and a small "submesic" cove. All sample plots were placed on subxeric land units found on southerly slopes. We see here an immediate application of the classification system as a technology transfer tool in that the results of this study applies to Piedmont subxeric sites, which can be identified from landform and soil spatial information.

The question remains as to what kind of vegetation dynamics in mixed pine-hardwood stands can be expected on better quality (intermediate and submesic) land units. Although the original study was not designed to investigate this question, one treatment area (winter felling of residuals plus a summer site preparation burn) contained three ecological land units (subxeric, intermediate, and submesic) which could be used for a comparison of stand dynamics. Subsequent to the original study, plots were established on the intermediate and submesic areas. Table 2 shows hardwood stocking of all stems taller than 1.5 m. There is a dramatic change in stem numbers and basal area of hardwoods between the intermediate and submesic land units. This is an indication of a threshold for pine-hardwood management.

Since our goal is to develop pine-hardwood mixtures, Tables 3 and 4 look at pine responses across ecological units. Although pines were successfully regenerated on all ecological units, Table 3 shows pines making up only 15 percent of the total basal area on the submesic land units, compared to 45 and 46 percent respectively for intermediate and subxeric units. The pine survival percent is also lowest on the submesic area.

Table 4 compares total "dominant" hardwood height with the height of planted loblolly pines. "Dominant" means the tallest hardwoods equivalent in density (numbers/ha) to the planted pines. The hardwoods show the expected sensitivity to the moisture gradient represented by the ecological units, while the pines do not. The lower total height of pine on the submesic area (4.7 m), compared to an average of 5.3 m on the intermediate and subxeric units, may be attributed to hardwood competition effects on pine growth. A further indication of the hardwood competitive effect is that the pines were ahead of the tallest hardwoods except on the submesic area. Although it can not be determined from this study, we can wonder if the pines would have survived at all without the summer fire treatment that set back the initial hardwood growth response. Although these results might only be working hypotheses that remain to be studied, they do indicate that there is potential of using these kinds of land classification systems to tailor forest operation prescriptions to the site characteristics of the land in order to get the desired solution.

CONCLUSIONS

By studying the dynamics of pine-hardwood mixtures in the Piedmont physiographic region, we have been able to develop forest operations that produce productive timber stands and diverse plant communities at a lower cost and with less degradation to site quality than by traditional pine plantation management. Although total wood volume is greater in pine plantations, the pine-hardwood mixtures can meet a wider array of land management objectives. The forest operation systems tested in this research are well suited to the economic conditions and land management needs of NIPF landowners.

Ecological classification offers a tool for transferring research results to the particular location to be managed. Although research is not complete, indications are that pine-hardwood management without the use of post-harvest fire works best on subxeric and intermediate land units. If we use post-harvest fire on Piedmont sites (which must be done with great care to avoid damaging the site), pine-hardwood management can be extended to more moist land units.

Paper Submitted: July 1995.
Address of authors: USDA Forest Service, Southern Research Station, 233 Lehotsky Hall, Clemson, SC 29634-1003 U.S.A.

LITERATURE CITED

Abercrombie, J. A., Jr. and Sims, D.H., 1986: Fell and burn for low-cost site preparation. *Forest Farmer*, vol.46, no.1. pp.14-17.

Augspurger, M.K., Van Lear, D.H., Cox, S.K., and Phillips, D.R., 1987: Regeneration of hardwood coppice following clearcutting with and without prescribed fire. Proceedings of the Fourth Biennial Southern Silvicultural Research Conference, USDA Forest Service General Technical Report SE-42. pp. 89-92

Ball, R.E.B., Waldrop, T.A., and Jones, S.M., 1993: Distribution and development of root mats in the South Carolina Piedmont. Proceedings of the Seventh Biennial Southern Silvicultural Research Conference, USDA Forest Service General Technical Report SO-93. pp. 229-234

Evans, T. L., Guynn, D.C., Jr., and Waldrop, T.A., 1991: Effects of fell-and-burn site preparation on the wildlife habitat and small mammals in the upper southeastern Piedmont. Fire and the environment: ecological and cultural perspectives: Proceedings of an international symposium. USDA Forest Service General Technical Report SE-69. pp. 160-167

Geisinger, D.R., Waldrop, T.A., Haymond, J.L., and Van Lear, D.H., 1989: Sprout growth following winter and spring felling with and without summer broadcast burning. Proceedings pine-hardwood mixtures: a symposium on management and ecology of the type. USDA Forest Service General Technical Report SE-58. pp. 91-95.

