RESIDUAL TREE DAMAGE DURING SELECTION CUTS USING TWO SKIDDING SYSTEMS IN THE MISSOURI OZARKS

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Abstract: Today, there is an interest in using alternative silvicultural systems like selection and two-aged management, because the public finds these systems more acceptable than clearcutting. However, repeated entries into forest stands to remove timber increase the risk of residual stand damage. Harvest techniques are desirable that (1) reduce the risk of stand damage and (2) are economically efficient. Animal logging provides a feasible alternative to conventional rubber-tired skidder harvesting systems used in the Ozarks.

Residual stand damage following selection harvests was examined for both (1) a rubber-tired skidder and (2) a mule logger, to provide a case study comparison of logging damage between the two systems. We found that only 7% of the residual trees >5" dbh were damaged by the mule-logging system while 22% of the residual trees were damaged by the skidder system. Conventional skidding destroyed three times as many residual trees as mule logging. Residual stocking was similar across both sites.

INTRODUCTION

Due primarily to public concerns about timber production on public forest lands, land management agencies are now implementing uneven-aged management plans on many federal and state forests. Questions still remain, however, about the long-term sustainability of uneven-aged management systems. Some tree species can not be easily regenerated under a residual forest canopy, which can cause a change in the species composition of the future stand. Furthermore, damage to residual trees during the selection harvest operations may decrease the quality of residual trees and increase stand mortality through insect and disease infestation. Before uneven-aged management regimes are embraced as a sustainable option for forest management, these questions must be addressed.

The implications of residual stand damage on public forest lands are important, due to the multiple-use designation on these lands. Clearcutting as a means of stand regeneration has become disfavored partly because of the lack of flexibility for other uses. Brunson and Shelby (1992) observed a relationship between the amount of overstory removal and public disapproval. For hiking, camping and scenic uses, stands with more residual trees were consistently given preference over clearcut areas. While uneven-aged management and partial cutting practices offer a compromise between timber production and other uses, excessive damage to residual trees during harvesting may compromise the aesthetic value of the residual stand (Schmid and Mata 1993). For this reason it is desirable to implement low impact harvest procedures when safety and productivity requirements permit. By reducing the negative impacts of harvesting on non-timber related uses, it is possible to increase the overall level of timber production which is socially optimal on public forest lands (Ficklin and others 1996).

In some areas cable/skyline systems and helicopter logging are viable options for low impact logging, but these systems are not widely available in the Ozark region. The use of animals such as mules and horses for skidding is both cost effective and available in the Ozarks, although skilled animal skidding loggers are becoming more difficult to find. There is also very little scientific data about the relative impacts of animal versus conventional

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rubber-tired skidding. In the 1930's a study of damage to loblolly pine (*Pinus taeda* L.) and hardwoods showed 12% of the residual pines were damaged, while over 35% of the hardwoods were damaged (MacKinney 1934). This study is significant because draft horses were the conventional means of skidding at the time. Other information about animal skidding is primarily anecdotal, with the assumption being that animal systems are lower impact than skidders.

Animal skidding is a lower productivity system compared to conventional rubber-tired skidders, so the needs of the forest landowner will affect the suitability of animal systems for a specific use. When high production is not needed or desired, the use of animal skidding may have long-term benefits from the avoidance of residual stem damage. There is considerable variability in the degree and extent of residual tree damage in the scientific literature. This fact can likely be attributed to differences in tree species, time of year, harvest techniques and logger attitudes. Schmid and Mata (1993) observed a range from approximately 20% to over 50% of residual lodgepole pine (*Pinus contorta* Dougl. Ex Loud.) trees damaged following partial cuts in Colorado and Wyoming. The authors suggest the thin bark of lodgepole pine is especially vulnerable to damage during the growing season; however, they further report that carelessness by skidder operators and poor sale administration attributed to the large number of damaged trees.

A study of residual damage to eastern white pine (*Pinus strobus* L.) in Ontario found that volume losses continued more than 10 years after the damage occurred (Whitney 1991). While 40% of the damaged trees were infected by decay-causing fungus, a full 90% of the damaged trees were stained. Although the stained wood is not structurally weakened like decayed wood, there is an economic loss associated with the discoloration. Projections of volume losses over 25-30 years conservatively estimated a loss of 25-30% of gross merchantable volume.

