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AN ASSESSMENT OF SOIL DISTURBANCE FROM FIVE HARVESTING INTENSITIES

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Summary:

Surface soil disturbance was compared among a commercial thinning, group selection, patch cut, 2-age, and clearcut. The thinning, group selection and patch cut units had significantly higher percentages of undisturbed area. The 2-age unit had a significantly higher percentage of area disturbed with litter in place. The clearcut unit had a significantly higher percentage of area with litter removed and soil exposed. The clearcut, 2-age, patch cut, and group selection units had significantly higher percentages of litter and soil mixed when compared to the thinning unit. No significant differences were found among all units for soil exposed greater than 4 inches. The clearcut and 2-age units had significantly higher percentages of area with newly deposited litter.

Keywords:

Harvesting, soil disturbance, silvicultural prescription, skid trail, erosion

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An Assessment of Soil Disturbance from Five Harvesting Intensities

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INTRODUCTION

Over the past decade public concern in the Pacific Northwest about the visual and ecological effects of clearcut harvesting has increased. In response, natural resource managers are testing new silvicultural approaches to determine if various levels of harvest intensity can reduce both visual and ecological effects while maintaining economically viable harvesting operations. During this same time, mechanized harvesting systems have been introduced that can efficiently handle the large tree sizes typically encountered in second-growth forests of the Pacific Northwest. The outcomes of using a combination of new mechanized equipment in these new silvicultural regimes leaves many questions unanswered. In this paper, the level of soil disturbance associated with such new approaches is examined.

With any mechanized harvesting system soil disturbance is inevitable. Clayton (1990) reports that tractor operations disturb an average of 30 percent of the activity area compared to 4 percent for helicopter, 9 percent for skyline, and 23 percent for ground cable systems. Logging activity causes soil to be displaced, compacted, scarred, or churned. Removing the organic layer and exposing the mineral soil can result in erosion problems and increased sedimentation in streams. Amounts of erosion and stream sedimentation following logging may vary directly with the degree of disturbance caused by timber removal (Dymess, 1965). The degree or severity of disturbance can be influenced by factors such as type of equipment, soil type, moisture content, slope, time of year, and skid trail orientation (Allen and others, 1999).

In addition to soil surface disturbance, there are concerns about the effect of soil compaction on site productivity. With reduced infiltration and aeration due to compacted soil, growth potential of seedlings can be significantly reduced. Froehlich reports that studies on growth show that growth reduction varies from 5% to over 50% (Froehlich, 1977). Since compaction is highest in skid trails and landings, it is desirable to minimize the total area occupied by these areas.

This paper presents results of a study conducted in south-central Washington State that assessed the effects of different harvesting intensities on soil surface disturbance. Five units that were harvested under different silvicultural prescriptions were surveyed. A comparison of percent soil surface disturbance for seven disturbance classes is presented. Percent area in primary and secondary skid trails and processing sites for each method is also reported.

Study Area and Stand Conditions

The soil disturbance survey is part of a much larger, long-term evaluation of alternative silvicultural options for managing second-growth forests in western Washington (Curtis *et al.*, 1996). The study area is located about 15 miles southwest of Olympia, Washington, on land

owned by the Department of Natural Resources (DNR). The topography of the site is gently rolling, with most of the area having a slope from 10 to 30 percent, although some short hill sections have slopes up to 50 percent. Elevation varies from about 1000 to 1,300 feet. The entire area is mapped as having the Olympic soil series (USDA SCS, 1987). The Olympic series consists of very deep, well-drained soils that occur on benches, hillsides, and broad ridgetops. These soils formed in residuum and colluvium derived dominantly from basalt. They are classified as silty clay loams, silt loams, and clay loams. DNR forest soil management interpretation guidelines allow ground skidding on these soils if conditions are not excessively wet (Table 1). The entire area was harvested without shutdowns due to wet conditions; however, equipment was moved to avoid particularly wet areas during periods of heavy rainfall.

Table 1. Summary of Forest Soil Management Interpretations for Olympic clay loam.'

Category	Rating
Slope Stability	
Natural	Stable
Disturbed	Stable
Timber Harvest	
Logging System Limitation	Moderate
Compaction Potential (Moist)	High
Displacement Potential (Dry/Moist)	Low
Puddling Potential (Wet)	High
Erosion Potential	Medium
Regeneration	
Drought Potential	Low
Plant Competition	Severe
Windthrow Potential	Low

[1] Taken from State Soil Survey, Report for the Central Area, Forest Land Management Division, State of Washington Department of Natural Resources, approx. 1983.

