# Effects of Soil Compaction on Residual Stand Growth in Central Appalachian Hardwood Forest: A Preliminary Case Study*

Jingxin Wang[1], Chris LeDoux[2], Michael Vanderberg[3] and Yaoxiang Li[4]
[1]Associate Professor and [4]Research Associate, West Virginia University, Division of Forestry and Natural Resources, Morgantown, WV 26506
[2]Project Leader, USDA Northeaster Research Station, Morgantown, WV 26505
[3]Research Assistant, Oregon State University, Corvallis, OR 97331
Email: jxwang@wvu.edu

**Abstract**

A preliminary study that quantified the impacts of soil compaction on residual tree growth associated with ground-based skidding traffic intensity and turn payload size was investigated in the central Appalachian hardwood forest. The field study was carried out on a 20-acre tract of the West Virginia University Research Forest. Skid trails were laid out in 170' – 200' sections, which allowed for one 50'treatment and two 50' replications of each treatment over the total skid trail. Treatments were arranged in a 3x3 factorial with three payload sizes of unloaded, half capacity, and full capacity and the number of loaded machine passes set at 1, 3, and 5. Three skid trails underwent no skidding activity in order to serve as control treatments. A John Deere 640G III cable skidder was employed to simulate the extraction operations. Measurements included soil type, pre-treatment and post-treatment soil bulk density and soil moisture, understory vegetation, and site slope and aspect. Merchantable hardwood trees within a 30-foot range of the centerline were randomly selected and measured for DBH, total height, merchantable height, grade, crown size, and growth rate. Each individual tree's geographic location was determined by GPS. Preliminary results suggest the interrelationship among traffic intensity, payload, and soil compaction. The comparison of initial and subsequent tree and soil measurements can be used to examine residual tree growth and soil compaction recovery in a further study.

## 1. INTRODUCTION

All harvesting operations cause some compaction, but the degree of compaction varies with harvesting equipment, techniques, intensity, and soil properties, especially moisture content and texture (Reisinger et al. 1988, Reisinger and Aust 1990, Aust 1994). Many studies have been conducted on the effects of timber harvesting as a silvilcultural activity on erosion and sedimentation and best management practices (BMPs) compliance and effectiveness (Kochenderfer et al. 1997, Briggs et al. 1998, Egan et al. 1998). Many studies compared the area disturbed by conventional logging with a tractor or skidder to a skyline system. Steinbrenner and Gessel (1955) studied tractor harvested areas in western Washington and found 26 percent of the total area to be occupied by tractor skid roads. Wooldridge (1960) compared soil disturbances by skyline-crane harvesting with those by conventional tractor skidding. In the tractor-harvested area, 29.4 percent of the ground surface was disturbed, while only 11.1 percent was disturbed in the skyline area. Dyrness (1965) stated the tractor-harvested unit had approximately three times

* *The 29th Council on Forest Engineering Conference. Coeur d'Alene, Idaho, July 30-August 2, 2006. W. Chung and H.S. Han, editors. pp. 333-341.*

more area in the compacted disturbance class than did the high lead unit. Dickerson (1976) reported that 21% of the soil on a clearcut stand was disturbed compared to 14% for an area with a selective cut. Dickerson also found twice as much severely disturbed soil (barred, rutted, and compacted) on the clearcut operation. Soil disturbance averaged 17% in selection cuts and 28% in strip and patch clearcuts of northern hardwoods (Nyland et al. 1977).

The forest floor has been found to be very susceptible to disturbance by harvesting operations (Turcotte et al. 1991). Soil compaction and loss of organic matter from the forest floor had a direct influence on the weathering rates of minerals, nutrient mineralization and consequently plant growth. Mechanical disruption of the forest floor might have an adverse impact on site productivity because the forest floor was a major source of nutrients for shallow rooted spruce and fir seedlings (Hoyle 1965, Shaw et al. 1987).

During the past decade, timber harvesting methods in central Appalachia have evolved to some extent. However, chainsaw felling and rubber-tired cable skidding is still the dominant system in the region due to terrain limitations and constraints surrounding the hardwood species. The soil bulk density changes associated with conventional manual and mechanized harvesting systems have been studied (Wang et al. 2005). In this study, we wanted to quantify and document how traffic intensity and payload of a typical rubber-tired cable skidder affected soil compaction and the residual stand growth in the region.

