HARDWOOD REGENERATION ON THE LOESSIAL HILLS AFTER HARVESTING FOR UNEVEN-AGED MANAGEMENT'

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Abstract-in 1991, study plots were harvested to four different residual diameter distributions. Generally, for all specks, the more extreme overstory removals promoted regeneration establishment while the treatment with the least overstory removal tended to provide less regeneration than the uncut controls. For oak species, most of the seedlings present in 1993 were those occurring in 1992. Survival of oaks from 1992 to 1993 exceeded 60 percent for all species. Yellow-poplars present in 1993 were primarily seedlings established since the inventory in 1992. Abundance in the overstory was a significant factor in predicting oak but not yellow-poplar regeneration. Diversity did not differ significantly across treatments, but diversity increased from 1992 to 1993 on the most heavily cut plots.

INTRODUCTION

The loessial hills occur in a band east of the lower Mississippi River Valley. The soil parent material consists largely of windblown silt deposited at the end of the most recent ice age. The soils are productive, but prone to erosion. Some of the most productive hardwood stands in North America occur on loessial hills (Johnson 1958). Most of the current stands arose after abandonment of agricultural land. Uneven-aged management is often preferred there because it maintains a continuous high forest and reduces the risk of erosion that could occur in large dearcuts.
However, cherrybark and shumard oak (Scientific and common names of most tree species mentioned in this article are provided in table 1.) are among the most valuable components of stands on the loessial hills, and single tree selection system, as it is commonly applied, does not promote regeneration of oak species (Clatterbuck and Meadows 1993; Sander and Graney 1993). The primary emphasis of the current study was to assess tree growth and stem quality for diierent residual diameter distributions, but we also observed regeneration after cutting to the prescribed diameter distributions. Development of regeneration in 1992 and 1993 is described in this paper.

METHODS

The study area is near Redwood, MS, on land managed by Anderson-Tully Co. (ATCO). Like most of the forest in the area, the stand probably was established after agricultural land abandonment between 1880 and 1925. A stand adjacent to the study area contains considerable eastern redcedar and honey locust (*Gleditsia triacanthos* L.), species that indicate previous use as pasture. The treated stand had received selection harvests in the past Trees of all sizes were present, but the smaller size classes included relatively few stems of desirable species.

In addition to a control, four treatments were imposed. Each is based on a different guide for achieving a residual diameter distribution (figure 1). (1) The Putnam guide (Putnam, Furnival and McKnight 1960) is a rotated sigmoid curve with a residual basal area of 68 square feet per acre. (2) The ATCO guide is a generalized approach to achieving desired stocking over relatively large areas rather than on an area the size of our research plots (0.5 acre measurement plot). It corresponds to a negative exponential curve with a basal area of 94 square feet, a "q" factor of 1.4, and a maximum diameter class of 36 inches. The main distinction between these two guides is for trees smaller than 16 inches d.b.h. The ATCO guide maintains many more small trees than the Putnam guide. The other two guides differ considerably from the first two. They reflect results of optimal stand structure studies derived for northern hardwoods, but with some larger diameter trees. The third guide (75BA) is an extreme rotated sigmoid with a residual basal area of 75; this guide includes a high density of 10 to 20 inch d.b.h. trees, with a maximum diameter class of 26 inches.

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Table I-Species observed on regeneration plots.

Scientific name	Common name
Preferred species	
Fraxinus americana L.	white ash
Liriodendron tulipifera L.	yellow-poplar
Pinus taeda L.	loblolly pine
Prunus serotina Ehrh.	black cherry
Quercus falcata var. pagodaefolia Ell.	cherrybark oak
Quercus alba L.	white oak
Quercus michauxii Nutt.	swamp chestnut oak
Quercus shumardii Buckl.	Shumard oak
Other commercial species	
Acer barbatum Michx.	Florida maple
Acer rubrum L.	red maple
Carya, spp. Nutt	hickories
Diospyros virginiena L.	persimmon
Fagus grandifolia Ehrh.	american beech
Juniperus virginiana L.	eastern redcedar
Liquidamber styraciflua L.	sweetgum
Magnolia granditlora L.	southern magnolia
Nyssa sylvatica var. *sylvatica* Marsh.	blackgum
Platanus occidentalis L.	sycamore
Quercus falcata Michx.	southern red oak
Quercus muehlenbergii Engelm.	chinkapin oak
Quercus nigra L.	water oak
Quercus *phellos* L.	willow oak
Sassafras *albidum* (Nutt.) *Nees*	sassafras
Tilia caroliniana Mill.	Carolina basswood
Ulmus, spp. L.	elms

The fourth guide (45BA) has a maximum diameter class of 18 inches and a residual basal area of 45. The shape is similar to the results of Hansen and Nyland (1987) in that the "q" factor becomes progressively greater from the larger to the smaller diameter classes.

