Differences between Ecological Land Type Maps Produced Using GIS or Manual Cartographic Methods

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ABSTRACT: The U.S. Forest Service primarily develops multiple-use land maps using manual techniques. In Region 9, the basic mapping units are called Ecological Land Types (ELTs) which, on a local level, are defined by soil type, slope steepness, and topographic aspect. In this study, ELTs were mapped manually for a 2900 hectare area owned by the University of Missouri and located in the southeastern Missouri Ozarks. To compare this ELT map with one produced using automated techniques, a geographic information system was developed using a Digital Elevation Model and a digitized soil map. After generating slope and aspect maps from the DEM, maps were overlaid so that the individual ELTs were mapped "automatically." The agreement between the two maps was approximately 45 percent. Agreement between the Manual ELT Map and computer-generated soils, slope, and aspect maps was 78 percent, 72 percent, and 60 percent, respectively. It was concluded that, until digital data bases are widely available, GIS mapping of ELTs will not be time-efficient.

INTRODUCTION

WHEN THE Multiple-Use Sustained Yield Act (Public Law 86-517 or MUSY) was passed in 1960, natural resource managers were formally directed to re-evaluate the uses and capabilities of public forest lands which had heretofore been managed primarily for timber production. Specifically, MUSY required that the Forest Service incorporate the multiple-use concept – e.g., mining, recreation, water yield – into future management plans (Dana and Fairfax, 1980). A similar law (PL88-607) directed at the Bureau of Land Management was also enacted in 1965 (Davis, 1976).

After these laws were passed, a greater awareness of the multiple-use concept became present in public land management as evidenced by the policies in a number of federal agencies. For example, though the Army Corps of Engineers has built numerous dams primarily for flood-control activities nationwide, surrounding lands have also been improved to provide numerous recreational opportunities. Similarly, a portion of the land under the jurisdiction of the Forest Service continues to be designated as "Wilderness" and excluded from commercial production to ensure the preservation and perpetuation of unique natural plant and animal communities, wildlife habitat, recreational features, and scenic beauty.

Because these changes represent a major shift in land-use philosophy, new technical procedures, methods of administration, and organization have had to be developed at all levels of each agency. Of particular relevance here, the Forest Rangeland Renewable Resource Planning Act of 1974 (PL88-607) now requires that a quantitative, ecologically-oriented information base be used to make land and resource assessments for Forest Service activities. Similar acts (PL94-597, PL95-192) also affect the Bureau of Land Management, Soil Conservation Service, and Fish and Wildlife Service (Coulombe, 1978). Of the activities resulting from the passage of these laws, the one of interest in this study is the changes in land classification and mapping.

Prior to these laws being enacted, a number of single-factor land classification systems were used by the Forest Service, some of which remain in use. To overcome the limitations of these systems for multiple-use management, an Ecological Classification System (ECS) was developed by an interdisciplinary team of scientists for the Mark Twain National Forest in southern Missouri. This system was a modification of a classification scheme developed earlier by Wertz and Arnold (1972, 1975).

Though the ECS is a hierarchical classification system with eight levels, the basic or smallest unit is the Ecological Land Type (ELT). (For one area in Region 9, an even smaller unit known as the Ecological Land Type Phase is utilized.) ELTs are defined as ecologically uniform areas capable of a particular level of production or use and are characterized by regional landform, soil type, topographic aspect, slope steepness, and natural vegetation (USDA, 1979). Since being developed for the Forest Service and modified for the Mark Twain National Forest, the ECS has begun to be adopted by other public agencies. For example, the ECS is being used by the National Park Service for the Eleven-Point River National Scenic Waterway in southern Missouri, and state land management agencies in Missouri have begun to evaluate its utility for their lands.

The concept of hierarchical land classification systems which describe the ecology of an area is not new. Bailey (1988a) used the term "ecogeographic analysis" to describe such an idea and argued that a hierarchy is necessary to utilize factors such as climate which operate on both a global and local level. Some have suggested that ecological land units can be mapped using the relationships among visible surface features but have warned that the connection between mapping units and ecotypes must also be evaluated (Rowe 1980). Others have attempted to derive a meaningful classification by using analytical statistical techniques with biotic and abiotic data (Omi *et al.*, 1979; Steiner, 1983). A similar approach was examined by Barnes *et al.* (1982) who adopted a system from Germany for a tract of land in Michigan. In this system, transects were established on the study area and a classification unique to each property was developed.

