EVALUATING AREA IN LOGGING TRAILS WITH A GEOGRAPHIC INFORMATION SYSTEM

P. Bettinger, D. Armlovich, L. D. Kellogg

ABSTRACT. *A geographic information system (GIS) was used to evaluate the area in logging trails categorized by number of machine passes. Preharvest logging trail surveys and observations of machine movements during harvesting were transferred to a GIS to determine areas. Detailed procedures and time required to build the GIS database are presented. There was excellent agreement between the trail area estimates based on the GIS database and those from an independent, line-transect method. However, the line-transect method gives no information on the number of machine passes.* ***Keywords.*** *Geographic information system, Soil compaction, Logging, Forest engineering, Harvesting.*

Land managers must determine past, present, and future site effects, or cumulative effects, when evaluating proposed projects on federal lands. Soil compaction is widely used as a basis for decision making when projects involving ground-based logging machinery are evaluated. Repeated passes of logging equipment over forest soils compress soil mass, often resulting in significant increases in soil compaction. Compaction can be characterized as a breakdown of surface aggregates, a decrease in macropore volume, and an increase in the proportional volume of solids (Pritchett and Fisher, 1987). The result is a reduction in air diffusion and water infiltration rates and an increase in soil strength. Compaction may persist for long periods in some soils and cause reduced growth in trees located near or along compacted areas (Pritchett and Fisher, 1987).

Knowledge of the extent of significant damage to the soil is important in assessing effects of harvesting machines. It is equally important to use technology to its fullest in providing information that can affect land management planning and decision making. For example, the Land and Resource Plan for the Siskiyou National Forest states that a minimum of 85% of an activity area must be left in a condition of acceptable productivity (USDA, 1989). Unacceptable productivity is measured as an increase in soil bulk density of 15% or more, or a reduction in macropore space of 50% or more compared with an undisturbed area. Using technology such as geographic information systems (GIS) along with site-specific data can help in evaluating these issues. Because these systems can compile, process, and analyze data collected over a long period of time, GIS can provide a practical means for evaluating cumulative effects (Johnston et al., 1988).

The severity of soil disturbance is related to soil conditions, logging equipment, and number of machine passes (Murphy, 1982). In general, ground-based skidding disturbs and compacts the largest area of a logging site; cable systems cause less soil disturbance, and helicopter and balloon logging the least (Pritchett and Fisher, 1987). Various studies of soil effects caused by different types of equipment have evaluated the percentage of area in logging trails at Pacific Northwest sites. Steinbrenner and Gessel (1955) found that 26% of a tractor-logged site was in skid roads, and Wooldridge (1960) found 29.4% of a tractor-logged site in trails and 11.1% of a cable-logged site in skyline trails. Froehlich (1973) observed that in thinning 50- to 90-year-old Douglas-fir stands, 40 to 60% of the site was disturbed, with 20 to 30% in heavy disturbance or compaction. Bradshaw (1979) found 22% of a partial cut in skid trails, and Sidle and Drlica (1981) found 13.6%. Murphy (1982) found that total area in trails ranged from 11.7 to 29.1% in partial cuts, and noted that planning and utilizing designated skid trails can cut the trail area by about 50%. Although these studies delineated the percentage of area in trails, they made no breakdown of the number of machine passes over the area, which may be important in determining the percentage of area significantly compacted during logging operations.

Many sampling methods have been used to assess the area of land in logging trails, including line transects of fixed widths (Wronski, 1984; McNeel and Ballard, 1992), point tallies along transect lines (Dyrness, 1965; Miller and Sirois, 1986), fixed-width plots located on transect lines (Garrison and Rummell, 1951; Murphy, 1982; Reisinger et al., 1992), a line-intercept process (Wooldridge, 1960; Snider and Miller, 1985; Zaborske, 1989), and measuring actual lengths and widths of skid trails (Bradshaw, 1979). An assessment of the accuracies of these methods is impossible, however, because sampling intensities varied across the studies and the intensities are unknown.

Zaborske (1989) found that the number of machine passes explained the greatest amount of variability in soil

Article was submitted for publication in November 1993; reviewed and approved for publication by the Emerging Technologies Div. of ASAE in June 1994.

Paper 2971 of the Forest Research Laboratory, Oregon State University, Corvallis. The mention of trade names does not constitute endorsement by Oregon State University.

