Gentle Logging System Evaluation
(QUANTITATIVE MEASUREMENTS REPORT)

October 30, 2001

Raymond O. Miller
Robert Heyd
Robert Rummer
Dwight Jerome

Published by
Michigan State University
Upper Peninsula Tree Improvement Center
Escanaba, Michigan

The title of this project is Improving Environmental Quality by Identifying, Demonstrating, and Evaluating Hardwood Harvesting Systems on Sensitive Soils. It was funded in part by the United States Forest Service Wood Education Resource Center and by cooperating organizations that include: Michigan State University, USDA Forest Service Hiawatha National Forest, USDA Forest Service Southern Research Station, Michigan Department of Natural Resources, USDA Natural Resources Conservation Service, and the Michigan Association of Timbermen.

Gentle Logging System Evaluation
QUANTITATIVE MEASUREMENTS REPORT

Raymond O. Miller, Robert Heyd, Robert Rummer, and Dwight Jerome[1]

Abstract

Partial cutting of many productive hardwood forests in Michigan's Upper Peninsula with traditional harvesting systems must be restricted to brief periods when damage to the site and residual stand can be minimized. These stands occur on sites that tend to be wet and vulnerable to soil damage most of the year. Newer harvesting equipment may be gentler to the soil and present the opportunity to extend the time during which operations may be safely undertaken on these sensitive sites. This project evaluated five, newer, cut-to-length harvesting systems as they operated on a vulnerable site near Munising, Michigan in May of 2001.

Allowing for variation of initial soil and stand conditions, all systems performed reasonably well; leaving the site fairly undisturbed and causing minimal damage to residual trees. The larger systems deviated slightly more from the forester's prescription for the stand than did a smaller system, but these larger systems were more productive in terms of cost per green ton harvested. Skid-steer prime movers disturbed a greater proportion of the ground than articulated prime movers but in no case did rutting or compaction exceed acceptable limits. Harvesting systems like these may provide the means for managing productive hardwood stands on sensitive sites where logging has previously been considered too risky.

Introduction

A significant portion of the northern hardwood forest in Upper Michigan grows on productive sites where seasonally moist soils are subject to damage from mechanized harvesting equipment. Management of these sites is severely limited without a viable harvesting option. Recent advances in harvesting equipment designs have produced machines that may be able to operate on these sites without causing as much damage as traditional systems. This project was designed to evaluate several types of newer harvesting systems on a typical, sensitive site in Upper Michigan.

A forest in north-central Alger County near Munising, Michigan was chosen for the evaluation. The land is managed by Shelter Bay Forests and supports a productive hardwood forest on seasonally moist soils. It was also easily accessible for both equipment and visitors.

The soils on the site are of loamy glacial till origin and are deep and moderately well drained. Typically, these soils have a firm, dense fragipan layer about two feet below the surface that restricts vertical water movement and creates a perched water table in the early spring. Areas near the bottom of slopes and in depressions can stay excessively wet well into the growing season. We chose to conduct our evaluation in early spring, shortly after snowmelt, to ensure that the water table would be high.

The fragipan and perched water table in sites like this forces trees to develop shallow root systems. This leaves the trees vulnerable to windthrow. As a result, this site was strewn with abundant windthrow mounds. These mounds produce drier microsites on their tops while the adjacent depressions form wetter microsites. Forwarders that pitch around while moving over mounds often cause injuries high on standing trees where their bunk stakes scrape the bark. This microrelief challenged equipment operators to both avoid disturbing the wetter depressions and avoid injuring residual trees in the stand.

The study forest is dominated by second growth, pole-sized sugar and red maple with black cherry, American beech, and yellow birch associates. There are conifers (eastern hemlock, balsam fir, and white spruce) scattered sparsely

[1] The authors are respectively: Research Forester, Michigan State University; Forest Health Specialist, Michigan Department of Natural Resources; Project Leader, Forest Operations and Engineering Research Unit, USDA Forest Service, Southern Research Station; and Resource Soil Scientist, USDA Natural Resource Conservation Service.

throughout the stand. A preliminary inventory showed that: the average basal area was 135 sq. ft., there were an average of 325 trees per acre with an average diameter of 10” DBH, and the average volume was 37 cords per acre.

