Influence of Wide-Tire Skidder Operations on Soils

T. P. Rollerson
MacMillan Bloedel Ltd.
Nanaimo, B.C., Canada[1]

ABSTRACT

This study assesses changes in soil dry bulk density (dry unit weight), and evaluates soil disturbance associated with wide-tire skidder traffic on five Vancouver Island forest soils. In general, soil bulk densities increased with increasing skidder traffic; the effect was more pronounced at higher soil water contents. The results did not vary dramatically from site to site. Soil disturbance, in the form of rutting, and exposure of mineral soil increased with increasing traffic and was generally more pronounced under moist soil conditions. The compactive effect of the wide-tire skidder is at the lower end of the range of compactive effects reported for ground-based yarding equipment, but is still expected to have a negative effect on seedling height growth.

Key Words: *Soil compaction, skidder, dry bulk density, dry unit weight, forest harvesting, soil disturbance.*

INTRODUCTION

Coastal British Columbia is seeing an increasing use of ground-based harvesting and yarding equipment where topography permits. This activity is most common in managed second-growth stands along the east coast of Vancouver Island and the more southerly mainland coast, but also occurs in lower volume, natural stands elsewhere on the coast. The most common machines in use are feller-bunchers and skidders. Increasingly, hydraulic log loaders, which can efficiently move wood to roadside with apparent minimal impact of soils, are being used as an alternative to skidders. These systems are seen as cost effective replacements for manual falling and cable-yarding systems.

[1]The author is Senior Soil Scientist, Land Use Planning Advisory Team, Woodlands Services Division, MacMillan Bloedel Limited, 65 Front Street, Nanaimo, British Columbia, Canada, V9R 5H9.

The increased use of these systems raises concerns for the long-term maintenance of site productivity over a wide range of sites. Certainly, the bulk of the research on skidder-soil interactions indicates a negative impact on productivity. Failure to address these concerns may lead to an increasing number of areas where site productivity has been degraded.

Data on the effect of skidders and other ground-based harvesting and yarding equipment on coastal British Columbia soils is limited. An investigation of early setting access logging [1] found conifer height growth on bladed skid roads to be 28 to 38 percent lower than that on undisturbed areas. A preliminary study of the compactive effects of a low ground pressure skidder [16] found increases in dry soil bulk density (dry unit weight), but concluded that for two of three sites the increases were too low to affect growth. A recent retrospective study [2] showed little or no growth loss on skidder trails relative to apparently undisturbed controls; superior growth along trail margins tended to compensate for reductions in growth on the trails. Preliminary results for a study of conifer seedling growth on comparable skidder and cable-yarded sites [15] shows 12 to 20 percent greater height growth on the cable-yarded sites. Within the skidder-yarded areas, differences in median growth between off-trail and primary skidder trails were in the order of 20 to 25 percent.

The objectives of the present study were to evaluate, under relatively controlled conditions, changes in soil bulk density, the degree of soil displacement, and the amount of mineral soil exposure caused by wide-tire skidder traffic. In addition, we wished to establish baseline sites suitable for long-term evaluation of the effects of soil compaction on conifer growth.

METHODS

Site Selection

Sites were selected to provide a range of parent materials, soil types, and soil textures. The areas selected had been recently cable-yarded so the compactive effects of yarding could be considered minor. Each site consists of an area four to six hectares in extent over which soils and topography are relatively homogeneous. Soil type and landform selection was constrained by the type, number and suitability of recently logged sites available.

Site Characteristics

The five study sites are located along the east coast of Vancouver Island (Figure 1).

Site 1 is a well-drained, level floodplain while Site 2 is a moderately well-drained, gently sloping, fluvial fan. Site 3 consists of a well to rapidly drained soil formed of shallow morainal veneers and weathered sandstones and siltstones, and Site 4 is a moderately well to imperfectly drained morainal blanket. Both sites are gently sloping to undulating. The soils at Site 5 are developed in a level, well to moderately well-drained morainal blanket. This area was subjected to marine inundation at the end of deglaciation [13], and appears to have experienced some surface washing.

