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MODELLING FOREST BIOMASS ACCESSIBILITY IN SOUTH CAROLINA WITH DIGITAL TERRAIN DATA

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ABSTRACT

In a cooperative study sponsored by the U.S. Forest Service, Clemson University's Department of Forestry attempted to model forest biomass accessibility in the Southeast using 1:250,000 scale digital elevation data available from the National Cartographic Information Center. Digitized elevation data were processed with a digital terrain model computer program to generate land slope values for forestland in the South Carolina Piedmont. Merged with Landsat-derived forest cover type classification, the digitally modelled slope values were used to characterize forestland accessibility and constrain estimates of forest biomass availability for energy use in the Region. The results of the digital terrain modelling were compared to ground sample based terrain characterization and large-scale topographic map terrain analysis and found to be insufficiently accurate for purposes of determining accessibility of forest biomass for intensive harvesting. The major limitation of the digital terrain model appears to be the small scale of the topographic maps from which the digital elevation data were derived.

I. INTRODUCTION

Because of the increasing need for non-fossil energy sources, the U.S. Forest Service has been asked by the Department of Energy to develop methods for accurately assessing the availability of forest biomass for energy use in the United States. The Department of Forestry at Clemson University through a cooperative research grant from the Forest Service Southeastern Forest Experiment Station has attempted to develop an integrated system for conducting an assessment of the availability of forest biomass residues in the Southeastern Region of the U.S.

Using the Forest Service's Renewable Resources Evaluation (RRE) Survey as the basic source of biomass inventory data, Clemson and several other cooperating universities have formulated a comprehensive and realistic system for estimating amounts of forest biomass that will be available for use under various economic, sociological, biological and geophysical constraints. The part the cooperative study reported in this paper deals with modelling the geophysical obstacles to availability of biomass from the forest with digitized elevation data available from the National Cartographic Information Center in Reston, Virginia. The primary objective of the study was to modify estimates of forest biomass availability by classifying forest acreage according to accessibility for harvesting.

From the beginning of the study, it was assumed that an important factor in forest biomass availability is its accessibility. Accessibility was defined as the degree of ease, both physically and economically, that forest biomass could be harvested and transported out of the forest to a location for consumption. Consequently, such factors as location of forest biomass relative to existing road systems and extreme terrain features and the amounts of biomass per unit area and its degree of association with conventional forest products were considered key factors in modelling accessibility of forest biomass. The Forest Service's ground sample based RRE inventory data provide much of this accessibility information, but because of the sampling method it is limited in statistical validity for assessing areas smaller than a typical survey unit, which normally can be 18-20 counties of a state. There is a need to establish availability of forest biomass for individual counties and for specific potential consumer site locations, such as the immediate vicinity (a 30-40 mile radius) of an industrial plant with high potential for converting from fossil fuel to forest biomass fuel. Such a specific vicinity assessment is important because of the bulky nature of biomass fuels and the importance of transportation costs in the economic evaluation of converting a steam plant to biomass fuel.

Based upon the need for an accessibility analysis for specific site locations, the use of a digital geographic information system seemed a logical approach. By using the Forest Service's basic inventory data which would characterize major forest cover types according to amounts and types of biomass per unit area and combining this data with a Landsat-derived forest cover type delineation and a digital terrain analysis, it was felt that the minimum area-related statistical limitations of the Forest Service's survey methods could be alleviated.

II. MATERIALS AND METHODS

The initial study effort was confined to using slope and slope variability as the key terrain features that would constrain accessibility of forest biomass. The concept was patterned after reports by Dissmeyer (1979) and Berry (1981). A digital terrain analysis model (DTM) was developed based upon digitized elevation data that calculated for each acre of classified Landsat scenes the maximum slope and degree of slope variability for the eighteen counties of the South Carolina Piedmont. Accessibility ratings were then assigned to the acres based upon the assumptions that slopes less than 30% were readily accessible, slopes of 30-39% were moderately accessible, and slopes of 40% or greater were inaccessible for intensive energy wood type harvests (Knight and McClure 1981).

