

Ground skidding and harvested stand attributes in Appalachian hardwood stands in West Virginia

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Abstract

A statewide logging-in-progress study was conducted in West Virginia to examine the associations among several ground skidding and harvested stand attributes. There was a strong positive association between skidding distance and cycle time, and a significant negative relationship between the percent of trees removed in the stand and total cycle time. The number of residual trees per acre and number of trees per acre in the preharvest stand were not significant in explaining total skidding cycle time. In addition, the number of trees and volume skidded per cycle were positively associated with cycle time, as was the number of turn bunching moves. Additional results suggested that differences in operator behavior may be more important in explaining the size of payloads per cycle than, for example, the size of the skidder used.

The Appalachian hardwood region offers some of the most challenging timber harvesting conditions in the eastern United States, including irregular, often steep, topography and large hardwood sawtimber. These conditions often combine to encourage the use of rubber-tired skidders and hand felling over more mechanized logging methods. In addition, the region is dominated by nonindustrial private forests (NIPFs), and many of these owners have indicated an interest in harvesting (Birch et al. 1992). This is framed, however, by concerns over a perceived proliferation of diameter-limit harvest designation among the state's private landowners and the resulting impacts on future timber supply, as suggested by both postharvest-only (e.g., Fajvan et al. 1998) and pre- and postharvest studies (e.g., Raschka 1998) of the phenomenon.

This logging-in-progress study was designed to provide in-depth information on skidder turn attributes and harvested stand conditions for a sample of

logging operations in Appalachian hardwood stands in West Virginia. The objective of this study was to examine the associations among several ground skidding and harvested stand attributes: skidding cycle and element times; ground skidding characteristics (including number of trees and volume per cycle, skidding distance, number of bunching moves, and skidder size); and harvested stand conditions (including residual stand density, number of trees removed, and residual stand damage). In so doing, we have attempted to elucidate relationships between skidding efficiencies and some harvested stand conditions and effects that will lead to an improved understanding of the ground skidding process.

The statewide approach to this study necessarily sacrifices an in-depth understanding of operator-machine interactions in favor of a broader understanding of the associations between harvested forest and skidding cycle attributes. Indeed, in most logging studies, the operator variable has been very difficult to either evaluate or hold constant (Gullberg 1995), even in more controlled investigations that focus on a relatively small number of experimental logging sites. Our approach was designed to provide a snapshot of harvesting conducted in West Virginia that is not available from either controlled experiments or more limited sample sizes, and in this sense deviates from these approaches. However, the trade-off is a better understand-

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ing of ground skidding on a statewide basis under non-experimental conditions, as well as several forest stand conditions in which skidding production cycles were observed.

Background

Previous research efforts have attempted to understand ground skidding and its association with a number of harvested stand attributes. For example, in an attempt to provide a means for establishing merchantability limits for harvests based on stand characteristics, Howard (1987) investigated the relationship between logging costs/profits and harvested tree size and species group. He found that tree size had the greatest effects on skidding costs, and that logging was not profitable for more than half of the sample timber sales studied, primarily due to the harvest of trees of submarginal volume. Cubbage et al. (1989) investigated the effects of tree size on harvesting costs. Using regression analysis to help identify factors that influenced the costs of conventional logging systems in the southern United States, the authors found efficiencies associated with harvesting pines with mechanized logging systems, while hardwoods were much more expensive to harvest. Their results confirmed the negative relationship between tree size, tract size, and tract volume and average logging costs.

Machine operator effects have received less attention. However, Hassler et al. (2000) investigated the effects of ground skidding trees felled during group selection harvests on logging productivity. Although the size of the harvested group had no significant effect on productivity, significant skidder operator differences existed, with some operators skidding greater turn volumes than others. In addition, Gullberg (1995) developed a method for analyzing operator-machine interaction effects in comparative time studies, but suggested that the method requires further testing over a variety of operators, machines, and logging conditions.