## 2. MATERIAL AND METHODS

### 2.1 Site and Skid Trails

The field data collection was carried out on a section of the West Virginia University Research Forest from May to July in 2005 and the site was selected as a representative sample of the central Appalachian hardwood region in respect to tree age and species composition. The study area was 20 acres in size, relatively flat, and of the same general southwestern aspect with the elevation of approximately 2000 feet (610 m) (Figure 1). The soils of the area are comprised of three associations. The Dekalb-Buchanan-Lily and Hazelton-Dekalb-Buchanan associations make up the majority of Research Forest, and are generally gently sloping to very steep, well drained and moderately well drained, acid soils; found on uplands and foot slopes. A smaller area of the Gilpin-Wharton-Ernest association is found in the northwestern portion of the Forest, and this association is more alkaline than the other two soils. The major species composing the WVU Research Forest are red oak *(Quercus rubra)*, yellow-polar *(Liriodendron tulipifera)*, red maple *(Acer rubrum)*, chestnut oak *(Quercus prinus)*, and black cherry *(Prunus serotina)*. Other species found within the forest are cucumber tree *(Magnolia acuminata)*, scarlet oak *(Quercus coccinea)*, black gum *(Nyssa sylvatica)*, sassafras *(Sassafras albidum)*, and American beech *(Fagus grandifolia)*.

Skid trails were laid out in 170 to 200 feet sections, which allowed for one 50-foot treatment and two 50-foot replications of each treatment over the total skid trail (Figure 1). There were 12 total skid trails, each with one treatment and two replications. The skid trails were laid out in such a way that skidder traffic traveled west to east, and generally on a slight uphill grade (0%-10%) on all trails. The design also called for three trails to be laid out end to end from west to east, and this pattern was continued to the south until all 12 trails were laid out. Traveling west to east, there was a 100 ft gap between the end of one trail and the beginning of the next. Traveling north to south, there was a 100 ft buffer from the centerline of one trail to the centerline of the next trail. All skidder traffic, other than the treatments, was confined to the area outside of the buffer zone and within the 100 ft gap between the end of one trail and the start of the next in order to preserve the area where the growth trees were located. A GPS unit was used to assist in the mapping of each skid trail in the study area.

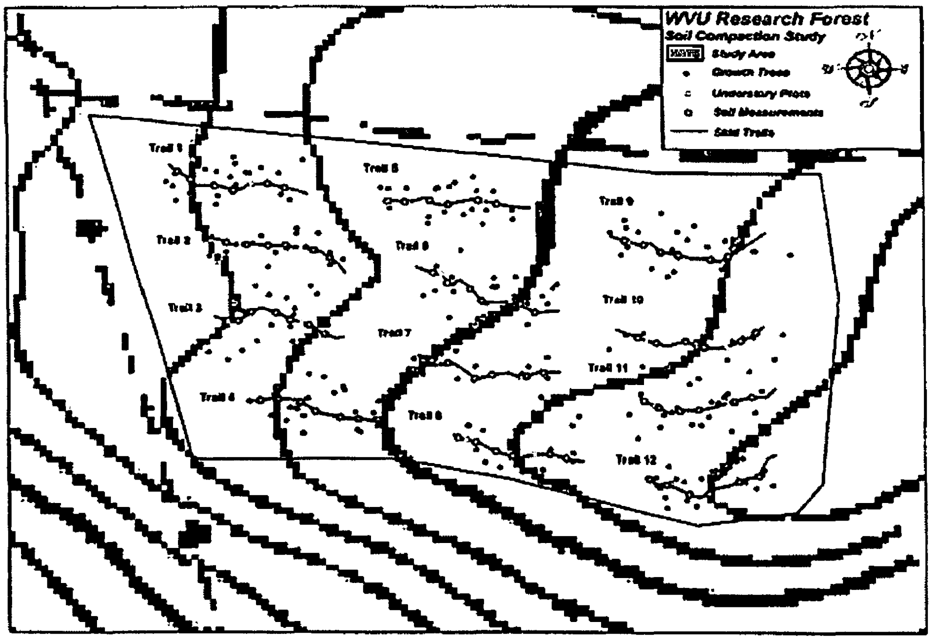


Figure 1. Skid trail layout, growth trees, understory plots, and soil measurement locations.