The first day of this two-day demonstration exhibited the harvesting systems to a broad audience of professionals. On the second day we evaluated the systems in some detail. Three separate reports provide the basis for evaluating the harvest systems:

- A diverse group of observers was selected to watch the systems and interact with the manufacturers and operators during both days of harvesting. A summary of their impressions and conclusions is presented in the ***Observer Report***.
- Loggers, foresters, landowners, resource specialists, and others who attended the first day’s operations were given a questionnaire and asked to share their impressions. More than 200 of these questionnaires were summarized and discussed in the ***Participant’s Questionnaire Report***.
- Forest scientists made a series of measurements in the areas harvested during the second day’s operation. Summaries of these data were made to describe the stand before and after harvesting as well as to assess the harvesting equipment itself. Those summaries are presented in this report, the ***Quantitative Measurements Report***.

We stress that there was no replication of this evaluation either in time or space. This leads to a great deal of statistical uncertainty about the numbers reported here. They should serve as only one of several methods for evaluating what happened on these two days in May of 2001. Manufacturer’s names are used in the summaries below to help the reader identify the various systems. We admonish the reader to refrain from using the data to rank systems as if looking for a winner or loser. Remember that on a different day, with a different operator, or in a different place these relative rankings would probably be quite different.

The study forest was divided into ten harvesting areas of roughly equal size – about 2.5 acres each. Five of these areas were used on the first day (May 9, 2001) for visitors to observe the harvesting systems in operation and to allow the operators to become familiar with stand conditions. The remaining areas were harvested on the second day (May 10, 2001). Quantitative measurements reported here were obtained from this second set of areas.

Trees to be cut were marked by a crew from the Michigan Department of Natural Resources several weeks prior to harvesting. Trees were painted so that the marks were visible from all sides. An attempt was made to leave a uniformly stocked stand (a basal area of about 80 sq. ft. per acre), but allowances were made for the natural variability throughout the site.

Five harvesting systems were chosen to represent a range of equipment types. A summary of this equipment appears in Table 1. Two systems employed large, tracked, skid-steer harvesters, two employed rubber-tired, articulated harvesters, and one employed a small, tracked, skid-steer harvester. All harvesting was “cut-to-length” but with a variety of booms and harvesting heads. All forwarding was done with either six-tired or eight-tired articulated machinery. All rubber-tired machines were equipped with steel Olofsfors Eco-Tracks over their tandem tires. No forwarding was done in the area harvested by the small “Harvest Systems” machine because the unit scheduled for that area was withdrawn at the last minute. Harvesting systems were randomly assigned to five evaluation areas and allowed one day to operate. All but the smallest system completed the thinning of their area within that time.

The site was fairly dry for the first day’s harvesting but a heavy rain on the evening of May 9, 2001 created the type of wet conditions we had anticipated for the second day. Measurements of the harvesting systems were made during the second day’s operation and on the following day (May 11, 2001). Five teams of researchers recorded data to describe the following:

(1) The overstory of the stand before and after the harvest,
(2) Compliance with the harvesting prescription,
(3) Damage to residual trees,
(4) Machine operating costs and productivity,
(5) Ground disturbance and the extent of rutting, and
(6) Rutting depth and compaction on main skid trails.

The methods employed and results obtained by each of these groups are discussed below.

Table 1. Harvesting system components used for Gentle Logging System Evaluation.			
System Description	**Manufacturer**	**Harvester**	**Forwarder***
Tracked harvester and 6-wheeled forwarder	Timberjack	608s, 25’ articulated boom (Figure 4)	1010, 6-wheeled (Figure 5)
Tracked harvester and 6-wheeled forwarder	Fabtek	FT133, 21’ articulated boom (Figure 6)	FT346b, 6-wheeled (Figure 7)
6-wheeled harvester and 8-wheeled forwarder	Ponsse	Ergo, 33’ telescopic boom (Figure 8)	Caribou, 8-wheeled (Figure 9)
	Valmet	911.1, 32’ telescopic boom (Figure 10)	840, 8-wheeled (Figure 11)
Small, tracked harvester with no forwarding	“Harvest Systems”	Link-Belt LS1600, 21’ articulated boom, (Figure 12)	NONE
* - all forwarders were equipped with Olofsfors Eco-tracks (Figure 13)			

1. Stand Overstory Assessment

Three, 1/10th-acre plots were randomly established in each of the five harvesting evaluation areas. All trees in the plots larger than 4” DBH were measured to determine their DBH, species, and merchantable height. A record was made for each tree to indicate whether or not it was marked for removal. Plot centers were marked with a steel pin driven flush with the ground, and located with GPS coordinates. Equipment operators were unaware of plot locations.

