HARDWOOD INVASION IN PINE FORESTS OF THE PIEDMONT PLATEAU [1]

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INTRODUCTION

Forest stands of pure pine are important factors in the wood-using economy of the Carolina and Virginia Piedmont Plateau. Thousands of portable and semiportable mills representing everything from small, part-time, family-operated businesses to fairly large, full-time mills are, for the most part, dependent upon pine stumpage for their existence. Both the farm-woodland owner and the industrial land-holder find that ready markets exist for a variety of pine forest products and that it takes hardwoods many more years to yield similar products. The demand not only for lumber but for pulpwood, poles, and a number of minor products has tended to call for a large proportion of pine in the total stumpage utilized locally. Although good grades of hardwood logs are usually accepted at the larger permanent mills, the market for these species, particularly oaks and hickories, has not been as steady as the market for pine. The large furniture industry of the piedmont region finds in nearby forests only a limited number of usable native hardwoods and is dependent on distant sources for sugar maple, birch, cherry, and other standard furniture woods.

Comparison of stumpage values and present growth rates of pines and hardwoods provides further evidence of the importance of pine species in piedmont forest enterprises. Records for 1940 show an average stumpage value of $5.83 per thousand board feet for 466 transactions involving a total of 204.2 million feet of yellow pine, principally shortleaf and loblolly, in the Carolinas and Virginia. From the upland hardwood type, dominated by oaks and hickories, a total of 4.2 million feet of oak stumpage was sold in 52 transactions at an average price of $5.73 per thousand board feet, while 258 thousand board feet of hickory in 9 transactions brought an average stumpage price of $4.16. Hardwood species that dominate the bottom-land hardwood type, on the other hand, have stumpage values equal to that of pine or even higher. Among these species are yellow poplar (*Liriodendron tulipifera*), sweetgum (*Liquidambar styraciflua*), red maple (*Acer rubrum*), black tupelo (*Nyssa sylvatica*), and sycamore (*Platanus occidentalis*), though markets for the last three are still quite limited.

Studies [2] of growth rates in existing stands indicate that pine types are much more productive than the upland hardwood type with which they are commonly intermingled. In the North Carolina piedmont, uncut second-growth sawlog-size stands occupy 25 percent

[1] Received for publication August 14, 1942.

[2] CRUIKSHANK, J. W. FOREST RESOURCES OF THE PIEDMONT REGION OF NORTH CAROLINA. U. S. Forest Serv. Appalachian Forest Expt. Sta. Forest Survey Release 6, 55 pp., illus. 1940. [Processed.]

of the forest land. For the various forest types within this condition class, current annual growth per acre in board feet was found to be 300 for shortleaf pine, 331 for loblolly pine, 199 for bottom-land hardwoods, and 159 for upland hardwoods. Partly cut second-growth stands occupy about 18 percent of the forest lands; within this class, current growth was 189 board feet for shortleaf pine, 215 for loblolly pine, 202 for bottom-land hardwoods, and 124 for upland hardwoods.

Present evidence therefore indicates that the pine types not only grow at a much faster rate than the upland hardwood types, but also produce wood of greater value. Attainment of maximum returns from upland piedmont forests consequently appears to require maintenance of as high proportions of pine as are economically and silviculturally feasible. This is not necessarily true for the stream margins and other moist locations characteristic of the piedmont bottom-land hardwood type. Here growth is somewhat slower than in the pine types, but the lower production is offset by the greater values of some of the dominant hardwood species.

In the Carolinas and Virginia, the piedmont region, with a total land area of about 26 million acres, lies between the foothills of the Appalachian Mountains on the west and the level Coastal Plain to the east. A rolling, upland country, sloping gently eastward from elevations of 1,000 to 1,200 feet in the Appalachian foothills to 400 or 500 feet at its eastern margin, this region is favorable to agriculture because of its topography, a 6-months' growing season, and a 40- to 50-inch annual rainfall.

Long-continued and widespread farming has had a marked influence in modifying forest types and conditions. Slightly more than half of the land surface of this region is occupied by forest, of which more than 70 percent is classified as pine types. The cycle of land clearing, cultivation, soil erosion and impoverishment, and finally abandonment, has created conditions particularly favorable to the development of pure pine stands. Exposure of mineral soil, as in abandoned fields, is a requirement for the best germination and early survival of pine. The dispersal of the light, wind-borne seed from pines growing in adjacent forest completes the conditions under which the pines could gain ascendency over their common plant associates. Since three-fourths of the present forest area of the piedmont region was in cultivation at some time in the past, there is little reason to wonder at the high proportion of pine types now present.

During the past generation both land clearing and abandonment of land for farm-crop production have abated. Agriculture has become relatively stabilized on the better lands. Woods burning has been reduced by the direct activities of State and Federal forest-conservation agencies, and by the educational programs of these and other public and private organizations. Under such conditions natural trends in the development of forest associations might be expected again to become operative. For this reason the presence of numerous hardwoods in the understory of pure pine stands and their conspicuousness in the growth following logging have led many to suppose that nature tends toward stands of pure hardwoods or of mixed hardwoods and pine, rather than pure pine.

If quantitative evidence can establish that the understory hardwoods now present in pure pine types are thriving, then the assumed hardwood invasion can be more fully substantiated as an active trend already operative in the territory—a development which may seriously reduce the proportion of pine in future forests and have a marked effect upon silvicultural practices. Late in the summer of 1938 a study was made to collect quantitative data that would establish the widespread presence or absence of this trend and provide specific measurements of its character.

OBSERVATIONS BY OTHER WORKERS

Early literature dealing with the natural resources of the piedmont region provides strong evidence that the original forests were dominated by hardwood species. In 1858, Wilkes (*13*)[3] made especial reference to the culled-over oak forests of the piedmont and predicted the disappearance of hardwood timber there. Bruce (*3*) and Curtis (*4*) mentioned the predominance of oaks and hickories, the former stating that one-fourth of the original forests of Virginia were walnut. However, because hickory at that time was classed as a kind of walnut, it is assumed that a large proportion of this abundant "walnut" was *Carya* species. Hale (*5*) and Parkins (*8*) mentioned pine species as subordinate to hardwoods in old-growth stands. In 1897, Pinchot and Ashe (*9*) referred to the remaining original forest stands on piedmont uplands as being composed of oaks and hickories with an admixture of shortleaf pine in some places. Second-growth forests, however, had "pine for the forest body generally, and hardwoods as subordinate."

