Analysis of Site Stand Impacts from Thinning with a Harvester-Forwarder System

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ABSTRACT

The use of a harvester-forwarder system for commercial thinning operations in a Douglas-fir plantation had little detrimental impact on the residual stand. Less than five percent of the sample trees in the residual stand exhibited damage from the thinning operation. Trails occupied less than 20 percent of the harvested area with significant portions of the developed trail, over 13 percent of the harvested area, in lightly disturbed harvester trails. Trail spacing was consistent and averaged 26 metres between trails for the area studied. Changes in bulk density were greater for harvester trails, increasing an average of 25 percent in the first 10 centimetres of soil depth. Bulk densities on forwarder trails averaged 20 percent greater than measurements on adjacent control sites for the first 10 centimetres of soil depth. These bulk density values, when compared against magnitudes from the literature, suggest that little site damage was caused by thinning operations with this system.

Keywords: *site degradation, soil compaction, residual stand damage, harvest-forwarder system, thinning harvest.*

INTRODUCTION

Commercial thinning operations are implemented to improve the expected value of timber through focused growth of the residual stand and selective removal of poor quality timber. However, the impact of these operations can also adversely affect the growth potential of the site. A number of studies [2,5,7,12] have reported significant increases in soil compaction, rutting, and soil disturbance caused by harvesting operations. In some cases, extensive soil compaction on skid trails was measured 32 years after the harvest [17].

Value losses associated with compacted areas, such as skid trails, occur as a result of slower growth rates and losses due to bole or root damage [14]. One study reported 74 percent less growth in trees regenerating on skid trails when compared with trees regenerating in undisturbed areas on the same site [17]. Injuries to the residual trees, particularly stem and root damage caused during the harvest, also produce indirect value losses through insect infestation and root rot, although these losses are often difficult to quantify [4,14]. Growth reduction models developed for thinned stands of Scots pine and Norway spruce in Scandinavia were based on the extent of root damage produced by the strip road (or main skid trail) and suggest that growth losses of up to 40 percent can be expected where root damage is extensive [18].

With the advent of plantation and second growth natural stands in the western regions of North America, research must focus on evaluation of harvesting systems that can be used to maximize residual stand value, while maintaining the environmental quality of the site. Conventional ground-based harvesting systems used in western Canada typically include feller-bunchers, grapple or cable skidders, and mechanical processors.

Using these harvesting machines for thinning could result in extensive residual stem and root damage with additional soil compaction, rutting, and nutrient relocation on the site. Feller-bunchers fully support the entire weight of the trees held in the felling head during operation, thus creating potential soil compaction problems along the track. Skidders often produce residual stem damage through skidding tree-length or long log length material through the residual stand. And, because the trees are rarely processed at the stump with these systems, nutrient concentration at the landing or roadside is common. A thinning harvest which produced these stand and site problems could substantially reduce both timber growth and subsequent value from the stand.

A recently introduced harvesting system developed in Scandinavia, the harvester-forwarder system, has the potential to significantly reduce the site-related problems that often occur when using tree-length or log-length systems for thinning harvests. The system is ground-based with two machines, a

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harvester and a forwarder, operating in tandem to fell, delimb, buck, and transport merchantable wood to the roadside or landing.

Individual trees are felled, delimbed, and bucked by the harvester using a boom-mounted, single-grip harvesting attachment. Tree limbs removed during processing are placed to the front of the machine, forming a mat which distributes the weight of the harvester over a larger area and reduces contact between the harvester tires and the soil surface. Nutrient loss at the point of harvest is minimized with this approach, since most of the removed limbs and foliage are left on site.

The forwarder follows behind the harvester in the same trail, picking up piles of processed timber and placing the material in a rear bunk for transport to the roadside or landing. Theoretically, the slash left during harvester processing continues to reduce the impact of forwarding operations on the forest soil. On main trails, where forwarder travel is substantial, the effect of this slash "cushion" may be minimal.

Harvested material is fully supported by the forwarder during transport to the landing or roadside. This feature eliminates gouging of the soil between the machine tracks that often results when skidding. In addition, forwarders are compact and have substantial control over machine and load movement to minimize scarring of residual trees. Loaded ground pressure measurements range as low as 42.1 KPa for a 14 tonne capacity forwarder equipped with three axles (six wheels) and steel treads on the four rear wheels. Siren [14] notes that these machines have undergone extensive design changes in recent years to reduce unit weight and minimize soil disturbance.