Plots were revisited immediately following the harvest to determine if (a) all marked trees had been cut and if (b) any unmarked trees had been cut. Residual trees were examined for harvest related injuries.

Pre-harvest stand density (expressed as basal area per acre and stems per acre) and volume (in cords per acre) was calculated for each harvest area. Similar calculations were made for the trees that were harvested and for those that remained after harvesting. These data were summarized and are presented in Table 2.

The stand was fairly variable prior to the harvest: Basal area ranged from 103 to 137 square feet; the number of trees per acre varied between 237 and 427 stems; and standing volumes ranged from 26 to 37 cords per acre. The foresters who marked the stand tried to reduce variation in stand density by thinning some areas more heavily than others. This produced a 20% to 40% reduction in basal area, a 30% to 50% reduction in stems, and a 17% to 40% reduction in standing volume. Some areas had numerous small trees removed while others had fewer larger trees removed. This created a difference among areas that undoubtedly effected harvesting operations independently of the system employed. The experimental design chosen here left no way to remove this variability from the analysis and it is for

Table 2. Stand conditions before and after the harvest including the amount of timber removed.

Harvest System	Area Size (acres)	Original Stand			Removed in Harvest			Residual Stand		
		BA/acre (ft^2)	Trees/acre	Cords/acre	BA/acre (ft^2)	Trees/acre	Cords/acre	BA/acre (ft^2)	Trees/acre	Cords/acre
Timberjack	2.5	103	247	26	32	87	7	71	160	19
Fabtek	2.7	106	237	27	36	83	9	70	154	18
Ponsse	2.8	127	427	32	46	137	11	81	290	21
Valmet	2.6	137	243	37	59	117	15	78	126	22
“Harvest Systems”	3.4	110	263	29	20	70	5	90	193	24

Table 3. Adherence to thinning prescription.		
MARKED TREES THAT WERE NOT CUT		
Harvest System	**% of marked trees**	**Average DBH**
Timberjack	4%	5”
Fabtek	7%	15”
Ponsse	0%	--
Valmet	3%	23”
“Harvest Systems”	63%	8”
UNMARKED TREES THAT WERE CUT		
Harvest System	**% of unmarked trees**	**Average DBH**
Timberjack	8%	7”
Fabtek	2%	6”
Ponsse	7%	8”
Valmet	2%	12”
“Harvest Systems”	0%	--

this reason that the admonition to refrain from ranking systems was issued above. In keeping with this, we limit the following discussions to the broad trends in the data. These data are labeled using the manufacturer’s names for convenience. The order of the lists is always the same and has no significance.

2. Compliance With Harvest Prescription

Foresters marked trees to be cut from the site according to accepted silvicultural guidelines for the region. Machine operators were told to cut only marked trees whenever possible but were allowed to deviate from the marking in order to reduce damage either to the site or the residual stand. Data collected from the harvesting area sample plots (described in section 1 above) were compiled to determine the extent to which the operators had deviated from the harvesting prescription. This was expressed in two ways. The number of MARKED trees that were NOT cut was tabulated to provide an indication of the number of undesirable trees left behind. The number of UNMARKED trees that WERE cut was tabulated to provide an indication of the number of future crop trees that were lost. These summaries are presented in Table 3.

The smallest machine (by “Harvest Systems”) did not complete the thinning in its harvest area because its rate of production was not as high as the larger machines. As a result, there were a number of marked trees that were not cut in that area. This does not reflect badly on the operator or the equipment. In fact, this was the only system that did not cut any unmarked trees, removing no future crop trees. Its small size was a distinct advantage in that respect.

In areas harvested by the other systems, 3% to 7% of marked trees were not cut. Most of these were probably left because they were inaccessible or too large for the processor to efficiently handle. In normal harvesting operations a power saw operator would have followed the mechanized harvesters to remove these scattered individuals, but this was not done here. There appears to be more chain saw work to be done in areas harvested by the large tracked harvesters than in the others.