More recently, general observations by ecologists have led to the hypothesis that the extensive second-growth pine forests of the Piedmont are beginning to revert to hardwoods. Weaver and Clements (*10*), and Wells (*11, 12*) have stated this point. Quantitative data substantiating the existence of such a trend have been published by Billings (*2*) who made detailed studies of seven old-field shortleaf pine stands occurring in Durham County. Even in the sandy soils of the longleaf pine type, Heyward (*6*) found strong evidence of replacement of pine by hardwoods where the forests had not been burned.

METHODS OF STUDY

The study was limited to stands of the two pines of the piedmont region most important commercially—shortleaf pine (*Pinus echinata*) and loblolly pine (*P. taeda*). A random selection of 40 piedmont counties in the Carolinas and Virginia was first made and sample stands within each of them were studied. It was necessary to exercise some choice of study areas in order to obtain samples of a wide range of stand ages, sites, and densities for both species. Sampling was further limited to areas where pine made up at least 90 percent of the overstory stem count and where neither grazing nor light cutting had taken place within 5 years, and no extensive cutting or thinning within 10 years. Bottom lands and swampy areas were excluded because they are not typical of the region and occupy a relatively small portion of the forest area. Within these limitations the selection of sample stands was objective, to prevent any partiality toward pine stands either with or without hardwood understories.

[3] Italic numbers in parentheses refer to Literature Cited, p. 127.

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In forest stands meeting the requirements named, detailed data were recorded on 117 plots (fig. 1). Of these, 65 were in the shortleaf type and 52 in the loblolly type. Most of the plots were one-fourth acre in size, but a few situated in dense, young stands were only one-tenth acre.

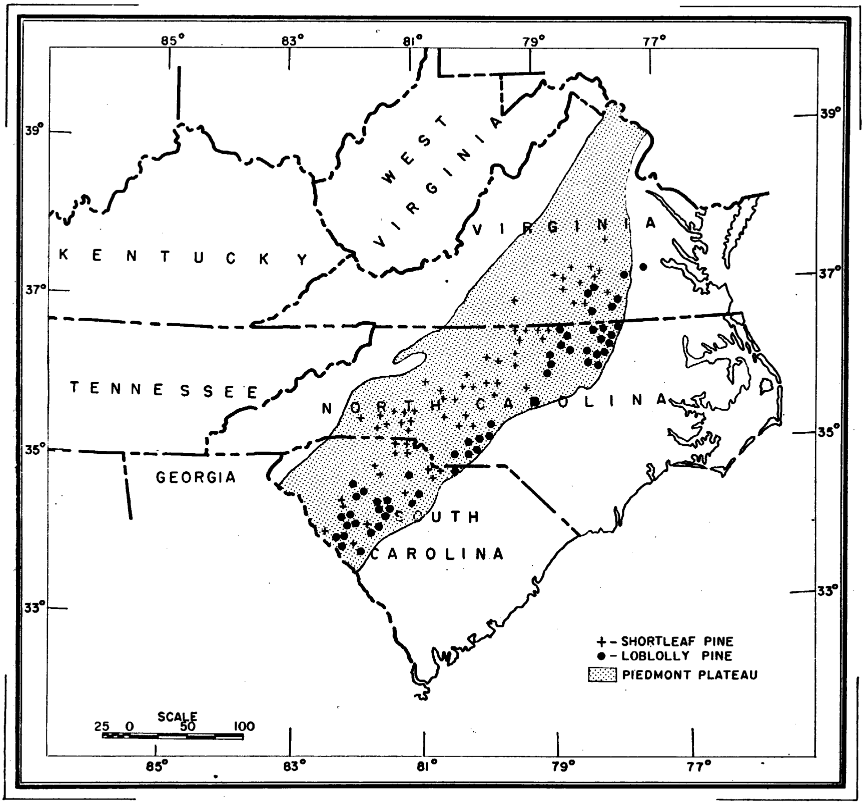

FIGURE 1.—Location of sample plots and extent of Piedmont Plateau in the Carolinas and Virginia.

On each sample plot a stem count of the woody vegetation, including both shrubby and arborescent forms, provided data for the three measures of the understory used, namely: (1) The percent of all hardwood stems represented by the climax species, oaks and hickories, (2) the number of oaks and hickories per acre, and (3) the number of stems of pine reproduction per acre. From measurements of sample trees, the pine overstory of each plot was described by age, site index, and density index. Methods of determining density of stocking in loblolly pine were those developed by MacKinney and Chaiken.[4]

[4] MACKINNEY, A. L., and CHAIKEN, L. E. VOLUME, YIELD, AND GROWTH OF LOBLOLLY PINE IN THE MID-ATLANTIC COASTAL REGION. U. S. Forest Serv. Appalachian Forest Expt. Sta. Tech. Note 33, 30 pp., illus. 1939. [Processed.]

Density index is defined by these authors as the ratio (expressed as percent) of the observed number of trees of all species per acre to the number expected in fully stocked stands of loblolly pine. In the coastal region fully stocked loblolly stands of the following average diameters at breast height are assumed to contain trees per acre, respectively: 5.0 inches, 924; 10.0 inches, 283; and 15.0 inches, 142. Site index is defined as the average height in feet attained by dominant and codominant trees in such fully stocked stands at the age of 50 years.

For shortleaf pine, density of stocking was based on similar but as yet unpublished density criteria. The number of years having elapsed since the latest fire was carefully estimated from such evidence as the age of sprouts arising from fire-killed hardwood trees and the number of annual rings in the callus growth over fire scars found in cut stems.

