EVALUATING SUSTAINABILITY: A METHOD FOR ASSESSING VEGETATION CHANGE IN SOUTHERN MISSOURI, U.S.A.: 1820-2003

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ABSTRACT

The General Land Office of the United States of America surveyed the state of Missouri during the first half of the 1800s. Frequently relying on witness trees to mark corners of surveyed units, surveyors also recorded other trees situated on or near the survey lines. Using plot-level data from inventories conducted by the U.S. Forest Service, Northern Research Station, Forest Inventory and Analysis program from 1999 – 2003, we examined the difference in forest cover type, stand structure, and composition between the 19th century inventory and the latest data. Focusing on that part of the Survey situated near the Current River in south-central Missouri, we estimated historic forest species composition and structure and compared them to present-day estimates. A "conversion suitability index," a categorical table that estimated the level of effort required to maintain a forest type or convert it to some other type was developed. In this study, we applied this conversion matrix to the 19th century and 21st century forest types and estimated the level of effort it would require to restore a landscape to a pre-European settlement forested condition.

Key Words: Public land survey (U.S.A.), pre-European settlement landscape, national forest inventory, restoration

INTRODUCTION

Ecologists and resource professionals trying to establish criteria for sustainability have looked to pre-European settlement landscapes, among other criteria, as a counterpoint to today's highly altered landscapes (Swetnam *et al.*, 1999, Bragg, 2003, Foti, 2004). Although pre-settlement landscapes were known to be disturbed by indigenous peoples (Guyette *et al.*, 2002) and biotic and abiotic causes (Schulte and Mladenoff, 2005), many people believe that they represent examples of "natural variability" (Landres *et al.*, 1999) and what the landscape "should be" (e.g., Florida Division of Parks and Recreation, 2006).

In this study, we examine one method for comparing current resource data to historical data about the forested landscapes in southern Missouri, U.S.A. Most scholars believe that the historical forests of the Ozark Plateau of Missouri and Arkansas, U.S.A., were composed of larger trees at relatively low densities, although there is conflicting evidence. According to Houck (1908), when the Spanish explorer Ferdinand DeSoto and his men reached the Ozark region in 1541, they spoke of seeing Indian villages in the distance, suggesting that the forests were of low density. Houck also recorded a French priest observing in 1683 that the forests were "open." Beilmann and Brenner (1951) recorded an account of one observer in 1789 who could drive a "coach and four" through the woods, implying a wide spacing between trees. They reported that in the early 19th century, trees were found only along water courses, as isolated specimens on high-productivity sites or occasionally in small groves.

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Beilmann and Brenner also noted that the low overstory density promoted vigorous understory vegetation, particularly grass, and described the appearance of early Ozark forests as more like "extensive meadows rather than rude and gloomy forests." While others, including Schroeder (1981) and Nigh and Pallardy (1983) generally supported Beilmann and Brenner's position, Steyermark (1959), on the other hand, argued that the historic forest landscape was just as dense as that of the 1950s.
Comparing historic data to more recent studies, Foti (2004) found a dramatic increase in density in the Arkansas Ozarks over time. While most researchers argue that the low historic density and species composition were due to the fires endemic to the region (Batek *et al.*, 1999, Guyette *et al.*, 2002), others also blamed poor soils for the sparse tree cover. Schoolcraft (1821) spoke of Ozark soils that "yield but few forest trees, and they are not of vigorous growth,..." Anecdotal reports such as these are useful, but not definitive enough to guide today's decision makers. To make an effective comparison between "then" and "now," resource managers need a reasonably accurate quantitative portrayal of historical natural resources.

METHODOLOGY

STUDY REGION

The study region is centered on the Current River Hills subsection in the southeast Missouri Ozarks (Nigh and Schroeder, 2002). This ecoregion is highly variable from both topographic and geological standpoints. The western portion of the region includes sections of relatively smooth uplands, grading to progressively more rugged and dissected terrain as one moves east and toward the major rivers, where the elevational change is frequently 100-250 meters and slopes range from 10 to 40 percent.

THE PUBLIC LAND SURVEY OF THE U.S.A. (1785-1900)

As a result of the colonists' victory in the American Revolutionary War (1775-1783), the United States gained large areas of land west of the original Thirteen Colonies. In order to spur development, the government adopted the Public Land Survey (PLS) system, a rectangular survey system that typically divides the land into 9,324 hectare square townships, which are further subdivided into 259 hectare sections (National Atlas, 2006). The Public Land Survey was conducted in the State of Missouri, U.S.A. (fig. 1) between 1815 and 1855 (Missouri Department of Natural Resources, 2006).
In delineating these survey transects, the surveyors recorded the species, diameter, direction and distance from each section corner and quarter-section corner to two or four bearing trees, which were measured and identified by species. Where possible, they recorded additional line trees and qualitative descriptions of the topography, soil, forest, and undergrowth.
Although there were probably biases in the selection of bearing trees and sometimes errors in measurements (Bourdo, 1956, Nelson, 1997, Bragg, 2003), these surveys are nonetheless the most descriptive quantitative data set on vegetation in the early 19th century (Schulte and Mladenoff, 2001, Bragg, 2004, Foti, 2004).

