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Harvesting Production in Uneven-Aged Loblolly-Shortleaf Pine Stands: The Crossett Farm Forestry Forties

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SUMMARY

Two Arkansas pine stands have been managed using uneven-aged management techniques since 1937. For many years the stands were harvested annually, but they have been harvested every 5 years since the 1970's. A study to determine productivity of the harvesting system was completed in the fa11 of 1990. The system consisted of chain saw felling and grapple skidding. Felling and skidding productivity varied significantly with the diameter of stems or average stem volume removed from each stand. The diameter distribution of the removed material caused significant differences in productivity between the stands.

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INTRODUCTION

Interest in the Good Forty and the Poor Forty (the Forties) at the U.S. Department of Agriculture Forest Service's Southern Forest Experiment Station field location at Crossett, AB, has remained high over a long period of time. These two 40-acre tracts were established to determine if previously unmanaged, understocked, second-growth loblolly pine *(Pinus taeda)* stands could be successfully rehabilitated and managed using uneven-aged management techniques (Reynolds and others 1984). "Good" and "Poor" refer to the initial stocking conditions on the tracts when research was established in the 1930's, not the site class, yields, or other stand characteristics. Similar studies comparing yields and silvicultura1 performance of good and poor tracts have been established elsewhere in the South Central United States (Farrar and others 1989). The Arkansas Good and Poor Forty studies have been of particular interest to managers because the uneven-aged management regimes have been imposed over a 50-year period. Interest in the studies continues because of the present debate over even-age vs. uneven-age management on both public and private forest lands.

The two 40-acre pine tracts were established in 1937. For many years, they were harvested annually, but since the late 1970's partial harvests have been done every 5 years. These harvests have resulted in uneven-aged stands of loblolly and shortleaf *(P. echinata)* pine. Most published studies of the Forties have reported silvicultura1 results from harvesting regimes imposed on the stands. However, no study has yet reported harvesting production for the two Forties. In November and December, 1990, the Forties were harvested as a part of the continuing management plan. At that time, sawtimber volumes were reduced to residual stocking levels as prescribed by uneven-aged volume regulation. A field team observed and recorded production information as felling and skidding progressed on the Forties. Time studies were made of individual felling and skidding cycles on each of the two tracts to determine whether differences existed between tracts and to establish baseline production data for harvesting stands under uneven-aged management. Those studies are summarized in this report.

Because the two 40-acre tracts are only harvested every 5 years, replication of the study was not possible. Historic records of harvesting at Crossett from the 1950's and 1960's do exist, but harvesting methods at that time cannot be compared to present-day operations. Earlier operations utilized early model chain saws and extracted timber with small crawler tractors in contrast to the current operation, which used lightweight, high-production chains saws and large, rubber-tired, grapple skidders.

Comparison of harvesting information across studies has additional complicating factors. Production is strongly affected by the preharvest diameter distribution of a stand and the diameter distribution of trees removed. The current cutting regime consisted of removing a few trees across a range of diameter classes. Additionally, harvesting contractor, equipment used, terrain, soil, and brush conditions all contributed to variability in harvesting rates. Because of the varying conditions under which the studies have been conducted, this report cannot be compared directly with other published studies; however, the general trends may be contrasted with other studies where appropriate.

METHODS

Stands

The Good Forty and the Poor Forty were both marked for harvest by the technical staff stationed at the Crossett Experimental Forest in accordance with stated management objectives for the two stands

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(Reynolds and others 1984). Both tracts were level, with no significant slope that would affect the harvesting effort. Brush conditions on both tracts were moderate to heavy, typified by honeysuckle, blackberry, and greenbrier. Soils on the tracts are moderately drained silt loams; site indexes ran from 85 to 100 (base age 50). The preharvest and postharvest quadratic mean diameters (QMD) for the stands were calculated. The QMD of the removed stand portions were also calculated. The stand distributions were compared on a preharvest and postharvest basis using the Kolmogorov-Smirnov (K-S) nonparametric test of distribution similarity. The distribution of removed stand portions were also compared with a K-S test to determine whether the harvest treatments were similar.