Tree class (modified from Putnam, Furnival and McKnight 1960) was assigned during the pre-harvest measurements. Tree class represents a cutting priority. Cutting stock was marked before cull stock, which was marked before reserve growing stock, which was marked before preferred growing stock. In some instances cutting stock was removed from an already deficient diameter class; this would be compensated

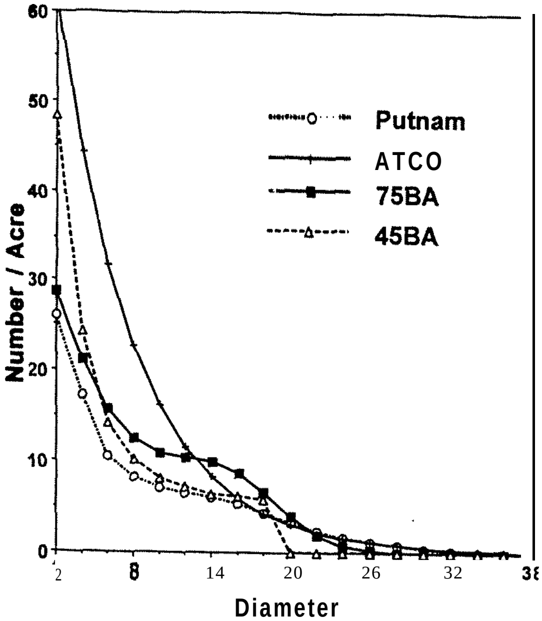

Figure I-Target diameter distributions for the four treatments.

for by leaving a surplus of reserve or preferred trees within an adjacent diameter class. When marking the stand, all diameter classes were treated. Small stems of undesirable species were deadened. Although stands were marked as close to the desired distribution as possible, deficiencies in the initial diameter distribution remained after the harvest. Some trees were inadvertantly killed during the logging operation.

The study area was harvested during the late summer of 1991. Each treatment was applied to three 1.6 acre plots. All trees with a d.b.h. of 1 .O inch or more were tallied within a 0.5acre measurement plot within each treatment plot. Regeneration was measured on four O.Ol-acre subplots within each measurement plot at two times-spring of 1992 and spring of 1993. Regeneration was assigned to one of three height classes: (1) less than 1 ft; (2) 1 ft to 3 ft; and (3) over 3 ft. Larger trees tagged during measurement of the 0.5-acre plot were recorded when they fell within the regeneration subplots. Only commercial timber species were recorded on the regeneration plots; a list of species is presented in table 1. For some of the analysis, species were clustered into groups. Group 1 is the preferred red oaks (cherrybark and Shumard). Group 2 is all other red oaks. Group 3 is preferred white oaks (white oak and swamp chestnut oak). Group 4 is other white oaks. Group 5 represents yellow-poplar. Group 6 represents loblolly pine. Group 7 includes the rest of the preferred species (white ash and black cherry), and group 8 includes all other commercial species.

In **addition** to analyzing numbers of stems in **different** classes, we used the system of Johnson (1980) to assign regeneration points to each plot. Each stem in size class one counts one point, each stem in class two counts two points, and each stem in class three counts three points. A 0.0%acre plot is considered stocked if it has 12 or more points. We also calculated Shannon's diversity index for each plot, averaging numbers for the four subplots within each plot

Analysis

Number of Stems.
Indiidal one-way **ANOVAs** were done for each species group in each measurement year; numbers of stems were transformed to their square roots to stabilize variance, and a was set at 0.05.

Change in Stem Numbers 1992-1993
The model selected to predict number occurring in 1993 was :

$$N_2 = b_{00} + \sum_{i=1}^{4} b_{0i}D_i + b_{10}N_1 + \sum_{i=1}^{4} b_{1i}D_iN_1 + e$$

where N_2 **is** the number of regeneration stems per O.Ol-acre **plot** in 1993 in all **size** classes, b_{ij} are parameters, D_i are dummy variables signifying treatments, N_1 is the number in 1992, and e is an error term. As we expected N_2 to be distributed as **a** Poisson variable, where the variance is equal to the mean, we weighted inversely to the expected value of N_2 and fit the equation by nonlinear least squares. As nonlinear regression may take very long to converge when there are numerous nonsignificant parameters, we built up to equation **[1].** Initially, the parameters b_{00}, all b_{0i} and b_{10} were included. Nonsignificant parameters were deleted, starting with the least significant, until all remaining parameters were significant Then the four b_{1i} parameters were added into the equation, and nonsignificant parameters were deleted. Previously deleted parameters were added back into the equation if they became significant following deletion of some other parameter. **This** process was done individually for species groups **1,2,3,5,7,and** 8.