The plots were then grouped into two categories: First (termed "unburned"), those which had not been burned over for 10 years or more; and second, those which had been burned at least once within 10 years. Data from each group were tested in a series of multiple regressions for relationships between measures describing the understory of each plot and measures describing the pine overstory. The multiple regression method was used because it provides a ready means for detecting the direction of trends and the testing of their significance. Graphic comparison of average regression lines with plotted residuals indicated that for most of the tests relationships were linear or nearly so. Because significant average trends rather than accurate predicting devices were sought, no attempts were made at refinements that would recognize the presence of curvilinear relationships in the few cases where this apparently occurred.

RESULTS FOR UNBURNED STANDS

The majority of the plots had not been burned within the preceding 10 years, and are referred to as unburned. It was from these unburned stands that the most significant and clear-cut results were obtained. Results from the burned stands were much less conclusive, probably because of the comparatively limited amount of data and the impossibility of reconstructing accurate fire histories.

Of the three criteria used to describe the pine stand—age, site index, and overstory density—the first is likely to be the most revealing in any study of long-time changes in the hardwood understory. This is clearly shown in table 1. The importance of the other two criteria lies in their conceivable effect on hardwood understories and hence on the correlation existing between age of the pine stand and the understory. Both density and site, however, as well as age, have significant effects upon understory pine reproduction. Such are the important generalities drawn from the study. They will be developed more fully in the following discussions.

Because oaks and hickories are commonly accepted as climax species of the region, their representation (percent of total stems) in the hardwood understories of pine stands is of particular significance. Furthermore, any consistent differences in their representation under pine overstories of varying age is strongly indicative of natural trends. Figure 2 shows that in unburned stands of both shortleaf and loblolly pine, oaks and hickories are abundant in hardwood understories, and also that their proportionate number increases with the age of the pine overstory. The climax species make up about 17 percent of the hardwood understory in 20-year-old shortleaf pine stands. This proportion rises steadily to approximately 42 percent in 90-year-old shortleaf. In loblolly pine stands the trend is the same but at a lower level. Strong evidence is thus provided that oaks and hickories are able to increase in competition with associated understory hardwoods.

TABLE 1.—*Summary: Correlation of dependent variables describing understory with independent variables describing pine overstory*

Dependent variable describing understory	Species and stand condition	Significant change with increase in overstory in respect to—		
		Age	Density index	Site index
Representation of oak and hickory stems in total hardwood understory.	Shortleaf:			
	Burned	None	None	None.
	Unburned	Significant increase.	do	Do.
	Loblolly:			
	Burned	do	do	Do.
	Unburned	Highly significant increase.	do	Do.
Number of understory oak and hickory stems per acre.	Shortleaf:			
	Burned	None	do	Do.
	Unburned	Highly significant increase.	do	Do.
	Loblolly:			
	Burned	do	do	Do.
	Unburned	do	do	Do.
Number of stems of pine reproduction per acre.	Shortleaf:			
	Burned	do	do	Highly significant increase.
	Unburned	Highly significant decrease.	Significant decrease.	Significant increase.
	Loblolly:			
	Burned	None	None	None.
	Unburned	do	Significant decrease.	Significant increase.

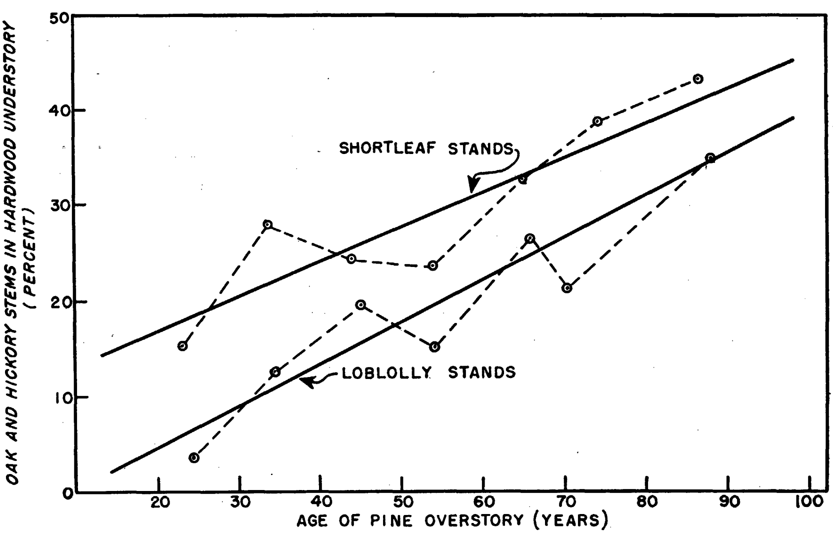

FIGURE 2.—Correlation between age of pine overstory and representation of oaks and hickories in the hardwood understory for stands unburned for at least 10 years. Plotted points are residuals.

Figure 3 shows that increasing representation of oaks and hickories is accompanied by an absolute increase in their numbers, in both shortleaf and loblolly pine stands. For the former the average number of understory oaks and hickories was about 200 per acre at 30 years of age, increasing to approximately 1,000 stems per acre at 90 years. For loblolly pine the average number of understory oaks and hickories was approximately 100 and 600 stems per acre at 30 and 90 years, respectively. These statistics showing absolute and relative increases in numbers of oaks and hickories substantiate the general observation that invasion by these climax hardwoods is now under way in the pine forests of the piedmont region.