Felling

The felling crew, consisting of two sawyers subcontracted by the skidding crew, was observed in both tracts. Sawyers were instructed to fe11 al1 marked trees within the stand boundaries. Trees were not directionally felled to optimize skidding. "Hung" trees occurred severa1 times in both stands. When trees were hung, the sawyer would stop work and have a skidder pu11 or push the tree to the ground. Trees were processed into tree-length stems. Limbing and topping were generally done at the stump immediately after felling.

A felling cycle was defined as the time it took the sawyer to walk to a tree (walk), clear the brush and determine felling direction of the tree (plan), fe11 the tree (cut), limb and top (limb and top) the tree, and delays. The field research team members timed each event in the cycle and recorded the time. **Delay time** (delay) and the reason for the delay were recorded. **Walk time** started when the sawyer completed limbing and topping the previous tree and ended when the sawyer reached the tree to be cut. **Plan time** began at the end of walk time and ended when the sawyer began cutting the tree. **Cut time** began when the saw first touched the tree and ended when the tree was on the ground or stopped falling because it became lodged (hung) on an adjacent tree. **Limb and top time** started when the tree hit the ground and ended when the sawyer allowed the chain saw to idle and began walking to the next tree to be felled. **Total cycle time** per tree was calculated as the sum of the events for each tree.

After a tree was limbed and topped, a researcher measured the d.b.h. (diameter at breast height) of the tree. Individual tree volumes were later determined using a formula developed from a local volume table. Production rates in cunits/hr (100 cubic feet per productive hour, excluding delays) were calculated for each observation. Averages for walk time, plan time, cut time, limb and top time, and delay time were computed by sawyer and by tract and for the overa11 study. An analysis of variance was used to test for differences in production rate by sawyer and tract with tree diameter as a covariate. A structural regression equation was developed to test the significance of each of the relationships of the felling factors to cunits/hr.

Skidding

Two 120-horsepower, turbocharged, John Deere 648-D skidders equipped with two-cord grapples and 34-inch tires skidded the tree-length stems on both tracts. Skidder operators prebunched enough stems for a ful1 load before traveling loaded to the landing. When skidders arrived at the landing, they dropped their load and pushed the stems into a pile for later loading. Skidders incurred delays at the deck and in the woods. At the deck, both skidders sometimes arrived simultaneously; when this occurred, one skidder waited for the other to finish dropping the load and piling the skidded stems. In-the-woods delays occasionally occurred when hung trees needed to be pulled or pushed down or when sawyers fe11 behind in their work and there were no stems to skid. No mechanical delays were observed for the skidders during the study.

At the deck, skidded trees were measured to obtain d.b.h., top diameter, and length using tree calipers and a logger's tape. For each skidder cycle, travel empty, travel loaded, bunching, positioning and ungrapple times were recorded. Skidding distances along skid trails were measured, and colored flagging was hung in nonharvested trees at measured distances from the deck to aid in measurement of exact skidding distance. Travel empty time began when the skidder left the deck going back into the woods. Bunching, positioning, intermediate travel, and grapple/deck times were recorded when the skidder was in the vicinity of the first stem to be bunched and continued until the skidder had a full grapple and started back toward the landing with a load. Travel loaded time began when the skidder left the bunch position and started moving toward the landing with a load. Travel loaded time ceased when the grapple was opened on the deck and the load dropped. Ungrapple time included time taken to push stems into a pile and maneuver to return to the woods for another drag.

Production rates were calculated for each observation. Averages for travel empty, bunching, positioning, intermediate travel, travel loaded, and ungrapple times were computed by skidder and by tract, and for the overa11 study. An analysis of variance was used to test for differences in production rate by skidder and by tract, with skidded volume and total distance as covariates. A structural regression equation was developed to test the significance of each of the factors contributing to total skidding time.

RESULTS

Stands

The preharvest and postharvest distributions (number of trees by d.b.h. class) are shown in figures 1 and 2 for both stands. Number of trees by d.b.h. class removed from each stand is displayed in figure 3. The Poor Forty (fig. 1) showed a strongly bimodal distribution with a 13.2-inch QMD preharvest and 12.3 inch QMD postharvest. Postharvest, the Poor Forty was not as pronounced in its bimodal pattern, but it still did not have the strong reverse-J tendency favored in uneven-age management. The Good Forty displayed a slight reverse-J distribution preharvest, with a 13.7-inch QMD preharvest and a 12.6-inch QMD postharvest. Postharvest, the Good Forty approached the traditional reverse-J shape.