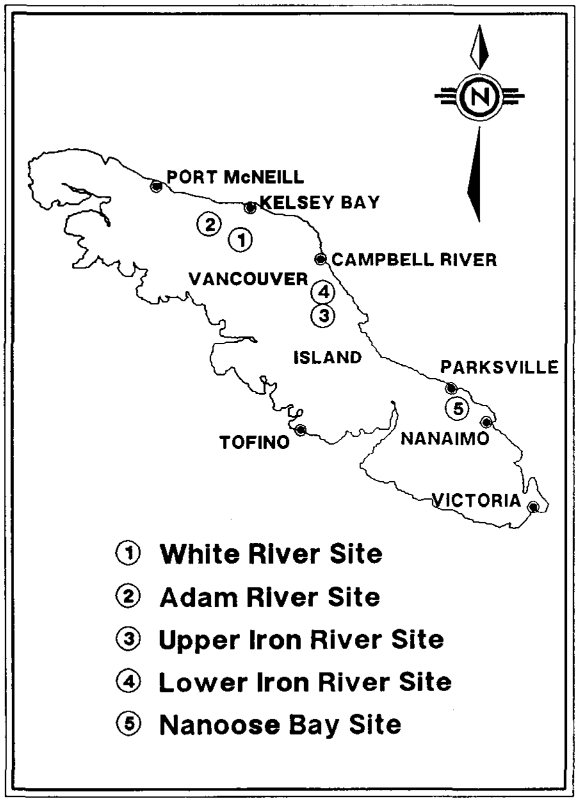

Figure 1. Study Site Location

Soils at Site 1 are classified under the Canadian System of Soil Classification, either as Orthic Humo-Ferric Podzols or Orthic Ferro-Humic Podzols. Soil textures range from loamy sands to sandy clay loams; coarse fragment content ranges from 0 to 8 percent by weight. The soils at Site 2 are Orthic Ferro-Humic Podzols. Soil textures are dominantly sandy loams, but both loamy sands and sandy clay loams are present. Coarse fragment content ranges from 3 to 73 percent. Soils at Site 3 are Orthic Humo-Ferric Podzols. Soil textures range from loams to clay loams; coarse fragment content ranges from 42 to 70 percent. Site 4 is dominated by Orthic Humo-Ferric podzols, but Orthic Dystric Brunisols are also present. Soil textures at Site 4 are primarily clay loams; some sandy clay loams are present. Coarse fragment content ranges from 45 to 70 percent. Soils at Site 5 are classified either as Orthic Humo-Ferric Podzols or Orthic Dystric Brunisols. Soil textures range from sands to sandy loams, with coarse fragment contents varying from 48 to 82 percent.

Study Design

The machine used was a John Deere 640 equipped with Firestone 73x44-32 tires. These tires are 44 inches (112 cm) wide and were inflated to a pressure of 19psi.

The skidder was run on five different sites under two different moisture conditions (dry: late summer or early fall, 1987; and, moist: winter or spring conditions, 1988). Snow and frozen soil conditions were avoided as these tend to be rare and unpredictable on the coast in areas where skidders are presently used.

At each site, two sets of five, 100-meter-long, test loops of varying numbers of return trips (5, 10, 20, 40, 80) were laid out (Figure 2). For each set, loop positions were randomly assigned. The skidder then ran on each trail for the specified number of return trips. Except for the 5-pass trail, the skidder would complete 10 trips empty and then 10 trips pulling a turn of logs. The process was continued until the total number of return trips (one return trip = one trip empty + one trip loaded) required for each loop was completed. One set of trails was used for dry soil conditions; the other for moist soil conditions.

Soil moisture conditions at the time of treatment were characterized by taking composite gravimetric soil moisture samples (10 sub-samples per trail) from the 0-20 cm depth interval in the mineral soil on each trail immediately following the skidder treatment of that trail.

Soil bulk density measurements were taken on each test loop and on an undisturbed strip adjacent to each trail. Bulk densities were measured only in the mineral soil. A total of fourteen, equally spaced, bulk density transects were established on