THE FOREST INVENTORY AND ANALYSIS PROGRAM OF THE U.S. FOREST SERVICE

We used data from the national Forest Inventory and Analysis (FIA) Program of the USDA Forest Service. The national FIA program consists of four regional programs that provide estimates of forest area, volume, change and forest health throughout the United States (McRoberts, 1999). The program's sampling design has a base intensity of one plot per approximately 2,400 hectares and is assumed to produce a random, equal-probability sample. We used data from the 1999-2003 inventory of the State of Missouri, U.S.A. to depict current forest conditions. Our task was to reduce the two datasets – historic (PLS) and current (FIA) –

to a common data structure, so we might compare relative distributions and estimate potential for restoration of the historic vegetation structure and function.

Figure 1. The location of the state of Missouri in the U.S.A.

FOREST TYPE MATRIX

During 2002-2003, the state agency charged with managing public land in Missouri considered updating the silvicultural technical specifications of its forest management guide. A team of natural resource professionals from MDC and the University of Missouri was assembled to provide advice. One product of this process was a table of current and potential forest type groups with the suitability (and, by implication, the ease) of conversion from one type to another based on site index. This table, (Table 1, Nigh *et al.*, 2006), which has been updated since 2003 to include pine forest types, is the basis for comparing the PLS data to the FIA data. The first step in our analysis was to create current and historic forest type and structure maps, using the forest types listed in the Table 1.

Each of these forest types consists of a species grouping and a structure (e.g., mixed oak savanna.) To do this, we had to classify each section corner in the study area into one of the possible forest types. Similarly, we needed to classify each FIA plot into one of the forest types. Once classified, an interpolation method could be used to predict the distribution of forest types across the landscape.

CLASSIFYING PLS DATA

Witness tree information was tied to section corners using an ARC-INFO geographic information system (© 1999-2004 ESRI Inc.) and species groups and structure was assigned (Hughes and Nigh, 2000). Most section corners had two to four trees associated with them as bearing or witness trees. We used only trees recorded as bearing/witness trees of section corners and their associated species group and structure designations, even though the survey crews recorded trees at the quarter corners and random trees that intersected their transect line. We assigned a species group based upon the majority of the trees (based on number). If there were only two trees, the larger one was chosen.

All trees in the data set were classified into categories of forest structure: savanna, woodland, forest, and dense forest. We grouped the last two into a "forest" category. After separating the trees into these categories, we calculated the sample mean and variance of the data by structure. Then we calculated the average distance of all trees on a section corner and compared that distribution to normal distributions based upon the observed means and variances. The section corner was assigned the structure corresponding to the normal distribution with the highest likelihood value. This method does assume that these distances follow a normal distribution within each structure category. This assumption may not be strictly met, but the method provides an automated and quantitative means to assign a structure call to a corner.

Table 1. Upland Forest/Woodland Types in Missouri and Management Options. Numbers associated with each site quality class indicate degree of suitability and effort from 1= highly suitable and low effort to 4= low suitability and maximum effort. An "X" indicates a very unlikely occurrence.) (Nigh, Larson, Kabrick, Moser, 2003, unpublished document; modified and expanded by Moser and Nigh, 2006)

Present Forest Type	Suited Forest Type	Site Quality 1	2	3	4
		SI 40-54	SI 55-64	SI 65-74	SI >75
Post oak woodland	Post oak woodland	1	2	4	X
	Mixed oak woodland	2	1	1	X
	Mixed oak forest	X	2	1	X
Mixed oak woodland	Post oak woodland	1	2	4	X
	Mixed oak woodland	1	1	2	4
	Pine-oak woodland	1	2	3	X
	Mixed oak forest	X	3	1	2
	Pine-oak forest	X	2	1	3
	White oak forest	X	3	2	1
	Pine woodland	1	2	4	X
	Pine forest	2	1	3	X
Pine-oak woodland	Mixed oak woodland	2	1	2	X
	Pine-oak woodland	1	1	2	4
	Pine-oak forest	X	2	1	2
	White oak forest	X	3	2	1
	Pine woodland	1	2	3	X
	Pine forest	2	1	2	X
Mixed oak forest	Post oak woodland	1	2	X	X
	Mixed oak woodland	1	1	3	X
	Pine-oak woodland	1	2	3	X
	Pine-oak forest	X	2	2	3
	Mixed oak forest	X	2	1	2
	White oak forest	X	3	1	1
	Pine woodland	2	3	4	X
	Pine forest	2	2	3	X
Pine-oak forest	Mixed oak woodland	2	2	3	4
	Pine-oak woodland	1	1	2	4
	Pine-oak forest	X	2	1	2
	Mixed oak forest	X	3	2	3
	White oak forest	X	3	2	2
	Pine woodland	1	2	3	X
	Pine forest	2	1	2	X