The K-S test of preharvest and postharvest stand distributions between the two Forties showed that the distributions were similar in the number of trees, or basal area by d.b.h. class, preharvest and postharvest (p=0.746). Additionally, both stands had a similar number of trees removed, and the distributions of removed trees by d.b.h. class were similar (p=0.483). Thus, the stands were statistically similar both preharvest and postharvest and in the harvesting treatment. This would suggest that there should be no signifícant differences in harvesting productivity rates between the two stands. However, the Good Forty had 60 more trees above a 20-inch d.b.h. removed than the Poor Forty, whereas the Poor Forty had 40 more trees removed below a 20-inch d.b.h. than the Good Forty. The QMD of the 451 trees removed from the Poor Forty was 16.4 inches, whereas it was 17.6 inches for the 471 trees from the Good Forty.

Felling

The analysis of variance of production rate revealed no production rate differences between sawyers or sawyers across tracts. However, the covariate, d.b.h.^{2} of processed trees, was significant in production rate. Accordingly, al1 118 felling observations of both sawyers and tracts were lumped together. Mean walk time was 0.59 minute; mean plan time, 0.11 minute; mean cut time, 0.68 minute; and, mean limb and top time, 0.95 minute. Mean production rate for the two sawyers was 14.41 cunits/hr (table 1).

Delays occurred infrequently; mean delay time was 3.16 minutes. Figure 4 shows that the major delay was maintenance, wbich included saw filing and refueling. Hung trees accounted for a small percentage of delay time (3.5 percent), whereas personal time (operator rest breaks, water breaks, etc.) accounted for 20 percent of the total delay time. Production

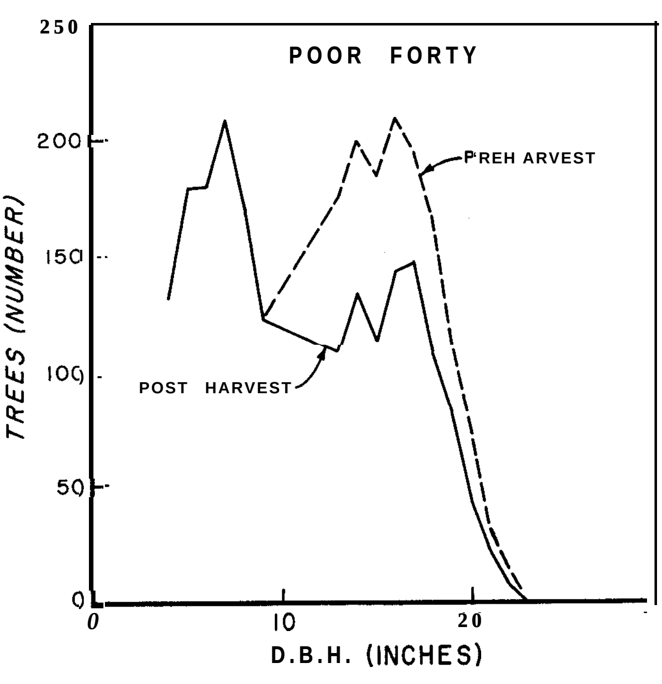

Figure 1. — *Number of trees by d.b.h. for the Poor Forty preharvest and postharvest.*

