INFLUENCE OF WHOLE-TREE HARVESTING ON STAND COMPOSITION AND STRUCTURE IN THE OAK-PINE TYPE

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Abstract.—Oak-pine stands in the Upper Piedmont of Georgia were harvested with small feller-bunchers in both the dormant season and early growing season to 1-inch and 4-inch lower diameter limits. After 9 years of natural stand development, both season and intensity of harvesting significantly influenced species composition and stand structure. Areas harvested during the growing season developed into essentially hardwood stands, while dormant-season harvests produced a substantial pine component. On the 4-inch-limit areas, competition to regeneration from the harvest residuals was still apparent.

INTRODUCTION

Intensive whole-tree harvesting can be a practical way to remove poor stands with little timber-producing potential (Butts and Preston 1979). Key questions remain, however, about the species composition and stand development of natural regeneration that follows intensive harvesting. To address these questions, a study was established in a mixed hardwood-pine association on the Upper Piedmont of Georgia. Study variables were intensity and season of harvest. Treatment effects on hardwood sprout coverage and pine regeneration through the first five growing seasons after harvesting were presented by McMinn and Nutter (1988). This paper presents results based on the entire stands nine growing seasons after harvest: it is the first time in the study that the same response variables--basal area and number of stems per acre--are applied to the hardwood coppice, pine regeneration, and harvest residuals.

METHODS

The study area is on the Dawson Forest, which is managed by the Georgia Forestry Commission. Prior to management by the Commission, the area had been abandoned for agriculture, undergone natural succession, and been subjected to high grading typical of stands in the region. Soils are eroded phases of Fannin fine sandy loam with inclusions of Tallapoosa fine sandy loam. Both soils are Ultisols in the Typic Hapludult and Ochreptic Hapludult subgroups, respectively. The initial hardwood component was comprised primarily of scarlet oak (*Quercus coccinea* Muenchh.), post oak (*Q. stellata* Wangenh.), black oak (*Q. velutina* Lam.), chestnut oak (*Q. prinus* L.), southern red oak (*Q. falcata* Michx.), hickory (*Carya* spp.), blackjack oak (*Q. marilandica* Muenchh.), sourwood (*Oxydendrum arboreum* (L.) DC.), white oak (*Q. alba* L.), dogwood (*Cornus florida* L.), and blackgum (*Nyssa sylvatica* Marsh.) in descending order of basal area (table 1). Predominant conifers were shortleaf (*Pinus echinata* Mill.), Virginia (*P. virginiana* Mill.), and loblolly pine (*P. taeda* L.).

Table 1.--Mean number of stems and basal area per acre prior to harvest by species group and size class

Species group[a]	Stem d.b.h. class (in) 0.5 - 5.4	5.5 - 9.4	>9.4
	Stems (no./acre)		
Shrub	67.7	-	-
Yellow pine	112.2	47.0	5.4
Soft hardwood	66.7	2.7	0.3
Hard hardwood	500.4	51.4	25.9
Miscellaneous	141.1	11.7	1.0
All species	888.1	112.8	32.6
	Basal area (ft^2/acre		
Shrub	0.4	-	-
Yellow pine	6.6	14.6	3.4
Soft hardwood	0.7	0.8	0.4
Hard hardwood	14.2	15.7	21.8
Miscellaneous	6.5	3.1	0.7
All species	28.4	34.2	26.3

[a]Species are grouped according to standard Forest Survey categories.

One-acre treatment plots were harvested with a typical whole-tree system that included a small feller-buncher and grapple-skidders. Harvesting removed all material down to 4-inch or 1-inch diameter limits in both January and June of 1980. Each combination of season and intensity was replicated three times in a completely randomized design. Detailed observations and measurements were confined to the interior 0.5 acre of each 1-acre plot. In November and December of 1988 nine 0.01-acre circular subplots were located systematically on each 0.5-acre measurement plot. D.b.h. of all stems greater than 0.4 inch d.b.h. on each subplot was measured to the nearest 0.1 inch. Basal area and number of stems per acre were computed by species group and compared among treatments by analysis of variance.

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RESULTS AND DISCUSSION

The 9-year-old stands originated from a combination of hardwood coppice regeneration, pine seedling regeneration, and in some treatments small pine and hardwood harvest residuals (table 2). At this stage, the stands have not reached a stable number of stems per unit area, but substantial mortality has occurred in pine seedlings and hardwood sprouts. To understand the factors affecting the species composition and structure of the stands, it helps to first focus on pine and hardwood regeneration alone and then the combination of regeneration and harvest residuals.