After the skid trails were laid out, a Caterpillar D3G tractor was used to clear the woody debris, standing understory trees, and some of the surface material (upper layer organic matter) from the skid trails in order to utilize the Troxler 3440 density and moisture gauge. No overstory trees were removed during the preparation phase. A John Deere 640G III cable skidder was employed for extraction operations with three levels of assigned loads: no load, ½ load, and full load. Full load was 798.6 board feet (BF) in Doyle Scale and was formed by four yellow-poplar long logs of 33 ft in length and varied in diameter while ½ load meant the skidder operated pulling two logs of 415.3 BF. No load meant that the skidder operated on the trails without any logs. The same two logs were used for the ½ load size during each cycle, and both were marked on the ends with high-visibility orange tree marking paint enabling distinct recognition.

### 2.2 Field Measurements

Understory sampling was conducted on two replications of each skid trail for a total of 24 sample locations. A 3'x12' cross section of the skid trail was laid out for each sample before any skidding activity took place. Regeneration and understory vegetation under 4' in height was counted by species within the sample area. A photograph was also taken of the plots for comparative purposes. A GPS unit was also used to assist in the mapping of each understory plot.

Trees were selected from the overstory canopy (dominant and codominant) on the basis of size and species. Only trees of sawtimber size were sampled (DBH 11.0 inches or above), and species were selected on the basis of local merchantability. Sample trees had canopies that were within 30 ft of the skid trail, and no more than five trees per replication per side of each trail were sampled. The total number of trees sampled was 225, giving an average of approximately 19 trees per skid trail.

Trees were labeled in a unique fashion with high-visibility, wet-coat orange tree marking paint based on the skid trail number, the replicate number, the tree number within the replicate, and the corresponding side of the skid trail when facing east. Tree measurements included species, diameter at breast height (DBH), total height, merchantable height in 8' sections, crown diameter, grade, distance from the side of the skid trail, and whether or not the tree was damaged during the skidding operation. All sample trees were measured for the past 10-years of growth by extracting a sample with an increment borer and then counting growth rings and measuring the cores in the lab. All increment boring was done on the southern side of the tree (azimuth = 180°) and was restricted to approximately 2.5 inches in depth.

Each replicate within each skid trail was measured in two locations for initial soil density and moisture content for a total of 72 cross sections over the 12 skid trails. Soil measurements were made on a cross section of skid trail, starting 1' from the edge of the trail, and then every 2' across the 12' wide trail for a total of 6 measurements per cross section. The total number of initial soil density and moisture content measurements was 432. The measurements were made at a depth of 6" with a Troxler Labs 3440 soil density and moisture gauge. The cross sectional measurements were then averaged to calculate a cross sectional mean density and moisture content.

The nine skid trails that had undergone skidding treatments (skid trails 2, 3, 4, 6, 7, 8, 10, 11, and 12) were measured for post-treatment soil density and moisture using the same process as the initial measurements. A total of 54 cross sections (which were placed in the same initial measurement locations) were measured across the nine skid trails. The total of post-treatment soil density and moisture measurements was 324.

### 2.3 Data Analysis

A t-test was used to test if significant differences existed in bulk density changes. The general linear model (GLM) was applied to the data to examine the impacts of individual factors as well as their interactions on soil bulk density and moisture content in the skid trails.

$$Y_{ijk} = \mu + P_i + L_j + P_i * L_j + \varepsilon_{ijk}$$
$$i = 1,2,3$$
$$j = 1,2,3$$
$$k = 1,2,3$$

Where $Y_{ijk}$ represents the $k^{th}$ observation of the soil density or the soil moisture content and $\mu$ is the overall mean of the response variable. $P_i$ is the effect of $i^{th}$ number of machine passes (1, 3, and 5 loaded machine passes). $L_j$ is the effect of $j^{th}$ payload size (no load, half load, and full load). $\varepsilon_{ijk}$ is an error component that represents all uncontrolled variability.

## 3. RESULTS

Greenbrier, red oak, and red maple were the most commonly found understory vegetation under 4 inches in height on the skid trails with a total number of 22, 20, and 17 per 100 $ft^2$, which accounted for 27%, 24%, and 21% of the total understory recorded, respectively (Table 1). Other understory included black cherry (7%), huckleberry (7%), chestnut oak (7%), and others (6%).

Table 1. Understory statistics in the skid trails before skidding.

| | Black cherry | Chestnut oak | Greenbrier | Huckleberry | Red maple | Red oak | Others |
|---|---|---|---|---|---|---|---|
| #/100 $ft^2$ | 6 | 6 | 22 | 6 | 17 | 20 | 5 |
| Percent (%) | 7 | 7 | 17 | 7 | 21 | 24 | 6 |

Red oak (36%), yellow-poplar (24%), chestnut oak (19%), black oak (9%), scarlet oak (8%), and red maples (4%) were the major overstory canopy with less than 2% of other species recorded. The total average height ranged from 83 to 99 feet for the major species, with merchantable height of 32 to 58 feet (Table 2). Crown diameter averaged 32.25 feet ranging from 30.87 to 36.49 feet for the dominant and codominant trees measured. The average 10-year growth rate varied from 0.54 of an inch for black oak to about 1 inch for red maple. Average distance of these sampled trees to the centerlines of skid trails ranged from 13.95 to 19.28 feet.

