ECOLOGICAL MODELING FOR FOREST MANAGEMENT IN THE SHAWNEE NATIONAL FOREST

Richard G. Thurau, J.F. Fralish, S. Hupe, B. Fitch, and A.D. Carver[1]

Abstract.—Land managers of the Shawnee National Forest in southern Illinois are challenged to meet the needs of a diverse populace of stakeholders. By classifying National Forest holdings into management units, U.S. Forest Service personnel can spatially allocate resources and services to meet local management objectives. Ecological Classification Systems predict ecological site conditions based on biotic and/or abiotic factors. Ecological Land Types were identified and mapped for the Illinois Ozark Hills subsection in a geographic information system to provide land managers with a tool for incorporating ecological characteristics into decisionmaking processes. Results are presented as mapping units and written descriptions that describe ecological characteristics based on physiographic land forms and soil characteristics.

INTRODUCTION

The Shawnee National Forest in southern Illinois is a continuously morphing patchwork of forested parcels that are managed by agents of the United States Department of Agriculture Forest Service (USFS) to meet the needs and demands of a diverse range of stakeholders. Currently, the Shawnee contains more than 284,000 acres of National Forest System lands (Shawnee ROD 2006), mostly forested, retired agricultural, or other natural cover. By classifying National Forest holdings into management units, while defining local ecological conditions, USFS personnel can spatially allocate resources and services to meet diverse management objectives. Ecological Classification Systems (ECS) model biotic ecological site conditions based on abiotic characteristics and other factors. ECS provide managers with site-specific ecological information that can be incorporated into decisionmaking processes that must account for opinions from a variety of stakeholder preferences.

Science and Management

Natural resource managers are continually challenged to construct management plans that account for ecological, social, and economic considerations that must incorporate a full spectrum of stakeholder interests. Making effective management decisions requires access to quality information. When employed effectively, geographic information systems (GIS) can be utilized to provide spatial information that is beneficial for understanding many issues important for land management. The development of process modeling in GIS has given managers tools that can generate a range of quality spatially dependent information from present data sources. Automated process models delivered to management personnel will allow spatial information to be updated as new datasets become available.

[1]Researcher, (RGT) Indiana University, School of Public and Environmental Affairs, Bloomington, IN 47405-1701; Emeritus Faculty, (JFF) Southern Illinois University, Department of Forestry, Carbondale, IL 62901-4411;Associate Professor (RGT), Southern Illinois University, Department of Forestry, Carbondale, IL 62901-4411; Natural Resource Program Manager, (SH) U.S. Forest Service; Soil Scientist, (BF), USDA Natural Resource Conservation Service, Carbondale, IL; Associate Professor, (ADC) Southern Illinois University, Department of Forestry, Carbondale, IL 62901-4411. (RGT) is corresponding author: to contact, call (812)855-8963 or email at rthurau@ indiana.edu.

Since the late 1970s, the USFS has adopted a strategy of classifying public lands at multiple scales, with divisions based on ecological considerations (ECOMAP 1993). The National Hierarchical Framework of Ecological Units (NHFEU) outlines protocols for delineating continental, regional, and local spatial units that describe relative ecological conditions. This paper will focus on two specific levels of the NHFEU: seven subsections have been delineated within the Shawnee National Forest, representing seven semi-distinct ecological units. The subsection units are typically mapped at a scale of 1:500,000. Within each subsection, six Ecological Land Types (ELTs) were derived using an automated model within a GIS, based on physiographic land forms and soil development characteristics. ELTs are typically mapped at a scale of around 1:24,000. This analysis will examine the six derived ELTs within one subsection (the Illinois Ozark Hills) in the Shawnee National Forest.

As charged by the National Forest Management Act of 1976, public lands managers are required to account for ecological processes when establishing and implementing management practices. Ecological classification systems define geographic units with ecological properties that can be considered during local management decision processes. Ecological classifications linking local biotic and abiotic characteristics have been developed for many ecosystems around the world. Ecological classification systems have been categorized as climatic, vegetative, physiographic, or ecosystematic (Kimmins 1996).

Climatic ecological classifications (e.g., Bailey 1980) usually provide general ecological information over large geographic areas. Climatic classification units may be hundreds of square miles across, lacking the spatial detail needed to make land management decisions. Vegetative classification systems are based on the assumption that the current vegetation is an all-telling indicator of the local ecological conditions. Vegetative classification systems are advantageous in their straight forward assumptions and ability to generate site-level information, but may misclassify areas where disturbance and/or natural succession have altered vegetative species composition.

Physiographic ecological classification systems utilize landform geometry and geography as well as available soils information to determine ecological structure, composition, and productivity. Most physiographic classifications attempt to model moisture availability as the driver of ecological composition. Physiographic ecologic classification models have been developed for many forests in the central hardwoods region, including the Hoosier National Forest, Indiana (Shao and others 2004), the Natchez Trace State Forest, Tennessee (Kupfer and Franklin 2000) and an earlier model in the Shawnee National Forest, Illinois (Fralish and others 2002).