The authors are **Pete Bettinger**, Faculty Research Assistant, Dept. of Forest Engineering, College of Forestry, Oregon State University, Corvallis; **Dave Armlovich**, Forester, Pacific Northwest Region, U.S. Forest Service, Portland, Ore.; and **Loren D. Kellogg**, ***ASAE Member***, Associate Professor, Dept. of Forest Engineering, College of Forestry, Oregon State University, Corvallis.

dry bulk density. He estimated the number of machine passes by counting the bunches made by a feller-buncher (bunch position was marked in the field) and by assuming the skidders would travel a certain number of times over a trail to skid each bunch. Zaborske then used a line-transect method to determine the percentage of area in various machine-operation categories.

The objective of our study was to use an existing survey of logging trails with GIS and information on machine passes to determine the percentage of a logging site in each machine pass category. This information was then compared with results from a line-transect estimate of total trail area. The procedures for implementing GIS, time required, and relevance of GIS in evaluating significant impacts and cumulative effects are discussed.

Study Area

The logging site was approximately seven miles south of Lyons, Oregon (44° 40′N, 1 22° 35W), in the Cascade Mountain Range. The operation consisted of thinning a 47-year-old second-growth stand of Douglas-fir (*Pseudotsuga menziesii*) and western hemlock (*Tsuga heterophylla*). The entire thinning area was 40.5 ha (100 acre), of which 5.0 ha (12.4 acre) was intensively studied for thinning economics (Kellogg and Bettinger, 1994), stand damage (Bettinger and Kellogg, 1993), and soil compaction (Armlovich 1992).

The thinning, which took place in June-July 1992, was conducted with a cut-to-length system, comprised of a single-grip harvester (Timberjack 2518 and Koehring Waterous 762 harvesting head) and a forwarder (FMG 910). The harvester operator had one year of experience in similar terrain; the forwarder operator had about nine months of comparable experience. The logging trails were laid out by the logging operation supervisor before the thinning; they were located to take advantage of old logging trails and topography and sometimes to avoid obstacles such as large, old stumps.

The harvester felled and processed all trees in the trails, selectively thinning the remaining stand as the machine progressed. The forwarder used the trails to assemble the wood into single-product loads (sawlog or pulpwood—67.5% of all loads) or multi-product loads (32.5% of all loads) for transport to a landing area along a main haul road. The harvester generally traveled up and back over each trail once; the forwarder traveled up and back two or more times, depending on the loading method and number of logs along each trail. Prior to harvesting there were 1327 trees/ha (537 trees/acre), with 520 m^3/ha (7430 ft^3/acre) volume. The thinning operation removed 900 trees/ha (364 trees/acre), leaving 427 trees/ha (173 trees/acre), with 344 m^3/ha (4921 ft^3/acre) volume.

Methods

The logging trails were surveyed by two researchers prior to the thinning operation. The survey information (slope, distance, and compass direction) was input into a spreadsheet, corrected for slope, and then output in a digital format suitable for use in MicroCAM (MicroConsultants, 1991), an automated mapping program. The resulting digital map was transferred to AutoCAD (Autodesk, Inc., 1992), and maps of the trail system were created. These maps were used in the field to record the actual extent of machine movement over all trails. The harvester operator delineated movement of the harvester on a map each day. The harvester was slow and deliberate; thus it was easy to record its movement on the maps. Movement of the forwarder, which was faster and less deliberate than the harvester, was recorded by the researchers; the machine operator could not have recorded the movement of the machine without significantly decreasing daily productivity. The researchers followed the forwarder over a four-week period, detailing on maps the extent of travel on each trail. Deviations from the initial trail system were incorporated into the maps and used later in the GIS analysis. This GIS approach was designed not only to provide information on the amount of area in trails, but also to provide information about the number of passes associated with each trail segment.

A line-transect process, designed solely to provide an estimate of the area in logging trails, was performed after the logging operation was complete. The line-transect method is fast, cheap, and simple compared with other sampling methods (Skidmore and Turner, 1992) and has been used for sampling fuels (Warren and Olsen, 1964; Van Wagner, 1968) as well as area in logging trails. Six transect lines were spaced 30 m (100 ft) apart; the beginning point of the first transect and the compass direction were randomly selected. The orientation of the survey lines was such that they crossed most of the trails at an angle, and generally did not run parallel to the trails (fig. 1). Total transect length was 1167 m (3827 ft), with transect lengths varying from 100 m (328 ft) to 300 m (984 ft). The length of each transect segment crossing a logging trail was measured to the nearest 0.03 m (0.1 ft). The area in trails was determined by comparing the length of transect lines across trails and total transect length. The area in trails derived from the GIS analysis was compared with the area based on the line-transect process.