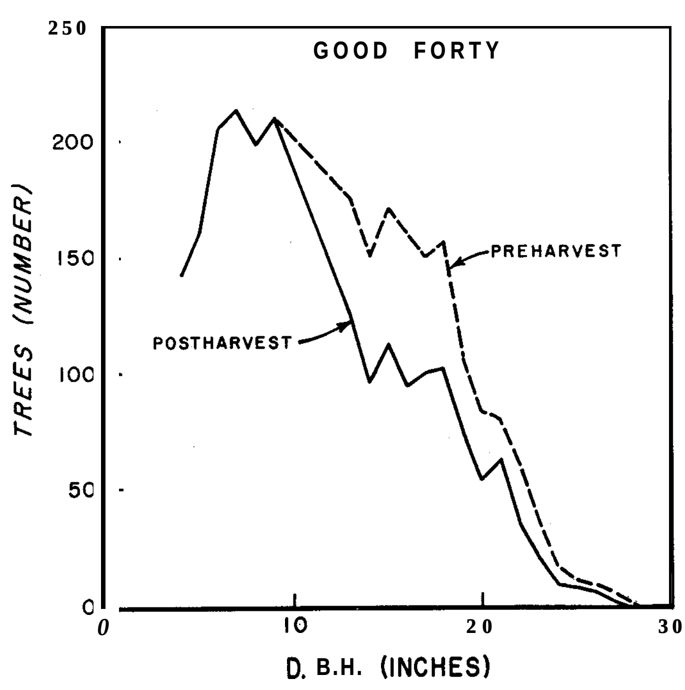

Figure 2. — *Number of trees by d.b.h. for the Good Forty preharvest and postharvest.*

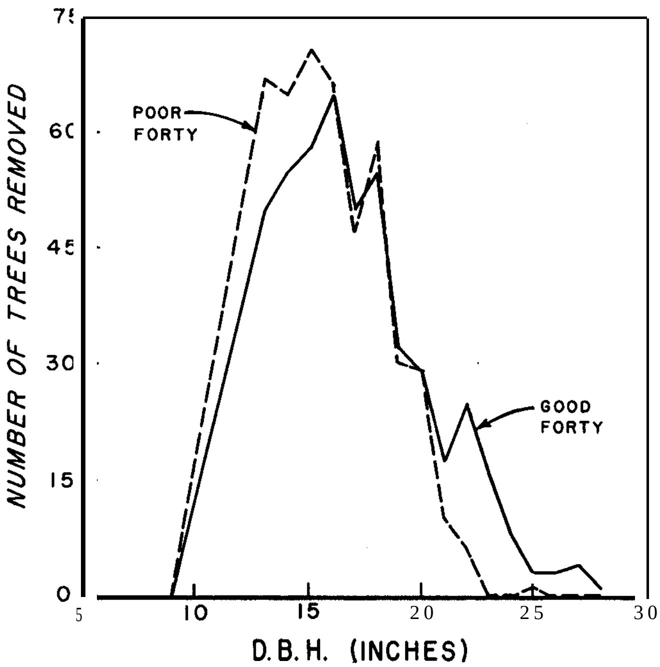

Figure 3. — Comparison of distribution of removed trees for the Good and *Poor Forties.*

Table 1.—*Summary of felling variables for the Good and Poor Forties*

Variable	Poor Forty	Good Forty	Average both tracts
		Minutes	
Walk	0.340 (0.278)*	0.737 (0.616)	0.589 (0.550)
Plan	0.164 (0.186)	0.072 (0.158)	0.106 (0.174)
cut	0.437 (0.199)	0.667 (0.476)	0.581 (0.410)
Limb and top	0.920 (0.540)	0.974 (0.699)	0.954 (0.642)
Total cycle	1.862 (0.765)	2.438 (1.231)	2.223 (1.113)
		Inches	
D.b.h.	15.407 (6.654)	14.028 (12.474)	14.408 (10.659)
		Cubic feet	
Volume per tree	42.759 (16.280)	45.187 (23.252)	44.282 (20.884)
		100 cubic feet per hour	
Productivity	15.047 (6.654)	14.028 (12.474)	14.408 (10.659)

*Numbers in parenthesis are standard deviations.

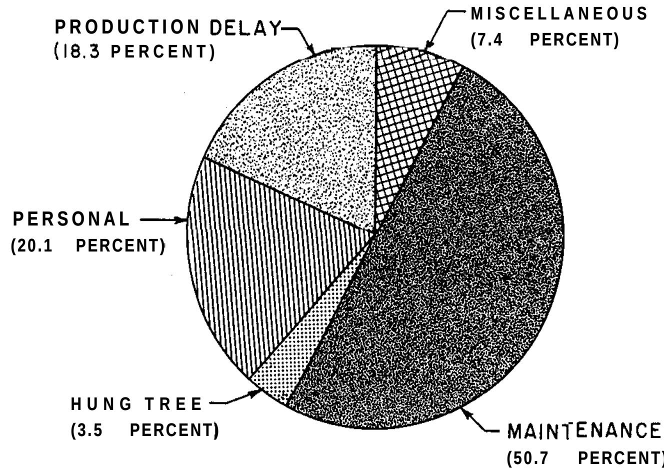

Figure 4. — *Distribution of felling delay time by* cause.