With this increasing use of the ECS and these similar systems, it is desirable that a methodology be developed to allow ELTs to be mapped relatively quickly and accurately. Currently, ELT maps of the Mark Twain National Forest are produced by manual techniques wherein a cartographic technician visually interprets USGS topographic quandrangles to develop separate slope and aspect maps. These are then physically overlayed with soils and vegetation maps and summarized manually to produce a final map of ELTs. This approach has a number of limitations. First, it is extremely time-consuming and labor intensive. Sec-

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ond, the development of slope and aspect maps can be extremely subjective given the manual techniques currently employed (Kickbush and Willis, pers. comm.). Cartographic technicians are also allowed to move soil boundaries based on their interpretations of the USGS quadrangles. Third, if maps of various features are available at a wide range of scales, the production of a final ELT map can also be somewhat subjective if a sufficient number of control points are not used. Unfortunately, it is generally considered impractical to utilize the required number of control points, particularly if the area being mapped is relatively large (Zuhlke, pers. comm).

It may be possible now and in the future to utilize geographic information system (GIS) technology to automate and streamline the ELT mapping process while decreasing the problems mentioned previously. This is dependent, in part, upon the continuing development of computerized digital data bases for spatial information. For example, the U.S. Geologic Survey has already produced Digital Elevation Models (DEMs) with 120-m resolution (1 point every 120 m on a regularly-spaced grid) for much of the United States and is beginning to develop DEMs with 30-m resolution. With the proper software, these data can be used to generate slope and aspect maps. Adequate vegetative maps might be obtained by using satellite imagery and computer-based automated land classification techniques. (Region 5 of the Forest Service has already begun to use Landsat imagery for a variety of planning purposes.) Finally, in Missouri soils series maps are being digitized by the Missouri Department of Natural Resources and can be obtained in computer-compatible form as they become available; soils maps for four of Missouri's 114 counties are currently available. By using these data nad overlaying them using GIS software, ELT maps can be produced at virtually any scale and with any color scheme desired. Furthermore, the problem of differing map scales is reduced, as is the problem of subjective interpretation of slope, aspect, and vegetation.

The relationships between "automatically produced" and manually developed ELT maps are unknown at this time. Before any land management agency can begin to utilize ELT maps developed from digital data bases, it is necessary to know how such maps will compare with ELT maps developed using present-day manual techniques. The purpose of this study was to compare maps of ELTs prepared by manual and GIS/automated techniques and evaluate similarities and differences relative to each of the factors which define an ELT.

STUDY AREA

University Forest is a 2900 hectare forest owned by the University of Missouri and is located in the Ozark Mountains of southeastern Missouri. Land acquisition began in 1953 and concluded by 1962 after a series of land trades with the Army Corps of Engineers allowed both organizations to consolidate their holdings in the area. All of the land that now comprises University Forest had been cleared for agricultural use until the 1920s when widespread land abandonment resulted in a massive conversion to oak-hickory forest. Because of this land-use history, University Forest is now covered by a naturally-regenerated 60- to 70- year-old even-aged oak-hickory forest typical of the Central Hardwoods Forest Type (Society of American Foresters, 1979). Within University Forest are a diversity of topographic features, including steep slopes and broad ridgetops underlain by five different soils types which range in texture from fine silt loam to loam.

MATERIALS AND METHODS

In 1986, an ELT map of University Forest was developed at a scale of 1:24,000 using manual techniques. This map was part of a Master's thesis (Zuhlke, 1986) which evaluated the relationship between ELTs and forest productivity. (This map will henceforth be referred to as the "Manual Map.") Vegetation was uniform on University Forest as was regional landform. Therefore, ELTs were classified solely according to slope steepness, aspect, and soil type. Table 1 lists the characteristics of the ELTs present on University Forest.