Present Forest Type	Suited Forest Type	Site Quality 1	2	3	4
		SI 40-54	SI 55-64	SI 65-74	SI >75
White oak forest	Mixed oak woodland	X	3	4	X
	Pine-oak woodland	X	4	X	X
	Mixed oak forest	X	2	3	4
	Pine-oak forest	X	2	3	4
	White oak forest	X	2	1	1
	Pine woodland	4	X	X	X
	Pine forest	2	3	4	X
Oak-mixed hardwood forest	Limestone dolomite woodland	2	3	X	X
	White oak forest	X	2	3	X
	Oak-mixed hardwood forest	X	3	2	1
	Mixed hardwood mesic forest	X	4	3	1
	Pine woodland	X	X	X	X
	Pine forest	X	4	X	X
Mixed hardwood mesic forest	Mixed oak forest	X	2	3	4
	White oak forest	X	2	2	3
	Oak-mixed hardwood forest	X	1	1	2
	Mixed hardwood mesic forest	X	3	2	1
Pine woodland	Mixed oak woodland	1	1	2	2
	Pine-oak woodland	1	1	2	X
	Pine-oak forest	X	2	1	2
	White oak forest	X	3	2	1
	Pine woodland	1	1	2	X
	Pine forest	2	2	1	X
Pine forest	Mixed oak woodland	X	2	2	3
	Pine-oak woodland	1	1	2	4
	Pine-oak forest	X	2	1	2
	Mixed oak forest	X	3	2	3
	White oak forest	X	3	2	2
	Pine forest	2	2	1	X
	Pine woodland	1	1	2	X

CLASSIFYING FIA DATA

In classifying the FIA data, we intended to use methods similar to the PLS data methods. We classified the FIA data into forest-type categories based on the basal area of the dominant species. We used basal area instead of the number of trees because most plots had many more than 4 trees on them. Given that the maximum distance a tree can be from the plot center is 7.3 meters, which might be far less than the between-tree distance in savanna or woodland systems, we decided to use basal area, average diameter, and number of trees to assign structure to each plot. If a plot had less than 7.5 square meters per hectare and it had an average diameter of at least 25 cm and fewer than 9 trees, it was classified as "savanna." Otherwise, it was classified as "woodland." Plots with more than 7.5 square meters per hectare and less than 15 square meters per hectare were called "woodland." Plots with more than 15 square meters per hectare were called "forest." Plots currently characterized as non-forest land (e.g., agricultural land, bodies of water) kept that classification.

SPATIAL ANALYSIS

We used a simple moving window (Point Statistics, ArcTools 9.0, Copyright © 1999-2004 ESRI Inc.) to spatial interpolate between our different data points. This method seemed appropriate because it does not rely on relationships between 'observed' historic forest types and current covariate data. It also provides a coarse-scale overview of the data, which was recommended frequently in the literature (e.g., Schulte and Mladenoff, 2001). To look at the data at an appropriately coarse scale, we chose a 1000 meter pixel and used a window of 5*5 pixels for the PLS data and 10*10 pixels for the FIA data. The larger window for the FIA data was necessary because of the lower sampling intensity compared to PLS section corners, which occur every 1.6 kilometers. The moving window works by centering on a target pixel and then looking at all the points within a certain distance (window) of the target pixel. It assigns the value of the majority of points in the window to the target pixel and moves to the next pixel. This process was used to create 5 maps; a historic species group map, a historic structure map, a current species group map, a current structure map, and a current site index map. The site index value was queried from the FIA data base and classified into 4 categories to match the forest conversion table (Table 1).

Creating the Suitability Map

The moving window maps were combined in ArcMap (© 1999-2004 ESRI Inc.) and joined with the forest conversion table. The forest conversion table gives suitability categories, which indicate how difficult it would be to convert a current forest type to another one based upon species composition, structure, and site quality.