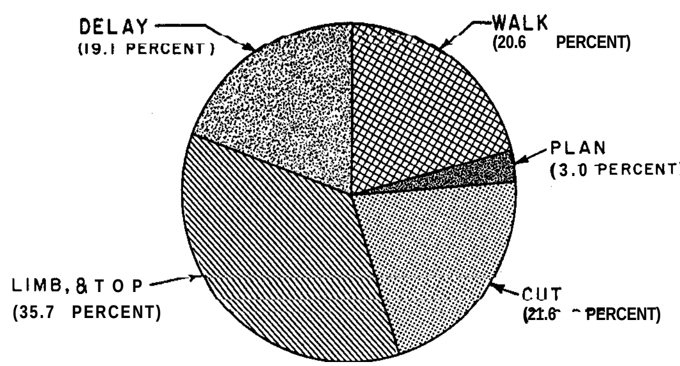

Figure 5. — Proportion of total time to fell and process a stem by function.

delays, 18 percent, such as waiting for a skidder to pull processed stems and working around other sawyers, was the third greatest reason for delay.

The distribution of total time for felling is shown in figure 5. Note in figure 6 that walk and plan times did not vary markedly over the full range of diameters observed. However, the proportion of cut and limb and top times increased with diameter, with limb and top time increasing faster than cut time. This fits the pattern found by Lanford and others (1972).

The structural regression coefficients for felling is presented in table 3. Structural regression is used to determine those independent variables most closely associated with a dependent variable and is not necessarily used in prediction. Several equation forms were attempted. Significant variables in the determination of productivity were the natural log of walk, plan, cut,

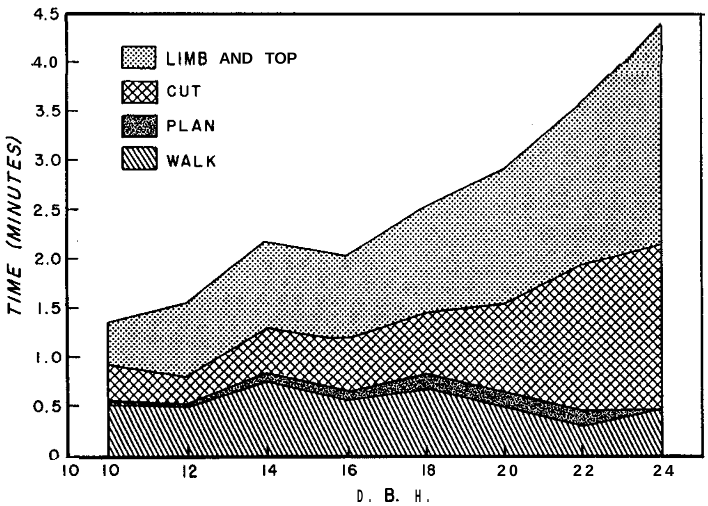

Figure *6.* — ***Distribution of limb and top, cut, plan, and*** walk ***time by d.b.h.***

