RELATIONSHIP BETWEEN SITE DISTURBANCE AND FOREST HARVESTING EQUIPMENT TRAFFIC

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ABSTRACT

A study was done to evaluate the use of global positioning systems (GPS) to track the position of forest harvesting equipment and use the information to assess site impacts. GPS units were attached to tree-length harvesting machinery in two clearcuts (1 feller-buncher, 2 skidders). Position of the equipment was recorded at 2-second intervals throughout the harvest of both stands. The positional data were differentially corrected, then filtered using a custom software package to calculate the area of impact based on the path taken by the machinery. Result of the calculations were raster maps with cell values equal to the number of tire passes over that location. For the current study, grid resolution was 0.5×0.5 m. Following harvest, visual assessments of site disturbance on a chain-by-chain grid were made and the results compared to estimates from the traffic maps. Soil physical properties were measured in a 1 ha area of one stand and the values correlated with local traffic levels. Results indicated that the GPS-based approach to assessing site impacts gave results equivalent to what would be expected from an intensive visual inspection. For the conditions tested, 25 percent of the stand remained untrafficked, 25 percent received more than 5 passes, and 50 percent of the stand received 1 to 5 passes. There was no clear correlation, however, between observed number of passes and changes in measured soil properties.

INTRODUCTION

There is a great deal of research interest in the sustainability of forest management practices. Forest operations to implement many management objectives require the application of heavy equipment on tracts, resulting in impacts to the soil. These impacts may persist over time and result in decreased stand productivity. It is important to understand how machinery impacts a stand and what factors influence the degree of impact.

A number of studies have quantified how machinery affects soils on a microenvironment scale, generally measuring changes in soil properties at a fixed point for a given traffic intensity level. Machinery impacts on soils have been shown to vary with soil type and moisture, machine type, size, and weight, number of passes, tire and drive train characteristics, and other factors

(Graecen and Sands 1980). Relating these impacts to stand productivity is difficult in practice, however, because of the within-stand variability of forest machinery traffic patterns. Productivity is a characteristic of a stand, tract, or landscape. Traffic, on the other hand, is a point-level phenomenon, varying greatly over small areas. Linking traffic with its effect on stand-level productivity requires some knowledge both of the nature of the impacts and their distribution over the stand.

Evaluating traffic effects on a large scale is now possible using global positioning systems (GPS). Traffic patterns of free-ranging machinery can be recorded with a high degree of accuracy for long periods of time and the data used in evaluating site impacts or machine productivity. McMahon (1997) proposed using maps of traffic density, or number of passes, as an index of site disturbance. This study was an application of the techniques of McMahon (1997) to evaluate the effectiveness of using traffic density maps relative to visual assessment of site disturbance. From a broader perspective, the study was intended to test new ways of applying GPS-derived machine traffic density maps in evaluating site disturbance and other aspects of forest operations. The study also included a component to test the relationship between soil physical property changes and traffic density as measured using the GPS. Specific objectives of the study were:

1. Compare visual- and GPS-derived estimates of percent disturbed area in forest harvesting.
2. Identify techniques for analyzing site disturbance and machine productivity of forest operations using positional data gathered from the GPS.
3. Correlate measures of traffic density with changes in soil physical properties.

EXPERIMENTAL METHODS

GPS and site disturbance data were collected on two harvest sites in northwest Lee County, AL. The sites were situated across a small creek from each other, and were very similar in soil type and stand characteristics. Soils were classed as Gwinnett series. The stands were planted loblolly, established in 1977, with 120 ft^2 per acre basal area pine, and 20 ft^2 hardwood. There were a nominal 600 stems per acre and expected total yield was 90 green tons per acre. Site 1 was 63 acres, and site 2 was 41 acres. Figure 1 is an area map showing the boundaries and a few other features of the sites.

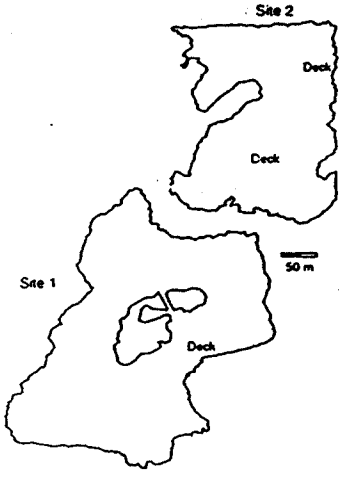


Figure 1. Map showing boundaries, scale, and relative position of the harvested sites. Also noted are locations of logging decks.

The sites were harvested beginning in late February, 1998, and completed in mid April. The sites were logged by the same crew using a single feller buncher (HydroAx 511E), with two grapple skidders (Timberjack 460D and 450C) pulling to two separate decks, each having a loader equipped with an integrated delimber/slasher. System production was hampered by wet weather and averaged about 7 to 8 loads a day.