In order to associate the terrain data thus derived with forest cover types (the basic biomass quantifier), the DTM was interfaced with a Landsat-based land cover classification process. The Computer Graphics Division of the University of South Carolina reformatted the digital terrain tapes for the statewide data base, the "S.C. Natural Resources Information System," and geo-referenced the tapes to state and county boundaries using the universal transverse mercator (UTM) coordinate system. Using "ELAS," a computer software system for maximum likelihood land cover classification, the USC Computer Graphics Division assisted Clemson in classifying three 1981 Landsat scenes encompassing the study area into forest and non-forest cover types (level I) and classified the forestland into pine, mixed-pine hardwood, and hardwood cover types (level II). Thus, each pixel or picture element of the study area, resampled to approximately 1 acre, was assigned a land cover type classification. Similarly, the Clemson DTM assigned a slope value to each acre of the classified scenes. This slope value is calculated by a computer algorithm that determines the maximum slope value for a 9-acre cell. The algorithm compares the digital elevation values assigned by the USGS tapes to each acre within the cell, determines the maximum elevation difference within the cell, uses it to calculate a slope value, and assigns this slope value to all 9 acres in the cell and moves on to the next cell, repeating the process until all acres are assigned a slope value (Gering 1982, Berry 1981). Thus, each acre in the study area is assigned a cover type and slope value, allowing a cartographic analysis of the forest cover types within each county. The forested acres were then classified and tabularized according to cover type and slope class and the results compared to those derived from the Forest Service RRE Survey data. The slope variability algorithm proved unreliable and was dropped from the study.

The digital terrain model (DTM method) results were then compared with accessibility evaluations of the same forested area from two other sources, ground sampled slope values (hand-held clinometer) and graphic slope estimates based on USGS 1:24,000 scale topographic maps (Quad Map Method). Sample points were systematically chosen on the Quad maps, then a clear plastic overlay with a scaled 9-acre square was placed over the sample location and the maximum slope occurring within the 9-acre sample was determined by counting the number of contour interval lines that cross each side of the square, multiplying the maximum by the elevation interval of the contour line, and dividing this value by the length of a side of the square (625 feet). This yields an approximation of the maximum slope occurring within the 9-acre sample and is similar to the manner with which maximum slope is calculated for the same 9-acre sample by the DTM method.

III. RESULTS AND DISCUSSION

The results of cartographic modelling of terrain constraints on biomass availability for six of the eighteen counties of the study area are compared to RRE Survey-derived values in Table 1.

Table 1. Comparison of Forest Land Accessibility Estimates by Ground Survey (RRE) and Digital Terrain Model (DTM) for Three Major Cover Types of Six Counties of the South Carolina Piedmont.[1/]

Land Slope Value (%)	Pine Type RRE	Pine Type DTM	Mixed Pine-Hdwd Type RRE	Mixed Pine-Hdwd Type DTM	Hardwood Type RRE	Hardwood Type DTM
	% Total Acreage					
0- 9 (Accessible)	36.7	79.5	16.5	70.2	26.6	69.9
10-19 (Accessible)	46.0	14.7	32.9	17.1	20.3	15.6
20-29 (Accessible)	9.0	3.5	17.2	6.8	23.7	6.7
30-39 (Marginal)	3.6	1.1	18.5	3.0	14.7	3.3
40+ (Inaccessible)	4.6	1.0	14.9	3.0	14.7	4.4

1/ Study area includes Anderson, Cherokee, Greenville, Oconee, Pickens, and Spartanburg Counties.

In general, the results from using the two methods of slope determination differ considerably. The DTM method consistently places a much higher proportion of the study area in the lower slope classes, e.g., the DTM method places 70-80% of the total area in the 0-9% slope class while the RRE method places 16-37% in the same class. This results in a 2 to 4-fold difference, depending upon the cover type examined. The acreage estimates in the other slope classes differ to a similar degree but obviously in the opposite perspective, i.e., the DTM method underestimates acreage in higher slope classes.