Although harvester-forwarder systems have been researched in North America, little work has been directed to site or stand impacts [1,11]. This research was initiated to evaluate the impacts associated with using a harvester-forwarder system on the site and residual stand during commercial thinning operations on West Coast Douglas-fir plantations. Specifically, the research addressed three objectives: 1) Determine the effect of harvester-forwarder operations on the residual stand; 1) Determine the area disturbed by the harvester and forwarder trails and estimate the impact of these trails on future stand growth; and 3) Determine the extent of soil compaction associated with harvester and forwarder operations for these trails.

METHODS AND PROCEDURES

The study site was a recently thinned stand of timber located in Snohomish County near Arlington, Washington. The stand, a Douglas-fir (*Pseudotsuga menziezii*) plantation of approximately 8.3 hectares in size, was commercially thinned using a harvester-

Table 1: Summary of residual and harvested stand characteristics for study site.

	DIAMETER[1] (cm)	TOTAL HT (m)	TOTAL VOLUME[2] (m^3/ha)
RESIDUAL			
Mean	24.6	22.0	171.8
Std. Dev.	(5.6)	(1.4)	(70.2)
Number	409	409	101
HARVESTED			
Mean	20.3	20.97	74.9
Std. Dev.	(4.7)	(1.1)	(53.9)
Number	260	260	101

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[1] Diameter and height data based on individual measurements.

[2] Volume data based on plot-by-plot measurements.

forwarder system approximately three months prior to data collection. The treated area had been planted in 1965 to a density of 1075 stems per hectare and pre-commercially thinned by hand in 1975 to an estimated density of 850 stems per hectare. The commercial thinning operations on the site were designed to reduce stocking to a level of approximately 360 stems per hectare. The site was of relatively flat to rolling terrain, with ground slopes ranging from 0 to 17 percent. The site contained many large old-growth cedar stumps and cull logs that often hindered harvesting operations. (See Table 1.)

Soils present on the study site were generally classified in a previous report as Indianola sandy loam [15]. This classification was confirmed during the study. Indianola soils are characterized by the presence of deep, well-drained sands with a 3 to 5 cm organic layer, a 20 to 25 cm A horizon of brown, very loose loamy sand with some small gravel. Generally, these soils are classified as very windfirm with harvesting operations possible at any time.

To determine the area associated with harvesting and forwarding trails, transect lines four metres in width were laid out at 20 metre intervals across the study site. Data were collected along each transect to determine the location and width of trails developed during the harvest. Each trail located on a transect was classified as either a forwarder or harvester trail. A trail was classed as a harvester trail if no significant soil disturbance was observed, ie., no exposure of the mineral soil. Trails classed as forwarder trails exhibited mineral soil exposure or, in extreme cases, rutting within the transect area. After classification, the length of each trail within the transect area was measured to estimate the proportional area of harvesting trails in each transect and across the site. The location of each trail was also recorded for later analysis of between-trail spacing distances.

Stand characteristics were recorded along the transects using fixed plot measurements of residual stand characteristics (diameter and height), and stump characteristics (stump diameter and stump height). Residual tree damage measurements were taken at each plot to quantify residual stem damage across the stand. Damage measurements were restricted to observations of damage to the bole of the residual trees with no measurement of root damage. Estimates of slope were also recorded at each plot. Measurements were taken on circular fixed plots with radius of 5.64 metres with complete sampling within the plot. Plots were located at 20 metre intervals along the transect lines. A total of 106 plots were measured during the study.

To determine the effect of equipment operation on soil bulk density, soil samples were taken from trail locations within the site. Several main, or "heavily travelled (HT)", trails were randomly selected, from which short "lightly travelled (LT)" trails diverged. Each main trail was split into proximal and distal halves, and a sampling point was randomly located in each half, and randomly to the right or left side of the trail. Soil core sampling was done in the machine wheel-track ("HT trail" samples) and 3 m to the side of the track ("HT control" samples). Lightly travelled (LT) trails, those trails diverging from the main trails, were randomly selected along each half of the selected trails. A sampling point was randomly located along the length of each LT trail and randomly to the right or left side. Samples were not collected in the final 2 m of the LT trails, where evidence of equipment travel was often difficult to discern. Soil core sampling was done in the machine wheel-track ("LT trail") and 3 m from other randomly located in-track points ("LT control"). Sampling points falling on large logs or stumps were replaced by systematically offset points (1 m offset in cardinal directions).

At every sampling point, soil core samples (200 cm^3, 5 cm high) were collected with a cylindrical core sampler, at core-centre depths of 10, 20 and 30 cm below the mineral soil surface. Cores damaged during sampling (usually because of large roots or coarse fragments) were discarded and replaced; such replacement was needed for 5 percent of the samples. In all, 180 core samples were collected, giving 15 replicates for each combination of treatment and depth variables.