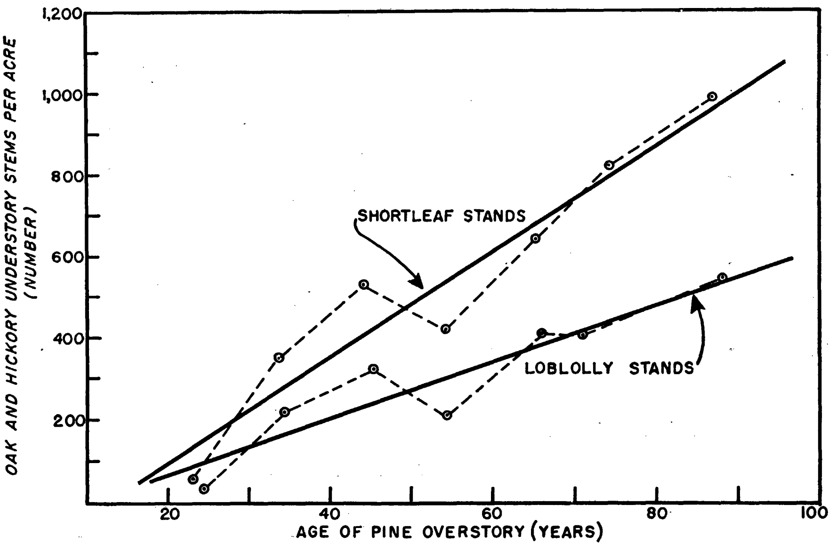

FIGURE 3.—Correlation between age of pine overstory and number of understory oak and hickory stems per acre for stands unburned for at least 10 years. Plotted points are residuals.

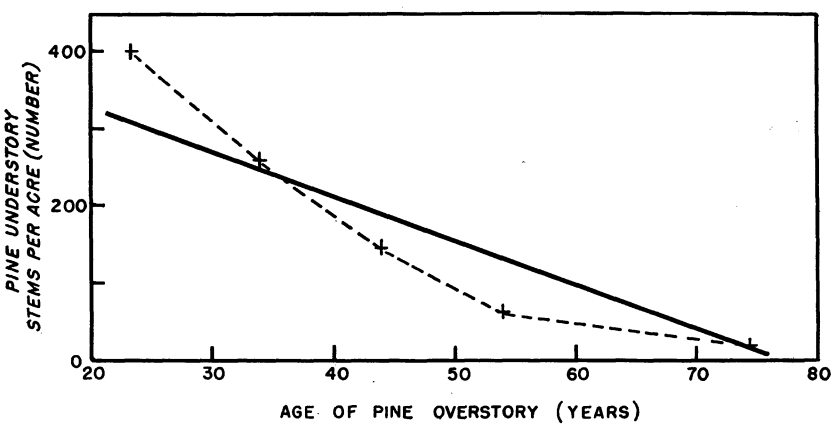

FIGURE 4.—Correlation between amount of understory pine reproduction per acre and age of pine overstory for shortleaf pine stands unburned for at least 10 years. Plotted points are residuals.

Relationships between pine reproduction and the pine-overstory characteristics already mentioned provide another measure of the importance of hardwood invasion. The pine reproduction showed a trend opposite to that of understory hardwoods. For shortleaf pine, figure 4 shows that the number of understory pine stems per acre decreases as the parent stand grows older and that average stands beyond 70 years of age contain very little pine reproduction. Figure 3 has shown that at this age 700 to 800 oaks and hickories per acre will be

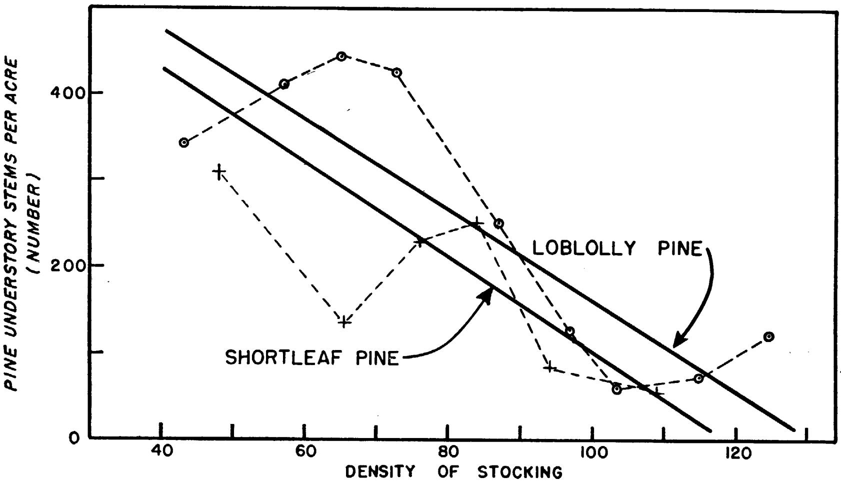

FIGURE 5.—Correlation between overstory density of pine stands and amount of understory pine reproduction per acre in stands unburned for at least 10 years. Plotted points are residuals.

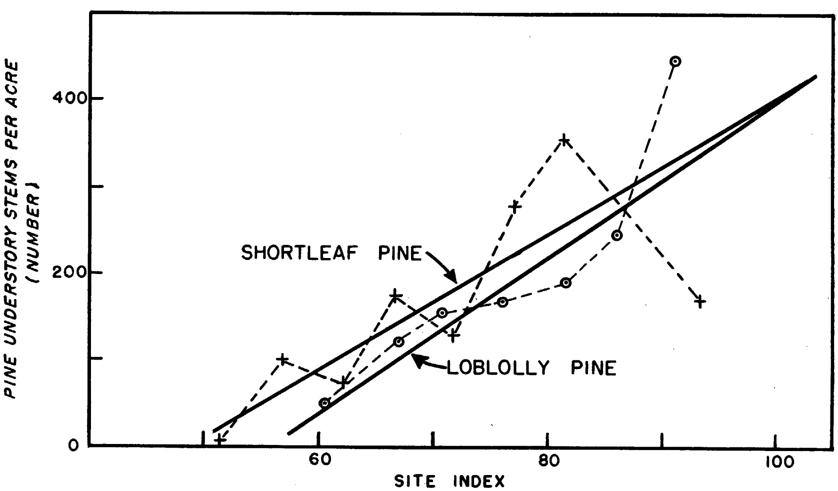

FIGURE 6.—Correlation between site index of pine overwood and amount of understory pine reproduction per acre for stands unburned for at least 10 years. Plotted points are residuals.

present. Understory reproduction of loblolly pine differed from that of shortleaf pine in its relation to age of the parent stand, since there was a slight increase in loblolly seedling count as the main-stand age advanced. From a statistical viewpoint, however, the amount of loblolly pine reproduction in unburned stands is not significantly correlated with overstory age (table 1). In other words, the average number of loblolly pine seedlings per acre does not differ greatly with respect to various ages of the overstory. For the stands studied, the average number per acre was approximately 200.

