A PILOT TEST OF INDICATOR SPECIES TO ASSESS UNIQUENESS OF OAK-DOMINATED ECOREGIONS IN CENTRAL TENNESSEE

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Abstract—We used tree indicator species occurring on 438 plots in the Plateau counties of Tennessee to test the uniqueness of four conterminous ecoregions. Multinomial logistic regression indicated that the presence of 14 tree species allowed classification of sample plots according to ecoregion with an average overall accuracy of 75 percent (range 45 to 94 percent). Additional analysis revealed that the largest ecoregion could be subdivided into northern and southern zones based on frequency of occurrence of five other indicator species. Under the premise that tree assemblages of varying composition indicate areas of differing environmental conditions, results of our test suggest the delineated ecoregions are unique.

INTRODUCTION

Ecoregions are large areas of the Earth's surface that enclose smaller ecosystems having common characteristics (Bailey 1998). Ecoregions may be delineated using differing mapping criteria, but are largely integrations of physical, biological, and cultural components, including climate, geologic formations, soils, terrestrial and aquatic fauna and flora, and land use (Bailey 1983, Omernik and others 2000). Assessment, evaluation, analysis, and planning across subregional areas are increasingly being based on ecoregions (Bryce and others 1999) and particularly land management decisions dealing with water-quality issues (Griffith and others 1999). Ecoregion maps are typically delineated in a subjective, qualitative manner, but generally are not tested because independent datasets are not available. Untested ecoregion maps have been used for purposes such as resource assessments (Rudis 1998).

Tree species in the Southern Appalachian Mountains are distributed individualistically along temperature and moisture gradients (Whittaker 1956) that are likely associated with physiological requirements of vegetation for establishment, growth, and reproduction (Kramer and Kozlowski 1960). McNab and others (2002) found that Southern Appalachian tree species can be used as indicators of forest site productivity. Kuchler (1964) and others used overstory cover types, consisting largely of tree species, as a means of stratifying large, subregional geographic areas into smaller, more homogeneous ecological units. We reasoned that if adjacent mapped polygons are dissimilar environmentally, then the frequency of occurrence of one or more tree species should differ also and provide a means of testing ecoregion uniqueness. Also, tree species could provide a biological basis for subdivision of large ecoregions into more homogeneous smaller units.

We are not aware of tests of ecoregion mapping in the South. We have successfully used data from an extensive series of U.S. Department of Agriculture, Forest Service, Forest Inventory and Analysis (FIA) plots to identify tree species that indicate site quality (McNab and others 2002). Our success suggests that FIA data could be used to test similarity of ecoregions, also using an indicator-species approach. The primary objective of our current study was to determine if species composition differed among ecoregions. We based our study on the premise that assemblages of tree species will vary among areas of differing environmental conditions. Our study should be considered a pilot test because it was made in a small geographical area that did not include the full extent of the mapped ecoregions.

METHODS

Our study was limited to FIA unit 4 of Tennessee (fig. 1), which consists mainly of the Cumberland Plateau physiographic province and smaller areas of three other provinces. Schweitzer (2000) describes forest statistics of this region, which extends over 4 million acres, includes 16 counties,

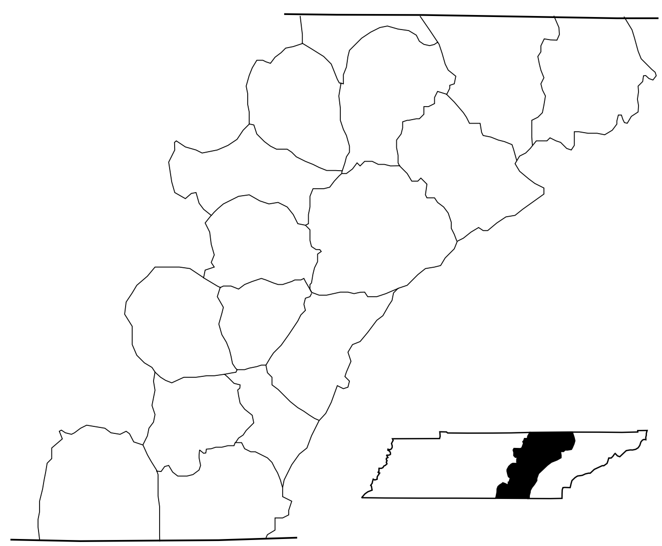

Figure 1—The study occurred in the plateau FIA survey unit of Tennessee.