Understory-Overstory Relationships.
Equation **[1]** was expanded to include both linear and power terms of the overstory basal area of the same species as the regeneration. Overstory included all trees of 1.0 inch or greater in d.b.h. The four subplots within **a** plot were aggregated for numbers of regeneration per 0.04 acre. We fit equations to estimate N_1 in fashion similar to that for estimating N_2. Model building and weighting were done as described in the previous section. This analysis was conducted individually for species groups **1,2,3,** and 5.

Stocking.
Stocking was calculated in two ways. First all commercial species were counted towards stocking, as suggested by Johnson (1980). Second, only preferred species were included, wlth the exception of yellow-poplar and loblolly pine, and with the addiion of non-select red oak species. Stocking was analyzed by a **5x2x2x2** contingency table, with flve treatments, two levels of stocking, stocked or not stocked, two years of measurement, and two measurements of stocking-all species or preferred species. Treatment effects were tested by partitioning G^2, the likelihood-ratio **statistic,** or deviance, within nested loglinear models (Fienberg 1980).

Points.
Johnson's (1980) stocking assesment guide assigns **different** point values to **different** sizes of regeneration. The number of points on a plot provide a single estimate of the **capacity** of a plot to regenerate. Points were calculated in two ways. First, all commercial species were counted, as suggested by Johnson (1980). Second, only preferred species were included, except yellow-poplar and loblolly pine were excluded, and non-select red oak species were included. Average points among the four subplots were used as data. Individual one-way **ANOVAs** were done for each point estimate (all species and preferred species) in each measurement **year** for a total of four independent **ANOVAs.**

Diversity.
ANOVAs were conducted for diversity at **1992, 1993,** and for the **difference** in diversity between 1992 and 1993.

RESULTS

Number of Stems

Treatments did not significantly affect reproduction numbers for any size class and species group in 1992 or 1993. The number per plot was highly variable and affected largely by factors other than the treatments. Ninety-five percent confidence intervals often included zero for most species and treatments. Across treatments, numbers of select red oaks ranged from 25 to 925 stems per acre in 1992 and from 0 to 800 per acre in 1993. Numbers of other red oaks ranged from 0 to 275 stems per acre in 1992 and from 25 to 300 stems per acre in 1993. Select white oak numbers ranged from 0 to 425 per acre in 1992 and from 0 to 575 stems per acre in 1993. Yellow-poplar numbers ranged from 0 to 125 in 1992, and from 25 to 1425 stems per acre in 1993. Across treatments, numbers per acre for select red oaks, other red oaks, select white oaks and yellow-poplar averaged 278, 108, 93, and 30 in 1992 and 200, 142, 95, and 253 in 1993, respectively.

Change in Stem Number 1992-1993

Final equations for each species group are presented in table 2. Fii indices vary from 0.81 for select red oaks, which is very high for regeneration data, to 0.17 for yellow-poplar. Most yellow-poplar regeneration in 1993 originated that year, while most select red oaks in 1993 were those which survived from 1992. Survivalis apparently less variable than initiation of new seedlings. For all species and treatments, the b_{1i} terms were between 0 and 1 .0, thus strengthening the interpretation of the parameter as an expression of survival.

For all red oaks, and the white ash and black cherry group, number of seedlings in 1993 was reduced by the ATCO treatment, where the least amount of overstory was harvested. The three most severe harvest treatments increased the amount of white oak regeneration. Yellow-poplar had the greatest number of new seedlings initiated in 1993, and numbers of yellow-poplar seedlings increased as harvesting intensity increased. There were relatively few yellow-poplar seedlings in 1992. The cause of their absence is not known, but could be related to weather. Variation in seed abundance is an unlikely factor because yellow-poplar seed can survive for several years. The heaviest harvest treatment (BA45) increased the amount of regeneration of other commercial species (group 8); the second heaviest treatment (BA75) increased survival of those species.

Table 2-Equations predicting number of stems in 1993 as a function of number of stems in 1992 and dummy variables for treatments. Fii indices included as indicative of goodness of fit.