Aside from their differing relations with overstory age, the amounts of understory pine reproduction in both shortleaf and loblolly pine stands react similarly to variations in site index and overstory density. The reproduction of both species decreases sharply in numbers per acre as density of the overstory increases (fig. 5). This gives further evidence of the intolerance to shade of these species and their general disinclination to grow in uneven-aged stands except those which are very open. Figure 6 shows that this trend may, however, be modified by site, the amount of reproduction of each species increasing with the site index.

Discussion of the development of understories in relatively unburned pine stands has thus far been confined to average trends. More specific comparisons of understory conditions for various combinations of overwood age, site, and density are presented in figure 7.

For shortleaf pine, figure 7 indicates that in stands 40 to 50 years of age and older, the climax hardwoods will outnumber pine reproduction except under the lower overwood densities. It is also apparent that the excess of climax hardwoods over pine reproduction is likely to be greater on the poorer shortleaf sites than on the better ones. The Forest Survey has shown that for shortleaf pine stands in North and South Carolina, site index 60 is the one of most frequent occurrence. It follows that the advance reproduction in stands of sawlog size, say those older than 45 years, is quite likely to be dominated by oaks and hickories rather than by the reproduction of the parent stand.

For loblolly pine the trends are somewhat different. The number of understory stems of this species is more nearly equal to the number of oaks and hickories. Nevertheless, on sites 60 and 70 oaks and hickories outnumber pine reproduction in the better-stocked older age classes. According to Forest Survey records, site index 70 is of most frequent occurrence in loblolly pine stands of the Carolinas. Consequently, advance reproduction dominated by climax hardwoods may be commonly expected in many of the better-stocked loblolly stands, although figure 7 indicates that the preponderance of oaks and hickories over pine in the understory will not be so great in loblolly as in shortleaf pine stands. On loblolly pine sites 80 and 90, particularly the latter, the amount of pine reproduction exceeds that of climax hardwoods except in the oldest and densest stands.

In the foregoing discussion comparisons have been made between the amounts of pine reproduction and climax hardwoods present in the understories or advance reproduction of pine stands. The climax hardwoods, oaks and hickories, were used in these comparisons because it seems reasonable to expect that pine reproduction will suffer more severe and persistant competition from them than from secondary hardwoods.

Although for certain combinations of overwood conditions, as already shown, oaks and hickories do not exceed pine stems in the understory, when the number of secondary hardwoods is added (fig. 2) the total is much greater than that for both pine species for practically

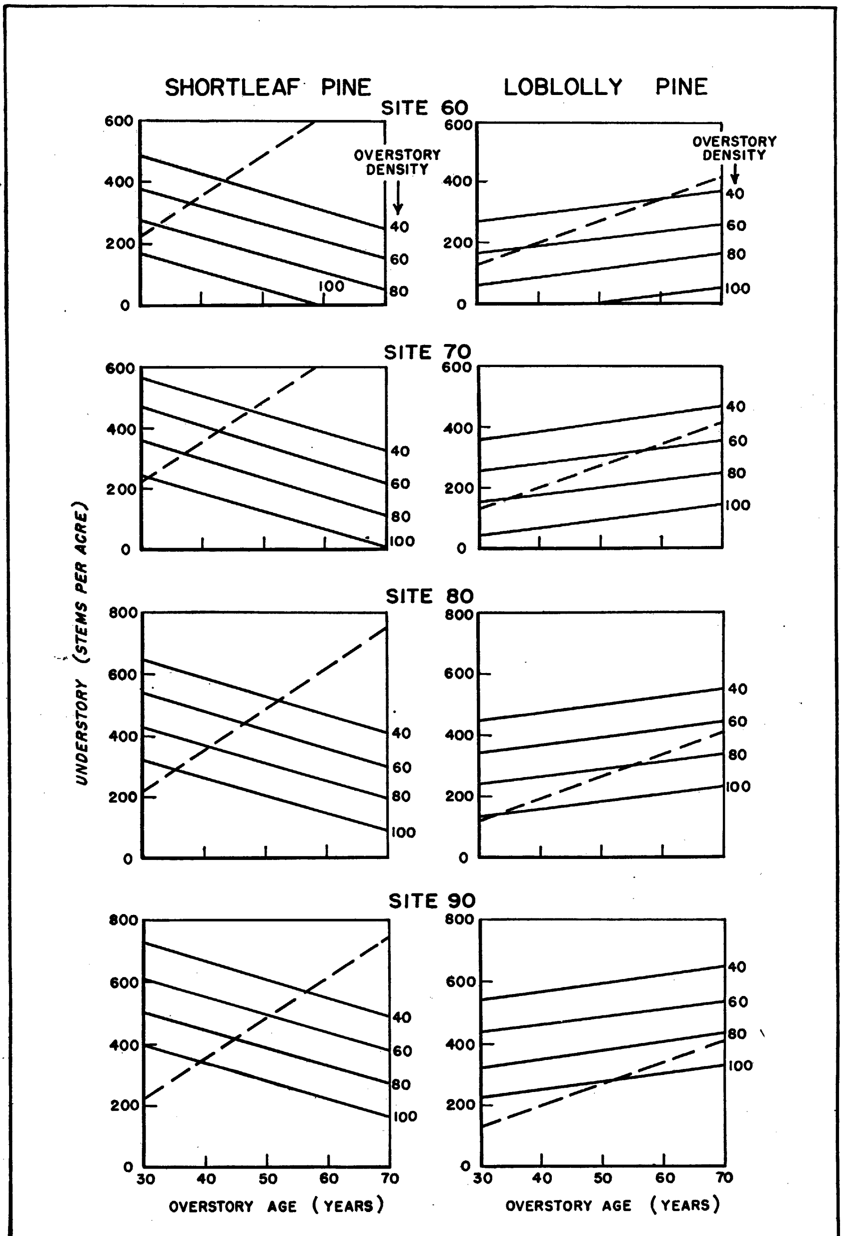

FIGURE 7.—Comparison of understory pine with understory oak and hickory stems in pine stands for various combinations of overwood age, density, and site. Broken lines show average numbers of oak and hickory stems, solid lines average numbers of pine understory stems. Stands unburned for at least 10 years.

all overstory combinations. Since the competition of secondary species may fully equal that of the oaks and hickories in limiting pine establishment and growth during the first few years after cutting, the combined effect of primary and secondary hardwoods is of first importance.

