# The Effects of Group Selection Harvest Size on Logging Productivity

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**ABSTRACT:** *Because increasing demands are being placed on industry to harvest timber by aesthetically, economically, and ecologically acceptable means, we investigated the effects of a ground-based group selection harvest on logging productivity. Results show that size of opening had little or no effect on skidding productivity. However, significant skidder operator differences existed. Some skidder operators consistently, in shorter periods of time, loaded their machine with larger payloads resulting in larger turn volumes. Group selection unit size, skidder operator, and utilization level had no statistically significant impact on delay times. Results also suggest that additional time spent training skidder operators to hook larger payloads faster could pay dividends in increased daily production and improvements in logging profitability. North. J. Appl. For. 17(2):51–56.*

New attitudes concerning forestland management have and will continue to bring about changes in the manner in which timber is harvested. With increasing demands being placed on both private and public forestlands to provide diverse opportunities, forest owners/managers are looking for acceptable ways to harvest timber in order to meet these objectives. In addition, there are growing demands to preserve the biological diversity of the forest ecosystem, and those often prohibit or severely restrict the ways timber can be harvested.

In an era where some believe that timber harvesting negatively affects the enjoyment of natural scenery and disrupts nature (Young and Reichenbach 1987), it is increasingly important to manage timber in such a way that it is economically and ecologically apt. Partial cutting by the individual tree selection, group selection, or thinning methods may be a more acceptable means of managing timber, especially in high-visibility areas. These methods provide the long-term benefits of sustainable forest management while being less obtrusive, and therefore may be more acceptable to the general public.

The main objective of group-selection harvest is to create a double-cohort or uneven- aged stand condition (Smith et al. 1997). The group-selection method can be used to capture mortality, to slow insect and disease infestations, to regenerate stands, or to harvest financially mature trees. It involves clear-felling small groups or clumps of trees in a somewhat dispersed pattern across a stand over time. Group size varies depending on the type of regeneration needed—the larger the group, the more likely shade intolerant species will regenerate. When viewed from the standpoint of ecological site factors, Smith et al. (1997) recommended that group width could be set at "approximately" twice the height of the mature trees. The group-selection method has certain advantages over single-tree selection cuttings: harvesting mature trees can be performed more economically with less damage to the residual stand, and reproduction develops even-aged aggregations, which help hardwoods develop in good form (Smith et al. 1997).

The economic success of group-selection harvests relies heavily on product markets, tree species and quality, and logging costs (Bell 1989, Boucher and Hall 1989, Brummel 1992, LeDoux 1997, LeDoux et al. 1993, LeDoux et al. 1991). Total harvesting cost increases as group-selection opening size decreases and may be prohibitive for groups smaller than one-half acre (LeDoux 1997, LeDoux et al. 1993, LeDoux et al. 1991). This is mainly due to moving costs. As the harvested area grows smaller, the ratio of cost to volume produced increases to a point where harvesting is prohibitive. However, the effect of group-selection opening size on harvesting productivity is not well known. When compared to clearcutting, group-selection harvests were found to be less productive (Brummel 1992). Potentially lowering productivity associated with the group-selection method may stem from the relatively small and often widely scattered harvest blocks that make up the system. Additional landings and more extensive road systems are often required to service the scattered units.

The objectives of this study were to monitor field production levels associated with harvesting group-selection units in typical mixed hardwood stands of the central Appalachian

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region. The project was designed to quantify, using time and motion methodology, differences in productivity when harvesting group-selection units of various sizes and alternative utilization levels. By evaluating harvesting productivity in variable sized units, the study should reveal insights on the economic feasibility of employing the group-selection method of timber harvesting in the central Appalachians. Results could prove useful to forest-land managers in their effort to appraise sale values restricted to group-selection harvest methods.

## Methods

### Study Area

Time study data were collected from a commercial logging operation during the winter of 1991–1992 on the West Virginia University Experimental Forest, Monongalia County, West Virginia. Total study area was approximately 54 ac. Stand composition consisted of typical Appalachian hardwoods dominated by yellow-poplar *(Liriodendron tulipifera)*, northern red oak *(Quercus rubra)*, chestnut oak *(Q. prinus)*, black cherry *(Prunus serotina)*, and red maple *(Acer rubrum)*. Cutting units representing group-selection harvests of 0.5, 1.0, 1.5, and 2.0 ac were randomly located within the study area. Each were replicated 4 times for a total of 16 group-selection cutting blocks totaling 20.0 ac. Group-selection harvest units were located so individual blocks were separated by a no-cut buffer zone of approximately 150 to 200 ft. Basal area ranged from 129-170 $ft^3$/ac, and average dbh ranged from 9.6–13.2 in. across the harvest units.