Residual damage to hardwoods in the Mississippi Delta was found to be more severe following a partial cut than in the pine studies. Meadows (1993) found over 50% of the residual green ash (*Fraxinus pennsylvanica* Marsh.) and 60% of the sugarberry (*Celtis laevigata* Willd.) trees were damaged. Meadows suggested that losses due to butt rot may be significant due to the characteristic spread of butt rot in both green ash and sugarberry. Furthermore, epicormic branching may increase due to reduced vigor from root damage and increased stem exposure, further affecting the marketability of timber from the future stand.

There is some evidence to suggest that timber production goals on areas under uneven-aged management may not be compromised by mechanized logging. Studies in West Virginia hardwood stands have shown that most of the damaged and destroyed trees are less than 5.0 inches in diameter (Lamson and others 1985), so the net loss of residual basal area was only 6%. The authors also suggest that trees that are damaged during one cutting cycle can be given priority for removal in subsequent cutting periods, which minimizes the occurrence of multiple damage to individual trees. However, financial losses associated with the reduced value of the damaged trees was not quantified, and the economic loss to other non-timber related uses was not examined. The issue of long-term sustainability of quality (undamaged) growing stock is also important, because of the large proportion of advanced regeneration damaged during the mechanized harvesting operation. Importantly, the study suggests that conventional mechanized systems are suitable for performing selection and partial cuts with minimal short-term loss of residual stand timber value.

Our study examines the use of animals (mules) for reducing both the extent and severity of residual tree damage compared to a rubber-tired skidder operation. Using animals for skidding may be a desirable option for landowners with primary management objectives besides timber production. The short-term objective of this study was to determine if animal skidding offers an alternative to rubber-tired skidders for reducing residual stand damage. Currently, there are very few loggers who use animals for skidding on a full-time basis; however, if provisions are made during the administration of timber sales, supply and demand dictates that a niche market will develop. Furthermore, the present use of animal systems is proof that such systems are economically viable, but the level of productivity with such systems is inherently lower than for conventional mechanized skidding systems. The long-term objectives of this project are: (1) to determine if relationships exist between tree damage during timber harvest and growth and productivity of the post-harvest forest, and (2) to determine if a relationship exists between the species of trees damaged during timber harvest and the future developments of tree rot and disease. These objectives can be accomplished through follow-up measurements on the residual trees that have been tagged and cataloged.

METHODS

Study Areas

Two upland oak-pine harvest sites under uneven-aged management regimes were selected in Reynolds and Wayne counties of the Missouri Ozarks. The primary tree species on both sites were black oak (*Quercus velutina* Lam.), white oak (*Quercus alba* L.) and shortleaf pine (*Pinus echinata* Mill.). Both timber sales were marked and administered by foresters with the Missouri Department of Conservation, and harvesting on both sites occurred between January and August 1995 with interruptions due to weather. One rubber-tired skidder logger harvested in Reynolds county on a tract of the Clearwater State Forest, and one animal (mule) logger operated on a tract of land owned by a private hunting club in Wayne county. Both loggers were made aware that a research study was in progress, because of concerns about the rebar which marked our permanent plot corners. However, neither logger knew what the project was about or who else was involved. Since we were unable to replicate this study with multiple animal and rubber-tired skidder loggers, extensive preliminary information was collected on stand conditions. Pre- and post-harvest stand conditions were measured on both sites, so inferences could be made about the relative levels of stand damage for both the animal and the mechanized skidder.

Pre-Harvest Data Collection

Six 4/5th-acre (132 ft x 264 ft) plots were established systematically from a random starting point on both study sites, and a minimum buffer area of 66 ft. was maintained between all the plots. The total harvest area was 24 acres on the animal skidded site and 19 acres on the conventionally skidded site; consequently, the 4.8 acres of plots on both sites encompassed a full 20% and 25% of the harvest areas, respectively. A full inventory was made of all trees 5 inches in diameter and larger across all of the study plots, and site indices and slope measurements were also made for each plot. Site indices for black oak ranged from 63 to 70 on the animal skidded site, while indices ranged from 62 to 73 on the conventionally skidded site. Slope measurements were measured across the steepest part of the plots, and no plots fell entirely in a summit or footslope position. Accordingly, slopes on the animal/ alternative site ranged from 14-27%, and slopes on the rubber-tired skidder site were a similar 16-26%.