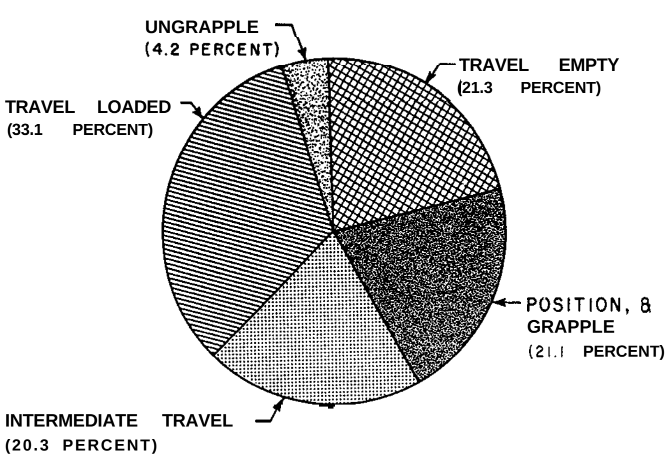

Figure *7.* — ***Proportion of total time for skid function.***

and limb, and top time and the natural log of tree d.b.h.2. The natural log transformation was used to ensure normal distribution of the variables rather than the skewed pattern found. Note that all regression coefficients are significant at the 0.01 level and the adjusted multiple correlation coefficient for felling, R^2, is 0.943. The standardized coefficients indicate that diameter squared, an accepted proxy for tree volume, was over two and a half times as influential as the next most important variable in determining productivity. The other important factors in order of importance were limb and top time, cut time, walk time, and plan time.

Skidding

Figure 7 shows the average percentage of time expended in each of the skidding functions. Travel (travel loaded, 33 percent and travel empty, 21 percent) consumed the most time whereas building bunches (position and grapple, 21 percent and intermediate travel, 20 percent) took almost as much time. No delay time occurred for either skidder.

Skidder one averaged more stems per cycle, 2.9 on the Good Forty and 3.7 on the Poor Forty, than, 2.63 on the Good Forty and 3.2 on the Poor Forty. The average number of stems skidded by both skidders was 3.5 on the Poor Forty and 2.75 on the Good Forty (table 2). Fewer stems were skidded per skid on the Good Forty ($p=0.009$). On the Poor Forty, three stems were skidded most often (58 percent), with four stems skidded 35 percent of the time and five stems skidded 6 percent of the time. On the Good Forty, one stem was hauled 6 percent of the time, two stems skidded 31 percent of the time, three stems skidded 44 percent of the time, and four stems skidded 19 percent of the time. Average stem volume skidded was greater ($p=0.014$) on the Good Forty than on the Poor Forty (56.2 vs. 40.3 cubic feet). On the Good Forty, the average skid load had fewer stems than on the Poor Forty, but average stem volume was greater than on the Poor Forty.

The analysis of variance of each of the skidding functions tested differences by tract and skidder while controlling for the effect of volume per skidder cycle and total travel distance. Position and grapple time differed significantly by skidder, with skidder two being consistently faster than skidder one. Field notes reflect the productivity aggressiveness attitude of the skidder operator two. Travel loaded rate differed significantly by skidder; skidder two was consistently faster than skidder one. However, even though skidder two was consistently faster than skidder one for position and grapple and travel loaded, total production was not significantly different for the two machines because skidder one averaged consistently larger loads.

Regression coefficients for skidding are given in table 3. The adjusted multiple correlation coefficient, R^2, is 0.643. Significant variables in the best-fit structural equation were a dummy variable for tract, natural logarithm of skidded volume, and the natural logarithm of total travel distance. Total travel distance is approximately one and two-fifths times as important in contributing to productivity as the next most important regressor, skidded volume. The tract variable, acting as an intercept shifter, indicates that significantly higher production was observed on the Good Forty than the Poor Forty when other factors are taken into account. All regression coefficients were significant at the 0.01 level.

Table 2.—*Structural regression coefficients for felling and skidding on the Good and Poor Forties*

Variable	Coefficient	Standard error	Standard coefficient	P
Felling (adjusted R^2 = 0.943)				
Constant	-5.060	0.357	.000	0.000
Ln walk	-0.200	0.020	-0.035	0.000
Ln plan	-0.082	0.200	-0.127	0.003
Ln cut	-0.311	0.049	-0.384	0.000
Ln limb and top	-0.457	0.052	-0.451	0.000
Ln d.b.h.+	1.258	0.062	1.137	0.000
Skidding (adjusted R^2 = 0.643)				
Constant	1.324	0.965	0.000	0.180
Tract[2]	0.194	0.068	0.518	0.008
Ln skid volume	1.134	0.177	0.716	0.000
Lu travel distance	-0.661	0.119	-1.061	0.000

*Felling and skidding dependent variable in ln cunits/hr.

†A dummy variable acting as an intercept shifter. Tract = 1 for the Good Forty and 0 for the Poor Forty.

DISCUSSION.