### Design

Following the location and marking of the individual group-selection cutting unit boundaries, the timber in each of the units was marked for harvest to assure the cutting and skidding of all trees meeting the minimum merchantability requirements during the harvest operation. Marking consisted of performing a 100% tally of the timber to be harvested from each group. Half the group selection cutting blocks within each size category were marked to a 4 in. minimum dbh limit, while the remaining half were marked to a 6 in. dbh limit. The 4 in. dbh limit was selected as a harvest scenario that represented nearly complete utilization of the timber within a cutting unit, while the 6 in. dbh limit represented a more practical and common level of utilization for pulpwood in the central Appalachian region. Pulpwood volumes were calculated using species-specific equations (Wiant 1989). Sawtimber volumes (International 1/4-inch rule) were calculated using equations developed by Wiant and Castenada (1977). Topwood volumes were not included in the volume estimations for sawtimber sized trees.

The harvesting operation was fairly large with respect to typical logging firms in the area, consisting of four log trucks, three skidders, two dozers, one log loader with a hydraulic sawbuck/slasher unit, one dump truck and two crew trucks as well as operators/drivers for each of the pieces of equipment listed above. In addition to truck and equipment operators the firm also employed four full time timber cutters. Each cutter had at least 5 years felling experience. Several stipulations were included in the sale contract to assure that the study objectives would be met during the harvest operation. Most notable were the following stipulations: (1) all timber must be manually chainsaw-felled, eliminating the possibility of mechanized felling methods, (2) once skidding begins in a unit, it must be completed before moving to the next unit, and (3) the contractor and logging crew cooperate wherever possible with the study objectives and those involved in the collection of monitoring data.

Prior to harvesting the group-selection units, a single centrally located landing and two primary preplanned and designated skid trails were located and flagged (Figure 1). Each trail provided a single access route to each unit. Within the boundaries of each of the group-selection units skidding was not restricted to designated skid trails. A random approach to skidding within a cutting unit was permitted, as long as the designated trails were used for entry and exit from the individual harvest units.

Skidding of the processed tree length materials on each of the study units was performed by one of three John Deere 640D cable skidders, each operated by one of five skidder operators. Skidding on an individual group-selection unit was performed by one or two operators in an attempt to minimize system imbalances that may have occurred as a result of all three machines working in close proximity to each other in the small cutting units.

Time and motion study data were collected during the skidding component of the timber harvest. Data were collected continuously throughout the harvest for each group-selection unit from start to finish. It was believed that this design would identify infrequent delays which may be missed should the study have been designed using only a random sampling approach. All skidding element times, including productive, nonproductive, and delay were recorded by data collectors stationed both at the group-selection site and at the log landing. In addition to productive and delay element times, skid distance, number of stems per turn, volume per turn, and number of machine moves in a hooking cycle were recorded for each skidding cycle. Due to a lack of available data collectors during 2 days of the harvest operation, detailed data were not collected for two units (units 4 and 5); therefore, these plots were eliminated from the analysis. Selection-unit 7

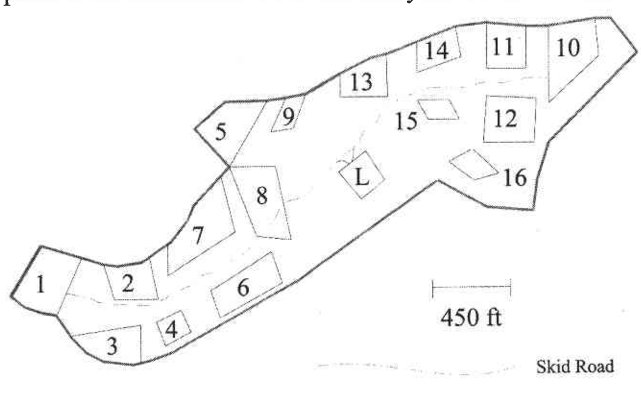


**Figure 1. Harvest unit layout for group selection harvest on the West Virginia University Forest.**

was also removed from the analysis because a fourth operator (not included in the analysis) skidded the entire unit.