Investigating harvesting systems in the Caspian forest in Iran, Sobhany and Stuart (1991) performed a timing study of conventional ground skidding logging operations common in the region. They found that skidding distance was strongly associated with total cycle time, while there was great variability in

volume per skidding cycle, suggesting some agreement with previous studies (e.g., Hassler et al. 2000).

Methods

A statewide logging-in-progress field survey of harvesting operations was conducted in West Virginia during the summers of 1996 and 1997. Logging sites were visited as logging notification forms were filed with the West Virginia Division of Forestry by timber operators. One-day field investigations at each site included approximately a half-day timing study of ground skidding cycles underway at the time of the visits, and half-day assessments of stumps and residual trees in the areas from which timber had been extracted during the timing study. As a result of these efforts, 156 skidding cycles from 33 different logging operations in the state were observed and timed. In addition, 660 0.05-acre sample plots were established over all study sites combined (20 plots per site) to gather information on both pre- and postharvest stand conditions, including the species and diameter of stumps, as well as species, diameters (at both 2 in. and breast height for trees 4 in. DBH and greater), and damage assessments of residual trees. Tree bole damage was assessed by measuring the extent of exposed surface abrasion following protocols adopted by Egan (1999a). Tree crown damage was assessed by estimating the proportion of the crown damaged by logging.

The outside bark diameters of remaining trees and stumps were measured at 2 inches from ground level (uphill side) in order to facilitate comparisons of pre- and postharvest tree sizes without resorting to often unreliable DBH reconstructions from stump diameters. Tree and stump diameters were measured at 2 inches to account for stumps that were cut near the ground, facilitating direct comparisons of diameters between removed trees and residual trees.

Continuous time recording methods (Niebel 1993) were used throughout the study, with elemental times read and recorded at each element's breaking point. In order to gather information on the turn building (bunching) process, timing methods varied somewhat between the two summers of field work. During the first summer ($n_1 = 104$ cycles on 21 logging sites) each turn building (or bunching move) per turn was noted and timed

separately. This provided the investigators with more in-depth information on how felled stems were gathered for each turn. During the second summer ($n_2 = 52$ cycles on 12 logging sites), turn building times were aggregated within the choker setting skidding element. Otherwise, data collection procedures for the two summers of field data collection were the same. Among the 33 logging sites visited, no logging crew was visited more than once. Unproductive delays were not included in the analysis.

The elemental breakdown for each skidding cycle element was as follows: Travel empty (return): Began when chokers were unhooked at the landing and ended when the skidder maneuvered for another turn; Maneuver empty: Began when the skidder maneuvered for another turn and ended when the operator emerged from the cab; Set chokers: Began when the operator emerged from the cab and ended when the chokers were set and the operator entered the cab; Winch: Began when the operator entered the cab and ended when the load was winched to the arch; Travel loaded (turn): Began when the skidder headed to the landing and ended when the skidder was stopped at the landing; Land: Began when the skidder stopped at the landing and ended when the next return started.

For the first summer of field work, turn building (bunching) times were noted by recording separate times for each bunching move per cycle that included maneuvering, setting chokers, and winching individual logs or groups of logs.

The model of each skidder used on the sample sites was noted and assigned to one of two size categories based on horsepower (at the flywheel) and consultation with equipment representatives: class I = 80 to 120 hp; class II = greater than 120 hp. Volumes skidded were measured after each cycle by measuring both small- and large-end stem diameters and stem length. These dimensions were converted to cubic-foot volumes using Smalien's formula:

$$(B + b) / 2 \times L$$

where:

B = large end basal area inside bark (ft.²)

b = small end basal area inside bark (ft.²)

Table 1. — Average pre- and postharvest trees per acre and trees removed, and average pre-/ postharvest and removed diameters at 2-inches over all sample sites. Values in parentheses are standard errors.

	Preharvest	Postharvest	Removed trees
Trees per acre	125 (2.9)	83 (3.1)	43 (2.1)
Average diameter	15.5 in.	13.4 in.	19.0 in.

Table 2. — Summary statistics for skidding cycle and elemental times.