The moving window method generated certain combinations of current and historic forest types that were not accounted for in the table. These were classified as 'No Information' on the map. In its current version, the forest conversion table does not account for savanna; therefore any data pair with at least one classification of "savanna" was classified as 'No Information.' If the current plot was characterized as "non-forest", we classified it as Non-Forest Land and did not assign a conversion effort level to it. The remaining combinations were classified into the following categories: Low Effort, Medium Effort, High Effort, Maximum Effort, and Not Possible. The last category is different from 'No Information' in that it is accounted for in the forest conversion table, but the particular conversion was deemed not economically feasible (and, by implication, not suitable).

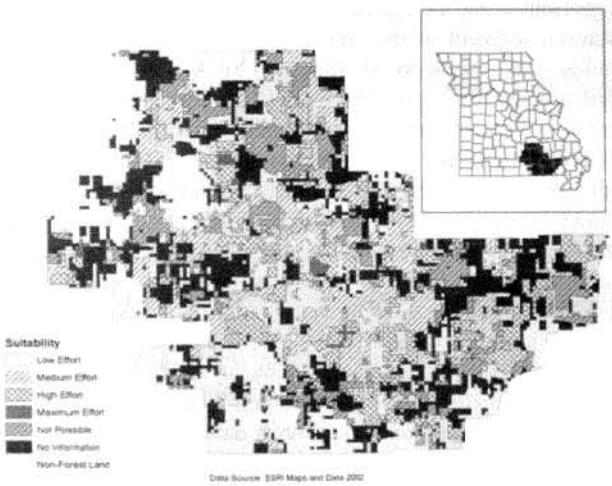

Figure 2. Map of categories of conversion suitability and effort. Suitability is inversely related to effort, e.g., high suitability for converting from one forest type to another is assumed to equal low effort required to do so. The "Not possible" category" represents those binary combinations that were deemed highly unsuitable: the "X" in Table 1. "No information" represents those pairs of current and historic forest types that were not considered in Table 1.

RESULTS

The output from our classification scheme produced six maps: the species maps based on the public land survey data and the FIA data, structure maps based on each source of data, and the site index map – all mentioned earlier -- and a conversion potential map (fig. 2) that combines the first 5 maps and estimates the effort required to restore the 1820's landscape.

Table 2. Summary of categories of conversion suitability, in hectares

Suitability	Hectares	Percentage of total
Low Effort	164,500	14%
Medium Effort	203,600	17%
High Effort	134,600	11%
Maximum Effort	10,000	1%
Non-Forest	246,400	21%
Not Possible	135,200	11%
No Information	304,300	25%
Grand Total	1,198,600	

Table 3 presents a matrix of past and current forest types and the number of hectares for each combination. Over 45 percent (543,700 hectares) of the current forest is classified as mixed oak forest or mixed oak woodland. The estimated historic extent for these two types and mixed oak savanna was 387,400 hectares (32.3 percent). The pine types (pine forest and woodland and pine-oak forest and woodland) make up about 7 percent of the total current (FIA) area, compared to over 32 percent using the classified historical (PLS) data. We listed the number of hectares that are considered unsuitable and the number of hectares for which we have no data, generally a result of not defining particular combinations of present-past forest types. Chief among these was savanna, for which we had no definition in our conversion matrix. As savanna was expected to represent a not inconsiderable portion of the historic landscape, this omission resulted in a substantial segment of the landscape being "unclassifiable" ("no information" in our table). Nonetheless, our results do not appear to be seriously out of line with other analyses that used a more disturbance (fire)-based protocol (e.g., Guyette et al., 1999).

Space does not permit a complete array of conversion suitability combinations, but we can look at two examples: Converting to (or from) pine forest and to (or from) mixed oak forest (Table 4). Using our methodology, we estimated that there are about 4,600 hectares of pine forest type today. To restore today's pine forest to the historic forest type on those parcels (which may or may not have been pines), 4 percent would require low effort to convert, 65 percent of the area would require a medium effort, and 9 percent a high effort. To convert to the historic pine forest (268 thousand hectares), 29 percent would require a low effort, 45 percent a medium effort, 16 percent a high effort and less than 1 percent would require a maximum effort. There is six percent that is currently non-forest and 4 percent where we do not have conversion effort defined for particular combinations of current forest type and historic pine forest type. The same analysis can be applied to the mixed oak forest data.

DISCUSSION

Using broad characteristics of species groups and structure, we compared current data with data from the Public Land Survey of the 1820's to develop a conversion suitability map. Our analysis provided a reasonable estimate of the potential for restoring pre-European settlement treed landscapes in the southern Missouri Ozarks.