Select Red Oaks (Fii Index' = 0.81)

$$N_2 = 0.764 - 0.764*ATCO + .732N_1$$

Other Red Oaks (Fit Index = 0.26)

$$N_2 = 1.168 + .930*N_1 - 0.885*ATCO*N_1$$

Select White Oaks (Fit Index = 0.22)

$$N_2 = 0.583*BA45 + 3.564*BA75 + 0.546*PUTN + 0.665*N_1$$

Yellow-Poplar (Fit Index = 0.17)

$$N_2 = 0.427 + 5.088*BA45 + 2.535*BA75 + 0.680*PUTN + 1.182*ATCO + 0.590*N_1$$

White Ash and Black Cherry (Fit Index = 0.20)

$$N_2 = 1.407 - 2.103*ATCO + 0.544*N_1$$

Other Commercial Species (Fit Index = 0.37)

$$N_2 = 4.076 + 6.206*BA45 + 0.352*N_1 + 0.295*BA75*N_1$$

1 Fit index = $1 - \sum (y-\hat{y})^2 / \sum (y-\bar{y})^2$

Understory-Overstory Relationships

Final equations for predicting numbers per plot of select red and white oaks in 1992 and 1993 and an equation for predicting number of other red oaks in 1993 are presented in table 3. Equations for yellow-poplar and initial number for other red oaks are excluded because basal area of those species was not a significant predictor of regeneration. Fii indices vary greatly. They are quite high for predicting numbers of select red oaks and select white oaks in 1993, but they are negative for predicting numbers of select red oaks and other red oaks in 1993. Negative or low fit indices are not altogether surprising. Number of seedlings per plot is highly variable. The variability is related to mean number; we assumed numbers were distributed as a Poisson where mean equals the variance. When fit index is calculated from the unweighted data, a few large residuals can cause residual sums of squares in the unweighted units to explode, even though the weighted residuals are not outliers. Negative fit indices may merely reflect that weighting was essential and the fit index is not applicable, or they may indicate that the equation does not tit the data.

Table 3-Equations predicting number of stems in 1992 and 1993 as a function of basal area of overstory trees of the same species (BA), dummy variables for treatments and, when predicting number in 1993, number of stems in 1992. Fit indices included as indicative of goodness of fit.

Select Red Oaks

$N_1 = 0.77*BA$

(Fii index[1] negative)

$N_2 = 1.242 + 2.802*ATCO + 0.778*N_1 - 0.337*ATCO*BA$

(Fit index = 0.890)

Other Red Oaks

$N_2 = 1.017*N_1 + .767*BA$

(Fii index negative)

Select White Oaks

$N_1 = 4\ 023*BA^{(0.346)}$

(Fit index = 0.158)

$N_2 = 0.609*N_1 + 0.347*BA$

(Fit index = 0.925)

[1] Fit index = $1 - \sum(y-\hat{y})^2 / \sum(y-\bar{y})^2$

Notable among the equations is the absence of dummy variables for treatment effects in ail but one equation. For numbers of select red oaks in 1993, the dummy variable for the ATCO treatment occurs twice. Overall, the ATCO treatment decreased the number of select red oaks. The coefficients of N_1 in the select red oak, other red oak and select white oak equations for predicting N_2 are not significantly different from the analogous parameters in table 2. As the equations of table 3 were based on data reflecting sums across four subplots and the equations of table 2 were based on data from the individual subplots, and thus the parameter estimates could potentially vary greatly, the interpretation of the parameter as a survival probability is strengthened. Although the coefficient of N_1 in the other red oak equation exceeds one, the confidence interval for the parameter is broad and includes one.

Stocking

Treatments did not significantly affect stocking (G^2 = 1.44, with 16 df-an extremely small value for G^2). When all species were included, only one plot was not stocked among all treatments and both years. When only preferred species were considered, stocking decreased between 1992 and 1993 for all treatments except BA45, the most severe harvest level, for which stocking increased (table 4).

Table 4-Number of stocked subplots for five treatments during 1992 and 1993. Stocked preferred indicates the plot was stocked considering only red oaks, select white oaks, white ash and black cherry.

	Treatment				
Stocking	Control	BA45	BA75	PUTNAM	ATCO
			1992		
Stocked	12	12	12	12	12
Not stocked	0	0	0	0	0
Stocked preferred	8	5	8	7	6
Not stocked preferred	4	7	4	5	6
			1993		
Stocked	11	12	12	12	12
Not stocked	1	0	0	0	0
Stocked preferred	7	8	7	6	5
Not stocked preferred	5	4	5	6	7