The productivity for each group-selection unit was determined using the continuous time study data. While these data, in aggregate, are of interest, only certain components were necessary for investigating differences between unit sizes. The focus of the monitoring study concentrated on the skidding component of the operation, since this element of the harvesting process is traditionally the weak link of most ground-based harvesting systems and will often set the pace for the rest of the operation.

Each skid cycle was divided into four productive elements: (1) outrun (travel to woods), (2) hooking (acquiring a turn of logs), (3) inrun (travel to landing), and (4) unloading/decking (unloading and decking logs). Of the four productive elements, outrun, inrun, and unloading/decking are not directly influenced by the size of group-selection units. The one component of the skid cycle that can be directly influenced by unit size is hooking. This influence can be manifested in several variables: hooking time (time required to obtain a complete hook, including moves), total turn volume, average volume per stem, and the number of logs per turn. Analysis of covariance (ANCOVA) was used to determine if differences existed in the variables of interest when adjusted for preharvest basal area and skid distance. Since hooking time and turn volumes could be influenced by distance from the landing, skid distance was included as a covariate to account for any indirect influences that may exist. Likewise, because of differences in cut stand densities, preharvest basal area also was treated as a covariate. Since delay times also could be influenced by group-selection unit size, an ANCOVA for total delay time was performed.

Two operators were removed from analyses because they only operated on one harvest unit, leaving 632 skidding cycles of data. The following ANCOVA model was used (all tests of significance were conducted at an $\alpha$ = 0.05 level):

$$Y_{ijk} = \mu + \alpha_i + \alpha_i\gamma_j + \phi_k + \alpha_i\phi_k + \gamma_j\phi_k + \beta_1 x_{ij} + \beta_2 x_{ij} + \varepsilon_{ijk} \qquad (1)$$

where $Y_{ijk}$ = harvesting productivity variable/delay time, $\mu$ = the overall mean of the harvesting productivity variable/delay time, $\alpha_i$ = effect of the $i$th group-selection unit size, $\gamma_j$ = random or fixed effect of the $j$th operator, $\alpha_i\gamma_j$ = interaction between the $i$th level of group-selection unit size and the $j$th operator, $\phi_k$ = effect of the $k$th utilization level, $\alpha_i\phi_k$ = interaction between the $i$th group-selection unit size and the $k$th utilization level, $\gamma_j\phi_k$ = interaction between the $j$th operator and the $k$th utilization level, $\beta_1 x_{ij}$ = covariate (preharvest basal area), $\beta_2 x_{ij}$ = covariate (skid distance), and $\varepsilon_{ijk}$ = random effect that represents all uncontrolled variability.

Since the sale was conducted on a competitive sealed bid basis, operator was considered a random effect. Therefore, group-selection area size was tested using the group- selection unit size/operator interaction ($\alpha_i\gamma_j$). The practical impact of operator designation is that a different result could occur if operator is treated as a fixed effect, which would then cause the group-selection unit size to be tested with the mean square error ($\varepsilon_{ijk}$). From the logging owner/operator point of view, the fixed effect assumption is more appropriate and more powerful for determining operator performance. The random effect assumption, in comparison, is applicable for making statements about operators in general.

Least-squares means were used to examine mean differences in the event of a significant F-value. The proper error terms for group-selection unit area and utilization rate also were specified in multiple comparison procedures.

## Results

There were considerable differences in the number of machine hours and productivity per machine hour between group-selection units of common size (Table 1). Machine hours (both scheduled and productive) normally increased with increasing group-selection size. $Ft^3$/SMH and $ft^3$/PMH

**Table 1. Observed total skidding distance, time, utilization and productivity on replications of different sized harvest units on the West Virginia University Forest.**