Post-Harvest Data Collection

Following the harvest operations, each plot was fully inventoried again, and a total of 861 remaining trees were tagged. Each residual tree was measured and classified by species, by type of damage, and by severity of damage. The extent of stand damage was determined by the frequency of injury to residual trees, and the severity of damage is expressed as the area of cambium exposed. These measurements will be needed to monitor the difference in growth rates and the occurrence and severity of rot due to damage in accordance with the long-term objectives of this study. The residual trees that incurred no damage will be used for the estimation of changes in growth rate between damaged and undamaged trees.

There are 4 categories of damage: none, skidding, felling and destroyed. Skidding damage to roots or the bole was measured as the area of cambium exposed (cm^2). The stand damage from felling was measured in two ways depending upon the type and location of damage. Felling damage which exposed the cambium in the butt log (8 ft) was measured in the same manner as skidding damage. Crown damage resulting from felling was estimated as a fraction (quarters) of the crown destroyed. The degree of crown damage is not included in the cambium injury measurements, but crown losses will be considered in the long-term evaluation of changes in overstory productivity.

Volume estimates were calculated using a database management system developed by Seamon (1995) for the Missouri Department of Conservation. This system is designed to work with TWIGS (Miner and others 1988) and to convert data files for modeling. Volumes were calculated for sawtimber (bd ft) and for total cubic feet of volume, including sawtimber, pulpwood and residue. The sawtimber values are the better estimate of the volume skidded through the stand, because most of the residues were not taken during skidding, but total volume does estimate the total volume of sawtimber, pulpwood and residue on the study sites.

Areas adjacent to access roads were not included in the sample plots on either site, due to the expectation of damage to trees along the roads. Because of the random location of sample plots within the harvest areas, the distance to the roads and log decks varied. To account for this variability, the area of both primary and secondary skid trails was measured within each plot. Access roads were closer to the plots on the site that was logged with rubber-tired skidders, so the skid trail lengths averaged 21% and 28% longer on the mule-skidded site for both primary and secondary trails, respectively. Width measurements were taken post-harvest in 10-ft intervals with a rolling tape, and total skid trail area was determined by a summation of the area of the resulting parallelograms. Because an intermittent drainage dissected one plot on the mechanized skidder study site, it was not possible to accurately measure the area of trails within that plot. This restriction was due to the felling of trees with the tops toward the drainage, which completely covered much of the area within the plot. As a result, the trail measurements on the mechanized skidder site are likely underestimated. Despite this limitation, the plot was included in the trail area calculations as having no skid trails, so that the conventional system would not be negatively biased in any way.

RESULTS

The cut trees, volume and basal area per acre were determined by the difference between the pre-harvest plot observations and the post-harvest measurements. Table 1 provides a summary of the post-harvest plot conditions.

Table 1. Plot conditions post-harvest (expressed per acre)

Animal skidder:	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Plot 6	Mean/Median
Residual trees/ acre	76	112	66	46	111	105	86/90.5
Cut trees/ acre	43	45	56	62	77	47	55/51.5
Residual basal area (sq ft)	59	63	44	37	59	64	54.3/59
Cut basal area (sq ft)	33	38	46	58	44	25	40.7/41
Residual volume (bd ft)	5766	4424	3851	4652	4189	6238	4853/4538
Residual volume (cu ft)	1800	1803	1297	1155	1657	1849	1594/1729
Cut volume (bd ft)	3637	3624	4397	6130	3235	1629	3775/3631
Cut volume (cu ft)	1054	1236	1410	1818	1274	699	1249/1255

Rubber-tired skidder:	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Plot 6	Mean/Median
Residual trees/ acre	80	80	75	82	135	108	93.3/81
Cut trees/ acre	40	22	43	24	10	24	27.2/24
Residual basal area (sq ft)	67	65	52	62	58	59	60.5/60.5
Cut basal area (sq ft)	36	16	35	32	16	24	26.5/28
Residual volume (bd ft)	6183	6139	4186	5592	2607	4113	4803/4889
Residual volume (cu ft)	2134	2049	1539	1976	1600	1684	1830/1830
Cut volume (bd ft)	4100	1871	3485	4024	2058	2240	2963/2863
Cut volume (cu ft)	1170	533	1090	1109	443	861	868/976

Note: Cubic foot volumes include residues, and board foot volumes are for sawtimber material only.