Machine positional data were collected using three GPS systems: 2 Trimble[1] ProXR, and 1 Trimble GeoExplorer. The GeoExplorer system did not perform as well in canopy conditions, but the lower-profile antenna made it more suitable for use on the feller buncher. The ProXRs were mounted on the skidders. Despite many precautions, there were several instances where the GPS data were lost because of equipment breakdown, or problems coordinating work schedules with the logging crew. This led to large gaps in data coverage, especially on site 1 where procedures had not been completely worked out. By the end of the study, however, data for nearly all daily traffic was being captured.

Positional data were differentially corrected then exported to a GIS for editing. Data from the GeoExplorer system was especially prone to seemingly random shifts in one or more sequential locations. These shifts were filtered out, reducing the total amount of data from the GeoExplorer system by about 10 percent. The ProXR data required significantly less filtering.

After removing errant positions, the data were transformed into a raster map with cell values being the number of passes over that point. The transformation was done using a custom software system (McDonald and others 1998) that modeled the movement of a machine given the position of its centerline. Resolution of the traffic intensity map was 0.5×0.5 m.

Visual site disturbance was classified for both sites on a chain-by-chain grid. A trained observer walked the site and at grid intersection points evaluated ground conditions. Characteristics recorded included the amount of soil movement (litter in place, mineral soil exposed, churning of litter and soil, etc.), whether or not machine traffic was evident at the point and some indication of the traffic density (untrafficked, skid trail, logging deck, off-trail traffic, etc.), and whether or not a rut had been formed and its depth ($<$ or $>$ 5 cm). The characteristics for each point were classified into 6 categories: undisturbed (no evidence of traffic), slightly disturbed (litter in place, not on a trail), disturbed (any rut, any soil exposed, not on a trail), skid trail, deck, and indeterminate.

Changes in soil properties with number of vehicle passes was evaluated on a portion of site 1 where there was nearly complete coverage of machine positional data. An area approximately 1 ha in size was sampled on a 3×9 m (approximate) grid for soil strength and bulk density. Soil strength was measured using a cone penetrometer (Rimik model CP20) to a depth of 400 mm. Bulk density was estimated from core samples taken at 2 depths - surface to 10 cm, and 10 to 20 cm. The position of each sample point was fixed using a GPS and the position referenced back to the traffic intensity maps to determine the number of passes at each location. A total of about 300 samples were taken.

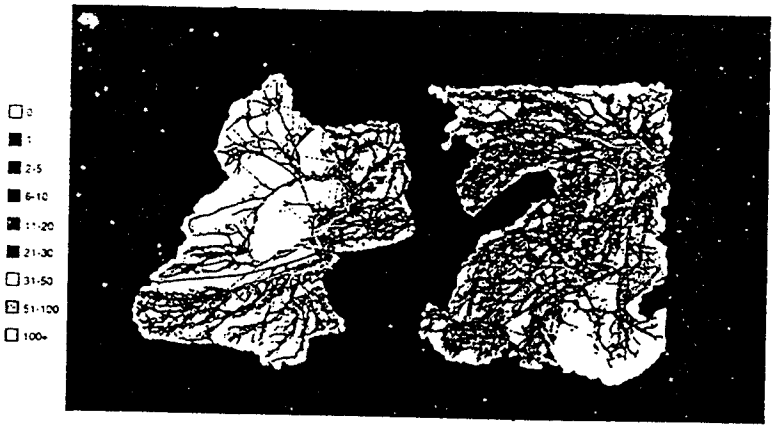
[1] — The use of trade names is for illustrative purposes only and is not intended as an endorsement by the USDA to the exclusion of other manufacturers.

RESULTS AND DISCUSSION

Figure 2 shows the traffic patterns as measured using the GPS on sites 1 and 2. Note that there were large areas within the stands showing no, or reduced, traffic, especially on site 1. These were a result of problems in data collection and illustrated the difficulty in obtaining a complete record of machine traffic. Further development of GPS systems to adapt them to harsh environments, and some method for checking status of the receivers remotely, would greatly improve the reliability of the data collection system. Because of the problems in this study, however, traffic intensity data were only summarized for those areas where it was most likely that a complete record of machine traffic had been acquired. Coverage on site 2 was very good except for areas in the extreme north and southeast ends of the tract where problems arose because of scheduling of the timber harvest activities. The portion of the stand in between, shown in figure 3, was felt to have the most complete record of machine traffic and summaries of traffic density were therefore based on data from this area.

Total area for the portion of the stand shown in figure 3 was 11.1 ha. Table 1 is a summary of the percent of area by traffic class. Note that, if the cut block had actually been 11.1 ha in size, the values in table 1 would likely have been slightly different, probably shifting some of the area from higher (> 10 passes) traffic density into lower traffic density classes. Total area trafficked would likely have been about the same.