Jones, S. M., 1989: Application of landscape ecosystem classification in identifying productive potential of pine-hardwood stands. Proceedings pine-hardwood mixtures: a symposium on management and ecology of the type. USDA Forest Service General Technical Report SE-58. pp. 64-69.

Jones, S.M., 1991: Landscape ecosystem classification for South Carolina. Proceedings of ecological land classification: applications to identify the productive potential of southern forests. USDA Forest Service General Technical Report. SE-68. pp. 59-68.

Lloyd, F.T. and Waldrop, T.A., 1993: Relative growth of oaks and pines in natural mixtures on intermediate to xeric Piedmont sites. Proceedings oak regeneration: serious problems, practical recommendations. USDA Forest Service General Technical Report SE-84. pp. 196-201

Lloyd, F.T., White, D.L., Abercrombie, J.A., Jr., and Waldrop, T.A., 1991: Releasing four-year-old pines in mixed shortleaf-hardwood stands. Proceedings of the Sixth Biennial Southern Silvicultural Research Conference, USDA Forest Service General Technical Report SE-70. pp. 852-857.

McGee, C.E., 1986: Regeneration after shear felling and chipping of upland hardwoods. USDA Forest Service Research Paper. SO-224. 13 pp.

McGee, C.E., 1989: Converting low-quality hardwood stands to pine-hardwood mixtures. Proceedings pine-hardwood mixtures: a symposium on management and ecology of the type. USDA Forest Service General Technical Report SE-58. pp. 107-111.

McMinn, J.W., 1989: Influence of whole-tree harvesting on stand composition and structure in the oak-pine type. Proceedings pine-hardwood mixtures: a symposium on management and ecology of the type. USDA Forest Service General Technical Report SE-58. pp. 96-99.

Perry, C.J. and Waldrop, T.A., 1995: Opening size and site preparation techniques affect regeneration success for uneven-aged pine-hardwood mixtures. Proceedings of the Eighth Biennial Southern Silvicultural Research Conference, USDA Forest Service General Technical Report (in press).

Phillips, D. R. and Abercrombie, J.A., Jr, 1987: Pine-hardwood mixtures-a new concept in regeneration. *Southern Journal of Applied Forestry*. vol. 11, no. 4. pp. 192-197.

Robichaud, P.R. and Waldrop, T.A., 1994: A comparison of surface runoff and sediment yields from low- and high-severity site preparation burns. *Water Resources Bulletin*. vol. 30, no. 1. pp.27-34.

Stone, S.L., Carraway, A.B., Waldrop, T.A., and Robichaud, P.R., 1995: Impacts of burning severity on a southern Appalachian site. Proceedings of the Eighth Biennial Southern Silvicultural Research Conference, USDA Forest Service General Technical Report (in press).

Van Lear, D.H. and Kapeluck, P.R., 1989: Fell and burn to regenerate mixed pine-hardwood stands: an overview of effects on soil. Proceedings pine-hardwood mixtures: a symposium on management and ecology of the type. USDA Forest Service General Technical Report SE-58. pp. 83-90.

Van Lear, D.H. and Danielovich, S.J., 1988: Soil movement after broadcast burning in the southern Appalachians. *Southern Journal of Applied Forestry* vol. 12, no. 1. pp. 49-53.

Waldrop, T.A., 1991: Pine-hardwood regeneration in small openings for uneven-aged management. Proceedings of the Sixth Biennial Southern Silvicultural Research Conference, USDA Forest Service General Technical Report SE-70. pp. 398-408.

Waldrop, T.A., 1995: Variations in the fell-and-burn system to regenerate pine-hardwood mixtures in the Piedmont. Proceedings of the Eighth Biennial Southern Silvicultural Research Conference, USDA Forest Service General Technical Report (in press).

Waldrop, T.A., (under review): Four site-preparation techniques for regenerating pine-hardwood mixtures in the Piedmont. Submitted to the *Southern Journal of Applied Forestry*.

Waldrop, T. A., Lloyd, F.T., and Abercrombie, J.A., Jr., 1989: Fell and burn to regenerate mixed pine-hardwood stands: an overview of research on stand development. Proceedings pine-hardwood mixtures: a symposium on management and ecology of the type. USDA Forest Service General Technical Report SE-58. pp. 75-83.

Williams, D.L. and Waldrop, T.A., 1995: Felling and burning to prepare southern Appalachian sites occupied by mountain laurel. Proceedings of the Eighth Biennial Southern Silvicultural Research Conference, USDA Forest Service General Technical Report (in press).