Table 2.--Mean values by stand trait and harvesting treatment after nine growing seasons

Stand trait	Season: Dormant / Diameter limit: 1-inch	Dormant 4-inch	Growing 1-inch	Growing 4-inch
	Regeneration only			
Stems per acre				
Pine	5188	1104	115	42
Hardwood	1984	1222	2070	1192
Basal area (sq.ft.per acre)				
Pine	61.4	13.5	1.2	0.4
Hardwood	16.5	9.8	15.8	8.3
	Residuals and regeneration			
Stems per acre				
Pine	5188	1141	119	100
Hardwood	1984	1637	2070	1619
Basal area (sq.ft.per acre)				
Pine	61.4	18.1	1.2	4.9
Hardwood	16.5	28.4	15.8	22.3

Regeneration Alone

Overall, different harvesting treatments gave rise to different stand characteristics, primarily through influences on pine regeneration (table 3). Very large effects of harvest season are probably related to the presence of viable pine seeds on the ground at the time of harvest. In this study, most of these seeds came from pines in the harvested stands, and harvesting provided the only site preparation for seeds that had already fallen. This regeneration technique has been formally characterized as the "seed-in-place" method (Langdon 1981). There were few pine seedlings in place prior to harvesting. In the absence of harvesting disturbance, few seedlings become established because the forest floor prevents seed contact with mineral soil (Pomeroy 1949; Yocum and Lawson 1977). Seed predators and fungi likely destroy a substantial proportion of the seed crop by early summer. Seedlings that do become established are vulnerable to destruction by the harvesting operation. Timing the harvest after an adequate seedfall and before hot weather, therefore, is crucial to regeneration success with this technique. Adjacent stands were the probable seed source for the few pine seedlings on plots harvested in the early growing season. The difference in pine seedling occurrence by harvest intensity is probably due partly to mechanical disturbance and partly to competition by residual woody vegetation. Significantly more mineral soil was exposed by the more intense harvesting.

Table 3.--Summary of analysis of variance results for naturally regenerated oak-pine stands nine growing seasons after harvesting

Stand trait	Source of variation: Season	Limit	Season x limit
	Regeneration Only		
Pine stem count	**[a]	**	**
Hardwood stem count	NS	NS	NS
Pine basal area	**	**	**
Hardwood basal area	NS	NS	NS
	Residuals and regeneration		
Pine stem count	**	**	**
Hardwood stem count	NS	NS	NS
Pine basal area	**	*	*
Hardwood basal area	NS	*	NS

[a]** = significant at the 0.01 alpha level, * = significant at the 0.05 alpha level, NS = nonsignificant.

At age 9 there was no significant difference in number of hardwood coppice stems or basal area by treatment. However, hardwood coppice crown coverage had been significantly greater at age 2 after dormant season harvests and with a 1-inch limit. At age 4 and 5 coppice coverage was significantly greater on the 1-inch areas and exhibited evidence of competition from pine seedlings established after dormant season harvests (McMinn and Nutter 1988). Although statistically nonsignificant, some effect of diameter limit was apparent in hardwood regeneration at 9 years. The 1-inch limit produced an average of 68 percent more stems with 79 percent greater basal area than the 4-inch-limit harvests. This difference is attributed primarily to competition from the harvest residuals. A negligible proportion of hardwood sprouts originated from trees less than 4 inches d.b.h. A high proportion of the smaller stumps were destroyed to below the groundline by the tracked feller-buncher, and all sprouting was associated with identifiable stumps.

The net effect of treatments after 9 years was a drastic difference in the relative predominance of pine and hardwood. Dormant season harvest resulted in stands with a large pine component, but there was a substantial difference between harvest limits within the dormant season treatment. Pine basal area on the 1-inch-limit plots was over 3.5 times the hardwood basal area. On the 4-inch limit plots, pine basal area was less than 1.5 times the hardwood basal area. In sharp contrast to the dormant-season treatments, the growing season treatments exhibited less than 10 percent as much pine as hardwood basal area.