In comparing the two methods, the point to look at most closely is how the methods distribute the acreage into the critical or threshold accessibility slope classes, i.e., slopes of 0-29% are considered generally accessible, 30-39% slopes are marginally accessible, and 40%+ slopes are inaccessible when considering efficient, machine-oriented, logging equipment. The DTM method consistently and appreciably underestimates acreage in the marginally operable and inoperable slope classes when compared to the RRE method. Although there is a difference in degree among the three cover types the underestimation is consistent and too large in magnitude to accept. For example, the DTM method places about 13,000 acres or 3 percent of the mixed cover type in the marginally operable class while the RRE method shows 46,000 or 18.5 percent in that class. In addition, the DTM method shows about 13,000 acres or 3 percent of the mixed type in the inoperable logging class while the RRE method places nearly 37,000 acres or 15 percent in the inoperable class. In other words, the DTM method places about 26,000 acres of the mixed cover type in the study area in a questionable accessibility status, while the RRE method shows that over 83,000 acres, or 3 times more, are of questionable status.

The primary reason for the large difference in acreage allocation among the slope classes by the two methods compared is probably the fact that the DTM method is based upon elevation differences derived from 1:250,000 scale topographic map digitization by the Defense Mapping Agency. While this scale of resolution may serve nicely for some purposes, it is apparently not sufficient for estimating slope as it relates to logging conditions on the ground. For example, if a particular terrain feature, such as a small drainage, ravine, terrace, ledge or ridge, has an inherent elevation difference of less than 100 feet, the feature would not be detailed on the 1:250,000 scale map and consequently would not be incorporated into the digitized elevation data base. As a result, many terrain features which have slopes in the 40% or higher class and which are a significant barrier to intensive harvest because they are an appreciable part of forest stands would not be part of the DTM data base.

Error in slope estimates associated with mislocation of sample points on the ground, maps, and UTM coordinate system probably did not contribute to the difference among methods of slope estimation since an earlier study by Cost (1976) indicates that UTM coordinates of ground points determined from 7½-minute quadrangle maps, as done in this study, are reasonably precise, e.g., 8-10 meter mean error of location.

In an effort to determine if scale of topographic data is the major source of error in allocation of forest acres among the various land slope classes by the DTM terrain analysis method, a third method of slope determination was used for a small sample of locations within the study area and compared to the DTM method. The third method, called the Quad Map method, consisted of graphically sampling the study area using large scale (1:24,000) USGS topographic maps.

The data in Table 2 again show that the DTM method consistently underestimates slope values, i.e., places a greater number of acres sampled into a lower slope class than does the larger scale map method. For example, of the 17 samples placed in slope class 5 (inaccessible) by the Quad Map method, 12 of these samples (71%) were placed in slope classes 1-3 (readily accessible) by the DTM method. This represents an error of the worst type, i.e., forest acres that may at best be marginally operable are included in the most accessible (operable) terrain class. Miscalculating a slope value by 5-10 percent would only result in an error of 1 slope class displacement which would not be disastrous in a terrain-based accessibility analysis, especially if the error was random and resulted in an equal number of over and under estimations. However, misclassifying an acre by 3 slope classes and doing so consistently in the critical slope classes, such as classes 4 and 5, is simply unacceptable accuracy.

The consistent misclassification of the slope of forest acres by the DTM method when compared to both the RRE method and the Quad Map method poses a major obstacle to modelling forest accessibility. Because of the similarity of the Quad method and the DTM method with regard to mechanics of calculation of slope values, it can only be assumed that the smallness of scale of the topographic maps from which the DTM data is derived (1:250,000) is again the cause of the problem.

Assuming that map scale was the major problem, an attempt was made to evaluate larger scale map-derived slope data by comparing Ground-Sampled and Quad-Sampled locations (Table 3). These two methods were closer in slope estimation than were the DTM and Quad Map methods, although the

Table 2. Comparison of Land Slope Values Generated by Digital Terrain Model with Values Determined for Same Locations Using 1:24,000 USGS Quadrangle Maps, Upper Piedmont South Carolina.[1/]

DTM-Derived Slope		Quadrangle-Derived Slope[2/]						
% Slope	Class	1	2	3	4	5	Totals	Percent Agreement[3/]
0- 9	1	127	112	27	6	8	280	45
10-19	2	7	9	8	3	1	28	32
20-29	3	2	9	5	1	3	20	25
30-39	4	0	2	1	2	2	7	29
40+	5	0	0	2	0	3	5	60
Totals		136	132	43	12	17	340	
Percent Agreement		93	7	12	17	18		43

[1/] Values underlined within the body of table indicate number of samples in agreement between the two methods of determining slope.

