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Soil Disturbance Resulting From Skidding Logs on Granitic Soils in Central Idaho

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RESEARCH SUMMARY

Yarding logs by ground skidding commonly results in lateral soil displacement and compaction. Displacement and compaction have been implicated in decreased site productivity in some western United States forest soils, particularly where soil disturbance is extensive and deep. In this study, soil disturbance resulting from log yarding with a crawler tractor and rubber-tired skidder is compared on course-textured granitic soils in the Idaho batholith. Two harvest units with designated main skid trails were logged in 1986, one exclusively with crawler tractors and the other with a rubber-tired skidder. A third unit was logged in 1987 without designated trails. Soil displacement, soil bulk density, and penetrability were compared prior to and following logging activities on each unit. Main and secondary skid trails and a log landing deck had significant increases in bulk density and static penetrability following operations. Density increases along designated skid trails yarded by tractor and on the landing exceeded 15 percent over natural bulk density. Soil displacement on areas adjacent to skid trails, fire lines, and the landing was greater with tractor yarding than rubber-tired skidder yarding. Ripping with a rock ripper to reverse compaction on the landing was ineffective below 10-cm depth. Results suggest that efforts to restrict skidding to marked trails, requirements for directional felling of trees, and encouraging operators to string cable rather than driving to logs would help to maintain soil productivity.

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INTRODUCTION

Soil-disturbing activities that cause lateral soil displacement, horizon mixing, and compaction are a concern to land managers because of the potential for accelerated erosion and loss of site productivity. Yarding logs by ground skidding with either Caterpillar-type tractors or rubber-tired skidders results in considerably greater soil disturbance than yarding with cable or aerial systems. Megahan (1980) documented soil disturbance from felling and yarding in 16 studies to compare helicopter, skyline, ground cable, and tractor systems. Tractor operations disturbed an average of 30 percent of the activity area (including roads) compared to 4 percent for helicopter, 9 percent for skyline, and 23 percent for ground cable systems.

Coarse-textured granitic soils of the Idaho batholith have a high potential for accelerated erosion following disturbance. These soils are low in clay content, averaging approximately 5 percent, and thus lack cohesion and have poor aggregate stability. Until recently, the major concern for protecting the soil resource when planning logging activities in the batholith was to reduce erosion in order to maintain site productivity and reduce stream sediment. These coarse sandy soils were thought to be relatively immune to compaction from logging operations with heavy equipment. Recently, Froehlich and others (1985) documented increased soil bulk densities along skid trails in batholith soils in central Idaho. They predicted that recovery to natural levels might take longer than 45 years.

The productivity loss accompanying increased soil density from compaction is not well understood, and this is particularly the case with coarse-textured soils. There are several case studies documenting productivity loss in western forest lands (Clayton and others 1987; Forristall and Gessel 1955; Helms 1983; Wert and Thomas 1981), but results are highly variable and often confounded by other unmeasured disturbance effects such as displacement. Daddow and Warrington (1983) reviewed results of several published studies and concluded that growth-limiting bulk densities are texture dependent. They suggested that coarse-textured soils will have higher growth-limiting bulk densities than fine soils (that is, they can be compacted to a higher density without decreasing productivity). Their prediction equations are limited to soils with less than 10 percent gravel, a severe limitation for many western forest soils. More research is needed to quantify the relationship between soil compaction and productivity decline.

The Silver Creek Experimental Watershed studies were begun in 1962 to evaluate effects of road construction and logging in the southwestern Idaho batholith. Both on-site and watershed scale evaluations of erosion, sedimentation, and other ecosystem responses to various prescribed treatments have been or are currently being made. A prior publication by Clayton (1981) described soil disturbance resulting from helicopter yarding in one watershed. This paper provides a comparison of soil disturbance from ground-skidding logs by crawler tractors and rubber-tired skidders in adjacent watersheds.