Table 2. Statistics of sampled trees along the skid trails by species.

| Species | THT (ft) | MHT (ft) | Crown Diameter (ft) | 10-yr Growth (in) | Distance to Trail (ft) |
|---|---|---|---|---|---|
| Black oak | 86.20 | 39.20 | 32.30 | 0.54 | 13.95 |
| Chestnut oak | 85.10 | 44.29 | 30.95 | 0.78 | 14.10 |
| Red maple | 86.11 | 35.56 | 32.22 | 1.00 | 21.22 |
| Red oak | 90.47 | 44.31 | 36.49 | 0.89 | 15.36 |
| Scarlet oak | 82.89 | 41.22 | 34.44 | 0.64 | 19.28 |
| Yellow-poplar | 98.66 | 58.42 | 30.87 | 0.89 | 17.55 |
| Others | 83.50 | 32.00 | 28.50 | 1.03 | 14.50 |

The DBH for the dominant and codominant trees sampled was between 12 and 25.6 inches with an average of 16.69 inches. Trees were categorized into six DBH classes: 14 (<=14 inches), 16 (>14 and <=16 inches), 18 (>16 and <=18 inches), 20 (>18 and <=20 inches), 22 (>20 and <=22 inches), and 24 (>22 inches). Heights, crown diameters, 10-year growth, and distances to the skid trail centerlines were summarized by DBH class (Table 3). The total height ranged from 84.10 to 97.76 feet and merchantable height varied from 36.62 to 54.33 feet as DBH changed from 14 to 24 inches. Crown diameter also increased from 27.88 to 41.31 ft. as the DBH changed from 14 to 24 inches. The average 10-year growth rate increased from 0.67 inches for 14 inches DBH class to 1.15 inches for 24 inches DBH class. Trees measured were located 15 to 24 feet away from the centerlines of skid trails.

Table 3. Statistics of sampled trees along the skid trails by DBH class.

| DBH Class (in) | THT (ft) | MHT (ft) | Crown Diameter (ft) | 10 yr Growth (in) | Distance to Trail (ft) |
|---|---|---|---|---|---|
| 14 | 84.10 | 36.62 | 27.88 | 0.67 | 15.25 |
| 16 | 89.00 | 46.86 | 30.98 | 0.77 | 15.78 |
| 18 | 90.91 | 48.18 | 34.34 | 0.88 | 18.31 |
| 20 | 93.31 | 50.39 | 36.39 | 0.89 | 12.47 |
| 22 | 96.06 | 51.50 | 41.24 | 0.93 | 15.67 |
| 24 | 97.76 | 54.33 | 41.31 | 1.15 | 23.38 |

A t-test was used to test the statistical differences of soil moisture content and soil bulk densities between control and treated trails. Before extraction treatment, both soil moisture content (df = 430; t = 1.82; p = 0.0703) and soil bulk density (df = 430; t = -0.46; p = 0.6426) were not statistically different between control and treated trails (Table 4). However, both soil moisture content (df = 430; t = 10.84; p = 0.0001) and soil bulk density (df = 430; t = -6.95; p = 0.0001) differed significantly between control and treated trails after extraction treatment. The soil bulk density increased 9.4% from 69.50 lb/ft$^3$ before extraction to 76.05 lb/ft$^3$ after extraction.

Table 4. Soil moisture content and bulk density in control and treated skid trails.

| | Treatment | Control | Treated | t-value | p-value |
|---|---|---|---|---|---|
| Moisture content (%) | Before | 43.32 | 41.25 | 1.82 | 0.0703 |
| | After | 43.32 | 31.56 | 10.84 | 0.0001 |
| Soil bulk density (lb/ft$^3$) | Before | 69.50 | 69.94 | -0.46 | 0.6426 |
| | After | 69.50 | 76.05 | -6.95 | 0.0001 |

Table 5. Means and significant levels of soil bulk density and moisture content in *skid trails*[a].

| | | Moisture Content (%) | Soil Bulk Density (lb/ft$^3$) |
|---|---|---|---|
| No. of loaded machine passes | 1 | 31.03A | 75.45B |
| | 3 | 33.20A | 74.64B |
| | 5 | 30.46B | 78.05A |
| Payload size | no | 37.81A | 72.51B |
| | half | 31.43B | 74.48B |
| | full | 25.44C | 81.16A |

[a] Means containing the same letter in a column of a group are not significantly different at the 5 percent level with Duncan's Multiple – Range Test.