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and is about 71 percent forested. Smalley (1982, 1983, 1984) developed a conventional forest site classification system for this region. In Hinkle's (1989) extensive vegetation study, oak and hickory assemblages dominate forest cover types.

We evaluated ecoregions mapped by Griffith and others (1998). Griffith and others (1997) described the mostly qualitative methods of their ecoregionalization process in Tennessee as "compiling and reviewing relevant materials, maps and data; outlining the regional characteristics; drafting the ecoregion boundaries; creating digital coverages and cartographic products; and revising as needed after review by national, state, and local experts." Essentially, the U.S. Environmental Protection Agency (EPA) ecoregions are areas of relatively uniform climate, geology, landform, natural disturbance, land use, terrestrial vegetation, and aquatic fauna. Other intermediate-scale ecoregion maps were available in digital format. However, we selected this one primarily because it delineated the escarpment as a sinuous but relatively large, distinctive, and detailed ecoregion that could be displayed relatively accurately on the base map. Also, the escarpment unit generally agreed with our field observations and knowledge of the area. Our study tested this ecoregion as a unique ecosystem, which apparently was an issue among reviewers of the final map product (Griffith and others 1997). Ecoregions were retained for analysis that included a minimum of 30 plots.

Using the FIA Eastwide database (Hansen and others 1992), tree- and plot-level data were available for 513 sample plots in the 1999 inventory that had been installed at intersection locations on a 3- by 3-mile grid. Arborescent vegetation ≥ 1 inch in diameter at breast height at each grid location was inventoried by species at four points with 1/24-acre and 1/300-acre nested plots. However, genera were used as inventory groups where species could not be determined accurately, such as for hawthorns (*Crataegus* spp.), serviceberries (*Amelanchier* spp.), and occasionally for hickories (*Carya* spp.). Schweitzer (2000) provides additional information on the vegetation sampling methods. In addition to a species list, available data for each plot included elevation (nearest 10 feet), aspect (nearest degree), slope gradient (nearest percent), and latitude and longitude. For tree species we recorded the inventory data on each sample plot as a binary variable: present or absent. To reduce the confounding influence of disturbance associated with regeneration of certain species, e.g., yellow-poplar, red maple, and sweet birch (Beck and Della-Bianca 1981, Golden 1974), we did not use a measure of abundance as independent variables, such as number of individuals of each species present or crown area by species. We excluded plots that were not forest land, or had been planted, or were not stocked with trees.

In the analysis, we included only those species present on 10 percent or more of the total plots to reduce the chance that uncommon species unique to this dataset could unduly influence the results. We excluded the hickory genus from the analysis because some species are highly site specific; e.g., bitternut, but were not identified. We used several types of analyses to investigate the distribution of tree species among and within ecoregions. We used chi-square to test hypotheses that the frequency of occurrence of each species among ecoregions did not differ from its frequency of occurrence over the entire unsubdivided study area. We used calculated species richness, i.e., the number of species present on each plot, and available plot basal areas to characterize the tree stands among ecoregions.

We used logistic regression instead of discriminant analysis to develop classification functions because most of our independent variables were qualitative (Press and Wilson 1978). We used multinomial logistic regression to examine the relationship of the presence of multiple species with the four ecoregions. Our statistical software package, STATA v. 7 (StataCorp 2001), did not provide a fast and efficient stepwise procedure to determine a suitable model with this type of analysis. Therefore, we began initial trial formulations with influential species from the chi-square goodness-of-fit tests and our own field experience. We followed the rationale of Hosmer and Lemeshow (2000) to develop and interpret a significant and parsimonious multinomial model.

We used ordinary logistic regression to study the effect of latitude on tree distribution within the largest ecoregion, the Cumberland Plateau. We arbitrarily subdivided the Plateau into north and south zones at 36° latitude, near Crossville, TN, to provide about equal plot numbers for analysis. Species included in this analysis were limited to those occurring on ≥ 10 percent of the plots. This model used backward elimination of species insignificant at the $P = 0.05$ level of probability.