Element	Mean	Standard error	COV ^a
	----- (min.) -----		(%)
Travel empty (return)	3.83	0.25	78
Maneuver empty	2.16	0.29	161
Set chokers	4.13	0.32	93
Winch	0.84	0.06	89
Travel loaded (turn)	5.54	0.34	74
Land	1.74	0.14	97
Cycle	17.94	0.77	50

^aCOV = coefficient of variation.

Table 3. — Mean cycle times, trees per cycle, and volumes per cycle partitioned by the number of bunching moves per cycle.

No. of bunching moves	Mean total cycle time	Standard error	Mean trees per cycle	Standard error	Mean volume per cycle	Standard error
	----- (min.) -----		---- (no. of trees) ----		----- (ft. ³) -----	
0	17.16	1.16	2.47	0.13	125.80	8.92
1	18.61	1.77	2.88	0.19	121.00	8.29
2	24.05	2.51	3.54	0.24	143.62	16.53

L = stem length

Results and discussion

There was an average preharvest stand stocking of 125 trees per acre (range = 60 to 212 trees per acre), and an average residual stand stocking of 83 trees per acre (range = 7 to 177 trees per acre) over all study sites combined. The average number of trees removed per site was 43 trees per acre (range = 17 to 152 trees per acre) (Table 1). The average preharvest diameter outside bark (taken at 2 in. above ground level) was 15.5 inches. The average diameter outside bark of stumps (taken at 2 in. above ground level) was 19.0 inches; the average diameter outside bark of remaining trees (taken at 2 in. above ground level) was 13.4 inches.

Skidder cycle and harvested stand attributes

Skidding cycle and elemental times were analyzed descriptively, and tests were performed to help better understand the skidding cycles ob-

served. All tests described were performed at $\alpha = 0.05$. The average cycle time over all 156 observed cycles was 17.94 minutes over a distance of 1,352 feet, skidding 2.95 trees and 114.61 ft.³ per turn. The coefficient of variation (COV) for the cycle times observed was 50 percent (Table 2). The turn element took the most time to complete (5.54 min.) and was the least variable (COV = 74%), while winching consumed the least amount of time (0.84 min.). Maneuvering empty was the most variable element (COV = 161%).

Multiple regression analysis of the data collected over both field seasons combined revealed that total cycle times were related to skidding distance and the proportion of trees removed in the stand. Of these variables, cycle times were inversely related to the proportion of trees removed (i.e., cycle times decreased as the percent of trees removed in the stand increased), and positively associated with skidding distance (i.e., cycle times increased as skidding distances in-

creased). While the former result may be explained intuitively by the notion that it is likely to be more efficient to gather a turn of logs when felled trees are in closer proximity to each other, we did not collect data on the spatial arrangement of felled trees that might help to support this. Both the number of trees and volume skidded per cycle were also significant in explaining total cycle times. However, the number of residual trees per acre, the number of trees removed per acre, and the number of trees per acre in the preharvest stand were not significant in explaining cycle times.

The relationships between the bunching cycle element and other skidding cycle attributes were also explored. Using the number of bunching moves as a discrete independent variable (i.e., as a factor), analysis of variance revealed a significant association ($\alpha = 0.05$) between the number of bunching moves and the number of trees skidded per cycle ($F = 6.037$; $p = 0.003$; power = 0.887) (Table 3). There was no apparent association between the number of bunching moves and 1) total skidding cycle times ($F = 2.727$; $p = 0.071$; power = 0.515); 2) volume per cycle ($F = 1.032$; $p = 0.395$; power = 0.308); or 3) skidding distance ($F = 0.102$; $p = 0.982$; power = 0.070). These results suggested that, when bunching, operators were generally more concerned with maximizing the number of trees skidded per turn than the amount of volume skidded per turn. In addition, distance from the landing was not associated with bunching behavior.

In addition, logistic regression analysis revealed that bunching behavior was not associated with any of the explanatory variables investigated, including skidding distance, skidder size class, either the percent or number of trees removed in the logged stand, or the preharvest or residual stand stocking. Logistic regression, however, corroborated that the number of bunching moves was associated with the number of trees skidded per cycle (likelihood ratio chi-square = 12.578; $p = 0.006$).