The Olympic soil series has a medium erosion potential rating on slopes of 0 to 30 percent, the predominate slope class for the study area. Surface erosion can be significant, and extensive erosion can occasionally occur on skid trials if the soil surface is heavily disturbed. The series also has high puddling and compaction potentials. The high puddling potential indicates that water puddling occurs during wet soil conditions after equipment traffic has destroyed soil structure by compression and shearing. This results in an impermeable surface that ponds water. The soil will not support equipment when wet. Puddling results in loss of productivity due to restricted air and water movement in the soil. The level of compaction increases with increasing passes of equipment and is sensitive to soil moisture conditions.

The site is covered with 70-year-old second-growth forests that naturally regenerated after the original forest was clearcut and burned in the early part of this century. The overstory is primarily Douglas-fir (*Pseudotsuga menziesii)* and western hemlock (*Tsuga heterophylla)* with small components of red alder (*Alnus rubra),* and western redcedar (*Thuja plicata*) (Table 2a).

Table 2a. Pre- and post-treatment stand characteristics of the six units.

	Pre-harvest (1997)			Post-harvest (1998)			Post-harvest Change (1998)		
Treatment	Basal Area (sq. ft.)	Stocking (trees/ac.)	Diameter[1] (in.)	Basal Area (sq. ft.)	Stocking (trees/ac.)	Diameter[1] (in.)	Basal Area (%)	Stocking (%)	Diameter[1] (%)
Control[2]	--	--	--	261	113	20.6	--	--	--
Clearcut	234	142	17.4	0	0	0	-100	-100	-100
2-Age	242	150	17.2	46	16	23.3	-81	-89	+35
Thinning	258	189	15.8	192	71	22.2	-26	-62	+41
Group Selection	242	146	17.4	142	45	24.0	-41	-69	+38
Patch Cut:									
Entire Unit[3]	233	129	18.2	161	53	23.6	-31	-59	+30
Thinned only[4]	233	129	18.2	201	66	23.6	-14	-49	+30

[1] Quadratic mean diameter:
[2] The Control unit was only measured in 1998.
[3] Includes the entire unit, both areas that were clearcut (patches) and areas that were only thinned surrounding the patches.
[4] Includes only the areas outside of the clearcut patches.

Table 2b. Volume harvested from each of the six units.

Treatment	Net Volume Harvested (MBF/ac.)
Control	0
Clearcut	44.1
2-Age	30.6
Thinning	8.3
Group Selection	13.0
Patch Cut	18.7

Silvicultural Treatments

Six silvicultural treatments were laid out as shown in Figure 1. Harvesting of five of the units was conducted from April to September of 1998. Table 2b lists the net volume harvested from each unit. The units received the following treatments:

- Control--no harvesting was prescribed. The area will be allowed to grow, unthinned, for 60-70 years.
- Clearcut--all of the merchantable and unmerchantable trees were cut. The area will be replanted and managed as an even-aged stand on a 60-year rotation schedule.
- Two-age--basal area was reduced by 81 percent, leaving approximately 16 large dominate and co-dominate overstory trees per acre. The area will be underplanted with a mixture of Douglas-fir, western hemlock, and redcedar. The residual overstory trees will be allowed to grow for 60-70 years.
- Thinning--basal area was reduced by 26 percent, leaving approximately 71 trees per acre. The unit will be repeatedly thinned by a similar amount every 15 years for 60-70 years.
- Group selection with thinning--basal area was reduced by 4 1 percent, leaving approximately 45 trees per acre. The area was first marked as a regular thinning unit, and then small, scattered areas (up to 1.5 acres) were marked to create openings over approximately 20 percent of the unit. The openings will be planted with a mixture of Douglas-fir, western hemlock, and redcedar. A similar treatment will be applied every 15 years.
- Patch cut with thinning--approximately 20 percent of the unit was clearcut in four large, scattered patches (1.5-5 acres in size). The remaining area surrounding these patches was thinned. For the entire unit (patches and thinned areas combined), the basal area was reduced by 3 1 percent, leaving approximately 53 trees per acre. For the areas that were only thinned, the basal area was reduced by 14 percent, leaving approximately 66 trees per acre. The patches will be planted with Douglas-fir. A similar treatment will be applied every 15 years.