Additionally, 2% to 8% of unmarked trees were cut by these larger systems but there is no clear trend among systems. Most of these trees had fairly small diameters. We had told the equipment operators that they could deviate from the marking prescription in order to reduce site impact from their machines. They were also aware that we would be reporting the number of deviations. There appears to be a balance to be struck between an optimal silvicultural thinning and the maneuverability of large machines on these sites. Foresters may need to allow a little more space for equipment than we did when developing prescriptions for these stands. They should also insist that loggers use only their most skilled machine operators.

3. Damage to Residual Stand

Harvesting operations frequently cause physical damage to the above-ground portions of the remaining trees. This damage may include broken tops that render the tree useless as a future crop tree, wounds that discolor wood and lower wood quality, and bark or limb injuries that provide routes of infection into previously healthy trees. Wound

Table 4. Damage to residual trees.				
Harvest System	**Serious Injury**	**Degrading Injury**	**Minor Injury**	**All Injuries**
	% of residuals			
Timberjack	4	13	2	19
Fabtek	2	16	5	23
Ponsse	6	1	2	9
Valmet	0	13	0	13
“Harvest Systems”	0	2	0	2

infection may even weaken or kill the tree. Residual trees in the inventory plots (described in section 1 above) were examined for injuries after the harvest.

Most of the wounds were scrape-type injuries that exposed but did not penetrate the xylem. Most were low on the tree (2’ – 6’ above ground) but there were a few high felling injuries to branches and tops. No forwarder bunk stake scrape injuries were noted. Trees with wounds exposing more than four square inches of xylem near the root collar were considered to have the most “serious” injuries. These often lead to sapstreak (*Ceratocystis coerulescens*) infection, which causes decline and eventual death of sugar maple. Trees with similar size wounds higher on the bole were classified as having “degrading” injuries because these frequently lead to wood discoloration and degrade future log value. Trees with smaller wounds were noted but were classified as having “minor” injuries. A summary of tree damage in the harvest areas appears in Table 4.

The number of trees with serious injuries varied from 0% to 6% of residual stems. Those with injuries likely to cause degrade of future products ranged from 1% to 16% of residuals. Skid-steer harvesters may do slightly more damage overall (22%) than articulated units (11%), but these differences may also be due to boom type, harvester head, stand density, or operator skill. Our experimental design does not allow us to determine which among these variables is responsible for the difference. The small “Harvest Systems” machine, being highly maneuverable, caused the least damage (2%) to the residual stand.

Damage was scored here using a conservative criterion of four square inches. A relaxed criterion would produce a dramatically different assessment of overall damage. There were very few wounds in excess of 20 square inches and none in excess of 100 square inches. Observers were generally pleased with the condition of the residual stand compared with other similar operations with which they were familiar.

4. Machine Productivity and Operating Costs

Productivity was established for each of the five harvesting systems as the ratio of volume produced to productive machine time. An observer was assigned to each harvesting area. They recorded the interval between the start of operation in the morning and the completion of operation in the evening (Scheduled Machine Hours). They also recorded the time of all delays or down-time for each piece of equipment. Productive Machine Hours was calculated as the difference between the time each piece of equipment was scheduled to operate and the time it was idle. Harvested material was forwarded to the roadside, sorted, and piled by product classification independently for each harvesting area. Pulpwood volume was estimated by measuring pile dimensions, converting these to cord volume, and subsequently to total green tons. All other products were piece scaled to cubic foot volume and converted to green tons. Volume production was calculated by summing the green weight of all products harvested from each area.

The forwarding function required less productive time than the harvesting function in all of our areas because the extraction distance was relatively short. For our analysis it was assumed that in larger operations, harvester productivity would be the limiting function and that a single harvester and forwarder would operate in balance. Maximum utilization of the harvester was assumed as 85 percent of total Scheduled Machine Hours.