[2/] Column totals indicate the number of samples placed in a slope class by the Quadrangle Method. Row totals are the number of samples placed in a slope class by the DTM Method.

[3/] Percent agreement is the proportion of samples placed in a slope class by one method that were placed in the same class by the other method. For example, of the 17 locations determined to be slope class 5 by the Quadrangle Method, 3 of them or 18% were put in class 5 slope by the DTM Method.

Table 3. Comparison of Land Slope Values Generated by Ground Sampling with Those for Same Locations Using 1:24,000 USGS Quadrangle Maps, Upper Piedmont South Carolina.[1/]

Ground Slope % Slope	Ground Slope Class	Quadrangle-Derived Slope[2/] 1	2	3	4	5	Totals	Percent Agreement[3/]
0- 9	1	50	11	0	0	0	61	82
10-19	2	31	58	11	1	0	101	57
20-29	3	6	26	8	1	1	42	19
30-39	4	2	7	4	1	2	16	6
40+	5	0	6	7	5	5	23	22
Totals		89	108	30	8	8	243	
Percent Agreement		56	54	27	13	63		50

1/ Values underlined within the table are number of samples placed in same slope class by both methods.

2/ Column totals are number of samples placed in a slope class by the Quadrangle Map Method. Row totals are number placed in a slope class by Ground Slope Method.

3/ Percent agreement is the proportion of samples placed in a slope class by one method that were placed in same class by the other method.

ground sampled estimations tended to be myopic, i.e., reflected terrain conditions only in the immediate vicinity (the surrounding 1-2 acres) of the viewer, while the Quad Map sampled data tended to overgeneralize terrain conditions for a specific 1 acre location (Table 3).

Of the 243 sample locations used to compare ground-sampled land slope estimation with large scale map-sampled land slope estimation, 122 or 50% were in agreement between the two methods (Table 3). However, the results varied considerably as slope values increased. For example, of the 204 samples estimated to be readily operable (slope classes 1 through 3) by the Ground method, the Quad Map method placed only 3 of these samples in the marginal or inoperable classes (slope classes 4 and 5). However, of the 16 samples estimated to be marginally operable (slope class 4) by the Ground method, the Quad Map method placed 13 of them (81%) in the operable classes (slope classes 1 through 3). Of the 23 samples classed as inoperable (slope class 5) by ground sampling, 13 (56%) were estimated to be operable and 5 (22%) were estimated to be marginally operable by the Map method. These results are of some concern because of the desirability of remote sampling methods for characterizing accessibility of forestland.

In an effort to improve the accuracy of remotely-sensed ground slope estimates, another graphical sampling method was tried. A crosshair on a plastic overlay with scaled 500 foot arms was placed over ground point locations on 1:24,000 scale quad maps with one arm aligned along the steepest adjacent slope. Slope values were calculated in a similar manner as with the Quad Map method and compared to ground sampled data. Again, the map-based method badly underestimated slopes in the upper classes, with no improvement in the results shown in Table 3. The comparisons raise strong questions about the accuracy of all of the remote sampling methods used in this study.

IV. CONCLUSIONS

In evaluating the results of this study comparing methods of characterizing forestland accessibility based on land slope estimation, a few pertinent observations can be made. Ground sampling observation tends to be myopic, i.e., confined to a small area, immediately surrounding the observer and often consisting of two acres or less in extent. In addition, ground estimates of slope are based on the maximum slope at hand which sometimes represents a minor terrain obstacle to harvesting the timber, i.e., perhaps some estimate of slope length and proportion of the area viewed that is made up of that maximum slope should be made. On the other hand, remote sampling tends to be generalized and, in the case of the methods used in this study, tends to average land slope over an area of 9 to 10 acres, depending upon the scale of the topographic maps that are used. The utility of such sampling is very dependent upon the relative accuracy with which the map base reproduces actual ground conditions and the manner in which the map slope is determined. As found in comparing the DTM data from 1:250,000 maps with both ground and 1:24,000 scale map sampling, as map scale decreases more detail of actual ground conditions important in accessibility ratings is lost. Results of this study indicate that digitally modelling terrain based on small scale topographic maps is simply not sufficient for characterizing forest biomass harvesting accessibility.

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