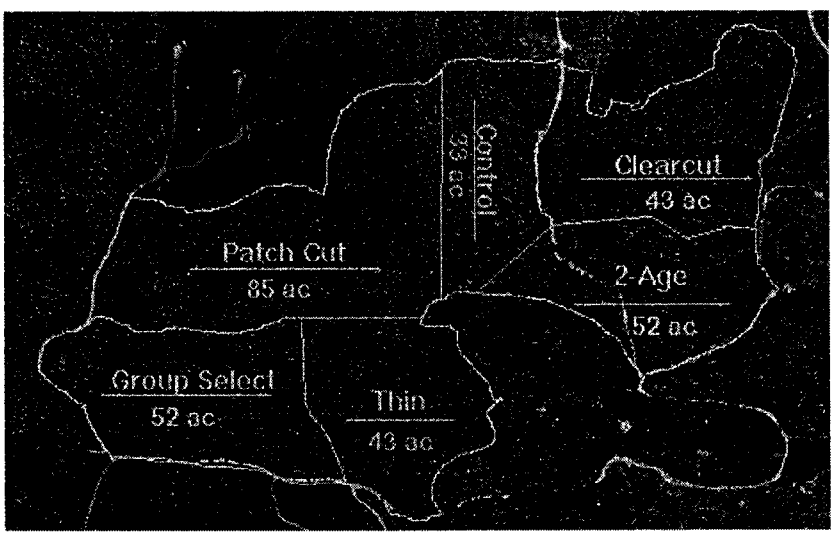

Figure 1. 1997 aerial photo showing pre-harvest conditions and unit boundaries of the six silvicultural treatment areas.

Figure 2 provides a visual simulation of the residual canopy similar to how it now appears after each of the harvest treatments were applied.

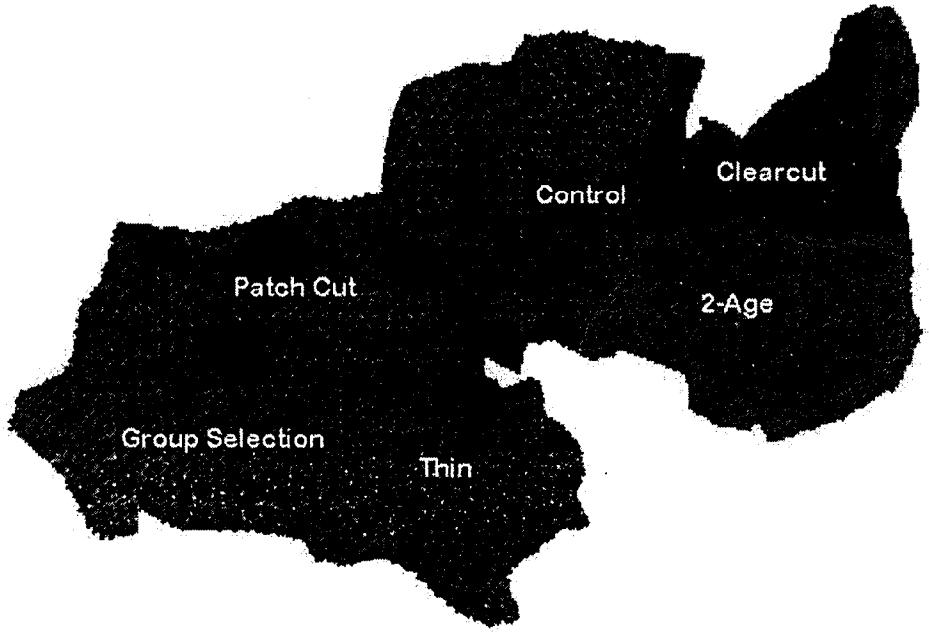

Figure 2. Computer-generated simulation of the residual canopy after all harvest treatments are applied to the study area.

Harvesting Methods and Equipment

One of the most fortuitous aspects of this study was the similarity of all the units with respect to soils, stand conditions, and topography. In addition, all of the units were harvested during the same year by a single contract logging crew using the same array of equipment. The track width and ground pressure of each harvesting machine is given in Table 3, along with a list of the harvesting units in which each machine was used.

All trees were marked before harvesting operations began. A Timbco' 445-B feller-buncher was used to mechanically fell most trees up to 30 inches in diameter. Oversized trees were manually felled after the feller-buncher had cut an area. Most skidding was completed with a D5H Caterpillar tractor fitted with a grapple. (A newer Model 527 tractor was used for the last few weeks of skidding). Whenever possible, trees were skidded as whole trees to the roadside. A Koehring 6644 hydraulic shovel, fitted with a grapple, was used to bunch for the tractor in the clearcut unit, 2-age unit, and the large patches in the patch cut unit. A Caterpillar 320, fitted with a Waratah processing head, was used to delimb, buck, and deck logs at processing sites along roadside. The majority of the area was skidded downhill or cross-slope. A brief description of

[1] The use of commercial names is for the convenience of the reader and does not imply any endorsement by the USDA Forest Service.

the harvest method used in each unit is given below. Coulter (1999) gives a more detailed analysis of the harvesting operations for each unit.

Table 3. Track width and ground pressure of equipment used in each harvesting unit.

