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Soil compaction from logging equipment: Effects on growth of young ponderosa pine

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ABSTRACT: Compacted soils in tractor skid trails produced by harvesting ponderosa pine proved to be long-lasting. Soil densities in skid trails at 7.6- and 15.9-centimeter (3-and 6-inches) depths and 22.9- and 30.5-centimeter (9- or 12-inches) depths were 18 and 9 percent greater, respectively, than those of adjacent, undisturbed soils 16 years after logging. Growth of residual young pine trees related negatively to the area and intensity of soil compaction in the root zone. Moderately impacted trees showed a 6 percent reduction in growth rate and heavily impacted trees showed a 12 percent reduction over a 16-year period.

LOGGING equipment may cause changes in soil physical properties depending upon the area affected, the relative increase in soil density with repeated trips, and the reduction in infiltration and porosity. Tractor trails commonly account for 25 to 35 percent of a tractor-logged site (*5*, *9*, *13*, *14*).

Seedling established on skid trails may be reduced by two-thirds and growth reductions of 40 percent or more may occur in comparison to adjacent cutover lands (*6*, *12*, *15*). Skid-trail compaction may also affect the growth of residual trees. Moehring and Rawls (*11*) showed that growth reduction in 40-year-old loblolly pine (*Pinus taeda* L.) related closely to the severity of soil compaction in the root zone. The growth decline was as much as 40 percent in the case of heavily impacted trees.

Because thinning by conventional logging methods may retard development of trees, I examined the longevity of soil compaction and its effect on the growth rate of residual young ponderosa pine (*Pinus ponderosa* L.).

Study methods

A heavy, partial cut of old-growth ponderosa pine removed most of the overstory from a stand of young pine in Oregon's Ochoco National Forest in 1961. Operators logged the area with large crawler tractors, then common to the industry. A year later the young stand was thinned to provide a release for selected crop trees. Trees were felled by hand and not yarded. In fact, no logging equipment entered the stand after overstory removal. In 1977, at the start of my study, the average age of the stand, at breast height, was 64 years (Figure 1).

The surface soil layer on the site extends 22.9-30.5 centimeters (9-12 in) deep, and is a dark reddish brown sandy clay loam with a strong, fine crumb structure. Subsoils are grayish brown sandy clay loams containing high proportions of stone fragments. These subsoils are 30.5 to 38.1 centimeters (12-15 in) thick. The underlying bedrock is tuffaceous sedimentary rock and breccias. Occasional basaltic outcrops occur. Rooting depth generally appears to be less than 46 centimeters (13 in).

The gently rolling terrain features slopes ranging from 5 to 25 percent. Elevation varies from 1,412 to 1,477 meters (4,400-4,600 ft). The site receives 63.5 centimeters (25 in) of precipitation in a normal year.

I selected a sample of 75 trees to obtain a wide range of soil disturbances in the root zone around each tree. On the basis of height and age of the 16 tallest trees in the sample, I classed the area as Site V for ponderosa pine (*10*).

I measured soil densities with a two-probe nuclear densitometer at two or more points in skid trails and one or more points in undisturbed areas around each tree, a total of 254 points, 120 in skid trails and 134 in undisturbed locations. At each point, I measured soil densities at depths of 7.6, 15.2, 22.9, and 30.5 centimeters (3, 6, 9 and 12 in) below the soil surface. I mapped crown extension and skid trail locations for each tree. Assuming the root zone equaled a circle with a radius 1.5 times the average crown radius of the tree (*3*, *4*), I determined the percentage of the root zone in the skid trail from the map.

I assigned each tree to one of three compaction classes: light, moderate, or heavy. Light represented less than 10 percent im-

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pact on the root zone. Moderate denoted an impact from 11 to 40 percent, with a density increase of more than 10 percent. Heavily disturbed indicated a tree with 40 percent of its root zone affected by a 10 percent or greater increase in density.

Cattle have used the area since 1965. Although I could not determine the exact usage, I subjectively assigned each tree to one of three cattle impact classes on the basis of present activity. I assumed that some trees, protected by slash from logging and precommercial thinning, were unaffected by cattle. Others showed signs of considerable cattle usage by close cropping of grasses and sedge, trail patterns, and signs of bedding. These trees reflected moderate or heavy impact.

I recorded variables for each sample tree (Table 1) to help determine growth rates before and after logging. Four increment cores taken at diameter at breast height (DBH) helped to determine age and basal area growth rates before and after overstory removal and subsequent thinning. I excluded trees with stem wounds, broken tops, or other visible defects from the sample.

Figure 1. Widely spaced ponderosa pine stand 16 years after overstory removal and precommercial thinning of small stems.

Results and discussion

Effects on soil density. Soil compaction from logging equipment was readily measurable 16 years after cutting. Soil density in skid trails at depths of 7.6- and 15.2-centimeters averaged 18 percent higher than the densities in undisturbed soils. At the 22.9- and 30.48-centimeter depths, skid trail density was 9 percent greater than the density at the same depths in undisturbed soils.

Soil compaction in skid trails varied considerably, especially at the 22.9- and 30.48-centimeter depths. This probably was due to increased stoniness. From the data collected, I was unable to explain the slightly higher density at 7.6 centimeters than at 15.2 centimeters on non-skid trail sites (Table 2).

It was surprising that skid trails were this dense 16 years after logging. Six measurements in skid trails at an active logging operation nearby showed essentially the same densities at each depth as did the 16-year old trails. Thus, little recovery occurred.