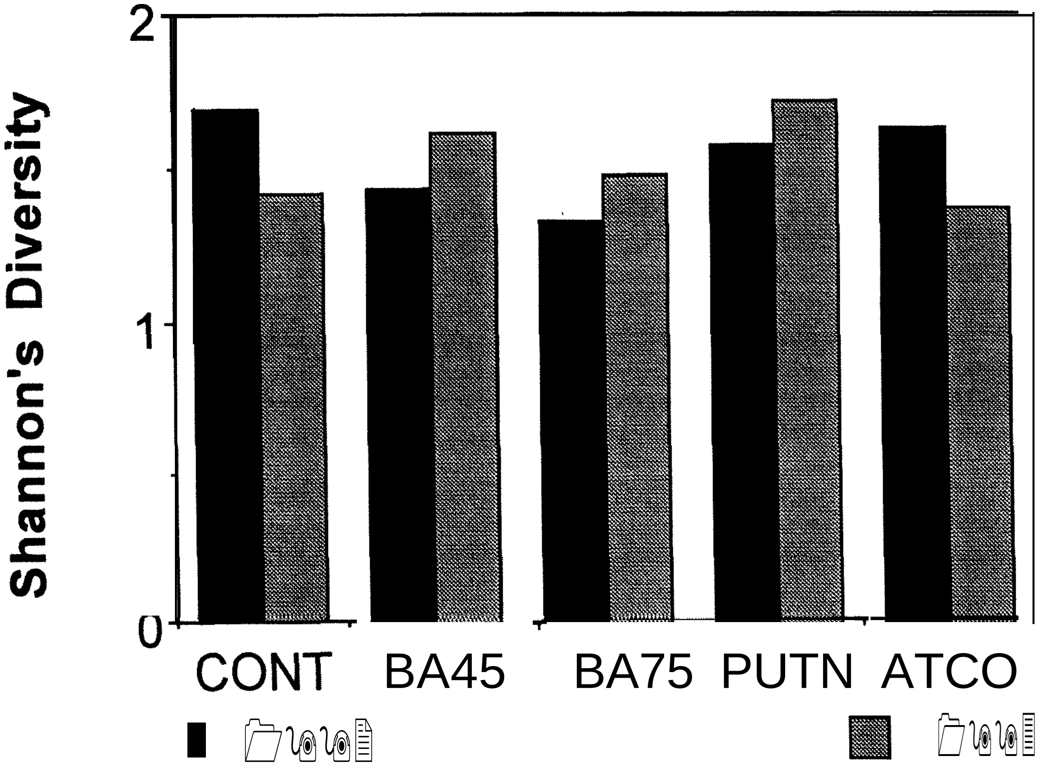

Figure 2-Average of Shannon's diversity index for each treatment in 1992 and 1993.

Points

There were no significant treatment effects for either method used to calculate points in either 1992 or 1993. The number per plot was highly variable and affected largely by factors other than the treatments.

Diversity

Although treatments did not significantly affect diversity in 1992 or 1993, the difference in diversity between 1992 and 1993 was significant at $a = 0.10$ level ($p=0.06$). Diversity tended to be higher in 1992 for the control and the ATCO treatment, the lightest harvest. In 1993, these two treatments had the lowest diversity (figure 2). Thus, diversity increased the most in the BA45, BA75 and PUTNAM treatments, while decreasing in the control treatment and staying about the same in the ATCO treatment. The disturbance caused by the heavier harvests seems to have reduced diversity temporarily, but this loss was rapidly overcome. Although only commercial species contributed to our diversity calculations, those species are probably the most indicative of diversity because the common understory species are ubiquitous.

SUMMARY AND DISCUSSION

Regeneration data are very variable and are strongly influenced by factors other than treatments. Several expressions of regeneration were not related to treatments, these included numbers observed in 1992 and 1993 as well as stocking. Treatments did influence the change in numbers between 1992 and 1993. Generally, for all species, the more extreme overstory removals promoted regeneration establishment, while the treatment with the least overstory removal tended to provide less regeneration than the uncut control. For oak species, most of the seedlings present in 1993 were survivors from 1992. Survival of oak species from 1992 to 1993 exceeded 60 percent for all species. Most yellow-poplar present in 1993 were established since the inventory in 1992. Abundance in the overstory was a significant factor in predicting regeneration for the oak species, but was not for yellow-poplar, whose seeds are disseminated more broadly . This result implies that oak must be a substantial portion of the overstory for the development of significant oak advance regeneration. After abundance of the overstory was factored into the prediction equations, dummy variables for treatment effects were no longer significant

The multiple approaches to analysis of the regeneration data uncovered several aspects of the dynamics of regeneration establishment However, the variabilii of the data often overwhelms the effect of the treatments. In uneven-aged management, regeneration must establish regularly and that regeneration must eventually be recruited into the overstory. Although regeneration establishment was spotty, there seems to be a sufficient amount on most plots. The real test of the treatments will be whether desirable regeneration develops into saplings, poles and sawtimber.

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