Each sample was air-dried and sieved for separation and weighing of organic and inorganic coarse (> 2 mm) fractions. Oven-dry (105°C) mass of these fractions was then determined. Oven-dry mass of the organic and inorganic fine (< 2 mm) fractions was determined by combustion of the organic material. Bulk density (solids mass/total volume) was calculated. Comparisons of trail vs. control samples for each equipment type at each depth were performed using t-tests. In addition, bulk density differences between HT and LT trails were examined by depth. Finally, the magnitudes of bulk densities were compared with magnitudes reported in the literature in studies of harvesting impacts and in studies of soil physical effects on tree growth.

RESULTS AND CONCLUSIONS

Approximately 43 percent of the stand was removed during the commercial thinning. All of the stems were selected by the operator at the time of harvest. The volume removed from the stand was estimated at 558.8 m^3 or 65.7 m^3 per hectare. An estimated 1307.1 m^3 or 153.8 m^3 per hectare of residual volume was left in the residual stand. The average DBH for harvested material was estimated at 20.3 cm based on data generated from a regression equation relating the diameter at groundline (DGL) to DBH.

A total of 409 live stems was sampled throughout the stand with only 19 observed incidents of damage recorded. This corresponds to less than 5 percent residual damage in the thinned stand. Measurements of scar size suggest that a typical scar caused by either the harvester or forwarder would average 106 cm^2 in size. However, the distribution of the sample data suggests that a damaged area of less than 40 cm^2 occurred most frequently. Generally, scars were located above 3 meters on the stem indicating that damage occurred during the forwarding operation when the forwarder tilted to one side or the other when moving along sidehills.

Stump height, a major concern with mechanized chainsaw felling, averaged 16.8 cm with a standard deviation of 9.3 cm. An ANOVA relating stump height to average slope on each plot indicated no significant correlation between these variables, suggesting that, while slope may affect stump height, other factors such as brushiness and the presence of obstacles may have a more significant impact on this factor.

Comparison of stump height data with corresponding stump diameter measurements indicates that the harvester was rarely required to fell trees that exceeded the capacity of the felling saw (45 cm). Stump diameter for harvested stems averaged 26.5 cm with a standard deviation of 6.7 cm. Only two large stumps, 30 and 34 cm Diameter at Groundline (DGL), observed during data collection had been incompletely felled with some "barber-chairing" present in the stump. No other harvesting related problems were noted during the study.

Approximately 19.70 percent of each transect area was covered by lightly and heavily travelled trails (Table 2). Lightly travelled trails covered a mean of 6.67 percent of each transect area with a standard deviation of 4.01 percent, while heavily travelled trails covered a mean of 13.02 percent with a standard deviation of 7.42 percent. In contrast, trail coverage noted in other studies [3,8,14,16] ranged from 25 to 30 percent. However, many of these

Table 2: Trail concentration and spacing characteristics by type within transects for the study site.

TRAIL TYPE[1]	CONCENTRATION (percent)	SPACING (metres)
LIGHTLY TRAVELLED		
Mean	13.02	24.76
Std. Deviation	(7.42)	(15.28)
Number	16	33
HEAVILY TRAVELLED		
Mean	6.67	28.65
Std. Deviation	(4.01)	(14.61)
Number	16	17
ALL		
Mean	19.70	26.40
Std. Deviation	(7.63)	(17.45)
Number	16	120

[1] Student's t-test indicated no significant difference in spacing patterns for the two types of trails identified in the study.

Table 3: Summary and comparison of soil compaction measurements by trail type on a coarse fragment-free basis.

	BULK DENSITY[1]			
	HEAVILY TRAVELLED[2]	HT CONTROL	LIGHTLY TRAVELLED[2]	LT CONTROL
DEPTH	(Mg/m^3)			
10 cm				
Mean	0.854 *	0.714	0.940 **	0.751
Std. Dev.	(0.212)	(0.178)	(0.215)	(0.150)
20 cm				
Mean	0.920 **ns**	0.818	0.996 *	0.825
Std.Dev.	(0.170)	(0.216)	(0.293)	(0.215)
30 cm				
Mean	0.987 **ns**	0.865	1.071 **ns**	0.947
Std.Dev.	(0.171)	(0.257)	(0.227)	(0.221)

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[1] Student's t-test results indicated by the following notation:

** Significantly different at the 0.05 alpha level.
* Significantly different at the 0.10 alpha level.
ns No significant difference indicated at the 0.10 alpha level.

[2] "Trail" samples were taken in the wheel track; "control" samples were taken 3 m to the side of the sampled trail.

studies evaluated clearcut operations which may account for the higher concentrations of trails.