The study plots on both sites encompassed group openings (~70 ft diameter) and individual-tree selection areas, as evidenced by the differences in basal area and volume across the plots. Neither the animal-skidded site nor the rubber-tired skidder site was consistently higher in all the plot parameters; however, the mechanized skidder site averaged 7 more trees and 6.2 ft^2 more basal area per acre than the mule skidded site. A Wilcoxon rank test was performed to compare the medians of plot measurements between the two study sites. The nonparametric rank test was used because of the small sample size (6 plots per site) and because of concerns about non-normal distribution. The only assumptions underlying the Wilcoxon test are independent observations, continuous random variables, at least ordinal measurement and equal variance between the independent populations (Daniel 1978). Siegel-Tukey tests were performed prior to the Wilcoxon tests to assure that there were no significant differences between population variances. Subsequent Wilcoxon test results indicate that residual trees per acre ($p=.630$), residual sawtimber volumes ($p=.749$) and residual basal area ($p=.420$) were not significantly different between sites. In absolute volumes, the measured difference in residual sawtimber volume was only 50 bd ft per acre higher on the animal-skidded plots than on the rubber-tired skidded plots. Based on these observations, we conclude that neither site was predisposed to greater damage based on residual stocking conditions.

Significantly, more trees were cut on the animal skidded tract than on the tract skidded conventionally with rubber-tired skidders ($p=.005$). There was slightly higher variability in basal area and volume cut among the plots, but the median basal area cut per acre on the animal-skidded tract was significantly higher ($p=.037$). While no difference in cut sawtimber volume (bd ft) was detected ($p=.423$), there was an additional 812 bd ft per acre removed from the animal-skidded site, and there was a higher volume (cu ft) of material felled on the animal-skidded site ($p=.078$). The significantly higher number of trees removed, the higher basal area removed and the higher cubic foot volume cut from the animal skidder site would be expected to increase the chance of damage to residual trees from both skidding and felling, since residual stand volumes were comparable.

The area of skid trails was an important contributing factor to residual stand damage. Both the primary and the secondary trails were longer on the mule-skidded site, due to the proximity of sample plots to the landings and access roads. However, the size and maneuverability of mechanized skidders resulted in wider skid trails compared to animals (Figure 1), so the overall area in both primary and secondary skid trails was significantly higher on the site logged with rubber-tired skidders when the area of each measured parallelogram was compared ($p=.0001$) for both trail types. The images in Figure 1 were taken at different times, so some interpretation is needed. The trails on the animal skidded site were photographed during the completion of the harvesting operation, whereas the trails on the mechanized skidder site were photographed 9 months after the harvest had been completed. As a result new regeneration can be seen on the mechanized skidder site but not on the animal skidded site. The difference in trail width, however, is readily visible.

The total area of skid trails measured within the 4.8 acres of plots on the animal-skidded site was 4,444.7 ft^2 for primary trails and 2,027.5 ft^2 for secondary trails—2.1% and 1% of the total harvest area, respectively. On the mechanized skidder site primary trails covered 10,704.5 ft^2 and secondary trails encompassed 9,627.5 ft^2—5.1% and 4.6% of the total area, respectively. This difference in trail areas was particularly significant, because the skid trail systems were longer on the site logged with animals. The primary and secondary trails extended 840 ft and 1,050 ft, respectively on the animal site, while the trails on the mechanized site were 670 ft and 760 ft long for primary and secondary trails, respectively. Despite the longer trail system and the inability to measure skid trails on one plot of the mechanized skidder site that we mentioned earlier, there was still less soil disturbance on the mule-skidded site. Since additional skidding area would be expected to cause greater damage to residual trees, the reduction of skid trail area is one of the main advantages of animal skidding. Similarly, residual damage would be expected to be minimized under mechanized skidder systems which use equipment that is not excessively large for accomplishing the removal of timber.