The digital map of the trails was transferred from AutoCAD to PC ARC/INFO (Environmental Systems Research Institute, Inc., 1992) for creation of a coverage (theme) consisting of logging trails. Numbers of machine passes were grouped into several categories to simplify the

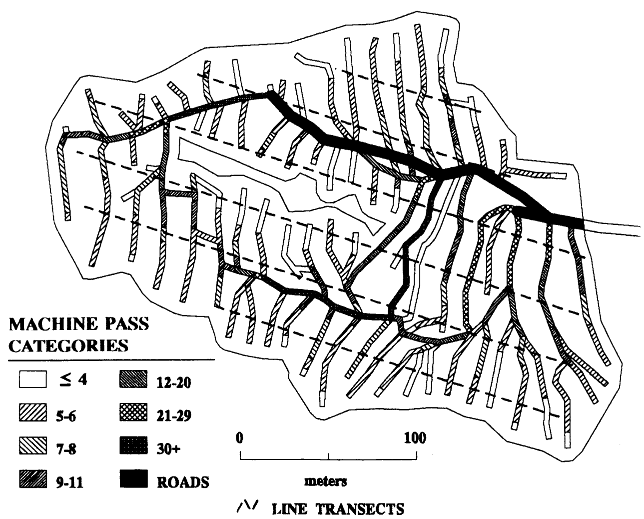

Figure 1–Study site and logging trails by machine pass category.

analysis (table 1). Each trail was represented as a vector (arc) in PC ARC/INFO and was split (a node added) at a point where the category of machine passes changed. Each arc was attributed with the trail number and the number of passes over each trail portion. Each group of arcs representing a machine pass category was individually selected and buffered a constant width based on field measurements of trail widths. High-use trails (temporary roads in which the soil surface was physically removed and the surface smoothed to allow the forwarder to travel faster) were wider than low-use trails and were buffered accordingly. The polygons created during the buffering process (representing trail area) were then combined through the UNION function in PC ARC/INFO. Polygons were edited in order to eliminate spurious polygons formed at machine pass category boundaries and to "square off" the end of each trail (when a line is buffered, the resulting polygon has a rounded end). We considered using the CLEAN function in PC ARC/INFO to eliminate these spurious polygons, but the polygons were exactly the same width as the trails, so cleaning would have eliminated the trails as well. Each spurious polygon was split down the middle, and the original two sides were then deleted, leaving one boundary consisting of a line, rather than a spurious polygon, between the machine pass categories.

Where a polygon representing a more heavily used trail overlapped one for a less used trail, the more heavily used trail polygon remained intact. Attributes were then assigned to polygons according to the machine pass categories of the arcs that were buffered. The STATISTICS function in PC ARC/INFO was used to compute the total area for each machine pass category.

Results and Discussion

The GIS analysis allowed us to determine the percentage of trail area by machine pass categories. A total of 23.48% of the logging site was in logging trails (table 1), which is remarkably similar to the line-transect result (23.53%). The greatest percentage of machine passes fell in the 5 to 6 pass category; the combined 0 to 6 pass categories accounted for 51.13% of the total area in trails. Areas with temporary roads, which may never be ameliorated, occupy 2.25% of the total logging site. The approximate time requirements for this comprehensive analysis included: logging trail survey (4 work days, based on a 10-h day), tracking machine movement (40 work days), data manipulation (2 work days), and GIS analysis (1 work day), for a total of 47 work days.

The line-transect analysis conducted on the logging site indicated that 23.53% of the site was occupied by logging trails. The advantage of using this process is that only a few hours of field work are needed, and a good estimate of the area in logging trails is provided. On this site, the line-transect process took about four hours to accomplish, with one hour of office work, for a total of 0.5 work days. However, this process shows only the percentage of area traveled by machines. Because this process was not designed to provide information on numbers of machine passes, no inference of these numbers can be made; we believe that a design for estimating these results would be very difficult to implement, because the number of machine passes would be approximated on the basis of trail conditions.