Results of the visual site disturbance estimate are summarized in table 2, along with a comparison to the GPS-derived traffic density measures. Assignment of numbers of passes to disturbance classes was made in order to equalize area values in the middle range (slightly disturbed and disturbed categories), allowing a comparison of the two methods at the high and low ends of disturbance. The results indicated that the visual disturbance method over-estimated the amount of area in skid trails and decks, and under-estimated the amount of undisturbed area relative to the GPS assessment. This conclusion was similar to that of McMahon (1995) in a study of the effect of sampling density on site disturbance measures using a visual assessment method. In the



Site 1 Site 2

Figure 2. Traffic patterns as measured using the GPS system. Shade refers to the number of passes. Resolution of the map was 0.5×0.5 m.

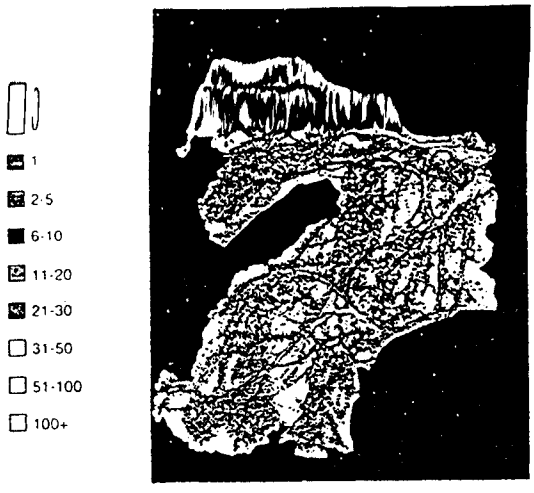


Figure 3. Traffic density for area with most complete machine traffic coverage. This area was used in estimating site disturbance for the GPS method.

Table 1. Summary of percent area of the stand by traffic intensity class.

Number of Passes	Percent Area
0	27.9
1	16.2
2-5	33.7
6-10	11.7
11-20	5.5
21-30	2.0
31-50	1.6
51-100	1.1
100+	0.3

study, lower sampling density resulted in undisturbed areas being under-estimated relative to more dense sampling schemes. Our results showed the same trend with respect to GPS-derived estimates, leading to the conclusion that the GPS system, when operating properly, provided results that were similar to densely-sampled visual disturbance assessments, but provided additional information on where disturbances occurred within the stand.

Results of the traffic intensity measurements indicated that about 25 percent of the harvested stand remained untrafficked. Figure 4 shows the untrafficked portion of the cut block from figure 3. It appeared from this view that much of the untrafficked area was in very small patches, which could help in explaining why the visual and GPS-derived estimates of undisturbed area were so different. If the sample point happened to land on an untrafficked spot that was relatively small and surrounded by trafficked ground, the observer might have assigned a rating based on the presence of traffic nearby, rather than on the patch of untrafficked ground.

Table 2. Summary of percent area of the stand by visual disturbance class, with associated estimate based on number of passes.

Disturbance Class (number of passes)	Percent Area	
	Visual	GPS
Undisturbed (0)	9.5	27.9
Slightly Disturbed (1-3)	37.5	37.9
Disturbed (4-20)	27	29.2
Decks and Trails (21+)	18.5	5.0

Figure 4. Untrafficked areas of site 2 shown in white.

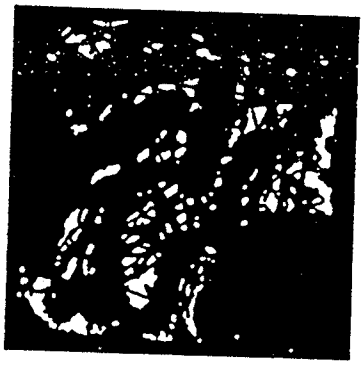


Figure 5. Untrafficked areas of site 2 after morphological closure with 3.5 m diameter disk.

A series of transformations known as morphological closures were applied to the data from figure 4. Morphological transformations (Serra 1982) filter data with respect to a set known as a structuring element. The closure transformation removes those portions of a set where the structuring element does not 'fit' (see McDonald and Chen 1990). By applying a sequence of closures using successively larger structuring elements (in our case, a disk shape), it was possible to eliminate areas of the data from figure 4 that were smaller than a circle of varying radius, essentially calculating a size distribution of the untrafficked 'patches'. Figure 5 is an example of a filtered image, in this case showing the data from figure 4 after eliminating areas smaller than a 3.5 m diameter circle. The plot in figure 6 shows the distribution of total area remaining after filtering with various sized disk shapes. About 50 percent of the untrafficked area was eliminated when filtered using the 3.5 m diameter disk, indicating that half of the untrafficked stand was in patches smaller than about a skidder width in size.