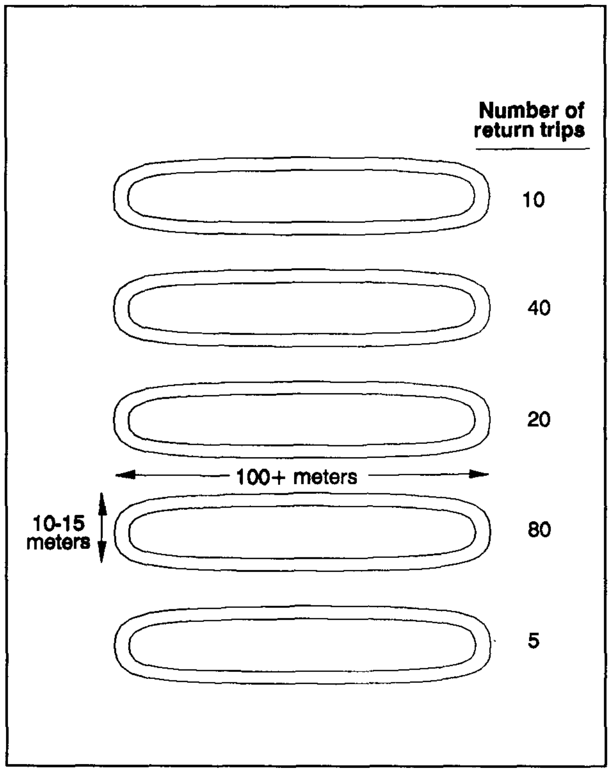

Figure 2. Generalized Skidder Test Loop Layout

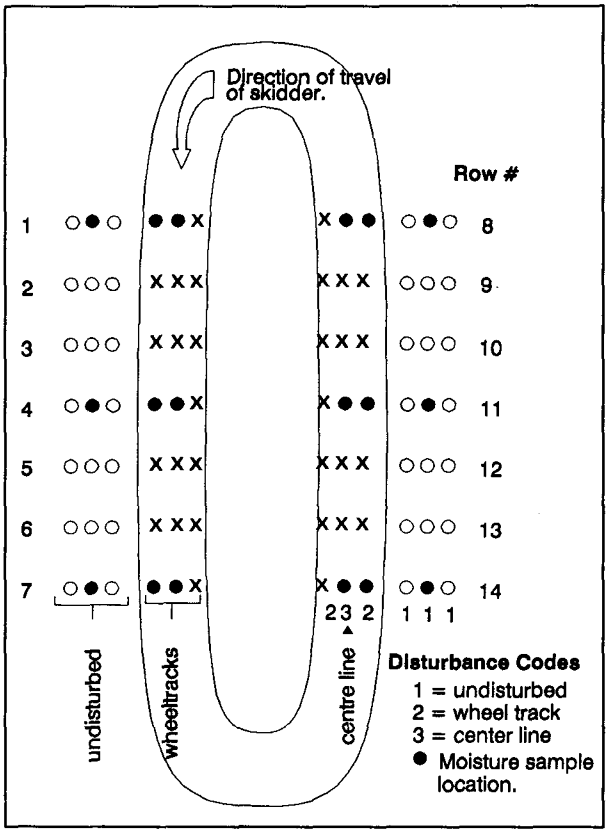

Figure 3. Soil Bulk Density Sample locations per trial and soil moisutre sampling locations.

each loop, seven on each side of the loop (Figure 3). At each transect, soil bulk densities were measured in the left and right wheel tracks and on the center line of the trail; an additional three points were measured in the undisturbed soils adjacent to each trail transect. Soil bulk densities for each trail are represented by 14 locations along the trail center line, 28 locations in the wheel tracks, and 42 undisturbed locations. At each location, bulk density measurements were taken for three depth intervals (0-10 cm, 0-20 cm, and 0-30 cm). The forest floor was removed from each sample location prior to measurement. Soil bulk density was measured using a Nuclear Moisture-Density Gauge.

In addition to soil bulk densities, rutting depths were measured in each wheel track at each transect location and the percentage of mineral soil exposed along the trail at each transect estimated. The estimate of exposed mineral soil was somewhat arbitrary; incorporation of forest floor materials into the mineral soil at times obscured the mineral soil, or mineral soil was deposited on top of slash and forest floor materials. Rutting depths were measured by placing a rigid rod across the full width of the trail, and measuring the distance from the rod (sitting on the top of the forest floor) to the soil surface in the center of each wheel track.

The data analysis applied to this study was primarily graphical. Analysis of variance and confidence interval multiple-range tests were applied when appropriate. The systematic sampling design used violates the assumptions of randomness underlying these tests. For the purposes of this study, we felt the logistical efficiency of the systematic approach outweighed the niceties of a random design.

RESULTS AND DISCUSSION

Soil Bulk Density Effects

In general, the five sites show a similar trend of increasing soil bulk density with increasing amounts of wide-tire skidder traffic. Similarly, moist soil conditions resulted in slightly higher bulk densities following skidder traffic than did dry soil conditions, although the trend is not entirely consistent. Figures 4 through 8 and Table 1 show these trends for the wheel tracks along the skidder trails at each of the five sites for the 0-20 cm depth interval. These trends are apparent for all depth intervals sampled. In general, compaction was slightly more pronounced at depth; occasionally the surface (0-10 cm) appeared more dense.