Machine	Track Width (in.)	Ground Pressure (psi)	Harvest Units
Timbco 445-B feller-buncher	24	7.9	All units
Caterpillar D5H tractor with Esco grapple	24	7.3	All units except Thinning
Caterpillar 527 tractor with Esco grapple	24	8.8	Thinning unit only
Caterpillar 320 with processor head	28	8.1	All units
Caterpillar 325 log loader	28	6.8	All units
Koehring 6644 hydraulic shovel with grapple	32	8.0	Clearcut and 2-age units Patches in Patch Cut unit

Clearcut Unit Harvesting Method--All trees in the unit up to approximately a 30-inche stump-diameter were mechanically felled by the Timbco feller-buncher. The operator felled trees so that they were well aligned for extraction by the Caterpillar tractor. However, due to the large tree size, the feller-buncher operator did not attempt to bunch felled trees into convenient turns for the Caterpillar tractor. After the feller-buncher had completed its work, a faller then manually felled oversized trees.

The Koehring shovel, fitted with a grapple, was then used to build turns for the tractor. This turn-building operation entailed picking up felled trees and aligning their butts so that the tractor could easily back up and grab the turn with its grapple. The shovel operator would also buck a 40-foot log from the ends of very large trees that were too large for the tractor to skid as whole trees. In areas that were within about 150 feet of the road, the shovel would simply swing trees to the roadside for processing, eliminating the need for skidding with the tractor.

Once the tractor had picked up a turn, the operator would skid the load of trees to a roadside processing area and then drop the load. The tractor would then drive the machine in reverse back out to the shovel to pick up another turn. The tractor and the bunching shovel were not limited to designated skid trails; therefore, each machine traversed most of the unit.

At the roadside processing area, the Caterpillar 320 processor immediately delimbed and bucked the turns and stacked the logs along the roadside. Usually within hours, a Caterpillar 325 hydraulic log loader sorted and loaded the processed logs onto trucks at roadside. After the unit had been skidded, the loader walked through the area to pile slash.

The feller-buncher, shovel, tractor, and loader all traveled through most of the unit. The processor stayed within about 50 feet of the roadside.

Two-age Unit Harvesting Method--The 2-age unit was felled, bunched, skidded, processed, loaded out, and slash piled in approximately the same manner as the clearcut unit; however, more care had to be used to avoid damage to the residue stand. The Koehring shovel could not swing long pieces through a large arc because of the 50-foot spacing between residual trees. The residual trees also restricted the travel paths of equipment within the unit area.

The feller-buncher, shovel, tractor, and loader all traveled through most of the unit. The processor stayed within about 50 feet of the roadside.

Thinning Unit Harvest Method--The thinning unit was felled with the feller-buncher, with oversized trees manually felled. However, once a tree was severed from the stump, the operator kept the tree in a vertical position. He then carried the tree to the nearest skidding corridor and laid the tree in the corridor with the butt-end toward the direction of skidding. In some instances, when the tree was very large or the ground was steep, this careful positioning of the tree for skidding was not possible. Because the thinning was from below (i.e. predominately smaller trees were thinned), the feller-buncher could effectively handle and bunch a larger percentage of the stems than in units with heavier cuts. The Koehring shovel was not used in the thinning unit because the residual stand spacing was too tight to allow it to operate without excessive stand damage. The tractor operator skidded predominately along the corridors established by the feller-buncher, taking care to minimize damage to residual trees. The trees were processed into logs and loaded at roadside using the equipment and machines as in the other units. Because only 8.3 thousand board feet (MBF) per acre were removed, the log loader only piled slash on or around the processing areas, not in the interior of the stand. Due to the steepness of the topography, much of the unit was skidded sideslope, resulting in longer skidding distances.

The feller-buncher and tractor traveled through most of the unit, with the tractor staying within the thinning corridors. The processor and loader stayed within approximately 50 feet of the roadside.

Group Selection Unit Harvest Method--The group selection unit was very similar to the thinning unit; however, small opening (up to 1.5 acres) were cut throughout the unit. The openings were cut concurrently with the thinning of the rest of the unit. The small group openings were not large enough to accommodate the shovel, so the tractor bunched and skidded the trees unassisted. Due to the presence of a small stream, skid distances had to be increased in much of the unit.

The feller-buncher and tractor traveled through most of the unit, with the tractor staying within the thinning corridors. The processor and loader stayed within approximately 50 feet of the roadside.

Patch Cut Unit Harvest Method--The patch cut treatment was a combination of the clearcut treatment and the thinning treatment. Four large patches (1.6-5.2 acres) were first clear-cut using the same techniques and equipment as were used in the clearcut unit. The only differences were that the patches were much smaller than the clearcut unit, and in two of the patches, the logs had to be skidded through the thinned portion of the unit to roadside for processing. The remaining areas between the patches were harvested using the same methods as were used in the thinning unit.