Using GIS to determine trail area by machine pass category is time-consuming, but it provides several advantages over the line-transect method: (1) It creates a visual representation of heavily trafficked areas (fig. 1), (2) it provides a database representing historic use of the site that can assist managers planning future operations, and (3) it shows the percentage of area in trails by machine pass category, which can be related to the severity of compaction. The disadvantages of using GIS are the time and associated cost of personnel for surveying logging trails, tracking logging machine movement, manipulating data, and doing the GIS analysis. These disadvantages imply that for most (if not all) landowners, such micro-management of logging sites may be infeasible. However, determining area in logging trails by machine pass category may shed light on significant site effects related to soil compaction.

The GIS and line-transect processes applied in our study gave similar trail area results to those found by Steinbrenner and Gessel (1955), Wooldridge (1960), Bradshaw (1979), and Murphy (1982), even though different equipment, logging sites, and trail-area evaluation techniques were used. Our attention, however, must be focused on the evaluation of significant soil compaction impacts and analysis of cumulative effects if these systems are to be considered for use in harvesting operations.

Table 1. Summary information for a GIS analysis of logging trail area

Machine Pass Category*	Area in Trails† (ha)	Poly-gons (no.)	Average Size of Polygons† (ha)	Total Site Area (%)	Total Trail Area (%)
≤ 4	0.2021 (0.4994)	45	0.0045 (0.0111)	4.0	17.2
5-6	0.3992 (0.9864)	50	0.0080 (0.0197)	8.0	33.9
7-8	0.1458 (0.3603)	26	0.0056 (0.0139)	2.9	12.4
9-11	0.1137 (0.2810)	21	0.0054 (0.0133)	2.3	9.7
12-20	0.0768 (0.1898)	9	0.0085 (0.0211)	1.5	6.5
21-29	0.0592 (0.1463)	6	0.0099 (0.0245)	1.2	5.0
30+	0.0667 (0.1648)	2	0.0334 (0.0824)	1.3	5.7
Roads‡	0.1126 (0.2782)	2	0.0563 (0.1391)	2.3	9.6
Total	1.1761 (2.9062)			23.5	100.0

* Range of number of machine passes.
† Areas in acres are shown in parentheses.
‡ Permanent and temporary roads.

Conclusions and Future Outlook

Cumulative effects assessment requires managers to determine past, present, and future site effects when evaluating proposed projects on federal lands. When such projects for ground-based logging are evaluated, soil compaction is widely used as a basis for decision making. It has been documented that the degree of soil compaction is associated with the number of machine passes (Murphy, 1982), but such field methods as the line-transect process do not assess the number of passes over the site, although they do provide a good estimate of the area in trails.

The GIS analysis was helpful in defining the percentage of area in machine pass categories, although the effort was greater than we had expected. The number of machine passes can explain a large amount of variability in soil bulk density (Zaborske, 1989). Determining whether the site has been significantly affected requires further information on the increase in soil bulk density (compared with areas where machines did not travel) for each machine pass category and the overall effects of compaction on stand growth. If land managers are to evaluate site impacts caused by ground-based logging systems such as the cut-to-length system before making project-level decisions, they will need baseline data from evaluations of several logging sites, such as the extensive evaluation we have performed here.

When harvesting timber with ground-based machinery is considered, we see no substitute for the methods described, if the required information for making adequate determinations of significant impacts or cumulative effects is to be obtained. However, a relatively recent technological development, the global positioning system (GPS), which uses satellite triangulation to determine location, has potential for increasing the speed and accuracy of data collection. Through the use of hand-held GPS units, skid trail patterns can be delineated as locational data is automatically recorded at selected regular time intervals. The recorded data can later be downloaded into GIS for processing, analysis, and map making, potentially rivaling the speed of a line-transect survey. Another possibility may include the use of GPS on-board logging equipment to monitor and record time, distance, and location of the machine's movement with reasonable precision. This would be useful in production studies as well as soil compaction studies related to the number of equipment passes over a particular site. The major drawback to using GPS is the potential for losing position fixes due to satellites leaving the receiver's field of view, or due to blockage by the forest canopy (Evans et al., 1992). However, it is anticipated that in the near future, the use of GPS and GIS will become routine in harvesting research.

References

Armlovich, D. 1992. Study plan draft: Soil compaction resulting from a shortwood cut-to-length harvesting system. Unpub. manuscript. Dept. of Forest Engineering, College of Forestry, Oregon State Univ., Corvallis.