SITE DESCRIPTION AND TREATMENTS

The research was conducted in the Silver Creek Study Area (44°25' N. Lat.; 115°45' W. Long.), Boise National Forest. Ground skidding was restricted to lower elevations and gentler slopes (generally <40 percent) in three central watersheds. Three cutting units were selected for study in two of these watersheds. A main skid trail was designated in two units: one logged exclusively by Caterpillar tractor (hereafter designated CAT), and the other logged exclusively by rubber-tired skidder (hereafter RTS). These two units were logged in September 1986. The third unit was left as a logger's choice with no restrictions as to equipment or skid trail location other than adhering to best management practices (hereafter LC). This unit was logged in July 1987.

The CAT and RTS units were 2.9 and 2.0 ha in size and located adjacent to each other on gentle, rounded ridges running perpendicular to the logging road. The designated trails ran along the ridge crests. The swale between the two ridges delineates a common boundary to the two units. The mid-elevation of these two units is 1,435 m. The LC unit is 3.4 ha in area. The lower third of the unit is located on a level terrace, and the upper two-thirds on a sideslope averaging 35 percent. The mid-elevation of this unit is 1,460 m.

The study areas receive an average of 90 cm of precipitation, the majority of which falls as snow during the winter (November to April) months. The habitat type on all three units is Douglas-fir/ninebark, ponderosa pine phase (*Pseudotsuga menziesii/ Physocarpus malvaceus, Pinus ponderosa* phase) (Steele and others 1981), and both Douglas-fir and ponderosa pine trees were harvested in each unit.

The CAT and RTS units have a sandy-skeletal, mixed Lithic Cryorthent along the ridge grading to a deeper sandy-skeletal, mixed Typic Cryorthent on the sideslopes and swale bottoms. Surface texture is gravelly coarse sandy loam for both soils. The LC unit has a coarse loamy, mixed Typic Cryoboroll on the terrace position with a coarse sandy loam surface texture and a loam B horizon (12 percent clay). Sideslopes in this unit have a Typic Cryorthent similar to the soil described on the sideslopes and swale positions of the CAT and RTS units.

METHODS

Field Sampling

Prior to logging, the CAT and RTS unit boundaries were mapped with a hand compass and chain. The LC unit was mapped with an electronic surveying instrument. Twelve random transects, 15 m in length, were established within each unit boundary according to the methods of Howes and others (1983). Prior to logging, four bulk density samples were taken with a cylindrical, hand-driven coring device (volume = 137.4 cm^3) at 3-m intervals along each transect. Cores were driven horizontally and centered at a depth of 8 cm below the surface of the A horizon. Static penetrability measurements were taken with a 30-degree cone penetrometer adjacent to the bulk density samples (30 cm separation). Cone resistance was recorded at 2.5-cm intervals through the surface 17.5 cm of soil according to the methods of Bradford (1986). Penetrability and bulk density sampling points were offset if coarse gravel or stones affected sample quality.

During logging, the number of trips by the ground skidder and the number of logs skidded over the designated main skid trail were recorded on the RTS and CAT units. (A "log" is approximately 5 m of length; thus a single bole 15 m in length would constitute three logs.) The volume in board feet of timber removed from the LC unit was recorded, but not the number of trips.

Following logging but prior to slash piling, main and secondary skid trails were mapped with a compass and chain on the RTS and CAT units. Skid trails, landings, and the fire line surrounding the LC unit were mapped using the electronic surveying instrument. Each logging unit was stratified into disturbance classes for more efficient sampling at this time. The RTS and CAT unit classes were: main skid trail, undesignated secondary skid trails, and "other." The need for the secondary skid trail classification was not anticipated, and therefore the criteria were somewhat subjective. These trails resulted from an unknown number of passes to retrieve local concentrations of downed timber that were not yarded by stretching cable from the main skid trail. Based on stump counts, I would estimate three to 10 passes over these trails. They were clearly more visible and more disturbed than single passes off the main trail for scattered logs, which are included in the "other" stratum. The stratifications for the LC unit included skid trails (unknown number of passes), landing, fire line, and "other."