Soil bulk density generally increased with the number of loaded machine passes and payload size. It increased 1.1, 6.2, and 8.9 lb/ft$^3$ after first machine pass with no load, half load, and full load compared to their initial bulk densities of 69.80, 68.25, and 71.80 lb/ft$^3$ in the skid trails without any machine passes, respectively (Figure 2). After three loaded machine passes, soil bulk density leveled out with these three payload sizes. The soil bulk density increased to 76.64, 73.86, and 83.64 lb/ft$^3$ after five passes for no load, half load and full load. However, the bulk density slightly decreased for the skidder with a half payload after five passes in comparison with the density after three loaded machine passes. Soil bulk density was not significantly different between after one pass and after three machine passes (Table 5). However, it increased significantly to 78.05 lb/ft$^3$ after five machine passes ($F = 5.87$; df = 2, 323; $P = 0.0031$). Similarly, the soil bulk density did not differ significantly between the with no load and the skidder with half payload. After five loaded machine passes, the bulk density for the skidder with a full payload differed significantly from the other two payload sizes ($F = 38.13$; df = 2, 323; $P = 0.0001$).

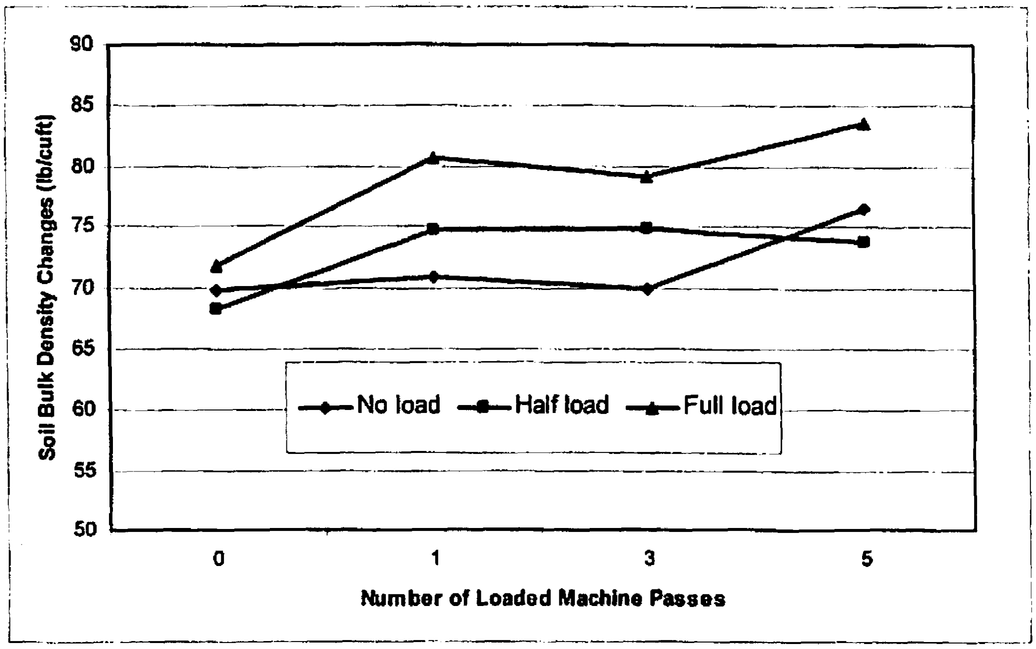


Figure 2. Soil bulk density changes by loaded machine pass and payload size.

## 4. DISCUSSION

Post-treatment soil bulk density increased as the number of loaded machine passes and the payload increased. The soil bulk density changes were significantly affected by the number of loaded machine passes and the payload size. The results from this case study also confirm that the majority of soil compaction in skid trails occurred after the first three passes of a loaded skidder (Greene and Stuart 1985, Wang et al. 2005). The small decreases in compaction measured after three or five passes were unlike most previously reported road compaction studies in which compaction generally has been reported to increase or remain constant with increasing numbers of passes. The decreases were recorded as rutting began to occur. When the formation of ruts appeared to stop, compaction began increasing again. Rutting may have created slight decreases in compaction by displacing soil to sides and out of the ruts, thereby acting like a stirring and aeration mechanism, resulting in less compact soil.