Regeneration and Residuals

After the 1-inch-limit harvests, regeneration comprised essentially the entire stands. After the growing-season 4-inch-limit treatment, a relatively modest number of residual stems translated into a substantially larger basal area at age 9: the majority of this basal area was hardwood. This effect was even more pronounced after the dormant-season 4-inch-limit treatment. Among regeneration, 58 percent of the basal area was pine. However, with residuals added, pine basal area comprised 39 percent of the stand.

The differences in total stand characteristics by treatment are most evident in diameter class distributions of stems and basal area by species group (tables 4 and 5). In the dormant-season 1-inch-limit treatment, 68 percent of the total stems and 59 percent of the total stand basal area was 1- and 2-inch pines. The greatest number of stems is in the pine 1-inch diameter class and the greatest basal area is in the pine 2-inch diameter class. By contrast, in the dormant-season 4-inch-limit treatment the largest number of stems is in the hardwood 1-inch diameter class and the greatest basal area in the hardwood 4-inch diameter class. The most skewed distribution of both stems and basal area occurred in the growing-season 1-inch-limit treatment: hardwoods in the 1- and 2-inch diameter classes accounted for 93.6 percent of the stems and 87.6 percent of the basal area. The growing-season 4-inch-limit treatment produced the most even distribution of basal area across diameter classes, but the majority of the basal area was from residual stems.

Table 4.--Diameter class distributions by species group and treatment after nine growing seasons

	D.b.h. class (inches)					
Species group	1	2	3	4	5	6
	- - - - - - - - -Stems (pct)- - - - - - - -					
	Dormant season, 1-inch limit					
Pine	46.8	20.9	3.9	0.7	0.1	0.0
Hardwood	22.0	4.4	1.2	0.1	0.0	0.0
	Dormant season, 4-inch limit					
Pine	25.2	11.9	2.5	0.9	0.3	0.3
Hardwood	40.5	9.6	3.7	4.0	0.9	0.1
	Growing season, 1-inch limit					
Pine	3.7	1.4	0.3	0.0	0.0	0.0
Hardwood	75.5	18.1	1.0	0.0	0.0	0.0
	Growing season, 4-inch limit					
Pine	2.2	1.6	0.7	0.5	0.2	0.7
Hardwood	68.0	16.7	4.7	2.9	1.6	0.2

Table 5.--Total stand basal area distribution by species group and diameter class after nine growing seasons for four harvesting treatments

	D.b.h. class (inches)					
Species group	1	2	3	4	5	6
	- - - - - - - Basal area (pct) - - - - - - -					
	Dormant season, 1-inch limit					
Pine	22.6	36.0	14.7	4.9	0.5	0.0
Hardwood	7.9	7.6	5.0	0.8	0.0	0.0
	Dormant season, 4-inch limit					
Pine	7.7	13.7	6.4	4.9	2.4	3.6
Hardwood	10.1	11.6	10.5	20.0	7.7	1.3
	Growing season, 1-inch limit					
Pine	1.8	3.5	1.8	0.0	0.0	0.0
Hardwood	42.9	44.7	5.3	0.0	0.0	0.0
	Growing Season, 4-inch limit					
Pine	0.7	2.6	2.2	2.2	1.8	8.1
Hardwood	17.7	19.6	13.7	15.9	12.5	3.0

CONCLUSIONS

Both season and intensity of whole-tree harvesting significantly influenced species composition and stand structure after 9 years of natural stand development. Areas harvested during the growing season developed into essentially hardwood stands, while dormant-season harvests produced a substantial pine component. On the 4-inch-limit areas competition of residuals with pine seedlings and hardwood coppice was apparent.

The results have some clear silvicultural implications for forest types similar to the one studied here. The intensity and timing of harvests can be expected to strongly influence the species composition and structure of naturally regenerated stands. To maximize the pine component of such stands, harvesting should be done during the dormant season with adequate numbers of seeds in place. Harvests during the growing season will produce almost pure stands of mixed hardwoods. Standing harvest residuals will influence the character of the stand indefinitely, so possible long-term silvicultural benefits should be weighed against the expense of removing all standing material. The treatments with only minor modifications appear to be good options for low-cost management.