Finally, the ecosystematic approach to ecological classification utilizes recent developments in understanding the complexities of ecological relationships and the technology (such as GIS) that permits the overlay of multiple inputs to define local ecological characteristics.

PROJECT OBJECTIVES

The primary objective of research described here was to adhere to ecological classification system ideals outlined in the ECOMAP (1993) by mapping ELTs to provide forest managers with spatially explicit ecological information that would aid in making informed decisions at a scale useful for management operations. Our approach in this paper describes how and why six ELTs were modeled and mapped in the Illinois Ozark Hills subsection of the Shawnee National Forest. This objective is achieved through the introduction and description of an automated ELT model, developed within a GIS.

Specific objectives of this paper are to:

1. Introduce ecological and computer methods used to model ELTs.
2. Provide descriptive statistics about the geometric and geographic characteristics pertaining to each of six ELTs in the Ozark Hills subsection.
3. Provide maps illustrating exact spatial locations and physiographic characteristics of ELTs in the Ozark Hills subsection.

Links between abiotic (soil and topographic) conditions and biologic (stand) composition in the forests of southern Illinois have been explicitly documented by decades of site-level research (Fralish 1976, Fralish 1987, Fralish 1994, Fralish and others 2002). By using GIS models, we identify site conditions on the landscape providing ecological information for the entire forest. Descriptive information about each ELT will provide managers with a sense of the physiographic conditions that characterize respective ecological units. Illustrated ELT maps overlaid with United States Geological Survey Quadrangle maps ("topo" maps) are an essential part of understanding the spatial complexity of ELTs over a large geographic area such as a subsection. Large-scale (highly detailed) ELT coverage provides spatially explicit ecological information useful for management purposes.

STUDY AREA

Illinois' only National Forest, Shawnee National Forest spans more than 85 miles across 10 counties between the Mississippi and Ohio Rivers (Fig. 1). The approximately 2.4 million people living within 100 miles (160 km) of the forest greatly influence management planning, which must accommodate for many uses, from backcountry camping in seven federally designated wilderness areas, to direct resource use such as timber harvesting.

Ecologically, the forest is located at the western edge of the western mesophytic hardwood forest region (Braun 1965) and is designated as part of the Ozark Plateau Ecoregion by Bailey (1980). The Shawnee National Forest contains seven distinct subsections (Fig. 2) varying greatly by soil depth, soil parent material, soil drainage, and topography.

METHODS

This section describes methods used to derive, map, and spatially characterize six ELTs in the Illinois Ozark Hills subsection. Factors used to delineate ELTs on the landscape were based on decades of empirical research conducted in southern Illinois. Environmental factors were then digitally modeled and mapped as landscape features using GIS. Finally, basic descriptive statistics were determined to geographically and geometrically characterize the six ELTs in the Illinois Ozark Hills.

Identifying Ecological Land Types

Ecological land type criteria were based on over 30 years of forest experimentation in the southern Illinois region (Fralish 1976, 1987, 1994, Fralish and others 2002). Work by Fralish in several locations within the Shawnee National Forest provided empirical evidence indicating a strong relationship between forest types and site conditions. Soil depth, percent slope, hill slope aspect, and alluvial soils were found to be correlated with available soil moisture, in turn driving biologic conditions and the species-site relationships in the region (Fralish 1978).