The feller-buncher and tractor traveled through those sections of the unit that were only thinned, with the tractor staying within the thinning corridors. The feller-buncher, shovel, tractor, and loader all traveled through the patches that were clearcut. The processor stayed within about 50 feet of the roadside.

Salvage Logging Operation--It should be noted that during the soil disturbance survey, a tracked log loader was conducting a salvage operation in the area. This operation consisted of the loader picking out pulp chunks from the slash piles and from along the roadside. The loader was not allowed to travel more than 200 feet from the road. This salvage operation had already been completed at the time of the disturbance survey in the patch cut, group selection, and thinning units, but not in the clearcut or 2-age units. It appeared that the disturbance caused by this salvage operation was relatively minor because the loader only traveled in areas near the roadside where disturbance was already very high.

SOIL DISTURBANCE SURVEY METHODS

Each of five treated units were intensively surveyed to determine the amount of surface soil disturbance using the Point Transect method as specified by McMahon (1995). The survey was conducted in early November 1998, several months after harvest. Parallel transect lines were run across each unit at 66-foot spacing. Lines were oriented either North/South or East/West, depending on the direction of machine travel during harvest and the shape of the stand (Fig. 3). Along each transect line, at regular distances of either 25 or 33 feet (larger units were sampled at 33-foot spacing along the transects), soil disturbance was visually assessed at each sample point and assigned a disturbance classification. Points landing on primary or secondary skid trails, or processing/deck areas were noted by assigning a code. These codes were later used to determine percent area of each of these types of locations. Skid trails were defined as primary if they led to landings and secondary if they were branches of primary trails. The clearcut, 2-age, commercial thinning, and group selection units were completely surveyed. Only the western half of the patch cut unit was surveyed due to the large size of the unit. In the patch cut unit, points falling inside the clearcut patches were noted with a code so that disturbance levels within the patches could be distinguished from those found for the thinned portions of the unit. The control unit was not surveyed. Approximately 800 points were assessed in each surveyed unit. The disturbance classes were defined as follows:

1. **Undisturbed--no** evidence of machine or log movement over the point.
2. **Disturbed with litter in** place--litter was still in place with evidence of machine movement over the point. Typically this class had machine track marks.
3. **Soil exposed and litter removed--bare** soil visible. Disturbance could be from machine or log movements.
4. **Litter and soil** mixed--soil and litter layers were mixed together by machine or log movements.
5. **Soil exposed with rutting over 4 inches** deep--points where machine travel had created significant ruts.
6. Nonsoil--standing trees, stumps, logs, rocks.
7. Missing--point covered by slash or debris piles.

8. **Newly deposited** litter--points that had been completely covered during the logging operation with fresh needles, leaves, and fine branches, totally obscuring underlying litter/soil conditions.

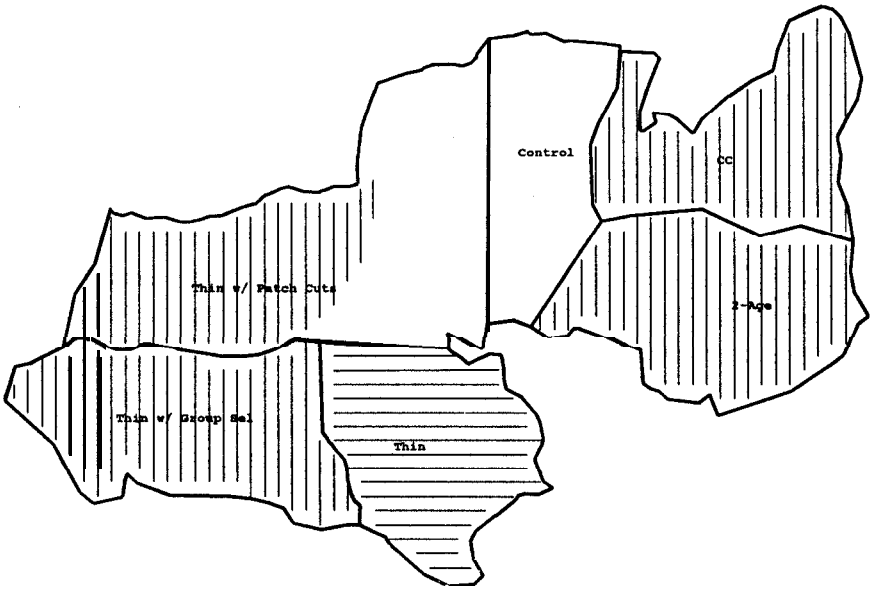

Figure 3. Map of the surveyed harvest units showing the approximate locations of soil disturbance transect lines.