RESULTS FOR BURNED STANDS

It is interesting to compare the foregoing evidence of successional trends in the relative absence of fire with findings in stands burned at least once during the past 10 years. Because sample-plot records from such burned stands were available only in limited quantity, however, and because both fire histories and intensity of individual fires probably varied greatly, few significant relationships were discovered.

As shown in table 1, no evidence of hardwood succession in burned stands of shortleaf pine was found. Neither the number of stems nor the percent of climax species in the understory was correlated with overstory age, density, or site. Apparently the fires in these shortleaf stands had the effect of halting the trend toward hardwoods. Climax species in the understory were not eliminated, however, but were present on an average in about half the numbers found in unburned stands. Pine reproduction in the burned stands, it may be added, was more abundant on the better sites, as it was also in the unburned stands.

The burned-over loblolly pine stands studied gave evidence of successional trends similar to those in unburned stands. Both the proportion of climax species in the understory and their absolute numbers were found to increase significantly as the pine overwood grew older. Moreover, in these respects there was almost no difference between burned and unburned stands. Figures 8 and 9 when compared with figures 2 and 3 illustrate this result. Evidently the fires that occurred in the loblolly stands had very little effect on the understory hardwoods.

Effects of fire on understory pine reproduction also differed between stands of the two pine species. In shortleaf pine stands, the number of understory pine stems was found to increase as the overwood grew older. This relationship, shown in figure 10, is in direct contrast to the trends of understory pine reproduction in unburned stands, as may be seen by referring to figure 4.

In burned loblolly pine stands all normal relationships between amount of pine reproduction and overstory characteristics appeared to be upset by the fires. Pine reproduction had not been eliminated in these burned stands, but was present in from one-half to two-thirds the amounts found in similar unburned stands.

To summarize the results from the burned stands, it can merely be stated that fire was apparently favorable to maintenance of shortleaf pine, but showed opposite effects in loblolly stands. No evidence gathered in the study was helpful in explaining this inconsistency. It is believed that the shortleaf and loblolly pine stands examined had generally dissimilar fire histories, and that the differences in fire effects are due primarily to such variations. It did not appear possible to reconstruct the fire histories accurately by the ex post facto procedures necessarily used.

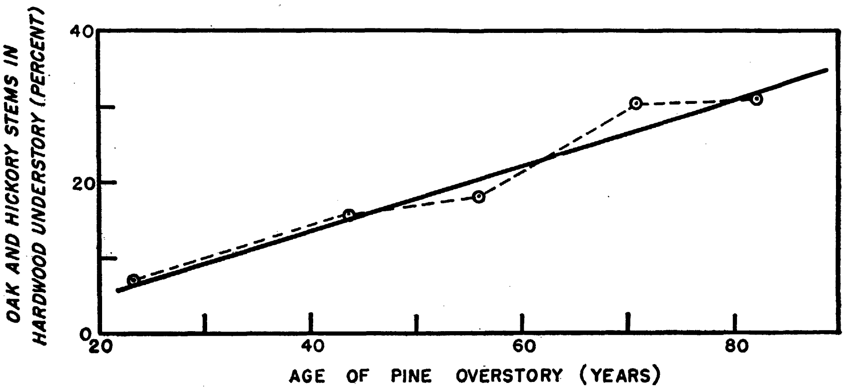

FIGURE 8.—Correlation between age of pine overwood and representation of oaks and hickories in the understory for loblolly pine stands burned at least once during the past decade. Plotted points are residuals.

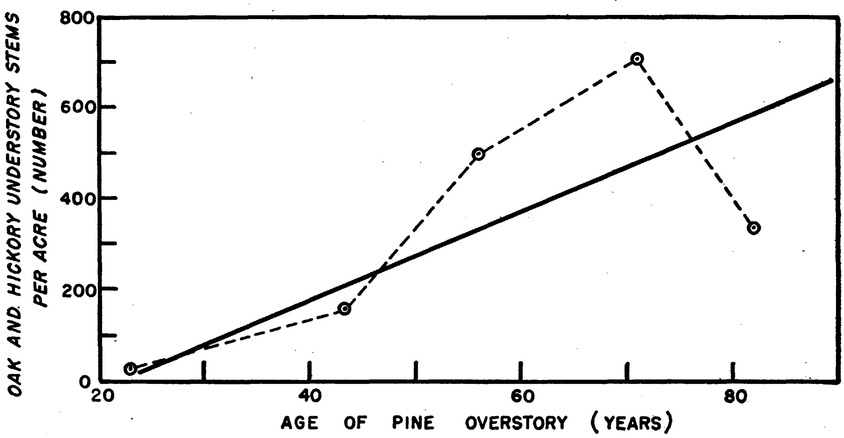

FIGURE 9.—Correlation between age of pine overstory and number of understory oak and hickory stems per acre for loblolly pine stands burned at least once during the past decade. Plotted points are residuals.