To produce a map of ELTs for University Forest using GIS techniques, the same soils map used to develop the Manual Map was obtained. This soils map was an unrectified aerial photograph enlarged to a scale of 1:4500 on which soil boundaries and types were identified. (Except for the scale, which varies, this is the manner in which county soil maps produced by the Soil Conservation Service are available.) This soils map was digitized and converted to a grid with 23 m (0.053 ha) pixels. A DEM for University Forest was created by digitizing points from a U.S. Geologic Survey 1:24,000-scale 7.5-minute quadrangle. Though these points were not arranged on a systematic grid, relatively uniform coverage of the entire area was attained with an average resolution of 28 m. Using topographic software and a linear interpolation algorithm, the DEM was used to produce maps of slope and aspect.

GIS overlay software was then used to produce an ELT map which will henceforth be referred to as the "Automated Map." To do this, the characteristics in Table 1 were utilized. For example, all areas underlain by Midco soil were identified as ELT 1. Areas underlain by Loring soil were dichotomized by slope class – 0 to 9%, and 10 to 14 percent. The former was identified as ELT 6 with the steeper slopes dichotomized further based on aspect. The Loring soil on a slope of 10 to 14 percent, with a southerly or westerly aspect was assigned to ELT 4. The same soil and slope conditions with a northerly or easterly aspect resulted in ELT 5. Similar procedures were also conducted for Ashton, Captina, and Clarksville soils to produce the Automated Map.

To evaluate differences and similarities between the two maps, the Manual Map was digitized and overlaid with the Automated Map and the number of pixels within each ELT was cross-tabulated. In addition, the digitized soils map was overlaid with the Manual ELT Map and the number of pixels in each soil class cross-tabulated. This was also done for the digital maps of slope and aspect. These latter procedures were undertaken to identify sources of mis-classification in the variables used to define ELTs.

RESULTS AND DISCUSSION

Figure 1 presents both the Manual and Automated ELT maps and Table 2 presents the cross-tabulation of pixels for all ELTs. It is apparent that there is a limited amount of agreement between the two maps – only 45 percent of the pixels are classified the same on both maps. Some misclassification is expected due to differences between the subjective interpretation of a topographic map and the linear interpolation of a DEM accom-

TABLE 1. CHARACTERISTICS OF ELTS ON UNIVERSITY FOREST

ELT Number	Soil Type	Aspect	Slope (%)
1	Midco	All	0-5
3	Ashton	All	0-5
4	Loring	S & W	10-14
5	Loring	N & E	10-14
6	Loring	All	0-9
7	Captina	All	0-9
8	Clarksville	S & W	15-30
9	Clarksville	N & E	15-30
10	Clarksville	S & W	10-14
11	Clarksville	N & E	10-14
12	Clarksville	All	0-9