ANALYSIS & RESULTS

Total number of observations and percentage in each disturbance class by silvicultural treatment were calculated (Table 4). Because each sample point represents the same amount of area within a unit, the calculated percentages provide a direct estimate of the percent area of each disturbance class found within a unit.

Table 4. Percentage of each unit containing each soil disturbance class.

Disturbance Class	Treatment						
	Commercial Thinning	Group Selection	Patch Cut			2-Age	Clear-cut
			Overall	Thin	Patches		
Undisturbed	36.4	35.3	29.2	37.4	7.3	10.7	11.1
Litter in place	14.5	17.2	19.0	18.6	20.2	20.9	16.1
Soil exposed	12.1	11.2	12.7	11.5	15.9	11.8	16.5
Litter/soil mix	9.5	11.6	17.8	15.6	23.6	14.9	14.4
Exposed > 4-in	0.9	1.0	1.1	1.0	1.3	0.5	1.3
Nonsoil	5.5	7.1	5.3	4.4	7.7	10.1	7.0
Missing/slash	3.9	3.8	2.9	2.1	5.2	6.6	7.2
New litter	17.2	12.8	12.0	9.4	18.9	24.5	26.4
Total Obs.	775	885	850	617	233	785	769

Percent Area in Each Disturbance Class by Silvicultural Treatment

Percent area ***undisturbed*** was largest in the thinning and group selection units at 36.4 and 35.3, respectively (Table 4). Taking the patch cut unit in total (i.e. combining the thinned areas and clearcut patches), the unit had 29.2 percent ***undisturbed*** area. The thinned areas of the patch cut unit had nearly the same percentage of ***undisturbed*** area (37.4) as was observed in the thinning unit. The small clearcut patches within the patch cut had only 7.3 percent ***undisturbed*** area. The clearcut and 2-age units also had low amounts of ***undisturbed*** area, with 11.1 and 10.7 percent, respectively.

Percent area ***disturbed with fitter in place*** was highest in the 2-age unit at 20.9, followed by the patch cut at 19.0, the group selection at 17.2, and the clearcut at 16.1. The thinning unit had the lowest amount of this class at 14.5 percent.

Percent area with ***litter removed and mineral soil exposed*** was highest in the cleat-cut unit and the small clearcut patches within the patch cut unit at 16.5 and 15.9, respectively. The percent area in this class was very similar for the remaining units, ranging from 11.2 (group selection) to 12.7 (patch cut).

Percent area with ***fitter and soil mixed*** was highest in the overall patch cut unit at 17.8. This catagory was even higher at 23.6 percent in the small clearcut patches within the patch cut unit. The thinned areas of the patch cut unit also contained a high amount of this class at 15.6 percent. The 2-age and clearcut units were very similar at 14.9 and 14.4 percent, respectively. The group selection had 11.6 percent in this class. The thinning unit had the lowest amount of ***litter and soil mixed*** at 9.5 percent.

Percent area with ***soil exposed with rutting over*** 4 ***inches,*** was very similar in all units, ranging from 1.3 (clearcut) to 0.5 (2-age). The small clearcut patches in the patch cut unit had the same amount of rutting as the clearcut unit.

Percent area in the ***nonsoil*** category, which consisted of logs and stumps from the recent harvest and from previous harvests, standing trees, and rocks, was highest in the 2-age unit at 10.1. *Nonsoil* ranged from 5.3 to 7.1 for the other four units.

Percent area in the ***missing*** (covered with slash piles) category was highest in the clearcut and 2-age units at 7.2 and 6.6, respectively. The thinning, patch cut, and group selection units were similar in this category, ranging from 2.9 to 3.9 percent.

The ground surface in some areas in each unit were completely covered with needles, leaves, and fine branches as a result of the logging operation. This ***newly deposited litter*** covered 26.4 percent of the clearcut unit and 24.5 percent on the 2-age unit. The thinning unit had 17.2 percent of this class. The group selection and patch cut units had the lowest amount with 12.8 and 12.0 percent, respectively.

Considering the four classes in which the soil surface showed evidence of machine traffic or log movement ***(disturbed with litter in place, soil exposed and litter removed, litter and soil mixed,***

and ***soil exposed with rutting over*** 4 ***inches deep),*** the overall patch cut unit had the largest percentage of area disturbed with 50.6 percent. The small clearcut patches within the patch cut unit showed even higher disturbance at 61 .O percent. The clearcut and 2-age units were nearly the same with 48.3 and 48.1 percent, respectively. Falling about midway among the treatments was the group selection unit with 4 1 .O percent. The thinning unit had the least amount in these four classes with a total of 37.0 percent.