Variance of felling production was high on both tracts; the Good Forty had a significantly higher production rate variance, than did the Poor Forty (standard deviation of 6.65 for the Poor Forty and 12.47 for the Good Forty, chi-square equal to 18.128, and p = 0.000). Additionally, there was not a significant difference in felling productivity by tract (p=0.514) due to the high variability of the felling observations and consequent inability to separate the means in the analysis of variance and structural regression procedures. However, felling productivity was significantly influenced by the covariate, diameter squared, (p=0.005) in the analysis of variance. This variable was also the most significant in the structural regression. This underscores the strong dependency of production rate on tree diameter for felling, even though other induced variance precluded mean separation for the two tracts.

Skidding production rate was influenced by total distance and volume per skid. The combination of fewer stems per skid and greater stem volume on the Good Forty increased productivity on that tract for two reasons. First, a lower proportion of total time was dedicated to building bunches (intermediate travel and position and grapple) on the Good Forty (p=0.004), leading to lower total time per skid when total travel distance was taken into account. Second, the significantly greater average stem volume (p=0.018) on the Good Forty led to significantly higher volumes per skid. Consequently, when total travel distance was controlled, productivity (cunits/HR) was influenced by the difference in average-stem volume by tract (p=0.056). Note that operator productivity aggressiveness, often cited as a contributing factor to higher productivity, did not significantly influence the outcome.

CONCLUSION

The most important result of our research on the Crossett Good and Poor Forties is that despite the relatively low number of observations and high variability in both felling and skidding, productivity rate varied significantly with the diameter of stems or average stem volume removed from each stand. The distributional similarity of the stands before and after harvest and the distributions of the harvested trees would imply production similarities in harvest. This however, was not the case. In this study, a slight change in the distribution of the removed material was sufficient to cause a significant difference in productivity Figure 3 shows the distribution of trees removed from the two stands. The Poor Forty had more small diameter trees removed than the Good Forty. Figure 8 shows the relationship of d.b.h. squared on felling productivity. Note that while there is no significant statistical difference in the productivity rates on the two tracts, there is a recognizable difference in the productivity rates experienced on them. It is our opinion that more observations (with a corresponding increase in the degrees of freedom) are necessary to explain the differences between the two tracts, and the difference would become statistically significant.

Table 3.-*Summary of skidding variable for Good and Poor Forties*

Variable	Poor Forty	Good Forty	Average both tracts
	.... *Minutes* ————		
Travel empty	1.262 (0.514)*	2.148 (0.832)	1.694 (0.811)
Position and grapple	1.227 (0.643)	2.138 (1.881)	1.669 (1.442)
Intermediate travel	1.716 (0.961)	1.506 (1.501)	1.614 (1.237)
Travel loaded	2.265 (1.185)	3.007 (0.931)	2.625 (1.118)
Ungrapple	0.618 (0.773)	0.038 (0.069)	0.337 (0.622)
Total cycle	7.092 (2.317)	8.837 (2.485)	7.938 (2.522)
	———— *Feet* ————		
Average total distance	830 (291)	2100 (703)	1446 (831)
	———— *100 cubic feet* ————		
Volume per skid	1.35 (0.27)	1.41 (0.39)	1.38 (0.33)
	———— *Number* ————		
Stems per skid	2.75 (0.87)	3.47 (0.62)	3.12 (0.82)
	———— *Cubic feet* ————		
Average stem volume	40.26 (11.56)	56.20 (22.27)	47.99 (19.10)
	————*100 cubic feet per hour*————		
Productivity	12.45 (4.28)	10.35 (4.27)	11.43 (4.32)

*Numbers in parenthesis are standard deviations.

For skidding, production rates (after correction for skidding distance and skidded volume) were higher for the Good Forty than for the Poor Forty (fig. 9). At total travel distances of less than 750 feet, distance was more significar-k in the determination of skidding productivity than was average tree size. However, at total travel distances beyond 750 feet, the larger average tree size observed on the- Good Forty produced higher production rates.