ACKNOWLEDGEMENT

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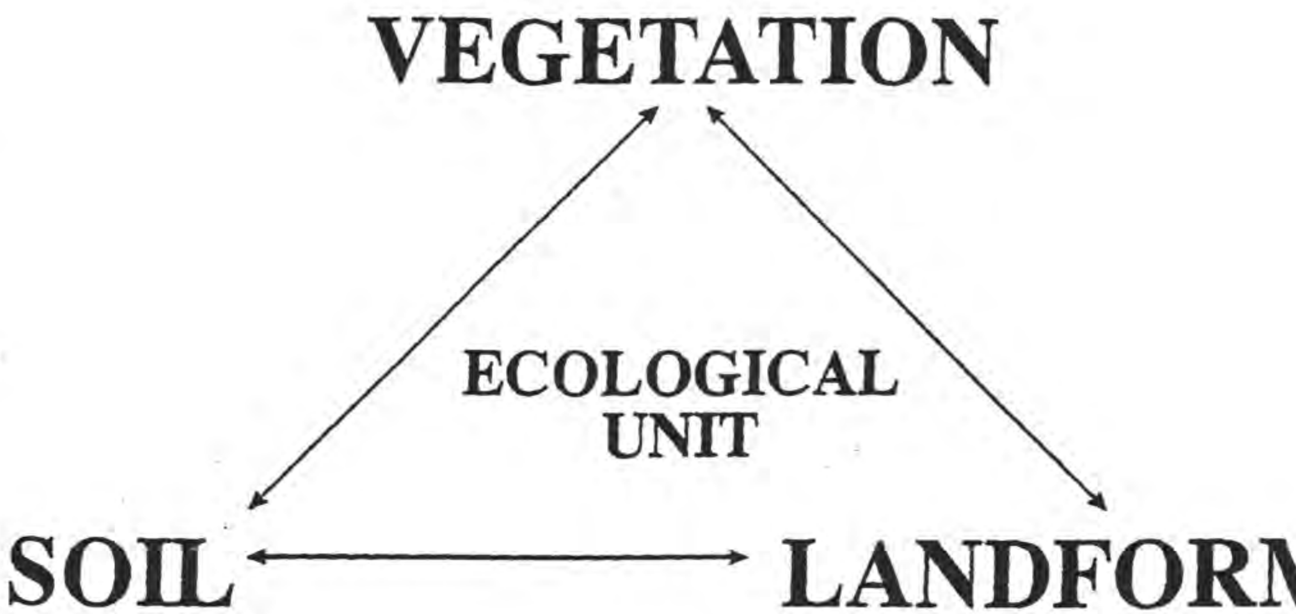
Landscape Ecosystem Classification (LEC) relies on the three major components of the ecosystem to classify sites.



The purpose is to identify uni of land distributed across the landscape that are similar relative to the productivity, type, and structure of vegetati

By combining values of slope position and aspect, a single value rating for landform was developed. The landform rating expresses the degree of exposure of a given site.

The two soil factors found to be related to the distribution of vegetation associations were depth of the horizon where clay percentage was a maximum and the maximum percentage clay. Quantification of these two soil factors were combined into a single value soil rating expressing soil aeration and available water holding capacity within the upper 24 inches of soil.

In relation to the five vegetative associations, the landform and soil indices were nearly equal in their discriminating power with landform being slightly more important in terms of explaining the variation in vegetation. Each of the five site units corresponded with unique combinations of slope position and aspect which interact with soil characteristics (amount and depth of clay) to produce a unique association of plant species. When the vegetation is disturbed or absent, the site unit can be determined quantitatively by calculating a total score from the landform and soil ratings (Jones 1988a) or qualitatively and more generalized through a descriptive key:

I. Ridge flats to slight slopes; or upper (0-20%) slope positions.
  A. Any aspect.
    1. Soils clay to sandy clay (>40% clay);
      a. Maximum clay horizon within 12 inches of surface.
        Xeric Site Unit
      b. Maximum clay horizon within 12 to 24 inches of surface.
        Subxeric Site Unit