Spacing averaged 26.40 m between trails, but was highly variable with a standard deviation of 17.45 m (Table 2). Adjacent trails of the same type, either HT or LT trails, were comparably spaced, with a mean between-trail distance of 24.76 m (±15.28 m) for adjacent LT trails and a mean of 28.65 m (±14.61 m) for adjacent HT trails. A Student's t-test comparing the mean between-trail spacing for each trail type indicated no significant difference in spacing distance by trail type.

Soil compaction is influenced by such variables as soil texture, grain size, and soil water content, as well as compactive stress. In this case, loamy sand or sandy loam texture characterized virtually every core sample. Low power magnification of a few subsamples indicated that sand grains were predominantly sub-angular. The thinning was carried out over a rainless period of several days. Average soil water content during thinning is estimated to have been between 0.04 and 0.14 kg water per kg solids. (Water content of air dried soils averaged 0.04 kg.kg^{-1}; Field capacity water contents, estimated from water retained by soil core samples at a matric potential of -20 J.kg^{-1}, averaged 0.14 kg.kg^{-1}.)

Mean soil bulk density measurements for the HT trails ranged from 0.854 Mg.m^{-3} at the 10 cm depth to 0.987 Mg.m^{-3} at the 30 cm depth (Table 3; Fig. 1). Bulk density measurements from LT trails averaged somewhat higher, with mean values ranging from 0.940 Mg.m^{-3} at the 10 cm depth and 1.071 Mg.m^{-3} at the 30 cm depth (Table 3; Fig. 2). In contrast, mean bulk density values for the HT and LT control sites ranged from 0.714 and 0.751 Mg.m^{-3} at the 10 cm depth to 0.865 and 0.947 Mg.m^{-3} at the 30 cm depth, respectively.

Comparison of in-trail and control bulk density measurements suggests an overall increase in soil bulk density, although significant differences were predominantly detected in the near-surface soils. Increases in bulk density of near-surface soils are about 20 to 25 percent, high enough to be considered "damage" in the rating system employed by Geist et al. [9]. These results are for a well drained, sandy loam which is typically less prone to compaction than soils having higher percentages of clay. However, the within-wheel-track sampling zone represents only a small percentage of the trail area and an even smaller fraction of the forest area, suggesting that the extent of compaction related damage is very limited.

Minore et al. [13], in a study of Douglas-fir, red alder, lodgepole pine, Sitka spruce, western hemlock, and western red cedar grown in sandy loam at various bulk densities, found that roots of all species exhibited good root penetration at a bulk density of 1.32 $Mg.m^{-3}$, that some species exhibited differences in penetration at 1.45 $Mg.m^{-3}$, and that none penetrated the soil at 1.59 $Mg.m^{-3}$. In this study, of the 90 soil core samples collected in LT and HT trails, only seven had coarse fragment-free bulk densities exceeding 1.32 $Mg.m^{-3}$, and the highest was 1.43 $Mg.m^{-3}$. Some of the observed high densities are inferred to be a result of previous logging impacts. In this connection, it is noteworthy that, of the 20 highest bulk density measurements taken during the study, six were from off-trail "control" areas that were essentially unaffected by harvester or forwarder operations.

There were no consistent differences in compaction between lightly and heavily travelled trails. Perhaps this reflects the tendency, commonly observed, for bulk density change to become very small in response to traffic after the first few trips [7;10]. In addition, effort was made during forwarder operations to reduce soil compaction by equipping the rear forwarder tires with steel treads which distribute axle loading over a larger ground contact area.

Partial reversal of compaction may be expected to occur over time [2,6]. In this study, the limited severity and extent of the compaction and the prospects for reversal of compaction over time suggest little cause for concern about residual stand growth.

CONCLUSIONS

This study suggests that a harvester forwarder system is well suited to partial harvests, particularly thinnings. The impact of the system on the residual stand was found to be negligible and the area taken up by trails, particularly the more heavily travelled main trails, was relatively small when compared against studies of other ground-based systems.

Some soil impacts were noted during the study, particularly within the track area of lightly travelled trails. However, the degree of compaction was not of a magnitude that suggests significant long-term damage. In addition, statistically significant levels of compaction occurred primarily in the first 10 cm of the soil horizon.

Based on these results, a harvester-forwarder system should be considered by forest managers interested in maintaining high site quality after the harvest. It produced little residual stand damage in this thinning harvest and, based on measured compaction levels, had minimal impact on site productivity. The limits of this study should be noted, however, since the results apply only to this soil type and soil moisture condition at the time of treatment.

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