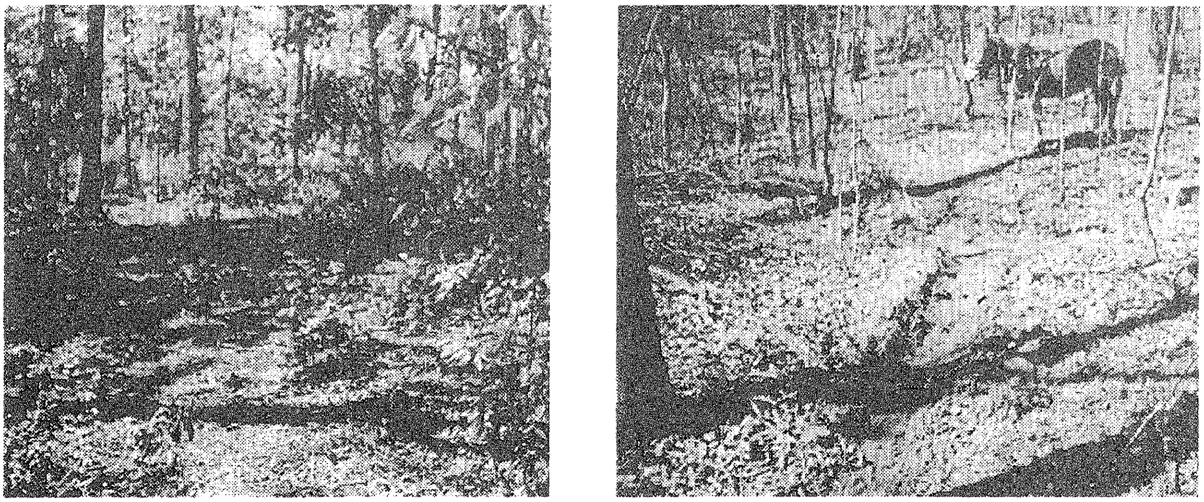

Figure 1. Primary skid trails-mechanized skidding [left] and animal skidding [right].

The species composition of the residual stands are summarized in Figure 2. Management objectives on the animal-skidded tract required an emphasis on shortleaf pine regeneration. Consequently, the residual percentage of pine on the alternative site was 26% compared to 1% on the conventional site. The largest component of both stands consisted of oaks [(white, black, and scarlet (*Quercus coccinea* Muenchh.)], and the proportion of other species, including hickories (*Carya* spp.), sugar maple (*Acer saccharum* Marsh.) and dogwood (*Cornus florida* L.), was similar between the two study locations.

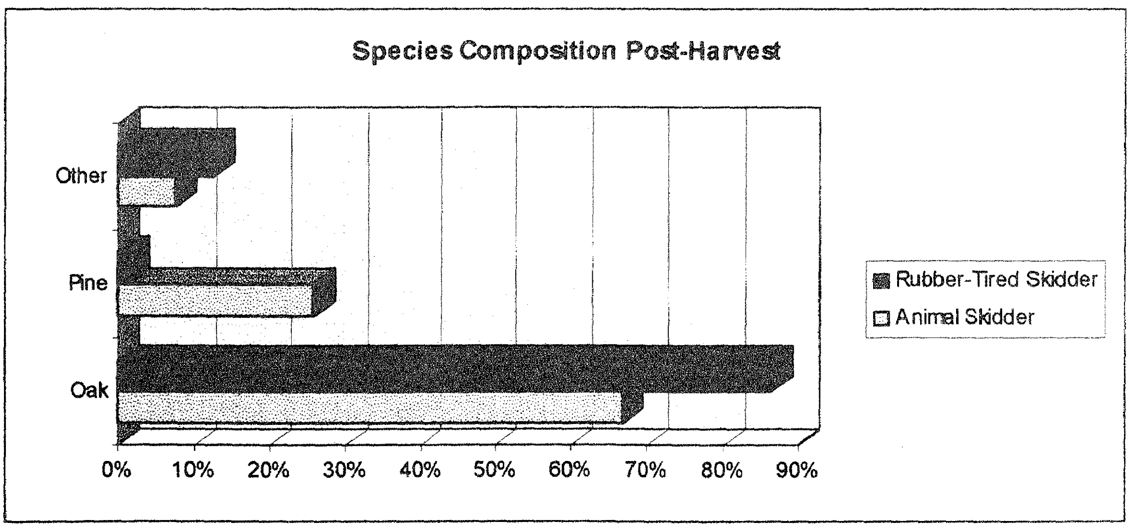

Figure 2. Comparison of species composition.