Bulk density sampling was repeated in the "other" stratification along the previously established transects in all three units. Prior to logging, 48 sampling points were taken in each unit; following logging, units were sampled as follows: RTS, 29 points; CAT, 34 points; and LC, 48 points. (The smaller sample in the RTS and CAT units resulted from omitting skid trails from this sample.) Soil displacement was measured continuously along these transects, except where main and secondary skid trails were present. The criterion for displacement was litter removed and more than 2.5 cm of A horizon laterally displaced. Penetrability sampling following logging was repeated only along the main skid trails in the RTS and CAT units, and in the landing in the LC unit as described below.

Following brush piling, skid trails, landings, and fire lines were sampled in the following manner. Bulk density and soil displacement were sampled on secondary skid trails (RTS and CAT) along evenly spaced, random transects running perpendicular to the trail length, the number of transects depending on trail length. Bulk density samples and penetrability measurements were sampled at 30 randomly selected points along the entire length of the main skid trails in the RTS and CAT units and 12 random points in the landing in the LC unit. No samples of bulk density or penetrability were taken in the fire line. The landing in the LC unit was ripped the first year following logging with a Cat 130 Patrol with rock ripper, and penetrability sampling was repeated to evaluate the effect of ripping.

Displacement was visually estimated to equal 100 percent along main skid trails (RTS and CAT), and the fire line and landing in the LC unit.

Data Analysis

Treatment effects on bulk density are presented as 95 percent confidence intervals on the difference in pre- and posttreatment mean values for skid trails, landings, and other disturbed areas. Treatment effects are considered significant if the confidence intervals do not include zero. In addition, the ratio of disturbed to undisturbed bulk density was tested using an unpaired t-test on log transformed data in order to provide a confidence interval on percentage increase. Penetrability values were separated into surface (top 7.5 cm) and subsurface (bottom 10 cm) values because of a distinct difference in soil resistance at that approximate depth. This increase is not linear, but rather there is a well-defined strength change in the 5- to 10-cm zone corresponding to a soil structure change arising from differences in soil organic matter content and root frequency differences in A1 and A2 horizons. Penetrability measurements following logging resulted in several skid trail and landing values that exceeded our ability to press the penetrometer into the soil. These values were recorded as greater than 2,000 kPa (approximately 300 lb/in^2). Differences in soil penetrability were therefore not analyzed statistically, but are presented as means (or censored means in the case of postdisturbance data) and ranges.

RESULTS

Soil displacement data as a percentage of total unit area for each cutting unit are presented in table 1. Displacement is tabulated by category of disturbance, and these figures were gathered by mapping or random sampling as previously described.

Although the total area of soil displacement was similar for all three units, there are marked differences in the categories where displacement occurred. Much more displacement as a percentage of total unit area is attributed to skid trails in the CAT and RTS units than in the LC unit. This is a result of the long, narrow shape of the CAT and RTS units with a main skid trail designated through the middle. The more circular shape of the LC unit allowed for a larger area to be serviced per length of trail by a factor of approximately 4.7. There was considerably less soil displacement in the other category on the RTS unit (3.5 percent) than the CAT (8.5 percent) and LC units (10 percent). Pivoting a Caterpillar tractor to maneuver into tight areas apparently results in considerable soil displacement.

Table 1—Percentage of area disturbed in skid trails, landings, fire lines, and other soil displacement

Disturbance	Unit CAT	 RTS	 LC
	- - - - - -	*Percent*	- - - - - - -
Main trail	16	18	[1]4
Secondary trail	9	7	—
Landing	—	—	8
Fire line	—	—	5
Other displacement	8.5	3.5	10
Total percent displaced	33.5	28.5	27

[1] No distinction was made between main and secondary skid trails in this unit.

The undisturbed soil bulk densities and confidence intervals on mean difference for various classes of disturbance within each cutting unit are presented in table 2. All three cutting units had similar bulk densities prior to logging. Following logging, there were significant increases in bulk density in all areas classified as skid trails in each unit. Samples from the "other" stratification were not tested because of the slight differences in the pre- and postdisturbance mean bulk density values. These data are displayed graphically in figure 1.