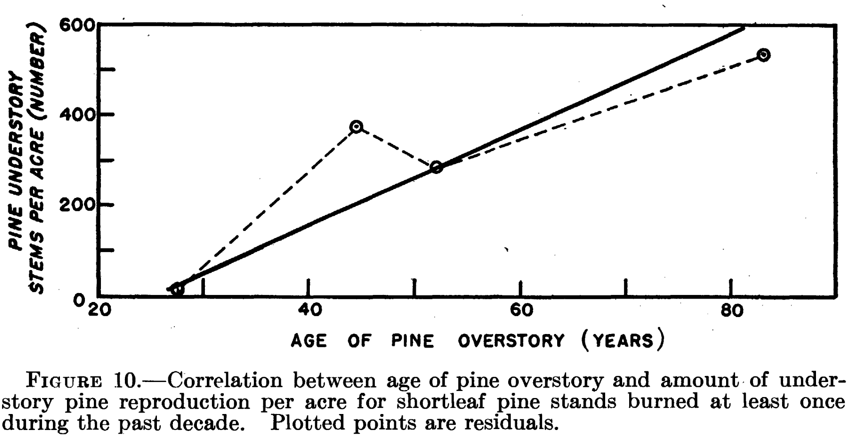

FIGURE 10.—Correlation between age of pine overstory and amount of understory pine reproduction per acre for shortleaf pine stands burned at least once during the past decade. Plotted points are residuals.

IMPLICATIONS OF RESULTS IN FOREST MANAGEMENT

The establishment of hardwood invasion as an aggressive successional trend in shortleaf pine stands and a less aggressive but nevertheless distinct trend in loblolly pine carries far-reaching implications with respect to the management of these stands. Not only do the oaks and hickories in the understory outnumber the pines on many unburned areas, but these climax species are only a part of the total number of understory hardwoods. Many of the associated hardwoods play a subordinate role in mature hardwood stands, but they may be equally effective competitors of pine in juvenile stages. Not only do these hardwoods compete with smaller numbers of growing pine seedlings for light, moisture, and nutrients, but their presence creates a condition unfavorable to the ready establishment of pine reproduction. The mantle of hardwood leaf litter tends to prevent contact of the pine seed with the mineral soil, which is essential for good germination and early survival of the pines. On the other hand, a litter of hardwood leaves forms the best natural seedbed for good germination and early survival of heavy-seeded species such as the oaks (*1*, *7*).

Although it is entirely probable that it will be advantageous to allow replacement of pine to take place on some areas, it is at present impossible to determine which these are, except for the more obvious locations in well-drained stream bottoms and other moist sites where the more valuable hardwoods are usually present in some degree. Investigation of soil characteristics, which have been markedly changed by several generations of cultivation and subsequent depletion, probably offers the best avenue for solution of this problem.

It is also probable that no practicable forest-management measures can entirely control a natural trend so pronounced and persistent as the one described. The drastic measures that originally accomplished control of hardwoods and creation of pure pine stands, namely, extensive land clearing and cultivation, cannot be considered practical in timber production. It is possible, however, that workable methods for partial control of hardwoods and maintenance of high proportions of pine can be developed.

One possibility that suggests itself is the use of fire. Controlled burning, for a variety of purposes, has long been a controversial subject in the South. Although this study provides some indication that fire may favor establishment of pine, the evidence is not at present sufficiently clear-cut and consistent to justify recommendations of burning as a general practice.

For the immediate future, the most promising measures for maintenance of a high proportion of pine in mixed stands are found in the methods of taking the final harvest and in the silviculture applied to subsequent new growth.

Where forestry is practiced, two general methods are customarily considered for harvesting mature pine saw timber, i. e., extremely heavy or clear cuttings by the strip, spot, or seed-tree method, and lighter or selective cuttings. Following seed-tree cuttings, no trees remain except the few chosen, and all or part of these may be removed after reproduction is established. In clear cutting, it is expected that renewal of the stand will be accomplished by seed already on the ground or dispersed from uncut bodies of timber purposely left adjacent to the cutting area. The objective of the clear-cutting method is to produce even-aged stands so distributed that annual or periodic harvests of financially mature portions of the forest represent a sustained yield from a given property. The method envisions thinnings, improvement cuttings, and salvage cuttings prior to the final cut, for the dual purpose of obtaining intermediate harvests and maintaining the most desirable growth rate of those stand components chosen for the final crop. The basic concept of this method, therefore, is the management of a forest property by even-aged groups and it is usually thought to apply best to species that do not reproduce well in the shade of older trees. The term "clear cutting" is understood to connote the orderly harvest of mature stands with area regulation to keep the rate of cutting within the limits of sustained yield, and carefully planned provision for reproduction.

In the lighter or selective cuttings, individual mature or poor-risk trees are removed throughout an entire cutting area and a comparatively heavy stand remains. The method usually combines essential features of both harvest and improvement cuttings in a single operation, which is repeated at short intervals. Here, renewal of the stand is accomplished by seedling establishment in the small openings created by the selective cutting. The usual concept among foresters is that the use of this method implies the maintenance of an all-aged or many-aged forest, wherein several or many age classes may be present on an area as small as a quarter or even a tenth of an acre. The method is commonly considered as being the best for optimum long-time production of shade-tolerant species. As used here, therefore, the term "selective cutting" applies only to those operations by which mature saw timber is harvested and provision is made for regeneration under a silvicultural policy aimed at development and maintenance of all-aged stands. It does not include thinnings and improvement cuttings made in young stands for intermediate harvests of pulpwood, poles, or piling.

Will these two methods provide equally well for a high proportion of pine in future forests, where aggressive hardwood invasion exists? In the all-aged stands produced by selective cutting it is probable that the loblolly and shortleaf pine overstory would average about 40 in density index and about 70 years in age. The most common site index in shortleaf pine stands is 60. For site index 60, density index 40, and age 70, figure 7 shows that the average understory will be composed of about 250 pine seedlings and 740 oak and hickory stems per acre. Figure 2 shows that oak and hickory stems will make up about 35 percent of all understory hardwoods; accordingly the total number of hardwood stems will be more than 2,100. For loblolly pine of the most common site, which is 70, there will be about 460 pine seedlings and 410 oaks and hickories per acre in the average understory. Figure 2 shows that these climax species will be about 27 percent of all understory hardwoods, totaling 1,500 stems per acre. With hardwoods so far outnumbering pine in the understory, the chances that pine seedlings will occupy each opening made by selective cutting appear poor indeed.