II. Mid-upper (60-80%) to mid (40-60%) slope positions.
  A. Southerly to westerly aspects (135° to 315°).
    1. Soils clay to sandy clay (>40% clay);
      a. Maximum clay horizon within 12 inches of surface.
        Xeric Site Unit
      b. Maximum clay horizon within 12 to 24 inches of surface.
        Subxeric Site Unit
    2. Soils clay loam to sandy clay loam (27%-40% clay).
      a. Maximum clay horizon within 12 inches of surface.
        Subxeric Site Unit
      b. Maximum clay horizon within 12 to 24 inches of surface.
        Intermediate Site Unit
  B. Northerly to easterly aspects (316° to 134°).
    1. Soils clay to sandy clay (>40% clay).
      a. Maximum clay horizon within 12 inches of surface.
        Subxeric Site Unit
      b. Maximum clay horizon within 12 to 24 inches of surface.
        Intermediate Site Unit
    2. Soils clay loam to sandy cl
       (27% to 40% clay).
      a. Maximum clay horizon wit
         24 inches of surface.
        Intermediate Site Unit

III. Mid-lower (20-40%) slope position
  A. Southerly to westerly aspects
     315°).
    1. Soils clay to sandy clay (>
      a. Maximum clay horizon wit
         24 inches of surface.
        Subxeric Site Unit
    2. Soils clay loam to sandy cl
       (27% to 40% clay).
      a. Maximum clay horizon wit
         12 inches of surface.
        Subxeric Site Unit
      b. Maximum clay horizon wit
         24 inches of surface.
        Intermediate Site Unit
  B. Northerly to easterly aspects
     134°).
    1. Soils clay to sandy clay (>
      a. Maximum clay horizon wit
         24 inches of surface.
        Intermediate Site Unit
    2. Soils clay loam to sandy cl
       (27% to 40% clay).
      a. Maximum clay horizon wit
         12 inches of surface.
        Intermediate Site Unit
      b. Maximum clay horizon wit
         24 inches of surface.
        Submesic Site Unit
    3. Soils sandy clay loam to san
       (<27% clay). Maximum clay ho
       any depth.
        Submesic Site Unit

IV. Lower (<20%) slope positions.
  A. Any aspect.
    1. Soils clay loam to sandy cla
       (27% to 40% clay).
      a. Maximum clay horizon with
         24 inches of surface.
        Submesic Site Unit
    2. Soils sandy clay loam to san
       (<27% clay). Maximum clay ho
       any depth.
        Mesic Site Unit

Preliminary results of current researc
cate that vegetation patterns within the
management/successional types were not a
of environmental conditions; rather, vari
vegetation was due to conditions of stanc
lishment or subsequent anthropogenic infl
The pine management/successional types we
separated into Virginia (Pinus virginiana
shortleaf (P. echinata), and loblolly (P.
pine types. The Virginia pine type was s
into a Virginia pine-hardwood type and a
pine-grass type, while the loblolly pine
separated into three types: loblolly-swee
(Liquidambar styraciflua), loblolly-water
(Quercus nigra), and loblolly-partridge p
(Cassia fasciculata). In addition, a pin

Planted Pine* Stocking Levels by Ecological Unit

	Stems/ac	Basal Area ft^2/ac	% of Total Stand BA	Percent Survival
Subxeric	140	10.7	46	72
Intermediate	130	9.1	45	67
Submesic	100	4.8	15	52

*Planted on a 15*15 ft. spacing (194 per acre)

Hardwood Stocking Levels by Ecological Unit

	Stems/ac	Basal Area ft^2/ac
Subxeric	760	6.8
Intermediate	920	5.6
Submesic	2960	16.8

Summary of Pine and Hardwood Heights

	Hardwoods*	Planted Pines	Natural Pines
		feet	
Subxeric	12.0	17.1	10.8
Intermediate	14.1	17.6	11.5
Submesic	16.4	15.3	10.8

*Tallest hardwoods at a density level (stems/ac) equivalent to pine planting density.

Growth Comparisons by Ecological Unit*

* 18 plots on the Sumter National Forest.

Basal Area

10-year pine basal area growth (adjusted for difference in initial basal area**).

Unit	10-year*** BA growth
	—ft^2/ac—
Subxeric	17.7
Intermediate	18.8
Submesic	21.1

** Average stand age and initial basal area are 57 years and 102 ft^2/ac, respectively.
*** Adjustment for age did not make a difference for these older stands (56 to 78 years).

Height Growth

10-year pine and hardwood (oak) growth by ecological unit for two time periods.

Unit	Pines Age 19-29	Pines Age 39-49	Oaks Age 19-29	Oaks Age 39-49
	feet		feet	
Subxeric	14.0	6.8	10.6	11.6
Intermediate	15.7	8.3	13.2	11.9
Submesic	15.3	9.2	14.6	12.8