Our results support the recommendations of state BMPs to focus skidding to a few well developed preplanned designated skid trails and minimize trafficking across the general harvest area to protect soil (and water) resources. The findings from this study suggest that under certain conditions (1) most bulk density increase on skid trails occurs after the first three loaded machine passes, (2) preplanned skid trails may minimize bulk density increase across the overall site, and (3) emphasis should be placed on the amount of trail constructed through careful planning. Two follow-up measurements will be conducted at 3 years and 5 years post initial study, specifically to evaluate how soil compaction affects (1) residual stand growth by tree species, tree size, and the distance from tree to skid trail, (2) understory vegetation dynamics, and (3) compaction recovery.

## 5. ACKNOWLEDGEMENTS

The authors would like to thank Mr. Bob Driscole and Mr. Mike Boyce for their help during the field studies of this project.

## 6. LITERATURE CITED

Aust, W. M. 1994. Timber harvesting considerations for site protection in southeastern forested wetlands. In Proceedings of water management in forested wetlands. Tech. Pub. R8-TP-20. USDA Forest Service, Southern Region, Atlanta, GA: 5-12.

Briggs, R.D., J. Cormier, and A. Kimball. 1998. Compliance with forestry best management practices in Maine. Northern J. of Applied Forestry. 15(2): 57-68.

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

Dyrness C. T. 1965. Soil surface condition following tractor and high-lead logging in the Oregon Cascades. J. Forestry. (4).

Egan, A. F., R. D. Whipkey, and J. P. Rowe. 1998. Compliance with Best Management Practices in West Virginia. Northern J. of Applied Forestry. 15(4):211-215.

Greene, W.D. and W.B. Stuart. 1985. Skidder and tire size effects on soil compaction. Southern J. of Applied Forestry. 9(3): 154-157.

Kochenderfer, J. N., P. J. Edwards, and F. Wood. 1997. Hydrologic impacts of logging an Appalachian watershed using West Virginia's Best management Practices. Northern J. of Applied Forestry. 14(4): 207-218.

Hoyle, M. C. 1965. Growth of yellow birch in a pozol soil. USDA For. Serv. Res. Pap. NE-38. 14p.

Nyland, R. D. 1977. Effects of logging in Northern hardwood forests. TAPPI 60(6):58-61.

Reisinger, Thomas W., Simmons, Gerry L. and Pope, Phillip E. 1988. The impact of timber harvesting on soil properties and seedling growth in the south. South J. Appl. For. 12(1):58-67.

Reisinger, T. W. and W. M. Aust. 1990. Specialized equipment and techniques for logging wetlands. ASAE Paper 90-7570. American Society Agricultural Engineers, St. Joseph, MI 12p.

Shaw, C. G., R.C. Sidle, and A.S. Harrison. 1987. Evaluation of planting sites common to a southeast Alaska Clear-cut. III. Effects of microsite type and ectomycorrhizal inoculation on growth and survival of sitka spruce seedlings. Can. J. For. Res. 17:334-339.

Steinbrenner, E. C. S.P. and Gessel. 1955. Effect of tractor logging on soil and regeneration in the Douglas-fir region of southwestern Washington. P. 77-80 in Soc. Am. For. Proc., Bethesda, MD.

Turcotte, D., E. Smith, C. Tattersall, and C. Anthony. 1991. Soil disturbance following whole-tree harvesting in North-Central Maine. North. J. Appl. For. 8(2):68-72.

Wang, J., C.B. LeDoux, P. Edwards, and M. Jones. 2005. Soil bulk density changes caused by mechanized harvesting: A case study in central Appalachia. Forest Prod. J. 55(11): 37-40.

Wooldridge, D. 1960. Watershed Disturbance from tractor and skyline crane logging. J. Forestry. 58:369-372.

COFE

*Council on Forest Engineering*

# PROCEEDINGS OF

# THE 29$^{TH}$ COUNCIL ON FOREST ENGINEERING CONFERENCE

July 30 – August 2, 2006
Coeur d'Alene Resort
Coeur d'Alene, Idaho

Compiled and Edited by
Woodam Chung and Han-Sup Han

Hosted by

University of Idaho — Tradition. Change. Excellence.
The University of Montana

Sponsored by
IUFRO Division 3
Plum Creek Timber Company
Potlatch Corporation
Forest Capital Partners, LLC