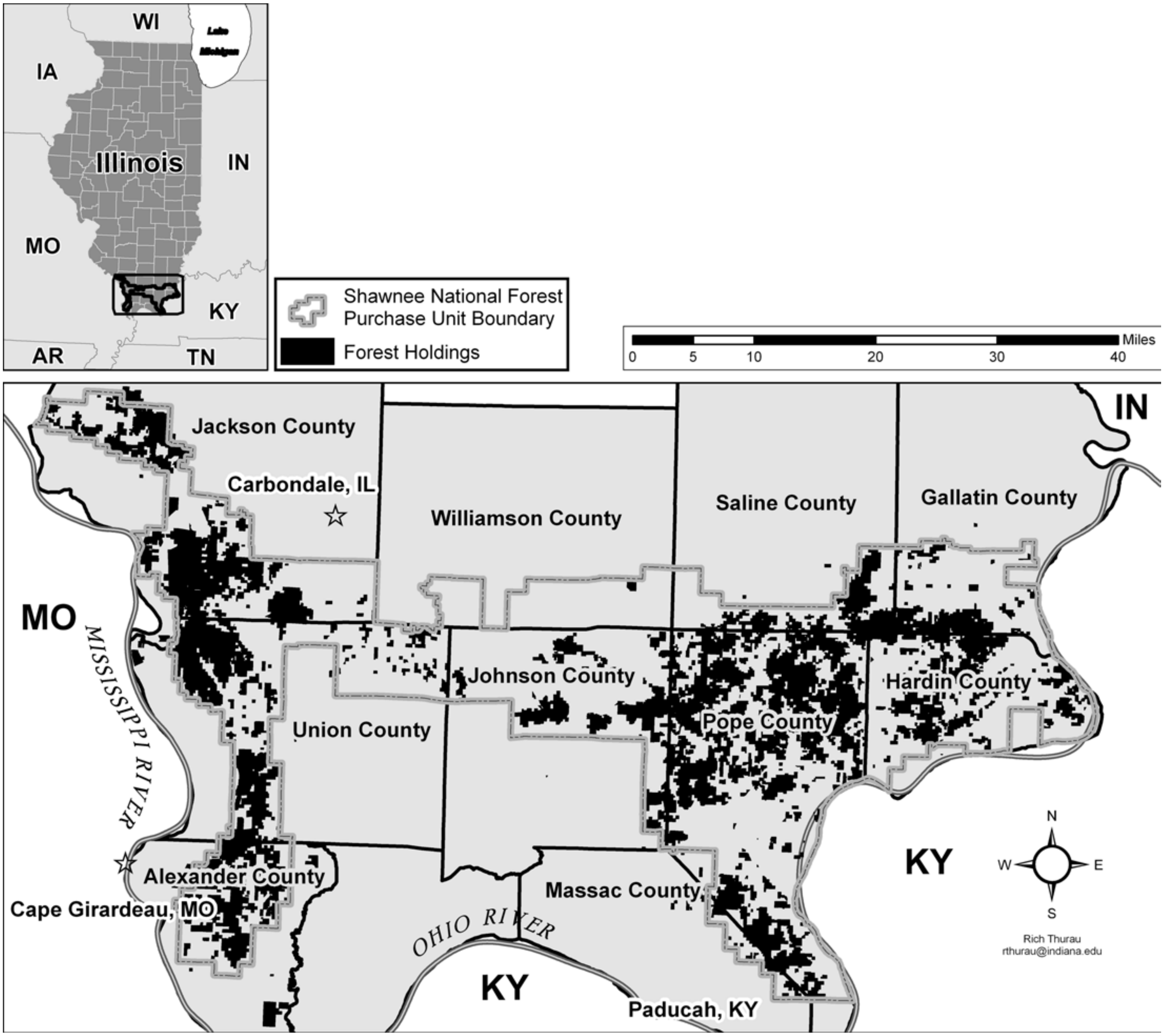


Figure 1.—The study area is the Shawnee National Forest in southern Illinois.