Damage was most severe on the conventionally skidded plots (Table 2). A Wilcoxon test detected a significantly higher median percentage of damaged trees (p=.025) and damaged cambium area (p=.055) per acre on the rubber-tired skidder site. The area of cambium damage is higher on the rubber-tired skidder site, but when the total area of cambium exposed is divided by the number of total residual trees, there is an average damage per stem of 22 cm^2 and 36 cm^2 on the animal and conventional sites, respectively. When the area of damage is projected across only the damaged residual trees, there is 240 cm^2 of cambium exposed on 8 damaged trees per acre on the animal-skidded site. On the rubber-tired skidder site there is an average of 130 cm^2 of injury on 26 trees per acre. Three times as many trees were destroyed by either skidding or felling under the rubber-tired logging system as under the mule-skidder system.

Table 2. Summary of residual tree damage

Animal skidder

	Residual trees damaged (%)	Area of cambium damage (sq cm)
Plot 1	12	1,848
Plot 2	9	7,194
Plot 3	9	1,118
Plot 4	11	305
Plot 5	5	998
Plot 6	2	50
Mean/Median	8/9	1,919/1,058

Rubber-tired skidder

	Residual trees damaged (%)	Area of cambium damage (sq cm)
Plot 1	33	4,384
Plot 2	19	1,628
Plot 3	28	8,429
Plot 4	23	2,231
Plot 5	8	1,957
Plot 6	30	1,992
Mean/Median	23.5/25.5	3,439/2,112

The breakdown of wounds by damage type is given in Figure 3. The percentages represent the fraction of damaged trees in each category, so similar percentages do not indicate similar absolute numbers. The greatest source of stand damage on both harvest areas came from skidding, which accounted for 43% of animal skidding and 47% of conventional skidding damage. Felling damage was also a key source of damage on both areas, and the proportion of trees damaged by felling was similar between the sites; however, a greater actual number of trees was damaged by felling on the rubber-tired skidder site. Felling prior to the animal skidding operation caused 40% of the total stand damage. Similarly, 38% of the damage on the rubber-tired skidder tract was due to felling. The summary of tree damage provided in Table 3 gives the absolute number of trees damaged across the study plots on a per-acre basis.

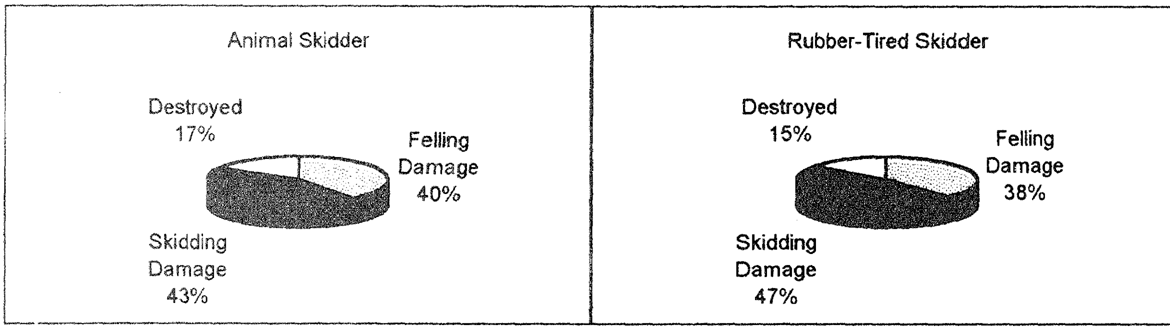

Figure 3. Residual tree damage by damage category (% of damaged trees).