The effect of skidder size on average skidding cycle times was also explored. When skidding distance was introduced into the analysis as a covariate, the interaction term skidder size class $\times$ skidding distance was not significant in explaining total cycle time ($p = 0.383$). How-

ever, as main effects in the analysis, skidding distance was significant ($p < 0.001$) and skidder size was not ($p = 0.765$). When the interaction term was removed, analyses maintained the significance of skidding distance in explaining skidding cycle times ($p < 0.001$); skidder size was still insignificant ($p = 0.469$). Neither the number of residual trees per acre nor the number of trees per acre in the preharvest stand was associated with the size of the skidder used during logging.

In addition, the relationship between volume skidded per cycle and skidder size was analyzed, adding as a covariate the number of trees skidded per cycle. The interaction of skidder size and trees per cycle was not significant ($F = 0.312$; $p = 0.578$; power = 0.084) over the skidding cycles observed. When the interaction effect was removed from the analysis, the volume skidded per cycle was not strongly associated with skidder size ($F = 2.976$; $p = 0.087$; power = 0.386), although, on average, machines in the smaller skidder category skidded more volume per cycle (127 ft.³) than did larger skidders (108 ft.³). Moreover, skidder size was not related to the number of trees skidded per cycle ($F = 0.300$; $p = 0.595$; power = 0.083), although, on average, smaller skidders yarded slightly more trees per cycle (2.98 trees) than did larger skidders (2.88 trees). These results appear to agree with Hassler et al. (2000) who found that individual operators running equivalent machines in similar harvested stands had vastly different production levels even when skidding distance was accounted for by including it as a covariate in the analysis.

Residual stand damage effects

Approximately 38 percent of trees on the study sites were harvested. Overall, 13 percent of residual trees (9.3 per acre) on the study sites were damaged by logging activity. Approximately 8 percent (6.0 per acre) were damaged through the skidding process by a dragged log (67% of trees damaged during the skidding process), by direct contact with the skidder (30%), or both (3%). The remaining damaged trees were injured through the felling process. The proportion of damaged trees per acre is smaller than that reported in partial harvests in the Northeast in which cable skidders were used, although

comparisons are difficult due to differences in damage assessment methods. Nichols et al. (1994), for example, reported that 22 to 44 percent of residual trees were wounded when chain saws and cable skidders were used in a partial harvest of northern hardwoods. Lamson et al. (1984) found an average of 47 trees per acre destroyed during logging during conventional logging operations in Appalachian hardwood stands. Both of these studies found most of the damage concentrated in saplings, a size class not investigated in this study.

Of the harvested stand attributes investigated and introduced in the analysis, the number of residual trees per acre and the proportion of trees removed were associated with the number of trees damaged during skidding ($p < 0.001$): as the number of residual trees per acre and the proportions of preharvest stands removed increased, the number of damaged trees per acre increased. However, the number of trees damaged by skidding was not associated with the number of trees removed per acre ($p = 0.348$). Indeed, using a forward selection stepwise regression procedure, both the number of residual trees per acre and the proportion of trees removed per acre were retained (number of trees damaged = $-3.666 + 0.129$ (percent removed) + 0.084 (number of residual trees); $F = 29.704$; $p < 0.001$; $r^2 = 0.382$). In addition, stand damage was associated with two ground skidding attributes: trees yarded per cycle ($p = 0.003$) and volume yarded per cycle ($p = 0.009$). However, regression coefficients indicated that the number of trees damaged increased as these two attributes decreased (number of trees damaged = $14.283 + -1.187$ (trees per cycle) + -0.017 (volume per cycle); $F = 8.851$; $r^2 = 0.126$). This result, together with results from previous tests that showed that the proportion of trees removed was significant in explaining the number of skidder damaged trees per acre, may suggest that the number of turns required to recover a given amount of felled wood may help to explain stand damage. However, this attribute was not studied during this investigation.