Autodesk, Inc. 1992. AutoCAD Release 12. Sausilito, Calif.: Autodesk Inc.

Bettinger, P. and L. D. Kellogg. 1993. Residual stand damage from cut-to-length thinning of second-growth timber in the Cascade Range of western Oregon. *Forestry Prod. J.* 43(11/12):59-64.

Bradshaw, G. 1979. Preplanned skid trails and winching versus conventional harvesting on a partial cut. Res. Note 62. Forest Research Laboratory, Oregon State Univ., Corvallis.

Dyrness, C. T. 1965. Soil surface condition following tractor and high-lead logging in the Oregon Cascades. *J. Forestry* 63(4):272-275.

Environmental Systems Research Institute Inc. 1992. PC ARC/INFO Version 3.4D Plus. Redlands, Calif.: Environmental Systems Research Institute Inc.

Evans, D. L., R. W. Carraway and G. T. Simmons. 1992. Use of global positioning system (GPS) for forest plot location. *Southern J. of Applied Forestry* 16(2):67-70.

Froehlich, H. A. 1973. The impact of even-age forest management on physical properties of soils. In *Proc. Even-age Management* 199-220, 1 August 1972. Oregon State Univ., Corvallis.

Garrison, G. A. and R. S. Rummell. 1951. First-year effects of logging on ponderosa pine forest range lands of Oregon and Washington. *J. Forestry* 49(10):708714.

Johnston, C. A., N. E. Detenbeck, J. P. Bonde and G. J. Niemi. 1988. Geographic information systems for cumulative impact assessment. *Photogramm. Eng. Remote Sens.* 54(11):1609-1615.

Kellogg, L. D. and P. Bettinger. 1994. Thinning productivity and cost for a mechanized cut-to-length system in the Northwest Pacific Coast Region of the USA. *J. Forestry Eng.* 5(2):43-54.

McNeel, J. F. and T. M. Ballard. 1992. Analysis of site stand impacts from thinning with a harvester-forwarder system. *J. Forestry Eng.* 4(1):23-29.

MicroConsultants. 1991. MicroCAM Version 3.0. Mililani, Hawaii: MicroConsultants.

Miller, J. H. and D. L. Sirois. 1986. Soil disturbance by skyline yarding vs. skidding in a loamy hill forest. *Soil Sci. Soc. Am. J.* 50(6):1579-1583.

Murphy, G. 1982. Soil damage associated with production thinning. *New Zealand J. Forestry Sci.* 12(2):281-292.

Pritchett, W. L. and R. F. Fisher. 1987. *Properties and Management of Forest Soils,* 2nd Ed. New York: John Wiley & Sons.

Reisinger, T. W., P. E. Pope and S. C. Hammond. 1992. Natural recovery of compacted soils in an upland hardwood forest in Indiana. *Northern J. of Applied Forestry* 9(4):138-141.

Sidle, R. C. and D. M. Drlica. 1981. Soil compaction from logging with a low ground pressure skidder in the Oregon Coast Ranges. *Soil Sci. Soc. Am. J.* 45(6):1219-1224.

Skidmore, A. K. and B. J. Turner. 1992. Map accuracy assessment using line intersect sampling. *Photogramm. Eng. Remote Sens.* 58(10):1453-1457.

Snider, M. D. and R. F. Miller. 1985. Effects of tractor logging on soils and vegetation in eastern Oregon. *Soil Sci. Soc. Am. J.* 49(5):1280-1282.

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. Am. Proc.* 19(3):372-376.

USDA. 1989. Land and resource management plan: Siskiyou National Forest. Portland, Ore.: USDA Forest Service Pacific Northwest Region.

Van Wagner, C. E. 1968. The line intersect method in forest fuel sampling. *Forest Sci.* 14(1):20-26.

Warren, W. G. and P. F. Olsen. 1964. A line intersect technique for assessing logging waste. *Forest Sci.* 10(3):267-276.

Wooldridge, D. D. 1960. Watershed disturbance from tractor and skyline crane logging. *J. Forestry* 58(5):369-372.

Wronski, E. B. 1984. Impact of tractor thinning operations on soils and tree roots in a Karri Forest, western Australia. *Australia Forestry Res.* 14(4):319-332.

Zaborske, R. R. 1989. Soil compaction on a mechanized harvesting operation in eastern Oregon. M.F. paper, Dept. of Forest Engineering, College of Forestry, Oregon State Univ., Corvallis.