RESULTS AND DISCUSSION

Ecoregion Study Areas

For analysis we retained ecoregions that included a minimum of 30 plots, which included, from west to east: (1) eastern highland rim, 40 plots; (2) plateau escarpment, 115 plots; (3) Cumberland Plateau, 216 plots; and (4) Cumberland Mountains (67 plots) (table 1). For brevity, these ecoregions are hereafter called rim, escarpment, plateau, and mountains, respectively. We excluded smaller portions of two ecoregions (Sequatchie Valley and Nashville Basin) because of their small size and lack of sufficient plots for analysis. Over the study area, plot elevation averaged 1,568 feet (range 670 to 3,200 feet), slope gradient averaged 24 percent (range 0 to 84 percent), and all aspects were represented.

Mean Basal Area and Species Richness

Stand basal area averaged almost 105 square feet per acre throughout the study area (table 2). Average basal area was lowest in the rim and highest in the Cumberland Mountains. Except for one plot in the plateau, stand basal areas among ecoregions ranged from about 10 square feet per acre to > 150 square feet per acre. The plot of highest basal area was located in the northern portion of the plateau and consisted of an unusual species combination of red maple, three oak species (chestnut, scarlet, and chinkapin), black gum, sourwood, bigleaf magnolia, white pine, and hemlock. The latter three species suggested that the site was situated near a mesic environment, such as a stream ravine. High stocking levels were not unusual in the plateau, where nine stands had basal areas exceeding 170 square feet per acre.

Table 1—Characteristics of principal ecoregions in the study area of Tennessee

	Ecoregions			
Characteristic	Rim	Escarpment	Plateau	Mountains
Physiography	Weakly dissected plateau	Mountainsides	Rolling tableland	Low mountains
Elevation (*ft.*)	800 – 1,300	800 – 2,400	1200 – 2,000	1,200 – 3,500
Geologic age	Mississipp.	Pennsylvan.	Pennsylvan.	Pennsylvan.
Primary bedrock or mixture	Limestone, chert	Sandstone-limestone mix	Sandstone, siltstone	Sandstone, siltstone
Soil order	Ultisols	Ultisols	Ultisols	Inceptisols
Precipitation (*in.*)	52 – 56	52 – 60	48 – 60	50 – 55
Frost free (days)	190 – 210	180 – 200	180 – 200	180
Jan. Min/Max (F)	25 – 46	24 – 44	24 – 44	21 – 43
Jul. Min/Max (F)	65 – 88	63 – 85	63 – 85	61 – 85
Potential natural vegetation	Mixed oak	Mixed mesophytic, mixed oak	Mixed oak	Mixed mesophytic
Primary landuse	Agriculture	Forests	Forests	Forests

Table 2—Mean (SE) and range of stand basal area and species richness by ecoregion in the study area of Tennessee

Ecoregion	Plots	Stand basal area (ft^2 per ac)		Species richness	
	N	*Mean* (*SE*)	*Range*	*Mean* (*SE*)	*Range*
Rim	40	99.9 (5.4)	10 – 158	13.5 (0.6)	7 – 24
Escarpment	115	104.3 (3.0)	34 – 206	13.2 (0.2)	6 – 20
Plateau	216	105.3 (2.3)	4 – 224	11.9 (0.2)	6 – 18
Mountains	67	106.8 (4.2)	16 – 186	12.3 (0.4)	3 – 19
All	438	104.8 (1.6)	4 – 224	12.5 (0.1)	3 – 24

Species richness averaged 12.5 throughout the study area and ranged from about 3 in the mountains to almost 24 in the rim (table 2). The lowest species richness (3) occurred on a single plot on a mesic site in the mountains where a stand with basal area of 48 square feet per acre consisted only of red maple, yellow-poplar, and black locust. Generally, a minimum of 6 to 7 species and maximum of 19 to 20 species were present on plots of all ecoregions. In the plateau ecoregion, species richness was negatively correlated with elevation ($r = -0.24$, $P < 0.0004$) and positively correlated with slope percent ($r = 0.28$, $P < 0.0001$). In the rim, richness was correlated with slope gradient ($r = 0.38$, $P = 0.009$) and transformed aspect ($r = -0.37$, $P = 0.019$).