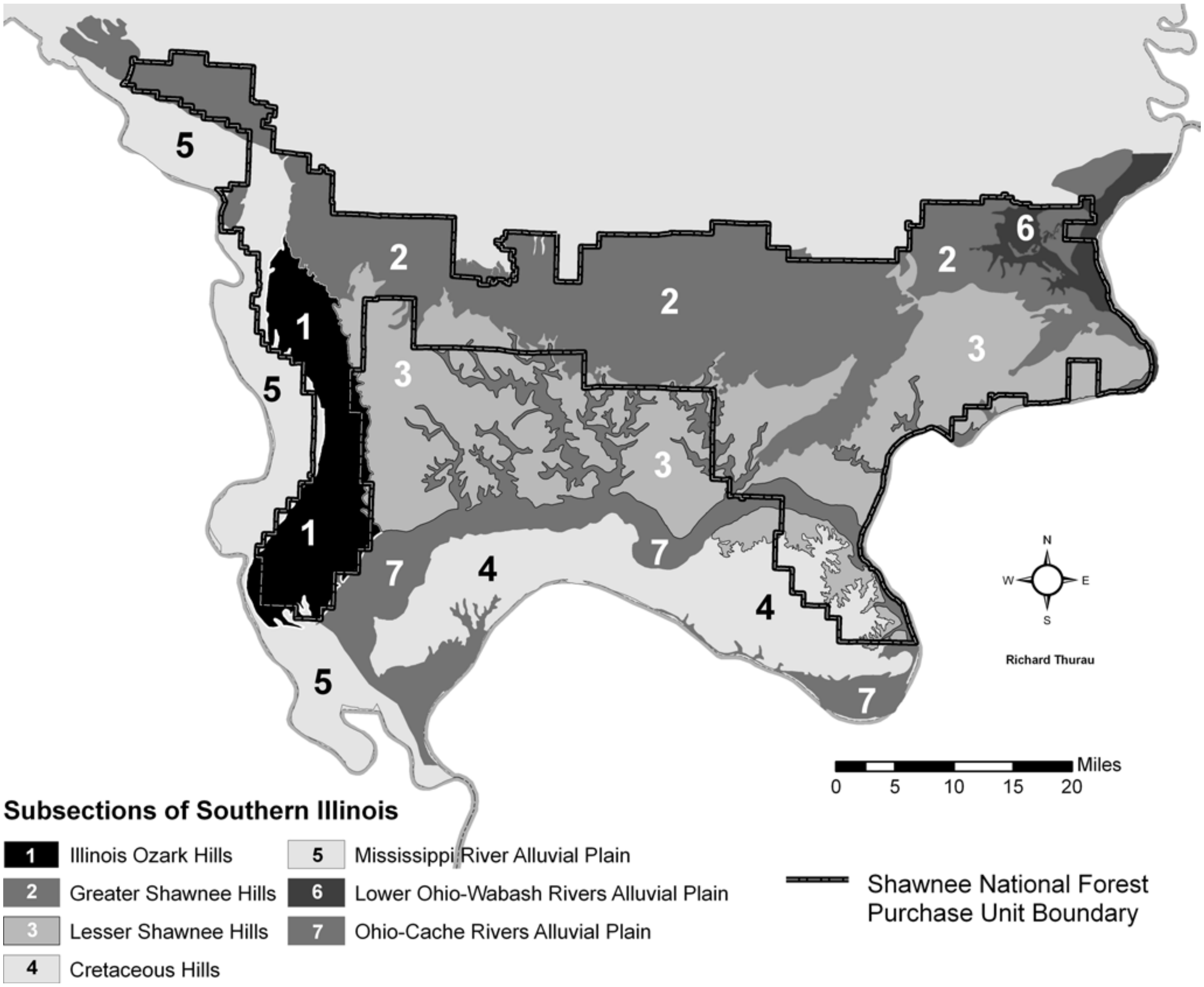


Figure 2.—The seven subsections of the Shawnee National Forest. This report focuses on the Illinois Ozark Hills subsection (1).

Previous work completed by Fralish and others (2002) provided a base for mapping the spatial distribution of forest types in the Shawnee. Although the previous characterization lacked the use of soil types and was based on coarse-resolution geographic data, ELT classes roughly estimated the parameters that have proven essential in the present study.

For this analysis, ELT delineation was based on physical land form and soil properties. Topographic features including hill slope percent, aspect, and curvature were derived and analyzed to define several ELT classifications. Additionally, soil series from alluvial parent material and alluvial soils classified as poorly and very poorly drained were identified as having spatial characteristics that effectively defined ecological site conditions.

Mapping ELTs with GIS

ELTs were delineated in a GIS with an automated model constructed and processed using ArcGIS 9.2 Modelbuilder (Environmental Systems Research Institute, Redlands, CA, 2006). All model parameter decisions are set before beginning any model process. Automation of the model was essential. First, automation allowed for changes to the model without requiring a reprocess of every model step. Second, an automated model will serve as a product for USFS personnel or other researchers who may recalculate ELTs as updated data become available.

Two data inputs were used to calculate ELTs for the entire Shawnee National Forest. Each of the 90 processes within the ELT model can be broadly categorized into one of three classes of tools: (1) Filtering tools used to reduce data artifacts, enhance the visual quality of output, and eliminate mapping units that were smaller than the spatial data precision; (2) Calculating tools used to combine and reclassify raster datasets and calculate topographic and geometric statistics of raster zones and vector polygons; and (3) Conversion tools utilized to aggregate zones of desired values into contiguous units.

Spatial Data Analysis and Preparation

Topographic and geometric landform characteristics were calculated from the National Elevation Dataset (NED) (USGS 1999) at approximately 10-m raster resolution for the study area. The NED represents the best available elevation datasets derived from a variety of sources and processes. Vertical accuracy of the 10 m NED datasets is considered to be +/- 7 to 15 m (USGS 1999).

Alluvial and poorly drained alluvial soils were identified from the Soil Series Geographic Database (SSURGO) made available by the U.S. Department of Agriculture, Natural Resource Conservation Service (NRCS 2005). SSURGO datasets are precisely digitized versions of paper soil series maps derived in the 1960s by the USDA. The NRCS states that SSURGO accuracy is as good as the paper series maps. SSURGO datasets for Randolph, Jackson, Williamson, Saline, Gallatin, Union, Johnson, Pope, Hardin, Alexander, Pulaski, and Massac Counties in Illinois were utilized in this analysis. Bryan Fitch, Soil Scientist at the Carbondale Major Land Resource Areas office, provided lists of soil series classified as alluvial and poorly drained alluvial soils. (Bryan Fitch, Personal communication, 2005-2007, Bryan.fitch@il.usda.gov)

ELT Classification

Six ELTs were derived in a GIS within the Ozark Hills subsection. General methodology for delineating ELTs by geomorphic characteristics is illustrated in a flow chart (Fig. 3). As part of data preparation SSURGO datasets were reduced to alluvial and poorly drained alluvial soils and classified as Alluvial Soils (ELT 5) and Poorly Drained Alluvial Soils (ELT 6).