Combining the three disturbance classes containing some form of exposed soil ***(soil exposed and litter removed, litter and soil mixed,*** and ***soil exposed with rutting over 4 inches deep),*** the clearcut and patch cut units were nearly the same with 32.2 and 3 1.6 percent, respectively, followed by the 2-age unit with 27.2 percent. The group selection and thinning units had the least amount of area in these categories with 23.8 and 22.5 percent, respectively. The small clearcut patches within the patch cut unit again showed even higher disturbance at 40.8 percent.

For those classes where a litter layer existed after harvest ***(undisturbed, disturbed with litter in place,*** and ***newly deposited litter), the*** thinning unit contained the largest amount of area with 68.1 percent, followed by the group selection and patch cut units with 65.3 and 60.2 percent, respectively. The 2-age and clearcut units had the least amount of area with an existing litter layer with 56.1 and 53.6 percent, respectively. The small clearcut patches within the patch cut unit again showed even higher disturbance with only 46.4 percent of the area containing an existing litter layer.

Significant Differences in Disturbance Class Areas Among Silvicultural Treatments

Because each treatment was not replicated, a contingency table analysis was used to make comparisons among the six disturbance class percentages within the five treatment units. For this analysis the ***nonsoil*** and ***missing*** classes were not included because they do not reflect soil surface conditions. Also, only the overall averages for the entire patch cut unit were included because the number of points sampled within the small clearcut patches was not large enough.

A 5x6 contingency table (Conover, 1980) was constructed to test the null hypothesis that the percentages within a disturbance class are equal to each other for all treatments. If at least two of the percentages within a disturbance class were not equal, then the null hypothesis was rejected. A 0.005 level of significance was used with 20 degrees of freedom. The test concluded that differences did exist and the null hypothesis was rejected.

To test for significant differences among certain treatments within a disturbance class, the contingency table was modified. To test within a certain disturbance class, percentages in all classes were combined except the class being tested. Caution should be used with this method because tests performed on different classes are not independent of each other. Because independence among tests does not exist the confidence level decreases as more tests are performed by the relation $1-(1-\alpha)^n$, where n is the number of tests and alpha (a) is the level of significance (Neter, 1990). Therefore, an alpha level of 0.005 was used to perform twelve tests in order to ensure a level of confidence close to the 95 percent level.

Excluding the nonsoil and missing/slash classes, the same trends exist across the other classes for each treatment (Table 5). Using these data for analysis purposes using a 5x6 contingency table with 20 degrees of freedom, resulted in the rejection of the null hypothesis that all percentages within a disturbance class were the same for all treatments. This led to the following tests to determine where the most significant differences or likenesses existed.

The patch cut, group selection, and thinning units had significantly higher percentages of ***undisturbed*** area when compared to the clearcut and 2-age units. Additionally, the group selection and thinning units had significantly higher percentages than the patch cut.

The 2-age unit had a significantly higher percentage of area ***disturbed with litter in place*** when compared to all other units. The clearcut, patch cut, group selection, and thinning units had statistically the same percentage of area disturbed for this class.

The clearcut unit had a significantly higher percentage of area with ***litter removed and soil exposed*** when compared to all other units. The 2-age, patch cut, group selection, and thinning units had statistically the same percentage of area in this class.

The clearcut, 2-age, patch cut, and group selection units had significantly higher percentages of ***fitter and soil mixed*** when compared to the thinning unit.

No significant differences in percentage of area with ***soil exposed with rutting over 4 inches 'deep*** were found among all units.

The clearcut and 2-age units had significantly higher percentages of area with ***newly deposited litter*** when compared to the other units.

Table 5. Percentage of each unit containing each disturbance class with nonsoil and missing/slash classes excluded.

	Treatment				
Disturbance Class	Commercial Thinning	Group Selection	Patch Cut	2-Age	Clearcut
Undisturbed	40.2	39.6	31.8	12.8	12.9
Litter in place	16.0	19.3	20.8	25.1	18.8
Soil exposed	13.4	12.6	13.8	14.2	19.2
Litter/soil mix	10.5	13.1	19.4	17.9	16.8
Exposed > 4-in	1.0	1.1	1.2	0.6	1.5
New litter	18.9	14.3	13.1	29.4	30.8
Total Obs.	702	788	780	654	660

Percent Area in Skid Trails and Processing Areas

In addition to determining percent area disturbed in each treatment unit by disturbance class, percent area occupied by primary and secondary skid trails, processing areas, and log decks was also of interest. Table 6 summarizes the results for this aspect of the study. Total area in primary and secondary skid trails ranged from 16.6 percent (patch cut unit) to 21.7 percent (thinning unit). These results are comparable to those obtained by Stokes et al. (1995) for group selection and clearcut harvest methods using manual felling and articulated rubber-tired skidders. Their results indicate that total area in skid trails averaged 14.6 for group selection units and 22.4 percent for clearcut units. Total process/deck area was relatively the same for all units, ranging from 4.5 to 6.5 percent. The total area that was heavily traveled (i.e. trails, processing and deck areas) was very similar for all units ranging from 2 1.2 percent in the patch cut unit to 28.1 percent in the thinning unit.