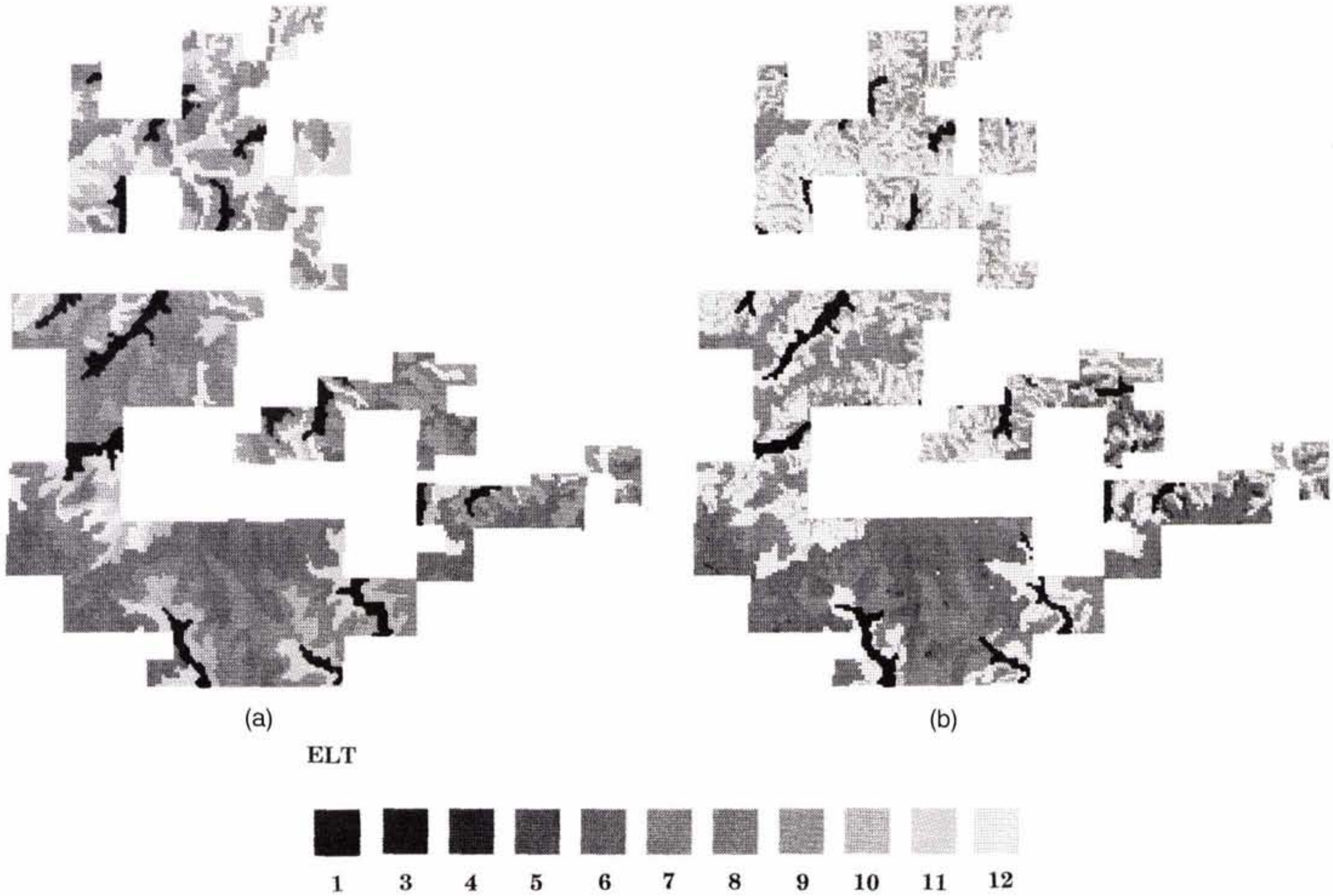

FIG. 1. Maps of Ecological Land Types for University Forest. (a) Manual map. (b) Automated Map.

TABLE 2. NUMBER OF PIXELS IN EACH ELT FOR MAPS PRODUCED MANUALLY AND BY AUTOMATED TECHNIQUES. (UNDERLINED VALUES INDICATE AGREEMENT).

		MANUAL MAP								
	ELT	1	3	6	7	8	9	10	11	12
A	1	1501	0	1	48	301	194	398	50	2
U	3	0	31	0	12	8	0	0	0	0
T O	4	0	0	287	8	87	70	7	1	5
M	5	0	0	140	31	39	407	6	36	11
A	6	0	0	8903	1597	63	405	115	244	49
T	7	80	0	1036	6722	221	612	792	658	232
E D	8	25	1	83	35	1199	469	82	77	386
	9	57	26	19	47	665	1861	33	191	294
M	10	82	1	113	263	1561	752	506	244	866
A	11	196	55	57	205	707	2304	240	644	779
P	12	941	80	619	1654	1770	2309	1846	1888	3801

Notes: ELTS 4 and 5 were not present on the manually-produced map. Total number of pixels = 55444. Number of pixels in agreement = 25168.

plished by computer. This type of discrepancy is evident, for example, for ELT 9 on the Manual Map, much of which was frequently classified as ELTs 11 and 12 by GIS techniques. The only difference between these ELTs is slope- both are underlain by Clarksville soil and exist on the same aspects.