For the majority of treatments, most of the increase in bulk density was achieved in the first 10 to 20 return trips. Beyond 20 trips there was usually very little increase in bulk density. Increases in bulk density were generally in the range of 5 to 20 percent, but did reach as high as 35 percent. The wheel tracks for individual trails, depth intervals at Sites 2 and 3 and one trail at Site 5 show apparent decreases in bulk density in the order of 5 to 20 percent. These occurrences were more common with dry than moist soil conditions. We feel that these apparent decreases are in large part a function of incorporation of well-humified forest floor materials into the upper portion of the mineral soil.

As would be expected, the wheel tracks were compacted to a slightly higher degree than the center line of the trail. The bulk densities for the center line were generally intermediate between those for the undisturbed soils and the wheel tracks, but often fell below the bulk densities for the undisturbed soils.

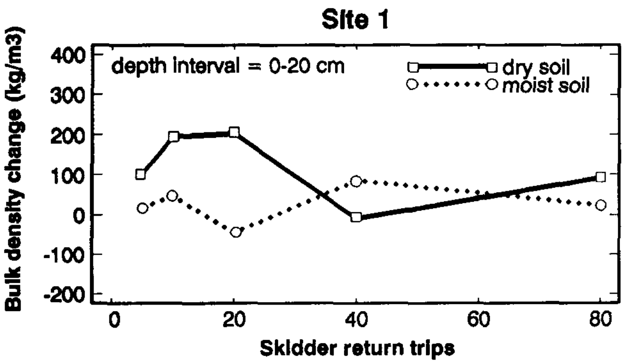

Figure 4. Changes in bulk density versus skidder return trips.

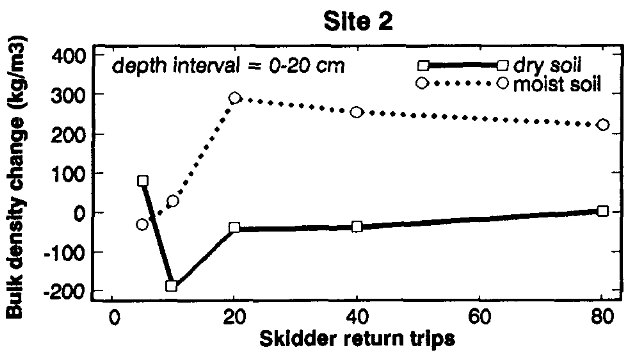

Figure 5. Changes in bulk density versus skidder return trips.

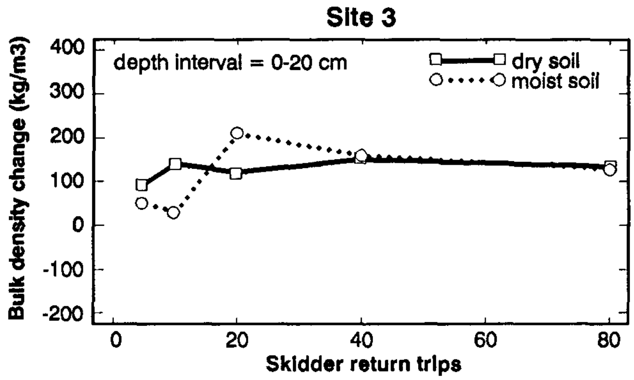

Figure 6. Changes in bulk density versus skidder return trips.

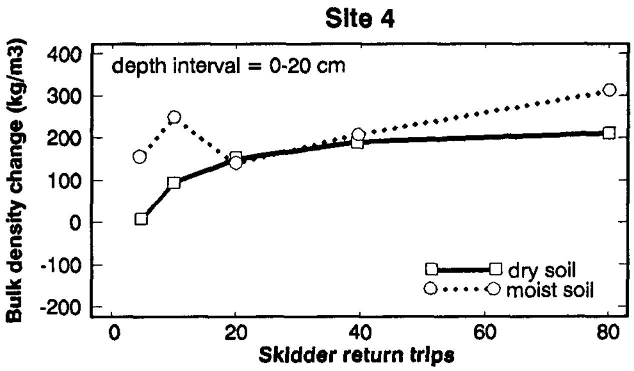

Figure 7. Changes in bulk density versus skidder return trips.