| Unit* | Ac | Util. level (in.) | Cycle† | SMH†† | PMH§ | % Util. rate‖ | $Ft^3$/SMH# | $Ft^3$/PMH‡ |
|---|---|---|---|---|---|---|---|---|
| 15 | 0.5 | 4 | 26 | 10.8 | 9.7 | 89.7 | 269.4 | 300.4 |
| 16 | 0.5 | 6 | 19 | 5.8 | 4.5 | 77.6 | 706.9 | 911.1 |
| 9 | 0.5 | 4 | 20 | 5.1 | 4.5 | 88.6 | 594.1 | 670.7 |
| 11 | 1.0 | 4 | 48 | 17.2 | 15.3 | 89.2 | 309.6 | 347.1 |
| 13 | 1.0 | 6 | 49 | 14.4 | 11.3 | 78.8 | 450.4 | 571.6 |
| 14 | 1.0 | 4 | 43 | 14.9 | 12.8 | 86.0 | 403.1 | 468.6 |
| 2 | 1.0 | 6 | 41 | 16.3 | 13.5 | 82.9 | 360.5 | 435.3 |
| 12 | 1.5 | 6 | 52 | 16.2 | 13.4 | 82.6 | 538.7 | 652.0 |
| 3 | 1.5 | 4 | 70 | 22.2 | 18.0 | 81.2 | 449.0 | 552.7 |
| 6 | 1.5 | 6 | 50 | 16.3 | 13.4 | 82.2 | 431.4 | 524.6 |
| 1 | 2.0 | 4 | 77 | 27.4 | 23.2 | 84.6 | 472.3 | 558.0 |
| 10 | 2.0 | 6 | 62 | 21.0 | 18.3 | 87.5 | 448.4 | 512.7 |
| 8 | 2.0 | 4 | 75 | 19.2 | 15.8 | 82.2 | 574.4 | 698.6 |

* Units 4 and 5 not used in analysis due to incomplete time study data; unit 7 was not used because a fourth operator (not included in the study) skidded the entire unit.
† Number of skid cycles by harvest unit.
†† Scheduled machine hours.
§ Productive machine hours.
‖ Percent utilization rate (PMH/SMH).
# Volume ($ft^3$) skidded per scheduled machine hour.
‡ Volume ($ft^3$) skidded per productive machine hour.

**Table 2. Summary of preharvest conditions as well as productivity and delay element means (standard deviation) by group selection unit size on the West Virginia University Forest.**

| Unit size | Preharvest basal area* | Mean turn vol.† | Average log vol./turn†† | Mean hooking time/turn§ | Mean no. of logs/turn | Mean total delay time§ |
|---|---|---|---|---|---|---|
| 0.5 | 161.68 | 153.86 | 40.11 | 6.39 | 4.08 | 2.76 |
| | (6.34) | (62.49) | (17.76) | (2.61) | (1.10) | (2.91) |
| 1.0 | 153.22 | 129.14 | 33.56 | 6.54 | 4.44 | 3.19 |
| | (6.27) | (44.21) | (21.74) | (2.55) | (1.30) | (3.57) |
| 1.5 | 148.61 | 149.66 | 43.60 | 6.07 | 3.99 | 3.45 |
| | (6.66) | (53.98) | (28.50) | (2.70) | (1.15) | (4.32) |
| 2.0 | 145.71 | 150.23 | 38.74 | 6.11 | 4.57 | 2.87 |
| | (10.76) | (58.89) | (33.47) | (2.45) | (1.26) | (3.63) |

* $Ft^2$/ac.
† Mean total turn volume ($ft^3$).
†† Individual log volume ($ft^3$).
§ Time in minutes.

also increased along a gradient of acreage for the 1–2 ac harvests. However, the 0.5 ac harvests had higher average $ft^3$/SMH and $ft^3$/PMH than did the 1–2 ac harvests. Although randomly placed, this may have been due to the location of the 0.5 ac harvests—all were relatively close to the landing.

Table 2 provides the means, by group-selection size, of the dependent variables used in analyses. Preharvest basal area declined along a gradient of increasing unit size. Productive elements did not show great variation among group-selection unit size; neither did they show consistency regarding measures of performance and size of area. For instance, the 0.5 ac cutting units had the smallest average delay time, but the second highest average hooking time.

Because preharvest basal area showed a decreasing trend according to group selection unit size, it was important to account for any effect by treating it as a covariate. Likewise, skid distance also was treated as a covariate. Analyses show that preharvest basal area had a significant impact on hooking time and skid distance had a significant impact on total turn volume and logs per turn (Table 3). Thus the impact of preharvest basal area and skid distance on the dependent variables was accounted for prior to determining the impacts due to group selection unit size, operator, and utilization level.

## Hooking Times

ANCOVA results show that group-selection unit size had no effect on hooking times (Table 3). However, there was a significant difference in hooking time among operators. Operator 3 had significantly lower hooking times than the other two operators. Similarly, the operator × group-selection unit size interaction was significant. Operator 1 and 2 had higher hooking times in the smaller (0.5 and 1.0 ac) harvests.