There was only a slight correlation between number of passes and changes in soil physical properties. Soil strength increased with one pass to a depth of 20 cm, but showed no response to

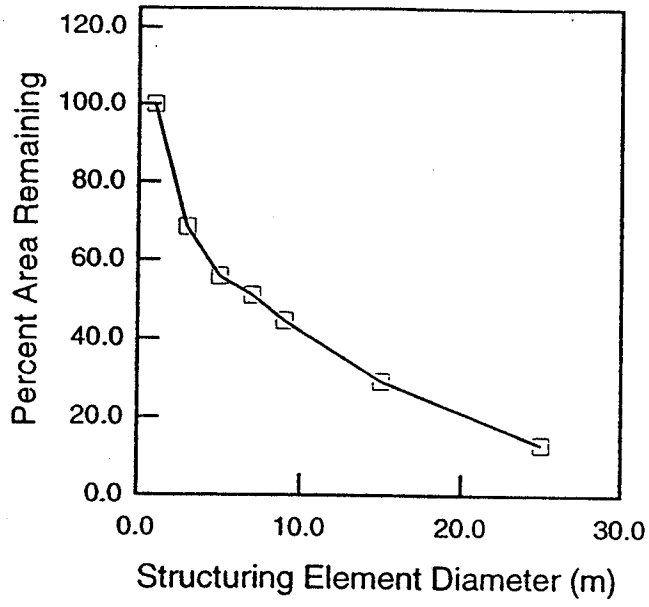


Figure 6. Size distribution of untrafficked areas. Value is the remaining area after removing portions where a disk of diameter x does not fit.

higher numbers of passes. Below 20 cm there was no change in soil strength with traffic - the values were uniformly above 2.5 MPa. Bulk density increased at the soil surface for up to 3 passes, then either decreased or stayed constant. None of the changes were statistically significant.

DISCUSSION

The traffic pattern maps generated using the GPS provided detailed pictures of both the extent and spatial distribution of machine movements during harvest. The lack of correlation between any observed soil properties and number of passes, however, illustrated the difficulty in assessing changes in future productivity from current forest operations. Without a clear relationship between an observable quantity, such as number of machine passes, and future growth of trees, prediction of impacts from logging on site productivity cannot be made with certainty for a given site. Mapping traffic intensity, coupled with similar maps of future stand growth and subsequent analysis of soil parameters, is a promising approach for defining the soil parameters that are affected by forest operations and that have an impact on future stand growth.

The use of GPS for tracking forest harvesting machinery can be of great value in the analysis of logging systems in general. From a practical standpoint, the data collection system is very flexible and can be applied in all types of conditions and, within budget constraints, any number or type of machines. With some additional communications hardware, the data collection system could be operated remotely, making it practical to gather data indefinitely. It would not be inconceivable that loggers could be trained to operate the systems themselves, especially if they could derive some benefit from the data. For example, data on production efficiency measures such as time per skidding cycle, or distance traveled per cycle could be extracted from the raw traffic data and reported to the logger. They could then use this information to track their systems' performance, or see the effect of unique characteristics of a particular tract on system productivity. This data could provide leverage for negotiating logging rates in unusual circumstances.

Traffic data is easily converted into maps that are compatible with GIS, making them archivable and available for review if questions arose concerning a particular tract. If, for example, a portion of a stand showed poor growth, the maps could be reviewed to see if there was an unusual amount of traffic in that area. It would be relatively simple to extract harvested area extent from the traffic maps, showing any deviations from the prescribed unit boundaries. Reviewing data on a regular basis could provide managers with feedback on the progress of logging jobs, perhaps requiring fewer inspection trips to sites. Equipping felling heads with some sort of tree volume estimation system coupled with a GPS could provide feedback to procurement foresters on the state of current feedstocks and a check on the accuracy of cruise information. It would also provide a means of tracking how much timber should be arriving at a mill from a site, increasing security. Finally, maps of productivity could provide feedback for 'precision' management prescriptions, allowing targeting of nutrient applications, weed control, or site prep activities to specific places on a sub-stand basis.

CONCLUSIONS

This study demonstrated the potential of using GPS to track forest harvesting equipment and evaluate site disturbance. Results indicated that about 25 percent of the stands remained untrafficked after harvest, 25 percent received more than 5 passes, and 50 percent were trafficked from 1 to 5 times. The spatial nature of the data also showed the arrangement of disturbance patterns, as well as the distribution in size of disturbed (or undisturbed) areas. About half of all remaining undisturbed areas, for example, were in patches with their smallest dimension no larger than the width of a skidder. This type of information could be useful in correlating logging impacts with future productivity of these sites.

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