Operating cost for each harvesting system was estimated using the “machine rate method.” This is a standard calculation of average hourly owning and operating costs over the useful life of a machine. The calculation includes purchase, operating, and labor costs but does not include profit, overhead, or mobilization costs. Approximate base

Table 5. Machine Productivity and Operation Cost.							
Harvest System	**Productivity tons/PMH***	**System Cost**	**Cost per SMH****		**Cost per Green Ton**		
			Harvester	**Forwarder**	**Harvester**	**Forwarder**	**Total**
Timberjack	15.02	$665,000	$115	$75	$9.01	$5.87	$14.88
Fabtek	15.47	$490,000	$85	$70	$6.46	$5.32	$11.78
Ponsse	15.52	$702,000	$120	$75	$9.10	$5.69	$14.79
Valmet	15.21	$707,000	$115	$75	$8.90	$5.80	$14.70
"Harvest Systems"	4.29	$145,000	$50		$13.71		

* - PMH = Productive Machine Hour
** - SMH = Scheduled Machine Hour

machine, tire and track prices were provided by manufacturers. Fuel and lubricant consumption were taken from a survey of 133 similar machines operating in Scandinavia. We assumed a labor rate of $20 per hour (including fringe benefits) based on current Davis-Bacon wage rates for general laborers in Alger County, Michigan. Because of the approximate nature of these cost estimates, hourly machine rates were rounded to the nearest $5. Operating costs were expressed both as dollars per Scheduled Machine Hour and dollars per green ton produced.

A summary of these calculations for each harvesting system appears in Table 5. Note that the "Harvest Systems" harvester worked without a forwarder and thus the reported productivity and costs are only for the harvesting function. Productivity of the four complete systems was essentially equivalent (about 15 tons per Productive Machine Hour). This suggests that tree size was well within the functional limits of these machines. The production rate of the small tracked "Harvest Systems" harvester was significantly lower. This rate was expected because this machine had only one-third to one-fourth the horsepower of the larger harvesters. The Fabtek system had the lowest overall cost of operation, primarily due to the lower initial cost of the Fabtek harvester. It is important to remember that these results are based on costs for new equipment operating in a single stand condition. Long-term studies would be necessary to identify differences in maintainability, reliability, and durability among the systems tested.

5. Extent of Ground Disturbance and Rutting

Nearly all forest activities disturb the soil. The effects range from purely visual to biologically significant. On sensitive sites like this one, the primary concern is with soil disturbance that penetrates or compacts the root zone. Manufacturers claim that newer harvesting systems disturb the soil less than conventional systems because they have lower ground pressure and make fewer and more diffuse trips through the stands.

Compaction and rutting in skid trails was measured and will be described later, but this portion of the assessment was designed to describe the extent of soil disturbance from these harvesting and forwarding operations. Transects running perpendicular to the main axis of machine movement were randomly established in each harvesting area. Transects ranged from 550' to 930' long and were 10' wide. Ground disturbance was scored throughout each transect using 5' x 5' square plots. Soil in these plots was classified as: (a) not disturbed, (b) leaf litter disturbed, (c) surface soil in the A horizon exposed, or (d) sub-soil in the B horizon exposed. Observers were told to look for signs that the machine had passed through the plots, so the presence of ruts (at least 2" deep) was also noted for each plot. These data were summarized and are presented in both Table 6 and Figure 1.

76% to 98% of the ground within each harvesting area was either undisturbed or merely had the litter layer disturbed. The systems with articulated harvesters disturbed 14% to 15% of the ground while the systems with

Table 6. Ground Disturbance and Extent of Rutting.						
Harvest System	**Undisturbed**	**Leaf Litter Disturbed**	**A Horizon Exposed**	**B Horizon Exposed**	**Rutting**	**Portion of Harvest Area Sampled**
Timberjack	54%	22%	10%	14%	16%	5%
Fabtek	53%	27%	11%	9%	11%	8%
Ponsse	56%	30%	8%	6%	6%	6%
Valmet	52%	33%	13%	2%	3%	6%
"Harvest Systems"	82%	16%	2%	0%	1%	5%

heavy skid-steer harvesters disturbed 20% to 24% of the ground. The latter type of equipment appears to have caused more disturbance of the A horizon as well. This was expected from machinery that scuffs the ground while turning. The smallest machine disturbed the least amount of the site (2%) but it only harvested 40% of the marked trees and these were not forwarded from the area.