Several derivatives of elevation datasets were utilized to delineate ELTs 1 through 4. Percent slope, hill slope aspect, and hill slope curvature were calculated and incorporated into ELT delineation. Slopes with a steepness of 14 percent or greater were classified as "slopes". "Slopes" were then further refined as either north- or south-facing and classified as North Slopes (ELT 3) or South Slopes (ELT 4) (see Fig. 3 for detailed classification criteria). Of the remaining areas, land units that have a gentle steepness gradient and are adjacent to alluvial soils (ELT 5 or ELT 6) or are mostly flat to concave are classified as Mesic Slopes (ELT 2). Remaining upland, convex areas are classified as Ridges (ELT 1).

Topographic and Geometric Characterization of ELTs

Zonal tools were used to calculate the topographic and geometric characteristics of each ELT. A zone in a raster dataset can be defined as an area, contiguous or disaggregated, that has the same value. Therefore, while ELTs are widely dispersed throughout the Ozark Hills subsection, each ELT represents a zone (i.e., there are six zones in the Ozark Hills, one for each ELT). Topographic and geometric statistics were calculated for each zone to characterize each ELT within the subsection.

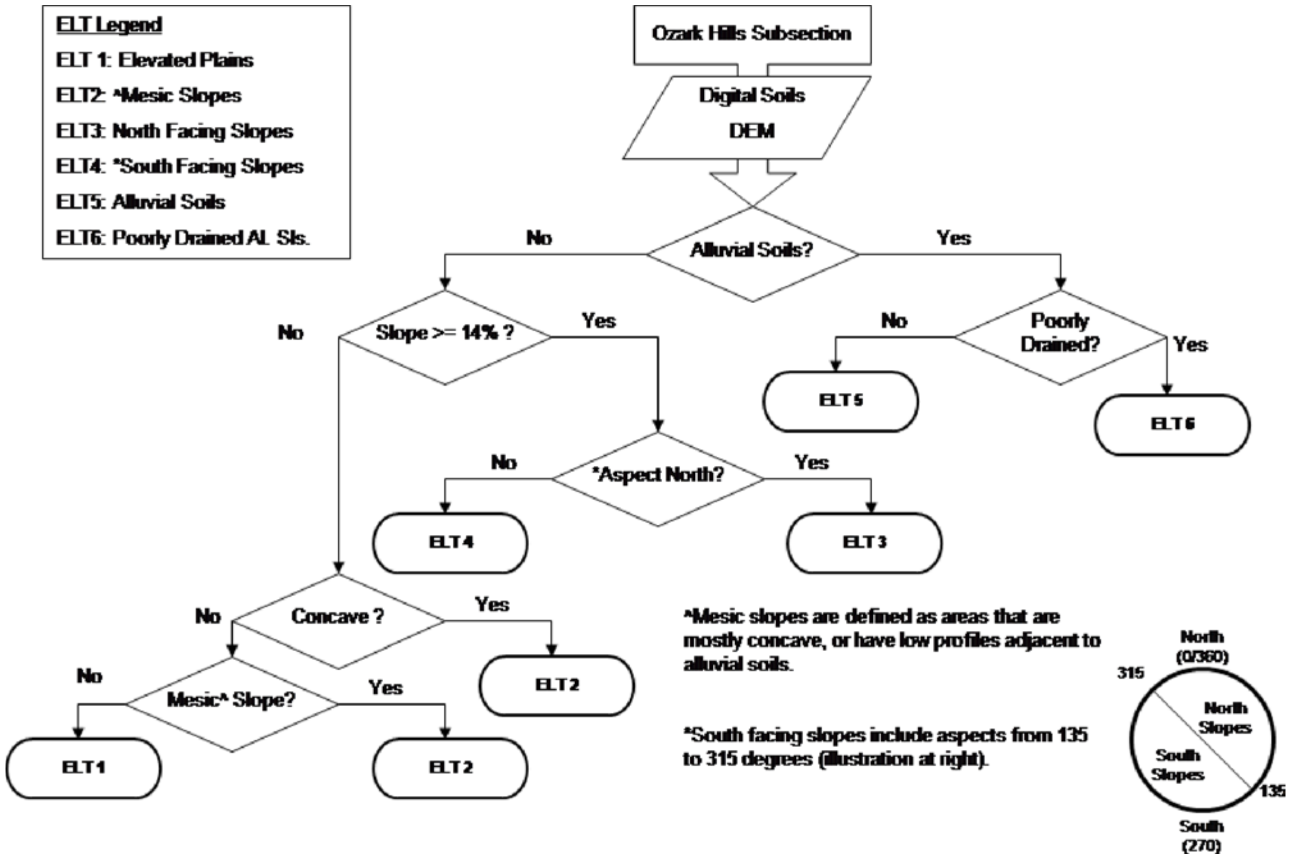


Figure 3.—Flow chart for ELT spatial unit delineation.