If overstories are maintained at densities higher than index 40, the average amount of understory pine reproduction will be reduced, with the possibility of higher odds against the filling of the openings by the growth of pine seedlings. If pine overstories are maintained at densities below index 40, the amount of understory pine reproduction increases with probable consequent improvement in the chance that some pine seedlings will grow through the hardwoods into dominant positions. But as overstory densities are reduced the cuttings depart further from the usual concept of selective cutting and approach the more drastic treatments that result in production of even-aged stands.

For the common pine sites of the piedmont region, therefore, this study indicates that selective cutting in pine saw-timber stands may promote the gradual replacement of pine with hardwoods. Because pine reproduction is better represented in understories of stands with low overwood densities and because it is generally conceded that both shortleaf and loblolly pine seedlings develop more rapidly in full light than in shade, it becomes necessary to consider the possibility that some form of drastic treatment, such as clear cutting by the strip, group, or seed-tree system, is more likely to maintain high proportions of pine in future forests than is selective cutting. Clear cutting brings about certain physical conditions that may reasonably be expected to favor maintenance of pine. The complete felling of the heavy pine overstory breaks down a portion of the hardwood understory present. For the removal of the comparatively high volume of logs, more swamping, skidding, and hauling are necessary, still further reducing the hardwoods. These operations also break up the mantle of forest litter and expose mineral soil, creating conditions favoring the germination of pine seed. Complete removal of overhead shade and the reduction of root competition will accelerate the growth of pine after establishment. Under the conditions created by such operations, the new growth of pine starts off on a more equal basis with the hardwoods than when selective cutting is practiced.

When a seed-crop failure occurs in the autumns preceding or immediately following the harvest cut, so that there is insufficient pine reproduction, the hardwoods may get a start of 2 or 3 years. After the establishment of seedlings from a subsequent cone crop, a cleaning several years later to release pine crop trees from hardwood competition may be essential.

Two kinds of stands encountered in shortleaf and loblolly pine types are possibly not in danger of hardwood invasion. One of these is loblolly pine on an unusually high-quality site, and the other occurs in areas where apparently an unusual series of repeated light fires over a long period of years has so reduced hardwoods that their invasion will be very slow. It has already been shown that on loblolly pine sites of 90 or more, the understory will contain a fair percentage of pine seedlings, which will outnumber climax hardwoods except in fully stocked stands of the older age classes. General observation indicates that here pine is frequently able to penetrate through and keep above the hardwood understory. Under these conditions it is possible that either even-aged or all-aged management may maintain the pine in high proportions.

In the second type of stand, where hardwoods have been largely eliminated by light fires, it is again probable that either type of management will maintain high proportions of pine for some time, particularly on the better sites. Under such conditions there will be few, if any, hardwoods to compete with pine seedlings.

Except for the two conditions discussed above, the evidence presented here points to a likelihood that clear-cutting measures will prove superior to selective cutting, where maintenance of high proportions of pine is an objective of management.

SUMMARY AND CONCLUSIONS

Conclusions based on results in stands unburned for at least 10 years may be summarized as follows:

(1) In both loblolly and shortleaf pine stands, the proportion of climax species, oaks and hickories, in hardwood understories increases with age of the pine overwood.

(2) The number of understory climax hardwoods per acre also increases with age of the main pine stand.

(3) Neither the density nor the site index of the pine stand has a significant influence upon the two trends mentioned above.

(4) In shortleaf pine stands, the amount of pine reproduction per acre decreases significantly as the overstory grows older, but under loblolly pine it tends to remain approximately constant for all ages of the overstory.

(5) In both loblolly and shortleaf pine stands the amount of understory pine reproduction per acre decreases with increasing density of overwood, but increases with improvement in the site index.

(6) Differences in age, density, and site of both loblolly and shortleaf pine overstories are associated in several different ways with the amounts of pine reproduction present in the understories. Under certain overstory stand conditions the oaks and hickories will outnumber pine reproduction, and under other conditions the reverse will be true, as shown in figure 7.

(7) The number of combinations of overstory age and density under which climax hardwoods will exceed the amount of pine reproduction is greater on poor than on good sites for both species of pine. In shortleaf the preponderance of climax hardwoods over pine reproduction is greater than in loblolly stands. Hence the trend toward replacement of pine by oaks and hickories appears to be the more aggressive in shortleaf pine stands.

(8) For site index 60 (fig. 7), which most frequently characterizes shortleaf pine stands of the Carolinas, oaks and hickories will outnumber pine reproduction with respect to the majority of possible combinations of overwood age and density. For site index 70 (fig. 7), of most frequent occurrence in loblolly pine stands, oaks and hickories will outnumber pine reproduction only in stands of higher densities.

(9) Climax oaks and hickories represent only a part of the entire hardwood understory of both shortleaf and loblolly pine stands. Figures 2 and 7 indicate that in most of these stands pine stems in the understory will be greatly outnumbered by hardwoods, counting not only the climax species but also the secondary hardwoods, which may be effective competitors of pine during the reproducing years following cutting.

In stands burned at least once during the past 10 years the findings were as follows:

(1) In the burned shortleaf pine stands studied, understory climax hardwoods were present in about half the amounts found in unburned stands. No tendency toward an increase in the representation or numbers of oaks and hickories was found.

(2) Understory pine reproduction in burned shortleaf pine stands showed a marked increase with advancing age of the overstory, a reversal of the trend found in unburned stands.

(3) Climax hardwoods in the understories of loblolly pine stands showed the same trends as those in unburned stands. Fires in loblolly stands apparently had little effect upon the numbers and representation of understory oaks and hickories.

(4) Pine reproduction, although not eliminated, was reduced in burned loblolly stands, and the pine understory had no consistent relationships with overstory density and site.

(5) The study failed to disclose any reasons for the inconsistencies in results for burned stands. Lack of consistency is attributed primarily to wide but undetermined variations in fire histories of the stands studied.

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