The trees created some ground disturbance when they fell and were processed. This may have accounted for much of the disturbance to the leaf litter seen by the observers. Machine operators also tried to travel on top of the slash left by the processing operation, and this also helped to reduce the observable disturbance to the site.

Ground disturbance can be reduced by increasing the distance between paths taken by equipment through the stand. This is influenced by the operator but can also be effected by the type of boom and harvesting head on the harvester. The booms mounted on the articulated harvesters had a longer reach (32' to 33') than those on the skid-steer harvesters (21' to 25'). Machines with longer booms could reach out further from a travel corridor and so required fewer passes through the stand to complete the harvest.

The abundance of minor ruts in the areas followed a pattern similar to that seen for ground disturbance. The articulated harvesters produced minor rutting (3% to 6%) while the skid-steer harvesters produced slightly more (11% to 16%). The reasons for this are probably similar to those discussed above. The smallest machine produced the least amount of noticeable rutting (1%) but, again, operations in this area were quite different from those in the other areas.

The criteria we used to assess the extent of ground disturbance and rutting was fairly conservative. Observers were quite pleased with the final appearance of all the harvesting areas. Based on these comments, and lacking a universal standard by which to judge the systems, we have to assume that none of the disturbance numbers reported here represent excessive damage.

6. Rutting Depth and Compaction on Main Skidways

Soil on this site is susceptible to rutting and compaction by harvesting equipment in the spring and at other wet times of year. Although this type of soil disturbance can change site hydrology, we were most concerned here about possible deterioration of the rooting zone and subsequent losses to stand growth and vigor. The extent of rutting was described previously. Here we look at the severity of rutting as described by skid trail rut depth and soil compaction in these ruts. The area where the Harvest System's machine operated was not sampled for rut depth or compaction because no forwarding was done there. Forwarding is the operation that tends to produce most of the ruts because of the weight carried by the loaded machinery (refer to Table 6 to see that there was nearly no evidence of rutting in the "Harvest Systems" area).

In general, State and Federal timber sale contracts in this region define rut depths in excess of 7" as unacceptable. Although less severe rutting is always desirable, contract language usually insists that operations cease when soil conditions allow ruts of this depth to form. We measured rut depths in each harvest area in randomly chosen portions of two, main skid trails at 50-foot intervals for a distance of 200 feet (Figure 2). The distance from the bottom of the rut to the average ground level on either side of the rut ("d" in Figure 3) was recorded at each location. Ten samples of rut depth were thus taken within each harvest area. A summary of these data is presented in Table 7.

Soils at the test site were of the Munising series with textures ranging from sandy loams to fine sandy loams. The United States Department of Agriculture's Natural Resource Conservation Service (NRCS) has defined an ideal bulk density for these types of soils to be between 1.40 and 1.60. They have further indicated that bulk densities in excess of 1.80 will restrict root growth in these soils. We measured the soil compaction at the same points in the

Table 7. Depth of Rutting in Harvest Areas.

Harvest Area	**Average Rut Depth (inches)**		
	First Skidway	**Second Skidway**	**Area Average**
Timberjack	4.3	3.4	3.8
Fabtek	3.4	3.3	3.4
Ponsse	5.1	4.8	5.0
Valmet	3.8	4.9	4.4

Table 8. Soil Compaction from Rutting.					
Harvest System	**Soil Moisture (%)**		**Bulk Density**		
	Outside Ruts	Inside Rut	Outside Ruts	Inside Ruts	% Increase
Timberjack	22	20	1.17	1.66	42%
Fabtek	24	24	1.16	1.48	27%
Ponsse	19	22	1.38	1.56	13%
Valmet	28	22	1.01	1.47	45%

major skid trails where ruts depths were measured. A pair of soil cores were extracted at each location – one core from within the rut and another from undisturbed soil nearby. Three-inch diameter soil core rings were driven to a depth of 3 inches and their contents were transferred to bags. Ten pairs of samples were obtained in this way for each harvest area. These samples were weighed, oven dried, and reweighed within one week of their collection. Moisture content and bulk density were calculated for each sample. A summary of these data is presented in Table 8.