A more disturbing type of discrepancy occurs elsewhere, however. For example, ELTs 8 through 12 – those underlain by Clarksvile soil – are sometimes classified as ELTs 5, 6, and 7 which are underlain by Loring and Captina soils. While it was expected that there would be some classification differences within ELTs 8 through 12 due to slope and aspect, it was not expected that many of these would be reclassified as ELTs underlain by different soil types. This type of cross-classification is surprising given that the same soils map was used to produce both ELT maps. Table 3 presents a cross-tabulation of pixels for the digitized soils map and the Manual ELT Map. Though the percent of pixels for which classification agrees (78 percent) is

TABLE 3. NUMBER OF PIXELS IN EACH SOIL TYPE COMPARED TO THE MANUAL MAP. (UNDERLINED VALUES INDICATE AGREEMENT).

Soil	ELTs (MANUAL MAP)								
Type	1	3	6	7	8	9	10	11	12
Midco	1501	0	1	48	301	194	398	50	2
Ashton	0	31	0	12	8	0	0	0	0
Loring	0	0	9336	1637	189	882	128	281	65
Captina	80	0	1036	6730	221	612	792	658	232
Clarksville	1301	163	891	2204	5903	7695	2707	3044	6126

Note: Total number of pixels = 55444. Number of pixels in agreement = 43073.

an improvement compared to the cross-tabulation of ELTs, considering that the same soil map was utilized to identify the ELTs for both the Manual and Automated Maps, this value is surprisingly low. This discrepancy was undoubtedly caused partially by changing the scale of the 1:4500 soils map to the 1:24,000 scale at which the Manual Map was drawn. A larger portion of this difference, however, is probably due to the subjective evaluation of the soils maps by the cartographer. When ELTs are mapped, boundaries on soils maps are considered inexact. Hence, in summarizing soils and topographic features to produce a final ELT map, the cartographer decides where, for example, the boundary between a bottomland and upland soil type will be drawn. Thus, the final ELT map may not utilize the same boundaries as the soils maps and considerable differences may result. A visual comparison of this ELT map with the soil map suggested that this was the case.

Agreement between computer-generated aspect and ELTs identified on the Manual Map is 88 percent (Table 4). This relatively high agreement is due partly to the fact that of the ELTs mapped by manual means on University Forest, aspect is only of importance in the classification of ELTs 8, 9, 10, and 11. If only these ELTs are examined, a more useful measure of agreement results and the classification agreement drops to 72 percent (17276/24095). Clearly, manual interpretation of the topographic map produced different results than linear interpolation conducted by computer. More sophisticated automated techniques – e.g., krieging – also are likely to produce differences.

Table 5 presents the agreement between slope and the Manual Map. The agreement between the two maps is 60 percent indicating, just as for aspect, that manual interpretation of topographic data will give different results than objective computer generation of a slope map from a DEM. However, the change in percentage agreement from 72 percent for aspect to 60 percent for slope indicates that slope is a more difficult parameter to estimate than aspect despite the grouping of slope into classes. (ELTs 8 through 12 were not examined separately as with aspect because slope is a determinant of all ELTs, whereas for some ELTs aspect is irrelevant.)

The problems evident in Tables 3, 4, and 5 are not unique to this study. Some discrepancies such as non-uniform soil boundaries have already been mentioned. The problem of differing slope estimates was noted by Klingebiel *et al.* (1988) who acknowledged that digital slope-class maps cannot be expected to agree perfectly with slope-class polygons as interpreted by soil scientists. Bailey (1988b) pointed out that when maps are overlaid errors may occur due to different projections and scales of base maps. He also warned that the use of a GIS will not solve these problems but may, instead, lead to mistaken conclusions about the quality of results. MacDougall (1975) went even further and suggested that, in some cases, errors in source maps may combine with "overlay errors" so as to render the resulting maps virtually useless. Newcomer and Szajgin (1984) echoes this point and demonstrated effects of "positional" and "identification" errors on thematic maps produced by digital overlay analysis. It is imperative that efforts be made to utilize high-quality input data.

TABLE 4. NUMBER OF PIXELS IN EACH ASPECT COMPARED TO THE MANUAL MAP. (UNDERLINED VALUES INDICATE AGREEMENT).