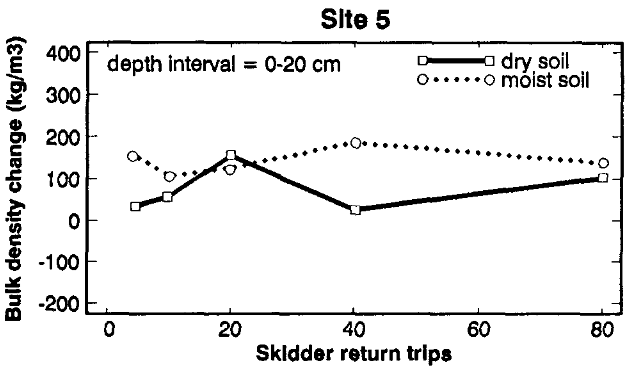

Figure 8. Changes in bulk density versus skidder return trips.

This effect was often more pronounced under moist soil conditions and it is thought to be a result of accumulation of soil displaced from the wheel tracks onto the center line of the trail. These phenomena are well illustrated by the results for Site 4, displayed in Figures 9 and 10. Bulk densities for the wheel tracks were significantly different from the bulk densities for the undisturbed soils 50 percent of the time, while the center line bulk densities were rarely significantly different from the undisturbed soils.

Table 1. Average Bulk Densities for Undisturbed Soil and Skidder Trail Components*

0 to 20 cm Depth Intervals

		Wheel Track		Centre Line		Undisturbed	
Site	Skidder trips	Average bulk density	(n)	Average bulk density	(n)	Average bulk density	(n)
1-DRY	5	1115 a	27	1210 ab	14	1012 b	40
	10	1148 a	24	1073 ab	13	952 b	39
	20	1147 a	27	1089 ab	14	943 b	42
	40	1052 a	26	1005 a	14	1060 a	42
	80	1135 a	28	998 b	14	1043 b	42
1-MOIST	5	1027 a	28	1023 a	14	1008 a	42
	10	1045 a	28	841 b	14	998 a	42
	20	921 a	28	950 a	14	996 a	40
	40	1077 a	28	959 a	13	992 a	40
	80	985 a	27	945 a	14	961 a	39
2-DRY	5	1091 a	27	1131 a	14	1012 a	42
	10	967 a	26	1183 a	14	1159 a	42
	20	862 a	28	714 a	14	904 a	41
	40	900 a	28	1018 a	14	935 a	42
	80	1164 a	28	972 a	14	1160 a	42
2-MOIST	5	917 a	28	1063 a	14	945 a	41
	10	1013 a	28	774 a	14	986 a	41
	20	1166 a	28	803 b	14	876 b	41
	40	1316 a	28	405 b	14	1061 c	42
	80	1175 a	28	562 b	14	952 c	42
3-DRY	5	1352 a	25	1261 a	13	1257 a	41
	10	1383 a	28	1333 ab	13	1241 b	42
	20	1319 a	28	1261 ab	14	1196 b	42
	40	1392 a	28	1268 ab	14	1240 b	42
	80	1350 a	28	1343 ab	13	1215 b	42
3-MOIST	5	1261 a	28	1190 a	14	1209 a	42
	10	1237 a	28	1208 a	14	1207 a	42
	20	1387 a	28	1118 b	14	1177 b	42
	40	1343 a	28	1242 ab	14	1182 b	42
	80	1269 a	28	1112 b	14	1139 b	42
4-DRY	5	1323 a	28	1322 a	14	1312 a	42
	10	1371 a	28	1255 a	14	1255 a	42
	20	1425 a	27	1397 ab	14	1276 b	42
	40	1425 a	28	1365 ab	11	1234 b	42
	80	1465 a	26	1431 a	14	1255 a	42
4-MOIST	5	1295 a	28	1186 ab	14	1134 b	42
	10	1420 a	28	1166 b	14	1172 b	42
	20	1248 a	28	1048 a	14	1109 a	42
	40	1257 a	28	1050 ab	14	1048 b	42
	80	1452 a	28	1269 ab	14	1141 b	42
5-DRY	5	1631 a	28	1657 a	14	1591 a	42
	10	1692 a	28	1680 a	14	1634 a	41
	20	1719 a	28	1656 ab	14	1562 b	41
	40	1642 a	28	1593 a	14	1615 a	42
	80	1550 a	28	1565 ab	14	1448 b	42
5-MOIST	5	1687 a	28	1543 b	14	1536 b	42
	10	1591 a	28	1484 a	14	1485 a	42
	20	1735 a	28	1633 ab	14	1608 b	42
	40	1682 a	28	1568 ab	14	1495 b	42
	80	1745 a	28	1605 b	14	1557 b	42

* means in each row followed by the same letter are not significantly different at the 0.05 level.