The products of this research are twofold: First, descriptive statistics are provided to geographically and geometrically characterize each ELT. These results are presented in Tables 1 and 2. Secondly, a GIS is utilized to combine ELT mapping results with datasets familiar to land managers to provide usable maps of ELT locations. Examples are provided in Figure 4.

Results recorded in Tables 1 and 2 identify the geometric and geographic characteristics of each ELT. Table 1 reports the spatial descriptive statistics averaged for all contiguous ELT units (polygons). Total area describes the aggregated coverage of all units for each ELT within the Illinois Ozark Hills subsection. Unit count, mean area, and standard deviation were summarized for all contiguous units in each ELT.

Table 2 reports descriptive spatial statistics based on geographic characteristics calculated for each raster pixel classified in each respective ELT and averaged over the entire study area. Minimum, maximum, range, and mean values are reported for elevation, landform curvature, and hill slope to geographically characterize each ELT. Elevation values are presented as elevation in meters above the geoid. Landform curvature ranges from negative (concave) to zero (flat) to positive (convex), and is used here to characterize the tendency of the geographic area represented by each pixel to shed or hold surface moisture. Hill slope is reported in percent and characterizes a site's soil moisture availability through water retention (low slope percent) or repulsion (high slope percent), as well as soil temperature in relation to solar radiation reflectance.

Table 1.—Geometric descriptive statistics as they characterize each of six ELTs in the Ozark Hills subsection

Spatial Characteristics:		Total Area		Unit Count	Mean Area per Unit	Stan. Dev. of Unit Area
	ELT[1]	(Thousand sq. km)	(percent)	(number of polygons)	(sq. meters)	(sq. meters)
4	South Slopes	1.57	34%	3,010	52,195	161,566
3	North Slopes	1.38	30%	3,735	37,053	109,337
5	Alluvial Soils	0.78	17%	816	95,901	829,194
1	Ridges	0.44	10%	2,858	15,521	94,787
2	Mesic Slopes	0.35	8%	3,759	9,413	30,878
6	Poorly Drained A.S.	0.05	1%	105	49,210	157,862
	Total	4.59	100%	14,283	259,294	-

[1]ELTs ranked by total area.

Table 2.—Elevation, curvature, and percent slope as they vary by ELT in the Ozark Hills subsection

Elevation (meters)

	ELT	Min	Max	Range	Mean
1	Ridges	99	314	215	168
3	North Slopes	91	311	220	165
4	South Slopes	90	310	220	165
2	Mesic Slopes	90	261	171	143
5	Alluvial Soils	91	237	146	131
6	Poorly Drained A.S.	95	172	77	109