Recall that although there was no significant difference in the removed portions of the two stands, there was a 1.2 inch difference in the QMD. Thus, for felling, we conclude that for the conditions of this

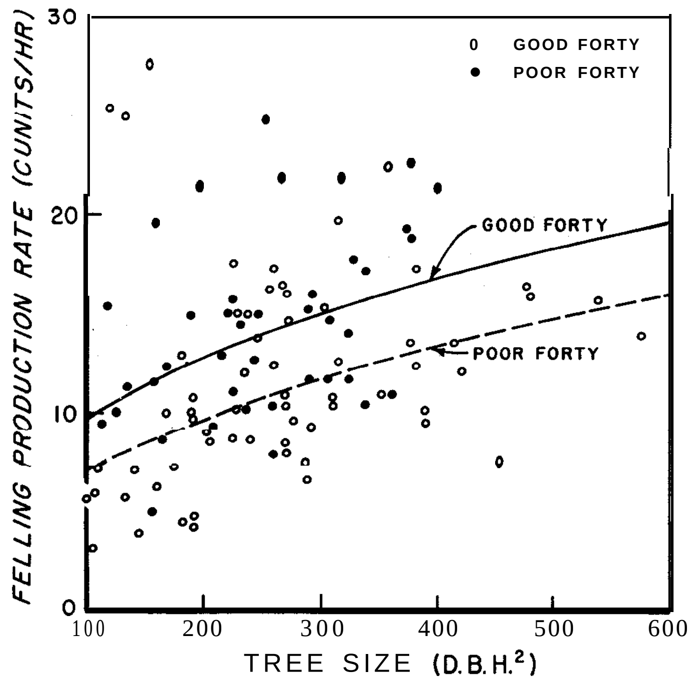

Figure 8. — *Relationship of felling production to tree size for the Good Forty and the Poor Forty, with the best-fit curve for each tract.*

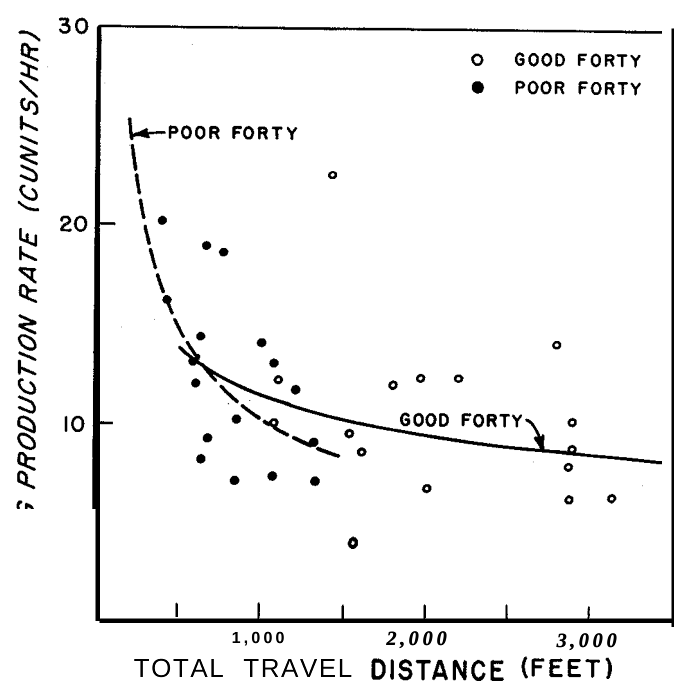

Figure 9. — *Relationship of skidding production to total travel distance for the Good Forty and the Poor Forty, with the best-fit curve for each tract.*

study the d.b.h. distribution of trees removed in a selection harvest is the single most important factor influencing productivity rate. Similarly, for skidding, the distribution of trees removed in a selection harvest is the third most important factor in influencing harvesting productivity rate, ranking only behind skidding distance and skidded volume. A removal distribution weighted to larger d.b.h. trees will produce higher productivity rates than a distribution weighted to lower d.b.h. classes. Size distribution of the removed stems and skidded volume are both included, instead of average stem volume alone, because a skidder may not always travel with a full grapple load. This research suggests that the difference in the removal diameter distributions between two stands caused a signifícant difference in productivity rates. This further implies that harvesting cost differences will occur for relatively minor changes in removal distributions.

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Two stands managed using uneven-aged techniques were harvested as part of a 5-year entry schedule. Felling and skidding productivity varied significantly with average stem diameter and volume and was affected by diameter distribution of the removed material.

Keywords: Felling, skidding.