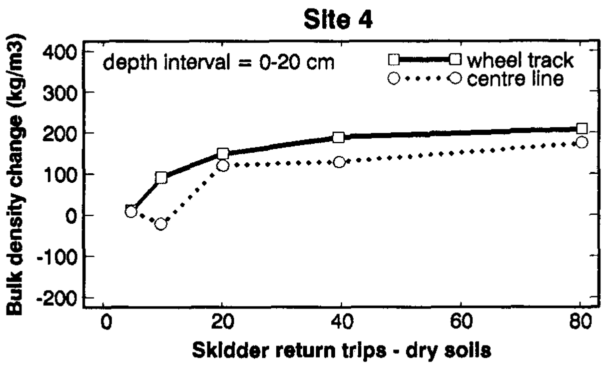

Figure 9. Changes in bulk density with location on trail.

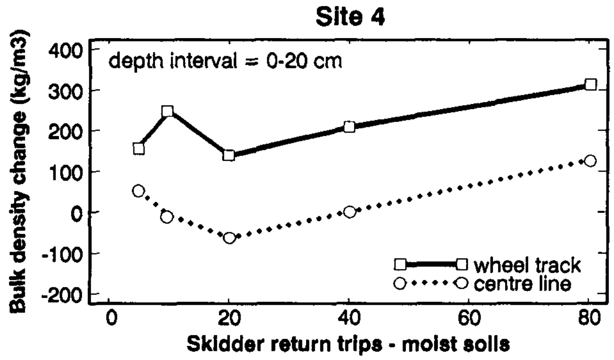

Figure 10. Changes in bulk density with location on trail.

Soil water contents were generally higher for the treatments carried out in the spring or winter than for those in the summer or fall; however, for individual trails that was not always the case. In the case of Site 5, surface soil water contents did not appear to be significantly different; however, antecedent weather conditions were wetter for the moist treatment and ponds of standing water were present nearby. The slightly higher bulk density increases achieved for the moist soil treatment at Site 5 suggest that soil water contents at depth may have been somewhat higher. The soils at this site are very coarse and at no time achieved very high soil water contents.

Variations in compactive effect between sites are likely a function of differing initial bulk densities, variations in soil texture, and particularly, in soil water content. Variations in the pattern of increasing bulk density with increasing wide-tire skidder traffic on individual sites are ascribed to variation in background soil bulk density, soil texture, and moisture content across the sites. In addition, burial or incorporation of forest floor materials and rotten wood into the mineral soil on some trails, and displacement of mineral soil by the skidder, will cause some variation.

Soil Displacement and Disturbance

Soil displacement tended to take two obvious forms: firstly, ruts created by the skidder tires; secondly, berms formed of soil displaced laterally during rut formation. These berms generally formed adjacent to the trails, but in some cases formed along the center line of the trail.

Table 2. Average Rutting Depths (cm)*

	NUMBER OF SKIDDER RETURN TRIPS				
SITE	5	10	20	40	80
Dry Soil Conditions					
1	8 a	12 b	6 a	8 ab	9 ab
2	2 a	3 a	13 c	3 a	7 b
3	8 a	8 a	8 a	8 a	8 a
4	8 ab	6 a	7 a	9 ab	10 b
5	0 a	0 a	0 a	0 a	2 b
Moist Soil Conditions					
1	10 a	14 ab	14 ab	19 c	16 b
2	10 a	13 a	22 b	35 c	45 d
3	16 ab	13 a	18 ab	20 b	28 c
4	13 a	17 a	29 b	20 a	17 a
5	7 a	8 ab	11 abc	13 bc	15 c

* means in each row followed by the same letter are not significantly different at the 0.05 level.

Table 3. Average Values for Exposed Mineral Soil on Skidder Trails (%)*

	NUMBER OF SKIDDER RETURN TRIPS				
SITE	5	10	20	40	80
Dry Soil Conditions					
1	12 a	10 b	35 b	53 c	53 c
2	8 a	19 ab	10 a	29 b	91 c
3	4 a	12 ab	10 ab	18 b	27 c
4	1 a	1 a	1 a	11 b	33 c
5	5 a	9 a	33 b	32 b	62 c
Moist Soil Conditions					
1	15 a	28 a	75 b	71 b	93 c
2	5 a	4 a	9 a	95 b	98 b
3	16 a	29 a	69 b	76 b	95 c
4	7 a	24 ab	43 bc	51 c	39 bc
5	1 a	5 a	5 a	17 b	21 b

* means in each row followed by the same letter are not significantly different at the 0.05 level.