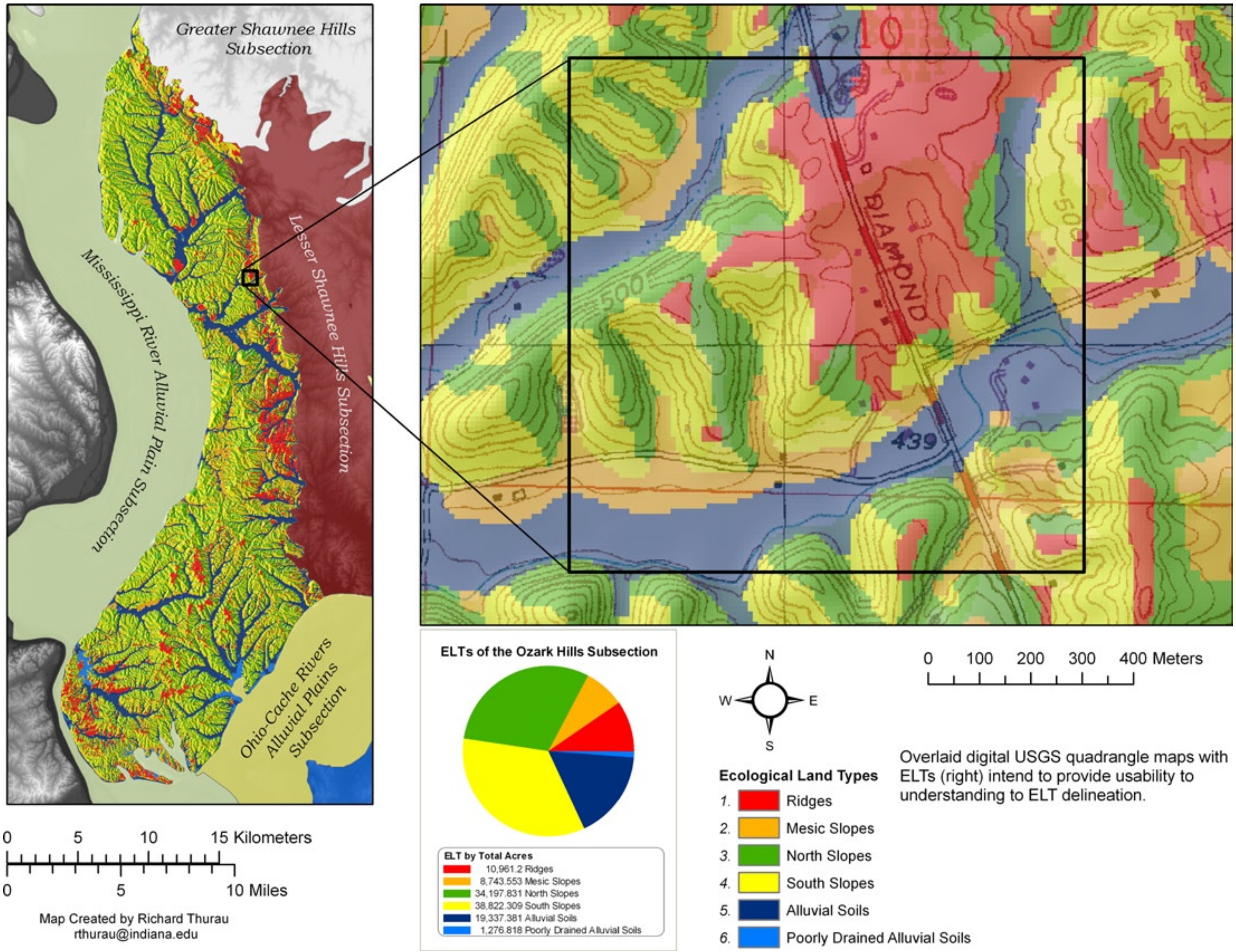
Landform Curvature (curve units)[1]

	ELT	Min	Max	Range	Mean
1	Ridges	-8	7	15	0.25
3	North Slopes	-40	40	80	0.10
4	South Slopes	-28	26	54	0.02
6	Poorly Drained A.S.	-17	26	43	-0.10
5	Alluvial Soils	-11	10	21	-0.23
2	Mesic Slopes	-8	8	16	-0.25

Hill Slope (percent)

	ELT	MIN	Max	Range	Mean
3	North Slopes	0	188	188	28
4	South Slopes	0	184	184	26
2	Mesic Slopes	0	48	48	10
1	Ridges	0	41	41	10
5	Alluvial Soils	0	72	72	7
6	Poorly Drained A.S.	0	169	169	4

[1]Curvature ranges from concave (negative) to flat (zero) to convex (positive).



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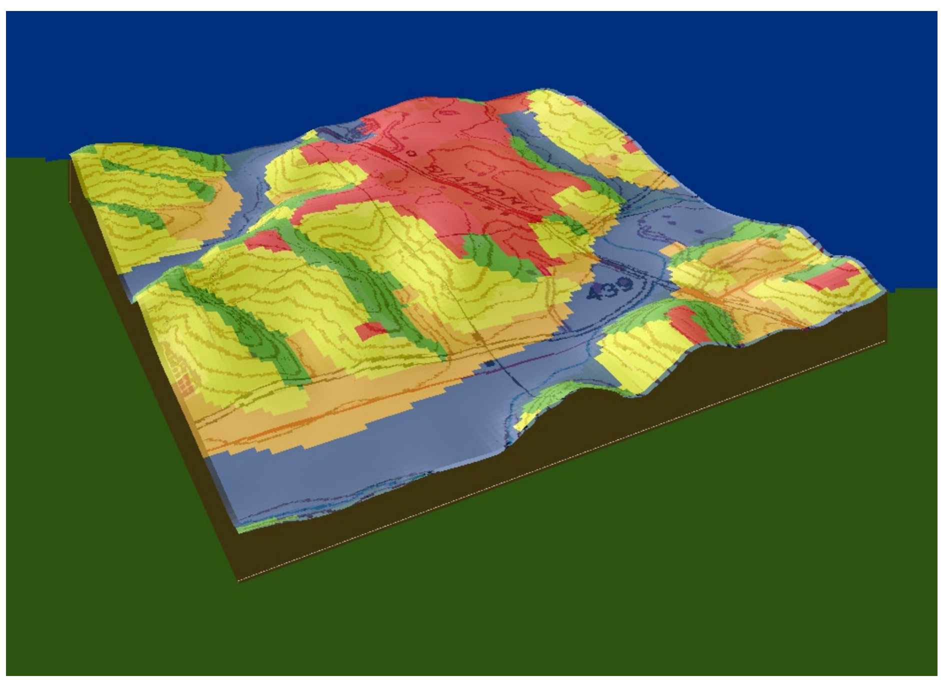

Figure 4.—ELTs in the Ozark Hills subsection. A zoomed-in subset (a) allows the viewer to discern features found on a typical USGS quadrangle map for relating on-the-ground observations with mapping units, while (b) three-dimensional rendering eases usability.