Proposed monitoring guidelines for Forest Service Regions 1, 2, and 4 (Nesser and others 1988) define detrimental compaction in nonvolcanic ash soils as occurring when soil bulk densities increase by 15 percent or more over undisturbed levels. There are (at least!) two ways of interpreting the 15 percent standard. The less rigorous is to simply compare the mean value of disturbed bulk density to undisturbed bulk density plus 15 percent. (This presumably would follow a prior t-test that showed a significant difference in the two samples.) Using that criterion, all skid trails and the landing would be considered detrimentally compacted. A more rigorous test is to compute a confidence interval on the percent increase. This was done on the data from this study by running a t-test on log-transformed bulk densities. This tests the ratio of disturbed to undisturbed densities, and after taking antilogs, provides a confidence interval on that ratio, which can be interpreted directly as a percentage increase. Using this test, only the main skid trail in the CAT unit and the landing in the LC unit exceed the 15 percent standard ($\alpha = 0.05$). The main skid trail in the RTS unit had a 95 percent CI ranging from 14 percent to 36 percent above natural, and therefore, arguably does not exceed the standard.

Table 2—Soil bulk density prior to logging and following disturbance (Mg/m^3)

Unit	Mean BD	*s*	95 Percent CI	*n*
		Prelogging		
CAT	1.13	0.125	[1]1.08,1.17	48
RTS	1.10	.141	1.05,1.14	48
LC	1.14	.136	1.09,1.18	48
		Postlogging		
CAT				
Main trail	1.46	.26	[2]0.180,0.497	30
Secondary trails	1.31	.30	0.084,0.313	30
Other areas	1.10	.18	not tested	34
RTS				
Main trail	1.38	.20	0.164,0.386	30
Secondary trails	1.27	.27	0.062,0.292	27
Other areas	1.14	.16	not tested	29
LC				
Skid trails	1.35	.27	0.100,0.413	37
Landing	1.51	.17	0.223,0.517	12
Other areas	1.09	.19	not tested	48

[1] Confidence interval on the mean.

[2] Confidence interval on the difference tested against prelogging data.

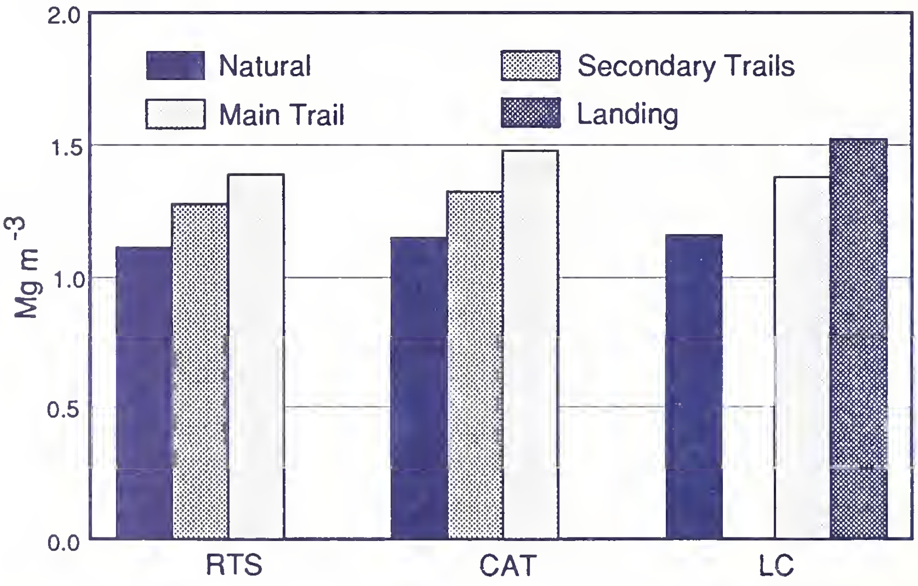

Figure 1—Natural and disturbed mean bulk densities in the three cutting units. The LC unit did not have a dedicated skid trail so all trails are referred to as secondary. Bulk density values on the landing are prior to ripping.