The only other significant factor was the group-selection unit size × utilization level interaction. No differences in hooking time occurred within a group-selection unit size between utilization levels. However, hooking times in the 6 in. utilization level × 2.0 ac harvests were significantly lower than those found in the 0.5, 1.0, and 1.5 ac × 6 in. utilization level harvests. Although other comparisons within the group-selection unit size × utilization level were significant, they were not reported because they were not logical (i.e., comparing 6 in. utilization level in a 0.5 ac harvest with the 4 in. utilization level in a 2.0 ac harvest.

## Logs Per Turn

There was no difference in the number of logs taken per turn among group-selection units of different size. However, utilization level was a significant factor (Table 3). The mean number of logs per turn was significantly greater in the 4 in. utilization harvests than in the 6 in. utilization harvests.

Likewise, the group-selection unit size × operator interaction explained a significant amount of the variability in the number of logs per turn. Operator 2 hooked significantly fewer logs per turn in the 0.5 ac harvests than did operators 1 and 3. We also found differences in logs per turn hooked by operators in different sized group-selection units. Operator 2 hooked significantly fewer logs per turn in the 0.5 ac than in the 1.0 ac group-selection units.

**Table 3. ANCOVA results (*Pr > F*) for the effect of group selection unit size, operator, with preharvest basal area as a covariate on hooking time, number of logs per turn, total turn volume, and average piece volume per turn. Bold *P*-values indicate a significant difference.**

| Source | Hooking time *Pr > F* | Logs/turn *Pr > F* | Total turn vol. *Pr > F* | Ave. piece vol./turn *Pr > F* | Total delay time *Pr > F* |
|---|---|---|---|---|---|
| Group selection unit size | 0.467 | 0.832 | 0.112 | 0.241 | 0.597 |
| Operator | **0.040** | 0.216 | **<0.001** | 0.096 | 0.312 |
| Group selection unit size * operator | **<0.001** | **<0.001** | 0.457 | 0.308 | 0.702 |
| Utilization level | 0.366 | **0.034** | **0.011** | **0.005** | 0.357 |
| Group selection unit size * utilization level | **0.010** | 0.355 | 0.397 | 0.778 | 0.783 |
| Operator * utilization level | 0.265 | 0.730 | 0.211 | 0.531 | 0.603 |
| Covariate—preharvest basal area | **0.002** | 0.623 | 0.137 | 0.506 | 0.890 |
| Covariate—skid distance | 0.346 | **<0.001** | **<0.001** | 0.141 | 0.163 |

Likewise, operator 3 hooked significantly fewer logs in the 1.5 acre than in the 2.0 acre group-selection units.

### Total Turn Volume

Group-selection unit size had no effect on total turn volume (Table 3). Significant operator differences continued to be evident, with operator 2 having smaller turn volumes than the other two operators. Utilization level also significantly affected turn volumes, with the 6 in. utilization level exhibiting higher turn volumes. This is likely a function of piece size; average piece size would have been larger in 6 in. utilization units (assuming that as utilization level increased, piece length wasn't shortened). All other factors were nonsignificant in their effect on turn volumes.

### Average Piece Volume Per Turn

Average piece volume per turn did not differ among the group-selection unit sizes. In fact, the only significant factor was utilization level, with the 6 in. level exhibiting larger average piece size per turn volumes. These results are not surprising because average piece volume is a composite measure of total turn volume and number of logs per turn.

### Total Delay Time

None of the factors in the model were significant, indicating that group-selection unit size, operators, and utilization level did not impact delay times. During the course of the study period, machine utilization rates were consistently high, the lowest rate being 77.6%.

## Discussion

It has been documented that logging costs increase rapidly with decreasing harvest unit area (LeDoux 1993). This is because of the ratio between move costs and volume harvested becoming larger as harvest unit area increases. This discrepancy could be further magnified if productivity declines with a decline in harvest unit area size. Decreased productivity would increase harvesting costs, thus increasing the ratio between logging costs and volume harvested. Previous research has shown that harvesting productivity under a group-selection silviculture approach can have lower productivity than clearcutting (Brummel 1992). However, we found little evidence that system productivity, as measured by hooking times, total turn volume, pieces per turn, and average piece size per turn, was strongly influenced by group-selection harvest block size. Average total turn volumes were greater in 6 in. utilization harvests; however, this was a product of the larger average size of logs hooked in these areas. Delay elements in group selection harvests appear to be the reason for the decreased productivity found by Brummel (1992). We did not find comparative declines in productivity in the group selection harvests we studied.