Table 6. Percent of each unit that contains each location category.

	Treatment				
Location	Commercial Thinning	Group Selection	Patch Cut	2-Age	Clearcut
Primary trail	12.3	9.6	10.0	11.6	10.9
Secondary trail	9.4	8.4	6.6	9.3	8.5
Total	21.7	18.0	16.6	20.9	19.4
Process/deck area	6.5	6.0	4.5	5.5	6.3
Other	71.9	76.0	78.8	73.6	74.3
Total Obs.	775	885	850	785	769

DISCUSSION

In general, as removal intensity increased the percentage of undisturbed area decreased. The thinning unit had the highest percentage of ***undisturbed*** area, while the 2-age and clearcut units were similar with the least amount. The clearcut, 2-age, and small clearcut patches in the patch cut unit all had high volumes of timber removed. To accomplish this, more machines passed over the units more times. More slash was generated, requiring piling by the loader, and in some areas, redistribution over the area by the tractor. Because the clearcut and 2-age units had the most slash on the ground after harvest these units both had the highest percent area in the ***missing*** class.

The summary revealed that the 2-age unit had the highest percentage of area ***disturbed with litter in place.*** This is most likely a result of the machine operators' efforts to avoid damage to residual trees. Although most of the trees were felled, bunched and skidded, care was taken to not hit or scrape the residual standing trees with either logs or equipment. This required the machines to concentrate their traffic more in the area between residual trees, only traveling near residual trees once or twice to pick up logs near them. This concentration of machine travel is

also reflected in the higher percent area in skid trails (20.9) in the 2-age unit, even though there were no designated skid trails.

There was a general trend of increasing area of ***soil exposed and lifter removed*** as removal intensity increased. The clearcut unit and small clearcut patches in the patch cut unit are similar with the highest percentage for this class. The 2-age unit had a low percentage for this class and was similar to the group selection and commercial thinning. This is a result of more area being lightly traveled to avoid tree damage instead of being repeatedly traversed with associated loss of the litter layer.

Percent area with ***litter and soil mixed*** was also highest on the units with the highest removal intensities. The clear-cut and 2-age units were similar in the amount of area for this class. Surprisingly, the patch cut unit had the highest percentages of litter and soil mixed, both in the portions that were only thinned and in the small clearcut patches. One possible explanation for this may be related to the feller-buncher operators' abilities. In about half of the area sampled in the patch cut, a new feller-buncher operator was being trained. This new operator was much less adept at positioning the machine and bunching trees in corridors. As a result, there may have been more impacts both from feller-buncher travel and from poor positioning of trees for extraction.

In general, the percent area in ***newly deposited litter*** (fine needles and branches from limbs and tops) increased as removal intensity increased. The clearcut unit had the highest percentage for this class, followed by the 2-age unit.

The amount of area containing ruts greater than 4-inches with soil exposed was low and similar in magnitude across all units. This result is a combination of two factors: displacement potential and use of wide tracks. The overall harvested area has a low displacement potential from timber harvesting activities. This soil characteristic, along with the use of wide-tracked harvesting equipment, resulted in little rutting.

Soil compaction is a major concern among land managers because it is directly related to reduced tree growth. Areas with the highest amount of compaction are mainly primary skid trails and processing/deck areas. Total percent area in these high traffic classes was not correlated with volume of timber removed. Instead, percent area in these classes is influenced not only by the harvest method but also by the unit topography slope. The skid trail assessment revealed that the thinning unit had the highest percentage of area in skid trails. This unit had a very steep area at its north end. This feature prohibited the tractor from skidding trees located in the northern portion of the unit directly to the top of the unit. Instead, the tractor was required to skid trees across the unit along a gentler route. This resulted in long skid trails within the unit, and consequently in more skid trails per unit area. The thinning harvest method also concentrated travel within near corridors, creating defacto skid trails. Despite removing much more volume per acre from the clearcut and 2-age units, the skid trail assessment revealed that all units were fairly similar in the percentage of total area in skid trails and decks.

Results from this study characterize soil disturbance resulting from one harvest entry into the units. Future silvicultural management dictates that the thinning, group selection, and patch cut

units will be treated again before the clearcut and 2-age units are thinned for the first time. Depending on the recovery rate of the soil, these multiple entries into the units could have a cumulative impact on soil compaction, particularly if machine traffic is repeatedly concentrated in the same corridors.

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