RESULTS

General results from Table 1 illustrate that the Illinois Ozark Hills subsection landscape is dominated by steep slopes (ELTs 3 and 4), but all ELTs vary greatly in total area, number of contiguous units, and average size per unit. Table 2 indicates that elevation may not be a good indicator of ELT except for ELT 6. Landform curvature is a subtle measurement, but may be a good indicator to differentiate between mesic and non-mesic site conditions, as the three mesic ELTs (2, 5, and 6) have an average concave value and non-mesic ELTs (1, 3, and 4) have an average convex value. Slope separation between ELTs is inherent in the model (as reported in the Methods), but Table 2 confirms the intuitive assumption that alluvial soils (ELTs 5 and 6) are substantially flatter than either ridges or mesic slopes (ELTs 1, 2, 5, and 6 are modeled under the same slope category).

Results from Table 1 illustrate that ridges (ELT 1) cover a relatively small portion (10 percent) of the Illinois Ozark Hills subsection, and are composed of nearly 3000 individual units, which have a relatively small average size. Standard deviation of polygon size is very large for all ELTs, indicating a wide variation in ELT size across the subsection.

Mesic slopes (ELT 2) also cover a small geographic portion of the study area, and are composed of the greatest number of polygons. Mesic slopes also are characterized as having the smallest average size per contiguous unit and the lowest standard deviation between unit areas.

North- and south-facing slopes (ELTS 3 and 4) cover the greatest proportion of the land area (64 percent combined) in the Illinois Ozark Hills subsection and sum to nearly half the total number of contiguous units. South facing slopes are, on average, larger than north facing slopes, and have a higher standard deviation between unit areas.

Alluvial soils (ELT 5) rank third in total area but are composed of substantially fewer polygons. That translates to a very large average unit size (nearly twice as big as the next largest), and a large standard deviation.

Poorly drained alluvial soils (ELT 6) are characterized to capture the most mesic areas on the landscape. Poorly drained alluvial soils represent a very small portion of the total study area (about 1 percent) and contain the fewest number of contiguous units, but unit size and standard deviation are about average among all ELTs.

CONCLUSIONS

USFS personnel have been directly involved with this project from its beginnings to ensure the maintenance of usability and applicability during the ELT development process. Non-spatial ELT characteristics (Tables 1 and 2) are likely too broad to be useful in the field but may provide important information for assessing potential management structure and for comparing ecological conditions among all seven subsections in the Shawnee.

Ultimately, it is the production of interpretable maps of ELTs with precise geographic boundaries that will be most useful to land managers. Mapping and GIS have the inherent ability to spatially relate relatively abstract concepts, such as ELTs, to something material and recognizable (i.e., the ability to drive to the field, point to a hillside, orient the map, and say "That is a South slope ELT"). Three-dimensional rendering of small geographic areas can relate important qualitative information quickly (Fig. 4b).

Designing an automated model (i.e., all model parameter decisions are set prior to beginning any model process) for ELT delineation was important for several reasons. The most important reason, and greatest constraint, was time. While this analysis examined results for the Illinois Ozark Hills subsection, ultimately our objective is to understand ELTs across every area within the entire 850,000-acre purchase-unit boundary. Secondly, this model will ultimately be delivered to USFS personnel as an operational tool. Therefore, ELTs can be delineated using the model at any time in the future, with the best available data. As stated by Regional Forester, Randy More, "The ecological, social and economic conditions on the Forest change over time. The public's opinions of what constitutes the best use of public lands also shifts over time. For these reasons, the management direction…is dynamic and will be re-evaluated periodically as new information becomes available" (Shawnee ROD 2006).

The diversity of criteria implemented in the development of ecological classification systems across the world varies greatly. While soils and landform characteristics determined delineation in this system, additional variables such as land use, property ownership, proximity to access or population centers, and more can be utilized or added to enhance our ideas of what ecological conditions will exist on specific parcels of land at any period in time.

Relationships between forest species and abiotic ecological conditions in the Shawnee are well understood. However, relating those ecological conditions to function within a GIS can present great challenges. As part of the development process, defined ELTs were mapped and visited at several locations. Qualitative observations and feedback were important in deciding how ELTs would be delineated.

Model validation with direct field sampling is yet to be conducted. Several datasets with spatial ecological information already exist within the study area. Historical witness tree data recorded in the early 19th century by the General Land Office Survey have been digitized for the entire Shawnee National Forest, and will provide the greatest geographic coverage for future model validation.

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