Cattle use, of course, may help keep the soil surface layers compacted. Alderfer and Robinson (*1*) found that soil compaction by cattle was limited mostly to the surface 2.5 to 5.0 centimeters (1-2 in).

I compared soil densities at the 7.6- and 15.2-centimeter depths for 30 sample points sustaining heavy current usage by cattle with an equal number of points receiving little or no current usage. I found no statistical difference between the two treatments. As a result, I did not use this variable in the equation for predicting tree growth.

Effects on residual tree growth. I developed two regression equations to test the effect of tree and soil parameters on the two dependent variables, growth ratio and growth rate.

The three tree variables most strongly related to growth ratio were diameter at the time of release, crown volume, and competitive stress. Equation 1 shows that a smaller diameter tree with a relatively large crown could respond to the release more effectively from the standpoint of in-

Table 1. Description of variables tested in the statistical analysis.

Variable	*Mean*	*Range*	*Standard Deviation*
Growth ratio (Basal area added during 15 years prior to release divided by basal area added during an equal period of time after release; measured from 4 increment cores)	3.5	0.7-7.1	1.5
Growth rate (Average basal area added per year during 15-year period after release; measured from 4 increment cores; sq. in./yr.)	1.6	0.2-3.4	0.7
Tree height (To nearest foot)	39.0	21-58	8.5
Crown length (Live crown to nearest foot)	24.1	11-38	5.9
Crown width (Average width to nearest foot)	11.2	8-15	1.7
Crown volume index (Computed from CV = $\pi \times$ diameter $\times$ length/100)	8.7	4-14	2.9
Crown/height ratio (Crown length divided by tree height $\times$ 100)	62.6	34-79	8.8
Competitive stress index* (Computed from distance to and diameter of all competing trees)	73.6	1-250	55.7
Diameter at thinning (Nearest 0.01 inch; measured from 4 increment cores)	4.41	2.0-8.2	1.3

*After (*2*).

creased growth. Although not specifically designed for use with ponderosa pine, the Competitive Stress Index (2) also had an important effect on growth ratio. Soil compaction, reflected by the assigned compaction classes, was much less significant than diameter, crown volume, or competition.

Equation 1 for predicting growth ratio (R^2 of 0.56*) is as follows: Growth ratio = 5.256* − 0.979 × diameter at release* + 0.294 × crown volume* − 0.146 × compaction class** − 0.005 × Competitive Stress Index* (*significant at the 1 percent level; **significant at the 15 percent level).

Equation 2 for predicting growth rate of released trees (R^2 of 0.64*), in square inches per year, is as follows: Growth rate = 0.131 + 0.168 × crown volume* − 0.102 × compaction class** − 0.004 × Competitive Stress Index* (*significant at the 1 percent level; **significant at the 5 percent level).

Crown volume apparently indexes growth response well. No other tree variable was as useful in explaining the variations in growth after release.

The Competitive Stress Index was especially meaningful in explaining the difference in rate of basal area growth. Thus, a tree with a relatively large crown, released the most completely from its competitors, responded with the greatest acceleration in growth.

Skid-trail compaction affected the growth rate negatively. In fact, soil density was less significant than either crown volume or competition.

Solving prediction equation 2, holding crown volume and competition at their mean value, showed that the average tree, with little or no compaction in its root zone, grew 10.6 square centimeters per year (1.6 in²/yr). Trees in the moderate and heavy soil impact classes grew 9.9 and 9.3 square centimeters per year (1.5 and 1.4 in²/yr), respectively, reflecting 6 and 12 percent reductions in growth rate. This is appreciably less than found in previous work on Douglas-fir [*Pseudotsuga menziesii* (Mirb.) Franco], where moderately and heavily impacted trees showed reductions in growth rate of 14 and 30 percent, respectively (7). In western hemlock [*Tsuga heterophylla* (Raf.) Sarg.], I found a 14 percent reduction in growth of moderately impacted trees (8). Despite persistently compacted skid trails, therefore, growth reduction of residual ponderosa pine at this site was relatively low.

Table 2. Soil density in skid trails and adjacent undisturbed areas.

Soil Depth (cm)	Soil Density (g/em)			
	Undisturbed		Skid Trail	
	Mean	Standard Deviation	Mean	Standard Deviation
7.6 cm	0.97	0.09	1.14*	0.12
15.2 cm	0.91	.11	1.07*	.15
22.9 cm	1.01	.16	1.10**	.19
30.48 cm	1.03	.15	1.12*	.20

*Significantly different from the mean undisturbed density at the same depth at the 5 percent level.
**Significantly different from the mean undisturbed density at the same depth at the 10 percent level.

Concluding remarks

These results raise certain provocative questions. Does the relatively wide spacing of residual trees allow them to compensate by extending roots away from skid trails? Are other stresses on trees so severe that soil density in this study plays a lesser role than in earlier studies? And perhaps the most important question: What is the effect of similar soil impacts on higher site ponderosa pine stands?

In my opinion the growth reduction caused by compaction is great enough to indicate that existing skid trails should be used to the extent possible in future harvests. Repeated entries into a stand markedly increase the area covered by skid trails, and that impact is cumulative. On low site class areas such as this, the potential growth loss apparently is not so high as to preclude ground-based logging, especially if the area in skid trails is minimized.

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