Looking at broad categories of forest types and structures and taking into account the different methods of classifying FIA data into forest types for this study vs. the standard FIA methodology, we found rough agreement between the two types of estimates, suggesting that the study methodology was not unreasonable. The difference between our study's estimate of current pine forest types and past pine forest types is higher than the ratio between the estimated historic range of 2.4 million hectares and the current 240 thousand hectares (Stambaugh and Muzika, 2001), but the reader should remember that our study area is in the heart of the Ozark shortleaf pine range and we are including pine-oak mixtures, which is defined differently depending upon whom you ask. Gaps in this suitability map result either from PLS-FIA combinations that are not deemed feasible at this time or to combinations that were not considered in the Nigh *et al.* (2006) table.

The detail of this map was also limited by the classification methodologies we used; based on findings by other researchers (Schulte and Mladenoff, 2001) we concluded that our scale was appropriate. There is great potential to use this methodology to evaluate sustainability worldwide. While other researchers have compared past landscapes to those of the present, this study provides an explicit transition matrix and the methodology to transform disparate data sources into common and comparable structures.

The limitations of the methodology lie with the spatial extent of the species groups and the reduction of a fairly complex vegetation pattern into a limited number of classes. The landscape-level data presented by studies such as ours are intended to examine overall patterns of sustainability and may not be directly connected to the on-the-ground, site-specific decisions made by resource managers.

Accordingly, resource managers should use this methodology only as a guide for their landscape-level resource-allocation decisions. Nested in these broad-scale categories will be individual, stand-level decisions that will be based on site conditions and the manager's individual knowledge and expertise.

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Table 3. Matrix of current vs. historic forest types, in hectares. Bold values are those hectares where current and historic types are the same. Note the 378,000 hectares of historic pine and pine-oak types vs. the 78,500 ha of current pine and pine-oak types

Current forest Type	Historic forest Type: Mixed hardwoods forest	Mixed oak forest	Mixed oak savanna	Mixed oak woodland	Mixed Unclassified forest	Oak-mixed hardwoods forest	Pine forest	Pine savanna	Pine woodland	Pine-oak forest	Pine-oak savanna	Pine-oak woodland	Post oak forest	Post oak savanna	Post oak woodland	Riparian forest	White oak forest	White oak savanna	White oak woodland	No Information	Grand Total
Mixed hardwoods forest	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	300	0	0	0	300
Mixed oak forest	0	75,100	0	9,000	0	0	88,200	0	14,600	16,400	0	700	0	0	2,800	0	13,600	0	0	0	220,400
Mixed oak woodland	0	116,400	0	16,700	0	0	110,600	0	24,000	23,300	0	900	0	0	8,300	0	23,100	0	0	0	323,300
Oak-mixed hardwoods forest	200	0	0	0	0	0	7,100	0	2,300	0	0	0	0	0	0	0	1,500	0	0	0	11,100
Pine forest	0	1,200	0	700	0	0	2,300	0	100	100	0	0	0	0	0	0	200	0	0	0	4,600
Pine woodland	0	0	0	0	0	0	1,700	0	0	200	0	0	0	0	0	0	100	0	0	0	2,000
Pine-oak forest	0	7,200	0	900	0	0	22,800	0	5100	3,400	0	100	0	0	0	0	800	0	0	0	40,300
Pine-oak woodland	0	0	0	700	0	0	18,900	0	5500	3,100	0	500	0	0	0	0	2,900	0	0	0	31,600
Post oak woodland	0	300	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	300
White oak forest	0	0	0	700	0	0	18,900	0	5500	3,100	0	500	0	0	0	0	2,900	0	0	0	31,600
No Information	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	314,300	314,300
Non-forest	1,200	91,700	32,300	32,100	400	1,100	15,600	1,600	3,200	2,300	1,400	1,100	17,900	18,800	9,900	400	9500	34,00	2,500	0	246,400
Grand Total	1,400	294,800	32,300	60,300	400	1,100	267,500	1,600	54,900	49,300	1,400	3,300	17,900	18,800	21,000	400	52,000	3,400	2,500	314,300	1,198,600

Table 4. Examples of conversion suitability possibilities for two forest types, pine forest and mixed oak forest, using historic (PLS) data and current (FIA) data

	PINE FOREST		MIXED OAK FOREST	
Suitability	Current forest type	Historic forest type	Current forest type	Historic forest type
Low Effort	4%	29%	13%	12%
Medium Effort	65%	45%	49%	14%
High Effort	9%	16%	16%	15%
Maximum Effort		0%	1%	0%
Non-Forest		6%		31%
Not Possible	22%	4%	20%	28%
Area in hectares	4,600	268,300	223,400	294,900