	ELTs (MANUAL MAP)								
Aspect	1	3	6	7	8	9	10	11	12
South & West	1066	11	6464	5296	4409	2270	2933	1210	3313
North & East	1794	813	4655	5292	2243	7115	1091	2819	3110
Level	22	0	139	34	0	0	1	4	3

Note: Total number of pixels = 55444. Number of pixels in agreement = 48658.

TABLE 5. NUMBER OF PIXELS IN EACH SLOPE CLASS COMPARED TO THE MANUAL MAP. (UNDERLINED VALUES INDICATE AGREEMENT).

Slope	ELTs (MANUAL MAP)								
	1	3	6	7	8	9	10	11	12
Level	531	11	1876	0	390	513	149	138	325
1 to 2%	474	12	2152	0	150	177	374	360	529
2 to 5%	2070	171	4610	6280	460	641	1097	936	1274
6 to 9%	0	0	2053	2772	1334	2062	1362	1172	1917
10 to 14%	0	0	492	1169	2426	3542	826	1025	1625
15 to 30%	0	0	212	170	1967	2560	120	292	661

Note: Total number of pixels = 55444. Number of pixels in agreement = 33437.

In addition to assessing the amount and source of discrepancies between the two ELT maps and identifying the sources of variation, a public agency must also consider the practical implications of automated ELT mapping. In this endeavor, the availability of computerized map data bases is a key consideration. For this study, a digital soils map had to be created, and a DEM had to be developed by project personnel. Creating a digital soils map required approximately 1 person-day to complete, and the DEM required 4 person-days to complete. The DEM can be created in less time, of course, by using a coarser resolution than the 28 m used in this study. Regardless, an additional 0.5 person-day, or 5.5 person-days total, was/were required to overlay the maps and produce the Automated Map. However, Forest Service personnel have estimated that the creation of an ELT map for 2900 ha by manual techniques would require approximately 1 person-day using less-skilled personnel than are needed to produce the Automated Map (Zuhlke, pers. comm.). At the present time, if computerized data bases are not already available, this method of mapping ELTs cannot be considered time-effective. Furthermore, even if these data exist, personnel with more training than is currently available are required to produce an Automated Map.

It is possible, however, that automated mapping of ELTs may become time-effective in the future. For example, if the necessary data are available for an entire USGS quadrangle, one will be able to map ELTs for this area in approximately the same amount of time that it takes a cartographic technician to map ELTs for an area the size of University Forest – approximately 0.5 day for data base organization and 0.5 day to overlay and summarize data. That is, if digital data are available, the time required to map ELTs automatically does not increase with the size of the area. The same cannot be said of manual ELT mapping techniques.

As a final point, it is emphasized that neither type of map is necessarily "better" than the other. To recommend either as superior would necessitate all factors which define ELTs being known without error. In reality, soil boundaries are not exact either on maps or in the field. In complex topography, human interpreters of slope and aspect become fatigued quickly, and available 30-m DEMs are too coarse for computers to be able to produce reliable results. The purpose of this study was not to identify the "superior" technique for producing ELT maps. Instead, it was the intention of this researcher to determine if Automated ELT Maps could be used in conjunction with Manual ELT Maps. Currently, the answer appears to be "no." Land management agencies face potentially severe problems if Manual Maps are used in one portion of a district, and Automated Maps are used in another portion, for example. Manual Maps are currently the most common and must continue to be developed and used until comprehensive digital data bases exist. Even after these data become available, because the Manual Maps of an entire district/region must be converted to Automated Maps, it is questionable whether or not Automated Maps will ever gain broad acceptance.

CONCLUSIONS

It is apparent that manual and automated techniques will not produce the same ELT maps. Rather than manual interpretation of topographic data being the sole source of this variation, changing scales of maps and subjective decisions about soil boundaries also contribute to this variation. It is not suggested here that, of the two maps, either one is "correct" or "superior." Automated techniques have the advantage of producing maps using objective interpretation of spatial data, and problems such as the conversion from one map scale to another can be controlled more easily. Until computer-compatible data bases for all necessary parameters become available, however, the production of ELT maps by automated techniques cannot be considered time-efficient.

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