The study did reveal some interesting results in the form of skidder operator influence on stump to landing productivity. Because each of the three skidder operators in this study ran identical machines, the influence of operator skill and efficiencies along with the measure of machine utilization was more obvious and easier to detect than if different model machines had been used. Of the three operators included in the study, the second operator clearly had lower productivity levels per machine hour, 426.7 $ft^3$/pmh (productive machine hour), compared to 625.6 $ft^3$/pmh (operator 1) and 621.6 $ft^3$/pmh (operator 3), differences of 46.7 and 45.7%, respectively (Table 4). These differences could be attributed to greater skid distances for operator 2. However, since skid distance was used as a covariate in the analyses, skid distance effects were offset.

The most influential factors in explaining productivity differences among operators were hooking time and mean turn volume. Average hooking times for operator 2 averaged 4.5% longer than operator 1 and 10.0% longer than operator 3. Operators 1 and 3 had mean turn volumes that were 27.6% and 25.5% larger than operator 2, respectively. This further manifests itself in the nontravel component of productivity (Table 4). Here operator 1 was 30.1% more productive than operator 2 (1133.2 $ft^3$/pmh versus 871.2 $ft^3$/pmh), while operator 3 was 15.0% more productive than operator 2 (1002.1 $ft^3$/pmh versus 871.2 ft/pmh). In this respect, turn volume lies at the center of defining operator productivity. While harvest stand density will help dictate an operator's ability to hook maximum turn volumes, it is critical that operators hook as many logs as possible, even if some in-woods maneuvering is required.

Operator 2 also hooked fewer logs per turn in the 0.5 ac harvest than did operators 2 and 3. However, the fact that the number of logs hooked per turn and average piece volume per turn did not differ among operators does present somewhat of a dilemma in explaining the differences in average total turn volumes among operators. First, although they were not significant, operator 2 averaged 4.23 logs per turn, as compared to 4.35 and 4.37 for operators 1 and 3, respectively. Operator 2's average piece volume per turn was 33.9 $ft^3$, compared to 40.6 $ft^3$ for both operators 1 and 3. Since the skidder operator has no control over the piece sizes encountered, it is possible that operator 2 made a conscious effort to hook smaller pieces when the opportunity presented itself. Another possible explanation is that by chance, piece sizes were abnormally small within that part of the group-selection unit in which operator 2 was working.

**Table 4. Summary of operator productivity.**

| Operator | Mean productivity ($ft^3$/pmh*) | Mean turn vol. ($ft^3$) | Mean hooking time (min.) | Mean logs/turn (#) | Mean one-way skid distance (ft) | Mean travel rate (min./100 ft) | Mean nontravel productivity† ($ft^3$/pmh) |
|---|---|---|---|---|---|---|---|
| 1 | 625.6 | 154.7 | 6.30 | 4.35 | 1,080 | 0.70 | 1,133.2 |
| 2 | 426.7 | 121.2 | 6.60 | 4.23 | 1,209 | 0.76 | 871.2 |
| 3 | 621.6 | 152.1 | 5.94 | 4.37 | 1,122 | 0.73 | 1,002.1 |

* Productive machine hour.
† Includes only in-woods hooking time, and unhooking and decking time at the landing.

Generally, equipment specifications and capacities are considered to be the overriding factor controlling productivity, but as can been seen from the results presented here, individual operators running equivalent machines can influence both to a great degree. Although skill and efficiency measures are hard to quantify, their importance should not be overlooked. Development of effective training programs designed to train operators to operate skidders more efficiently and at lower costs within the capacities of the equipment may warrant further investigation.

Operator differences, as identified here, and the location of landings with respect to group harvest units, will have the most effect on the productivity variables within a given unit size, at least for units ranging up to 2 ac. Although it is known that logging costs increase with a decline in harvest unit area, we found little evidence that logging productivity varies with harvest unit area. However, it is important to note that when faced with group-selection harvests, or any other type of harvest, logging managers should be aware of their operators' productivity so as to design jobs to minimize the impact or take the best possible advantage of the less productive employees.

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