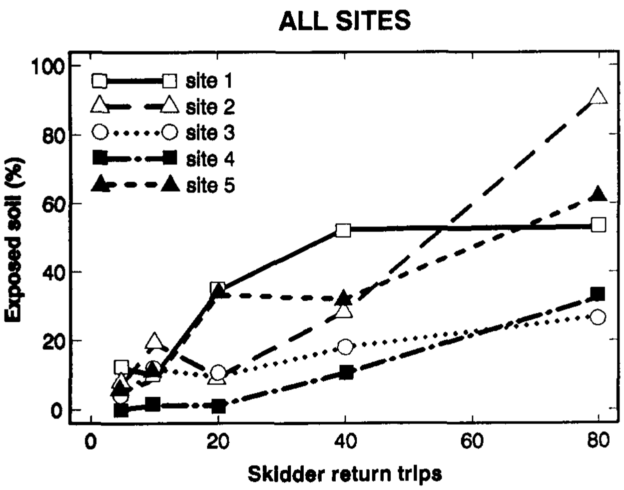

Figure 11. Plots of exposed soil on skidder trails — dry soil.

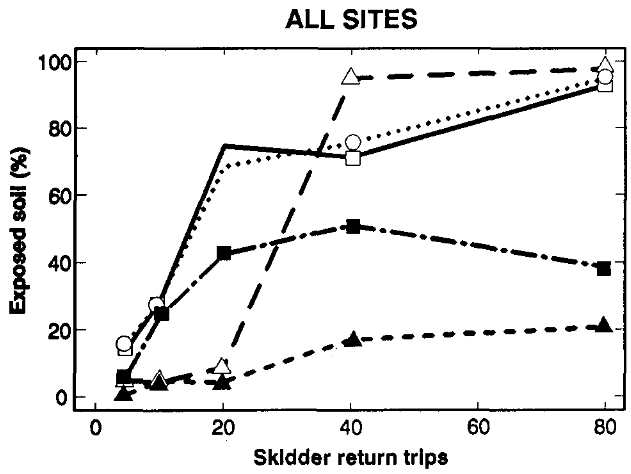

Figure 12. Plots of exposed soil on skidder trails — moist soil.

In general, increasing levels of skidder traffic led to increasing depths of rutting. Rutting depths tended to be deeper for moist than for dry soil conditions, the effect often becoming more noticeable with increasing traffic (Table 2). Average rutting depths under dry conditions were generally less than 10 cm even with heavy traffic. Average rutting depths under moist condition ranged between 7 and 45 cm.

For both dry and moist soil conditions, increasing levels of skidder traffic led to increasing amounts of exposed mineral soil (Figures 11, 12, and Table 3). Under dry soil conditions the increase in mineral soil exposure was relatively linear for most sites. Extensive exposure of mineral soil tended to occur with fewer passes under moist soil conditions. In the case of moist soils, the response relationship was not linear; most of the increase was achieved somewhere between 20 and 40 return trips. There was little increase in exposed soil after 40 return trips. The exception to the above was Site 5, where there was greater exposure of mineral soil under dry rather than moist soil conditions. Visual observation of this site suggests that slightly higher slash accumulations in the area of the moist treatment may have resulted in lower mineral soil exposure.

CONCLUSIONS

The results of this study indicate that a relatively low number of skidder trips (10-20) will cause a significant portion of the compaction on a skid trail. These findings indicate that limiting the area disturbed by utilizing designated, rather than operator's choice, skid-trail patterns is appropriate if overall site degradation is to be minimized.

While there is a moderately consistent trend of increasing compaction with increasing moisture content, the relationship does not always hold. What is clear is that compaction will occur irrespective of the time of year or soil moisture conditions. It follows that timing of skidder operations to avoid moist soil conditions will not necessarily result in less soil compaction. The safe assumption is that compaction will occur irrespective of timing. However, the findings associated with rutting depths and exposure of mineral soil clearly indicate that dry season operations will result in less site disturbance in general. If, as we would expect, rutting and soil displacement are linked to destruction of soil structure (e.g. puddling), seasonal restrictions on operation of skidders will be important.

Except for Site 2, there are no dramatic differences in compaction or rutting depths from site to site even though the physical characteristics and parent materials of the various soils are quite different. This finding suggests that it will be difficult to find sites that are not susceptible to compaction. From the standpoint of management decisions, it may be best to take a conservative position and assume that all sites will be vulnerable. This conclusion again leads one to argue for either a designated skid trail approach followed by rehabilitation, or a reliance on other yarding systems.