Analysis of variance revealed an association of borderline significance between skidder size and the number of residual trees per acre damaged by skidding ($F = 3.653$; $p = 0.058$; power =

0.460): smaller skidders damaged 7.78 trees per acre and larger skidders damaged 9.48 trees per acre.

Conclusions

The maneuvering empty cycle element was the most variable skidding cycle element studied (COV = 161%). This result is perhaps not surprising, since this element often represents a search for the next turn or log to be skidded that might vary widely from cycle to cycle, whereas other elements, such as the turn (COV = 74%) and return (COV = 78%), represent more discrete, well-defined tasks. The variability in the time required to maneuver empty, or search, can often be decreased, for example, by planning the next cycle during the turn and/or return. Interviews with skidder operators who demonstrate low COVs for this element may reveal other strategies for reducing the variability in the time it takes to complete it (e.g., better communication with the timber faller), thereby reducing overall cycle times.

Predictably, there was a strong positive association between skidding distance and cycle time, and a significant negative relationship between the percent of trees removed in the stand and total cycle time. Other stand attributes – number of residual trees per acre and number of trees per acre in the preharvest stand – were not significant in explaining total skidding cycle time. In addition, the number of trees and volume skidded per cycle were positively associated with cycle time, as was the number of bunching moves. Bunching data indicated that almost one third (approximately 31%) of all skidding cycles observed had at least one bunching move – that is, skidder operators hooked a complete turn without bunching in 69 percent of the cycles observed – and cycles with two or more bunching moves accounted for 14 percent of all cycles observed. Only 2 percent of all cycles observed had three or more bunching moves.

However, bunching behavior was not associated with greater volumes skidded per cycle, suggesting that skidder operators may be more influenced by the number of chokers available per turn (i.e., the number of trees they are capable of hooking per cycle) than by a determination to maximize volume or weight per turn. However, with an aver-

age of only 2.95 trees skidded per cycle, other factors may also play a key role in determining either the number of trees per cycle or the decision to bunch or not. Spatial arrangement of felled trees, uphill versus downhill skidding, the skidder operator's desire to achieve fast cycles (versus maximizing payload), or other operator-behavior decisions need further investigation in this regard. Again, interviews with skidder operators may serve to elucidate these phenomena. In addition, that there was no association between the number of bunching moves and total skidding cycle times ($p = 0.071$) at $\alpha = 0.05$, suggests that further study of this relationship may be warranted.

That skidder size was not related to volume or number of trees skidded (indeed, on average, smaller skidders in this study yarded more trees per turn than larger skidders) perhaps supports other studies that have suggested that differences in the sizes of payloads has more to do with the operator's behavior and judgment than skidder size (e.g., Hassler et al. 2000). Further training and monitoring of skidder operators may be required to optimize skidding efficiency in this regard.

Observation of logging as it occurred provided a better opportunity to more accurately describe the specific cause(s) of damage to residual trees than would have been available from postharvest-only observations. Research has suggested that forester involvement in timber sales is significant in explaining greater compliance with best manage-

ment practices (Egan 1999b). Whether the same professional involvement is associated with mitigating negative residual vegetation effects is unknown, and therefore perhaps an important area of future study.

Although this study included sample logging sites from a broad range of summer logging conditions in West Virginia, logging-in-progress studies that are conducted during all seasons of the year are needed. Observation of greater numbers of skidding cycles per site would also provide improved opportunities to analyze within-site variability in elemental and cycle times as well as skidder operator behavior across all sample sites.

Finally, this type of statewide study is often confronted with logistical challenges not generally associated with studies performed under more controlled conditions or with more limited sample sizes, including identifying active logging operations, obtaining permissions to both enter the logging site and observe the logging operation, trips that found loggers not working due to breakdown, local weather, and/or ground conditions, etc. However, the attempt to develop an understanding of yarding cycles and the immediate harvesting effects on residual trees on a statewide basis has obvious merit and complements research designed with more experimental control.

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