The proportion of damaged trees that were destroyed was also similar between the tracts with 17% and 15% of the damaged trees destroyed on the animal and mechanized sites, respectively. Although the proportions of damaged trees in each category are similar, the actual number of damaged trees was higher in all damage classes using a rubber-tired skidder. Therefore, some component of the mechanized system other than skidding alone contributed to residual damage. One possible explanation would be the higher rate of production under the mechanized system. Although it was not possible to perform an analysis of operating costs between these two systems, it is certain that the overhead costs of the mechanized system were higher than for the animal-skidder system. The animal logger only had a truck and chainsaw, and the logger worked alone. Conversely, the mechanized system had an additional cost for skidder equipment, which would necessitate higher production to meet operating costs.

Table 3. Breakdown of tree damage per acre by category

	Animal skidder	Rubber-tired skidder
Felling damage	3	8
Skidding damage	3	10
Destroyed	1	3
Total per acre:	7	21

DISCUSSION

In contrast to some past studies of residual stand damage, less than 25% of the residual trees were damaged by rubber-tired skidders, which suggests that the logger was both competent and conscientious. The contribution of a well administered sale cannot be discounted, either. Regardless, the results found on the animal skidded site were a sharp contrast to the rubber-tired skidder area. Skidding and felling damage were both much less frequent on the animal skidded site, and there were three times as many trees destroyed with the mechanized skidding system. Stand stocking conditions post-harvest were not significantly different between the sites, but the pine component was different between the sites.

Because more trees were damaged by skidding on the conventionally [mechanized] skidded tract, more surface area of cambium was exposed (Table 2), and a greater loss of merchantable volume will be expected. Future re-measurements of tagged trees, damaged and undamaged, can permit the estimation of losses due to decreased growth rate and disease. Although a greater surface area was exposed by conventional skidding, the actual severity of tree damage by rubber-tired skidders was not greater per residual tree. The average area of injury per stem is actually lower on the conventionally logged site (130 cm^2 vs. 240 cm^2), which suggests that rubber-tired skidders caused injuries no more severe than the mules caused. Despite the smaller surface area, it would be inappropriate to conclude that the rubber-tired skidder did less damage, because so many fewer trees were damaged on the animal skidded site.

One similarity between the systems was the proportion of damage in each damage category. This fact cannot be explained by the difference between an animal and a rubber-tired skidder, since the felling damage and most of the destroyed trees were injured prior to skidding. Two key factors can be identified as the cause for the increased felling damage on the mechanically logged site. First, the higher productivity of the rubber-tired skidder system does not allow previously felled material to be removed prior to the completion of felling. On the mule-skidded site, the logger removes fewer logs per day; consequently, the mule logger gradually opens up the stand by cutting fewer trees at one time and removing the material. On the rubber-tired skidder site more trees have to be felled at one time to supply the skidder, putting the residual trees at higher risk of felling damage. This hypothesis was not tested, but it does offer a possible explanation for the increased damage in all categories.

The species composition of the residual stands is the second factor contributing to the increase in felling damage. The morphological characteristics of shortleaf pine and oaks affect their susceptibility to both skidding and felling damage. As Figure 2 shows, there was a significant pine component on the animal skidded site, but only 1% of the residual trees on the rubber-tired skidded site were pine. Because of the self-pruning of pine, there were fewer lower branches to be damaged by falling trees. There was only one occurrence of felling damage to pine across both sites (Figure 4) which suggests that pine were less susceptible to damage during felling. These results are similar to those observed by MacKinney (1934) in stands of loblolly pine and hardwoods following harvesting with draft horses.