Table 1. Predicted periodic (10 years) basal area growth of survivors at four ages in pine-hardwood mixtures which have merchantable basal area composed of 40 percent pine, 40 percent oak, and 20 percent other hardwoods.

Species group	--Initial stand age[1]--			
	15	30	45	60
	----m^2/ha/10 years----			
Pine	4.0	2.4	1.7	1.3
Oak	4.0	2.8	2.4	2.1
Other Hardwood	1.0	0.8	0.8	0.8
Total	9.0	6.0	4.9	4.2

[1]Total merchantable basal area at the beginning of each period was 18 m^2 at age 15, 21 m^2 at age 30, 23 m^2 at age 45, and 25m^2 at age 60.

Table 2. Stocking levels of hardwoods (> 1.5 m tall) by ecological unit.

Unit	Stems	Basal area
	no/ha	m^2/ha
Subxeric	1,877	1.56
Intermediate	2,272	1.29
Submesic	7,311	3.86

Table 3. Planted pine (4.5 m x 4.5 m spacing) stocking levels by ecological unit.

Unit	Stems/ha	Percent of total basal area	Percent survival
Subxeric	346	46	72
Intermediate	321	45	76
Submesic	247	15	52

Table 4. Heights of hardwoods[1] and planted pines.

Unit	Hardwoods	Pines
	-----meters----	
Subxeric	3.7	5.2
Intermediate	4.3	5.4
Submesic	5.0	4.7

[1]Tallest hardwoods at a density level equivalent to pine planting density.

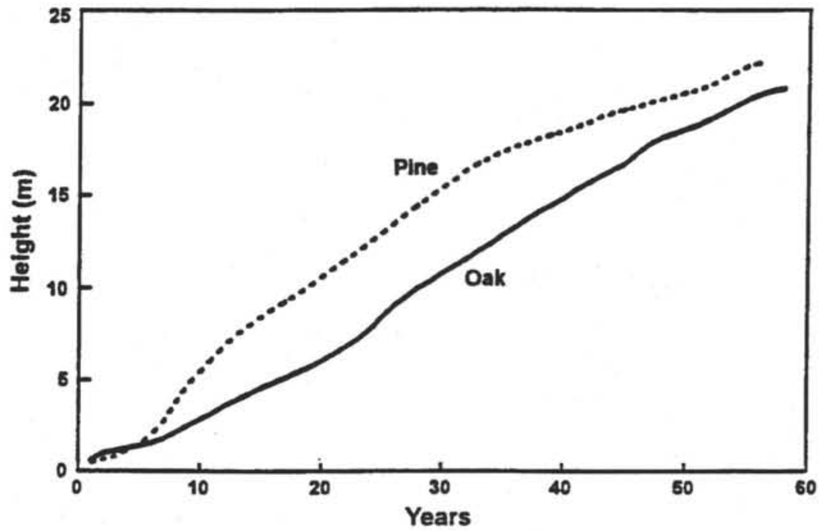

Figure 1. Mean height of pines and oaks growing on xeric and intermediate Piedmont sites for 60 years.

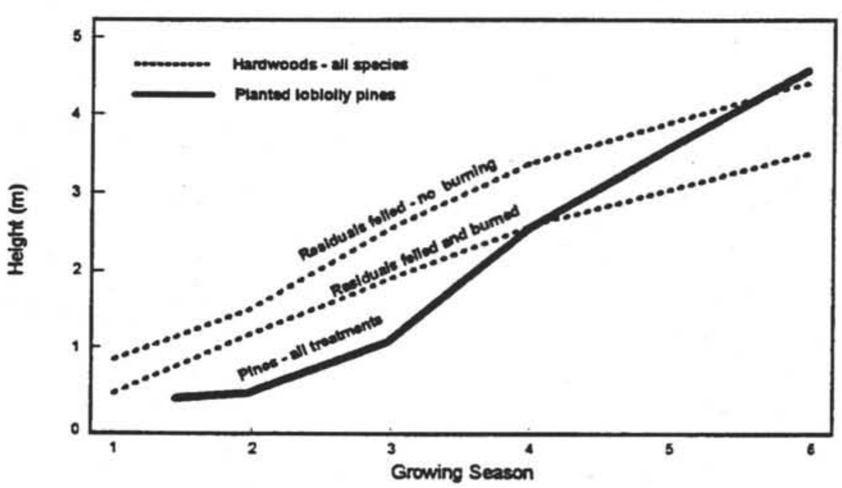

Figure 2. Mean height of natural hardwood regeneration (by site preparation treatment) and planted loblolly pines (all treatments combined) for 6 years after harvest.