The average rut depth throughout the study area was less than 5”, well below the level of concern mentioned above. Only 12% of all rut measurements were in excess of 7” and these were confined to the wettest part of the site. These areas could have been avoided but we did not give the operators that option. Rutting was also more pronounced in the depressions associated with past windthrows. The soil in these “pits” had an elevated organic matter and moisture content, leaving it more susceptible to rutting than the sandier and drier soil in the adjacent “mounds.”

The average bulk density of undisturbed soil was less than the “ideal” figures provided by NRCS, which indicates a lack of compaction throughout the site prior to harvesting. The average bulk density of disturbed soil within the ruts was well below 1.80. Only one of the 40 disturbed-soil samples exceeded the bulk density threshold set by NRCS as being unacceptable. Root growth and consequent stand vigor and health will probably not be reduced in the wake of any of these harvests.

The proportional increase in bulk density reported in Table 8 varied widely among systems. This could be due to equipment weight, load weight, number of equipment passes, soil moisture, soil texture, or organic matter content. Since this study was not designed to study soil compaction comprehensively, we cannot determine the exact reason for the variation seen in bulk density increases. In general, though, all of the equipment tested here had sufficiently low ground pressure or drove over slash effectively to avoid compacting the soil beyond tolerable limits.

Conclusion

The area where we conducted this evaluation was typical of the variable, second-growth hardwood stands of the upper Lake States. We conclude that, under conditions similar to those at this site, thinnings can be performed during wet times of the year on these sites by large, modern harvesting equipment without causing undue damage to either the site or the residual stand. The land manager must, however, pay close attention to how the thinning is marked, to the type of equipment selected, and to the skill level of the operators of that equipment. This will require the foresters to be familiar enough with the equipment and the sites to develop management plans that accommodate both. We recognize that there will still be times when harvesting operations must be stopped due to wet soil conditions, but expect that this new equipment will widen the window of opportunity on these sites.

Throughout the preceding discussion we pointed out that differences among systems may be due to many factors, including: steering methods, boom type, harvesting head, machine weight or ground pressure, stand conditions, intensity of thinning, and operator skill. Our study design prevents us from identifying which factors are chiefly responsible for the variation in performance that we observed. Future research should examine these factors in more detail so that harvesting operations can be further improved. There may be engineering answers to some gentle logging questions but all the observers of this demonstration agreed that the person in the cab was not only steering the machine, they were steering the success or failure of the operation.

There is nothing new about expecting foresters to understand the biological systems of the forest or for loggers to understand the mechanical systems of their equipment. The critical, new element that this equipment brings into focus is the need for each group, foresters and loggers, to better understand the business of the other. Foresters need to recognize and accommodate the operational needs of newer harvesting systems. Operators of these modern machines must not only be familiar with the operation and maintenance of their equipment but also with the biological objectives of the forester. With increased expectations and oversight by resource professionals, landowners, and the public, there is little margin for error in the management of forests on sensitive sites. Everyone from the planner to the forester to the operator on the ground must join in to obtain the desired result – healthy and productive forests that sustain a range of values for future generations.

Figure 1. Extent of ground disturbance in harvested areas.