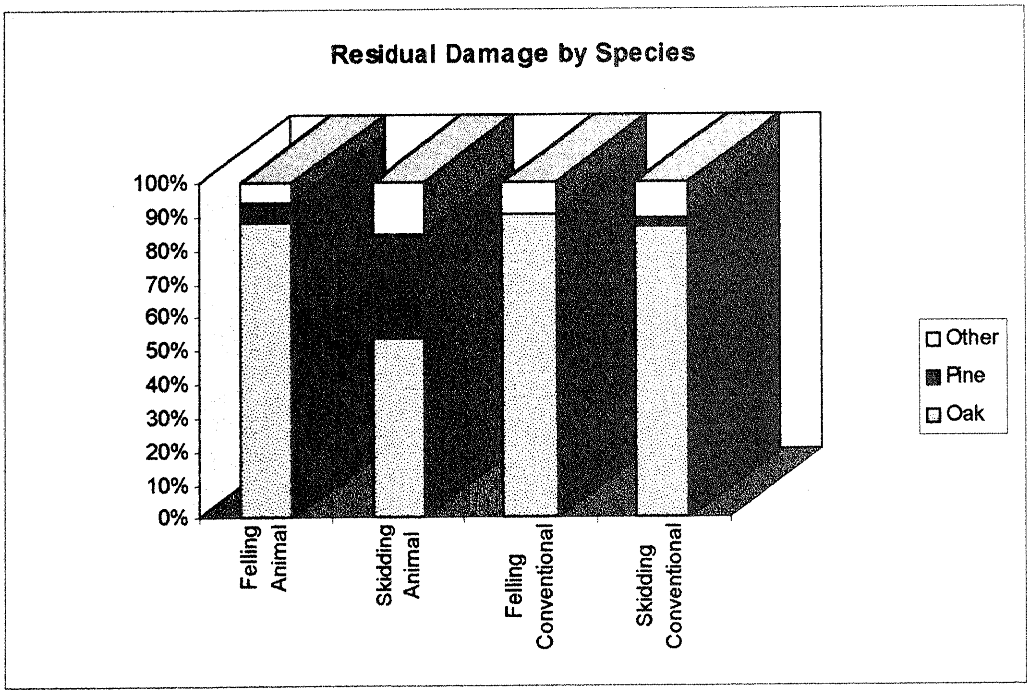

Figure 4. Residual tree damage by species.

Lateral branches on the oak and other non-pine species were an obstacle during felling, so the higher incidence of felling damage on the conventional site is partly explained by the lack of a significant pine component. However, more than three times as many oak and other hardwoods were damaged during felling on the mechanized study area compared to the animal skidded area, so some aspect of the mechanized skidding system must account for the discrepancy in felling damage between the sites. Under the higher production of the rubber-tired skidder operation, our results indicated that more trees were likely to be damaged during felling, so careful planning of roads and skid trails should be done to help minimize felling damage. Skidding damage, unlike felling damage, did not appear to be dependent upon species in this study, because the proportion of pine and other species damaged by skidding was similar to the composition of the residual stand.

CONCLUSIONS

Although this case study cannot conclusively state that animal skidding reduces residual stand damage under all conditions, the summary statistics do suggest that the mule skidding operation resulted in less damage to the residual stand. The reduced damage on the alternative harvest area may be partly attributable to logger care and stand composition, but the animal skidding system was the most significant reason for the reduced damage. Residual plot measurements of trees per acre, volumes and basal areas were similar between the two study areas, but the animal skidder removed more trees and more of the standing volume. With similar residual stocking densities between sites, removing more trees from one stand would be expected to increase the level of stand damage. However, there was a much lower frequency and severity of damage on the mule skidded site which had the most timber removed.

The area disturbed by skidding was also a factor that had a sharp contrast between the two skidding systems. Only 3.1% of the animal skidded tract was disturbed during harvesting, but a minimum of 9.7% of the area logged with rubber-tired skidders was disturbed. This relationship implies that residual damage may be reduced by minimizing the size of machinery used during conventional logging operations. Given the limited availability of loggers who use animals, it is important to apply the results of this and other studies to the standard harvest methods that are available. However, when animal skidding operators are available, there is a clear advantage of using animals to reduce the area disturbed during harvesting.

For forest landowners with primary management objectives other than timber production, animal logging may be a viable option for minimizing residual stand damage. If animal skidding is available, our results suggest that this alternative logging system is effective in reducing tree damage and soil disturbance. Timber cutting can be an important component of any wildlife or recreation management plan, and alternative logging systems could mitigate concerns over the impact of harvesting. Furthermore, the use of effective low-impact logging systems in a multiple-use management paradigm may increase the level of timber production on public lands which is socially optimal. The long-term effects of residual stand damage on site productivity is still unclear, but minimizing stand damage through effective sale administration and appropriate harvest techniques is an achievable and worthy goal.

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