A review of a number of papers on the subject [1, 3, 4, 6, 7, 8, 12, 19, 20] indicates that the increases in bulk density generated by the wide-tire skidder are at the low end of the compaction range typically reported. These results indicate that preferential use of wide-tire machines, rather than conventional narrow-tire skidders, will cause less site degradation. However, many of the average increases in density noted (10%-35%), are sufficiently high to result in a 10 to 20 percent reduction seedling height growth on the skidder trails [7, 10, 11, 20]. The lower densities recorded for the trail center lines suggest that these locations should be preferentially selected for planting if rehabilitation by subsoiling or other means is not undertaken.

REFERENCES

[1] Bradshaw, G. 1979. Preplanned skid trails and winching versus conventional harvesting on a partial cut. Forest Research Laboratory, Oregon State University, Corvallis, Oregon. Research Note 62. 4 p.

[2] Butt, G. 1987. Effects of skidder compaction on tree productivity. Contract to: MacMillan Bloedel Limited, Woodlands Services Division, Nanaimo, B.C. 62 pp.

[3] Dickerson, B.P. 1976. Soil compaction after tree-length skidding in northern Mississippi. Soil Sci. Soc. Am. J. 40:965-966.

[4] Dyrness, C.T. 1965. Soil surface condition following tractor and high-lead logging in the Oregon Cascades. J. For. 63:272-275.

[5] Foil, R.R. and C.W. Ralston. 1967. The establishment and growth of Loblolly Pine seedlings on compacted soils. Soil Sci. Soc. Amer. Proc. 31:565-568.

[6] Froehlich, H.A., D.E. Aulerich and R. Curtis. 1981. Forest Research Laboratory, Oregon State University, Corvallis, Oregon. Research Paper 44. 13 pp.

[7] Froehlich, H.A. 1979. The effect of soil compaction by logging on forest productivity. Final Report Contract No. 53500-CT4-5(N), Bureau of Land Management, Portland, Oregon. Part I. 19 pp.

[8] Froehlich, H.A. 1978. (1) The physical effects of timber harvesting on forest soils. Proceedings of Society of American Foresters National Convention, Alburquerque, NM. pp. 229-237.

[9] Froehlich, H.A. 1978. (2) Soils compaction from low ground pressure, torsion-suspension logging vehicles on three forest soils. Forest Research Laboratory, Oregon State University, Corvallis, Oregon. Research Paper 36. 13 pp.

[10] Froehlich, H.A. 1976. The influence of different thinning systems on damage to soils and trees. Proceedings, XVII IUFRO World Congress. Division IV. pp. 333-344.

[11] Hatchell, G.E., C.W. Ralston and R.R. Foil. 1970. Soil disturbances in logging, effects on soil characteristics and growth of Loblolly Pine in the Atlantic Coastal Plain. J. For. 68:772-775.

[12] Mace, Jr., A.C. 1970. Soil compaction due to tree length and full tree skidding with rubber-tired skidders. School of Forestry, University of Minnesota. Minnesota Forestry Research Notes, No. 214. 4 pp.

[13] Mathews, W.H., J.G. Fyles and H.W. Nasmith. 1970. Post-glacial crustal movements in southwestern British Columbia and adjacent Washington State. Can. J. Earth Sciences. 7:690-702.

[14] Packee, E.C. 1969. Access logging: Research Project Report, Project E68-7, MacMillan Bloedel Limited, Forestry Division. 3 pp.

[15] Rollerson, T.P. 1989. 1988-1989 Progress Report - Buckley Bay Mechanized Harvesting Seedling Survival and Growth Study. MacMillan Bloedel Limited, Woodlands Services Division, Nanaimo, B.C. 19 pp.

[16] Rollerson, T.P. and C.A. Kennedy. 1984. Compactive effects of a low ground pressure skidder. LUPAT, Woodlands Services Division, MacMillan Bloedel Limited. 68 pp.

[17] Smith, R.B. and E.F. Wass. 1976. Soil Disturbance, Vegetative Cover and Regeneration on Clearcuts in the Nelson Forest District, British Columbia. Canadian Forestry Service, Pacific Forest Research Center, Victoria, B.C. BC-X-151. 37 pp.

[18] Statistical Graphics Corporation. 1987. Statgraphics. Version 2.6. Rockville, Maryland, U.S.A.

[19] Steinbrenner, E.C. and S.P. Gessel. 1955. The effect of tractor logging on physical properties of some forest soils in southwestern Washington. Soil Sci. Soc. Proc. 19:372-376.

[20] Youngberg, C.T. 1959. The influence of soil conditions following tractor logging, on the growth of planted Douglas-fir seedlings. Soil. Sci. Soc. Proc. 23:76-78.