Soil penetrability data prior to and following logging are presented in table 3. Penetrability measurements were taken through the top 17.5 cm of soil unless cone resistance was too great to allow sampling to that depth, which was common on more compacted soils following logging. In undisturbed soils there is a marked increase in cone resistance with increasing depth. This increase is not linear, but rather there is a well-defined strength change in the 5- to 10-cm zone, which corresponds to a soil structure change arising from soil organic matter content differences (and possibly root frequency differences) in A1 and A2 horizons. For this reason, the top 7.5-cm average strength is designated SURF and the lower 10-cm value is designated SUB. Main skid trails in the CAT and RTS units and the landing in the LC unit all showed marked increases in penetrability following logging (table 3, fig. 2). The data in table 3 and figure 2 show increases in mean resistance; however, the mean values are really censored means because of our inability to exert a pressure greater than approximately 2,000 kPa. None of the subsurface readings at the landing were able to penetrate to the 17.5-cm depth. The summer following logging in the LC unit, the landing was ripped in one direction using a Cat 130 Patrol equipped with rippers. This treatment effectively reduced penetrability readings in surface soil to levels below prelogging conditions, but had no effect on subsurface conditions except directly in furrows.

Table 3—Soil penetrability data prior to logging and following disturbance in skid trails and the landing

Unit	Prelogging Mean penetrability	 *s*	 95 percent CI	 *n*
	kPa			
CAT SURF	715	260	640,790	48
CAT SUB	970	315	875,1060	48
RTS SURF	705	285	624,790	48
RTS SUB	1,085	395	900,1270	48
LC SURF	765	340	665,865	48
LC SUB	1,065	360	905,1220	48

Unit	Postlogging Treatment	 Mean penetrability[1]	 *n*
		kPa	
CAT SURF	Main skid trail	1,240	30
CAT SUB	Main skid trail	1,865	30
RTS SURF	Main skid trail	1,380	30
RTS SUB	Main skid trail	1,930	30
LC SURF	Landing	1,580	12
LC SUB	Landing	2,000	12
LC SURF	Landing, ripped	485	12
LC SUB	Landing, ripped	1,900	12

[1] The mean values for postlogging penetrability include many unknown values that exceed 2,000 kPa.

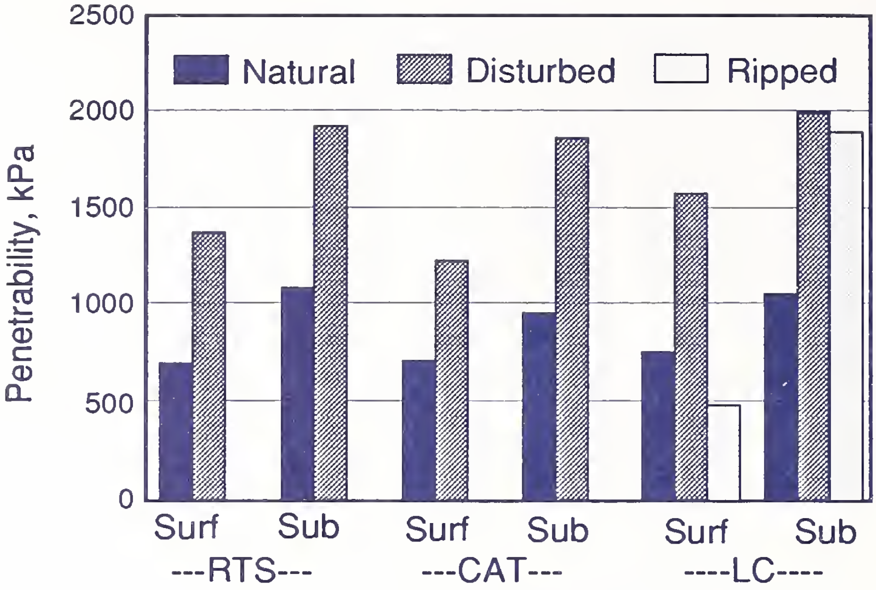

Figure 2—Surface and subsoil penetrability values prior to disturbance (natural) and following disturbance. The values for the RTS and CAT units are along main skid trails; the LC unit is for the landing.