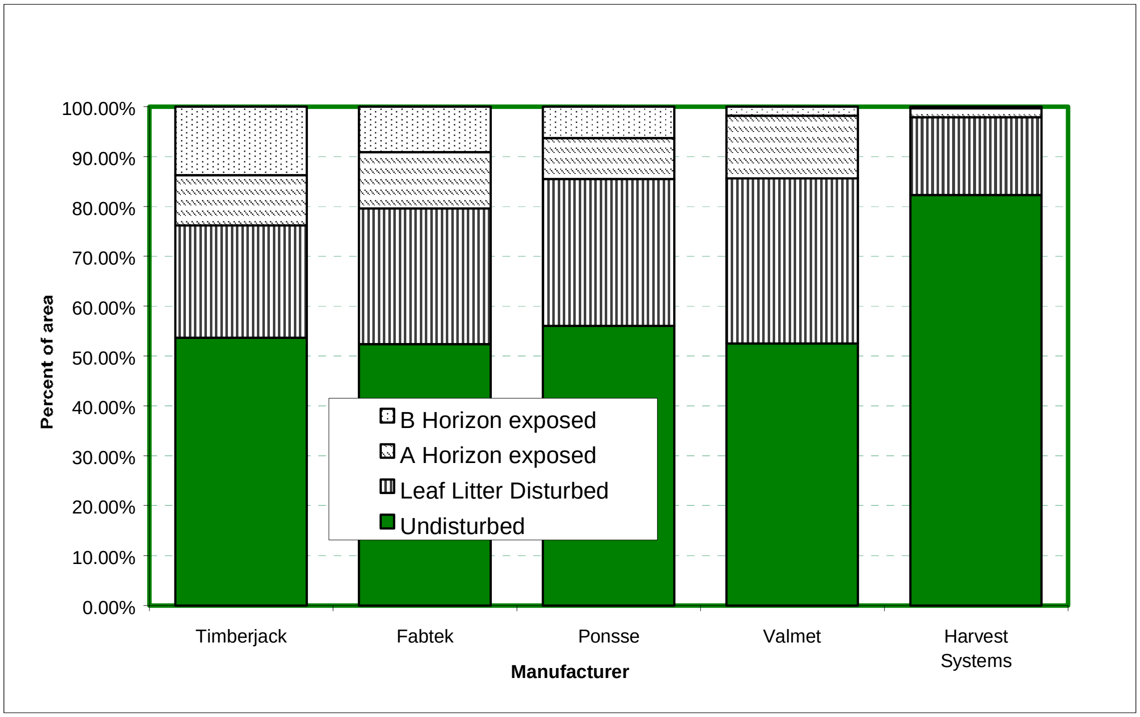

Figure 2. Representation of sampling points along a major skid trail.

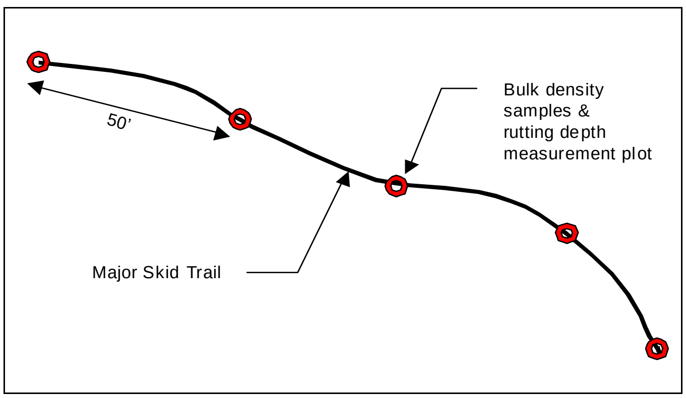

Figure 3. Rut depth and bulk density core sample locations.

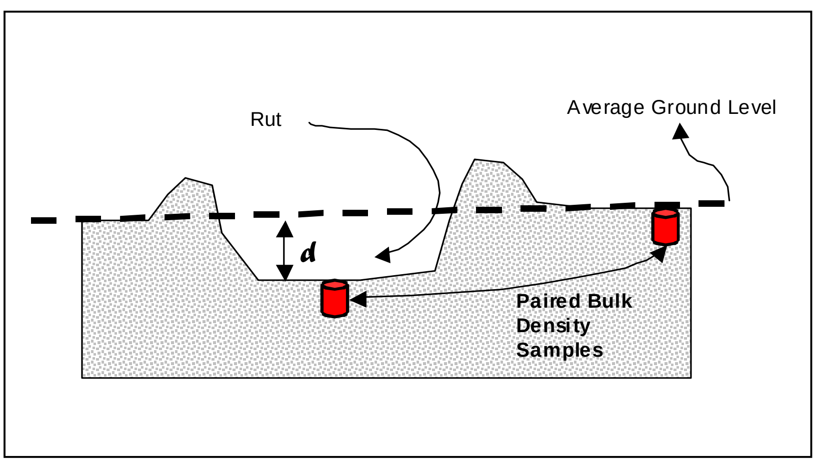

Figure 4. Timberjack 608s Harvester

Figure 5. Timberjack 1010 Forwarder

Figure 6. Fabtek FT133 Processor

Figure 7. Fabtek FT346b Forwarder

Figure 8. Ponsse Ergo Harvester

Figure 9. Ponsse Caribou Forwarder

Figure 10. Valmet 911.1 Harvester

Figure 11. Valmet 840 Forwarder

Figure 12. “Harvest Systems”

Figure 13. Olofsfors Eco-Tracks