DISCUSSION

Total soil displacement in the three cutting units averaged approximately 30 percent, if skid trails, the landing, and fire lines are included in the estimate. This compares to 1.5 percent displacement resulting from helicopter yarding in an adjacent watershed (Clayton 1981) not including landings that were constructed away from the cutting units. In Oregon, Dyrness (1967, 1972) found that balloon logging deeply disturbed 5 percent of the soil surface, whereas skyline logging disturbed 2.6 percent. His deeply disturbed category corresponds to displaced soil in this study. Megahan (1980), summarizing results of several published studies, found tractor yarding disturbs soil at levels very similar to the results of this study. Much of the soil displacement occurs on skid trails and landings that are also compacted, and this is likely to adversely impact productivity. Displacement in the "other" soil category is not associated with compaction, and may or may not detrimentally impact productivity. Minor displacement and surface soil mixing is often thought to be beneficial for regeneration because it prepares a seedbed and reduces competing vegetation (Clayton and others 1987). On the other hand, exposing soil accelerates erosion and disrupts soil biological processes important to nutrient cycling. More research is needed on the potential benefits and detrimental impacts of soil displacement.

Multiple passes with both Caterpillar tractors and rubber-tired skidders resulted in statistically significant increases in bulk density at all three sites. Although the mean bulk density on skid trails in the CAT site was higher than the RTS site, the difference was not significant at the 95 percent level. Froehlich and others (1980) found that tractor yarding produced greater density changes and displaced more soil than yarding with rubber-tired skidders. We also found greater soil displacement off main skid trails with tractor yarding. Froehlich and McNabb (1984) suggest that compaction differences may be due to higher peak dynamic pressures exerted by Caterpillar tractors. Lysne and Burditt (1983) measured peak dynamic pressures of tractors and rubber-tired skidders with approximately equal static ground pressures and found that peak dynamic pressures were as much as 50 percent greater for tractors under certain conditions.

Increased bulk density and soil strength in skid trails may last over 40 years according to recent studies (Froehlich and others 1985; Vora 1988). Greacen and Sands (1980) suggest that the longevity of compaction effects may be greatest in sandy soils because natural processes to reverse compaction such as shrinking and swelling or freezing are less effective. Such predictions indicate that effective ameliorative treatments like ripping with a winged subsoil ripper should be considered to maintain soil productivity. The ripping treatment used on the LC landing was not effective for reducing subsoil compaction. Andrus and Froelich (1983) demonstrated that using standard rock rippers or brush blades below a critical depth is ineffective and can even exacerbate compaction. The critical depth is variable, being a function of soil moisture and texture.

The productivity losses accompanying compaction are not well defined. Greacen and Sands (1980) report that there is usually an optimal bulk density above which and below which a decrease in yield occurs. Generally, compaction of soil above natural bulk densities decreases yield, but not always. Cochran and Brock (1985) documented that initial height growth of ponderosa pine is negatively correlated with bulk density in central Oregon volcanic soils. Similarly, the relationship between penetration resistance and productivity is not well defined. Greacen and Sands (1980) suggest that there is a critical strength above which all root penetration ceases. This critical value ranges from 800 to 5,000 kPa, with a mean of 2,500 kPa. Sands and others (1979) found that root penetration of radiata pine (*Pinus radiata*) was greatly restricted when penetration resistance exceeded 3,000 kPa.

CONCLUSIONS

Results of this study clearly show that multiple passes with either rubber-tired skidders or crawler tractors compact coarse-textured granitic soils. On two of the three cutting units, bulk density increases were sufficiently large on skid trails and a landing to meet the proposed monitoring category "detrimentally compacted." Although there were significant increases in bulk density in the third unit, we are less than 95 percent confident that the density increase is 15 percent or more. In order to minimize the area affected, efforts should be made to: (1) restrict skidding to marked trails; (2) require directional felling; and (3) encourage operators to string cables to logs rather than driving to them. Standard rock rippers were ineffective in reducing compaction at the landing. Other implements such as the winged subsoiler should be tested in these soils.

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KEYWORDS: soil displacement, soil compaction, ground skidding logs, granitic soil

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