Species Composition of Ecoregions

A total of 87 species or species groups, e.g., *Amelanchier* spp., were identified in the study area, of which 35 species were present on ≥ 10 percent (43) of the total 438 plots (table 3). The nine most common species occurred on more than one-third of the sample plots in each of the four ecoregions. Red maple was the species of widest distribution, occurring on 83 percent of the total study area, followed by white oak and black gum. Some species were uniformly common in three of the four ecoregions, such as sugar maple, chestnut oak, and American beech. Species such as shortleaf pine, hophornbeam, and southern red oak occurred with higher frequencies in two of four ecoregions. None of the common species occurred with obviously higher frequency in a single ecosystem, which alone could be used as an indicator species. Several of the less common species, including tree-of-heaven, bigleaf magnolia, and willow oak, occurred almost exclusively in a single ecoregion, but their scarcity makes then unsuitable as an indicator species. Chi-square tests of hypothesized proportional frequency ratios indicated that the frequency of occurrence (expressed as a percentage) of many species varied among ecoregions (table 3). Although the individual variation in occurrence of species suggests differences exist among ecoregions, a multispecies model should provide increased classification accuracy.

Classification Among Ecoregions

A multiple logistic model utilizing the 36 common species occurring on the field plots indicated that 14 were significantly associated with the four ecoregions (table 3). Overall classification accuracy was 75 percent. The model classified inventory plots in the plateau with greatest accuracy, 94 percent, and those in the rim with lowest accuracy, 42 percent.

Table 3—Arborescent taxa occurring on ≥ 10 percent of the total 438 sample plots occupying four ecoregions in the study area of Tennessee and their significance as potential indicator species

Arborescent taxa	Ecoregion[a]					Indicator	
	Rim	Esc.	Plt.	Mtn.	All	Ind.[b]	Mul.[c]
	- - - - - - - - - -percent of plots- - - - - - - - - -						
Red maple (*Acer rubrum*)	73	64	94	87	83	0.032	.
White oak (*Quercus alba*)	63	51	94	67	76	0.001	*
Black gum (*Nyssa sylvatica*)	78	57	82	69	73	0.085	*
Sourwood (*Oxydendrum arboreum*)	40	40	85	45	63	0.001	*
Yellow-poplar (*Liriodendron tulipifera*)	73	65	47	76	58	0.012	.
Black oak (*Quercus velutina*)	40	43	67	42	54	0.005	.
Sassafras (*Sassafras albidum*)	40	42	57	48	50	0.171	.
Pignut hickory (*Carya glabra*)	45	59	44	45	48	0.253	.
Dogwood (*Cornus florida*)	68	49	46	34	47	0.104	.
Chestnut oak (*Quercus prinus*)	13	46	47	63	46	0.003	.
Scarlet oak (*Quercus coccinea*)	30	24	61	31	44	0.001	.
Northern red oak (V:*Quercus rubra*)	43	57	27	54	40	0.001	.
Mockernut hickory (*Carya tomentosa*)	55	27	46	39	41	0.030	.
Virginia pine (*Pinus virginiana*)	18	21	53	30	38	0.001	.
Sugar maple (*Acer saccharum*)	55	71	6	55	35	0.001	*
Black cherry (*Prunus serotina*)	45	32	25	36	30	0.142	.
Shortleaf pine (*Pinus echinata*)	0	12	39	22	26	0.001	.
Shagbark hickory (*Carya ovata*)	35	49	9	13	23	0.001	*
American beech (*Fagus grandifolia*)	43	30	8	36	21	0.001	*
Post oak (*Quercus stellata*)	20	5	35	6	21	0.001	.
Green ash (*Fraxinus pennsylvanica*)	43	32	5	15	17	0.001	.
White ash (*Fraxinus americana*)	28	42	2	13	16	0.001	.
Eastern redbud (*Cercis canadensis*)	33	43	0	10	16	0.001	*
Eastern white pine (*Pinus strobus*)	0	3	28	9	16	0.001	*
Southern red oak (*Quercus falcata*)	33	2	24	6	16	0.001	*
Black locust (*Robinia pseudoacacia*)	3	26	5	33	14	0.001	*
Eastern hemlock (*Tsuga canadensis*)	0	9	20	15	14	0.005	.
American holly (*Ilex opaca*)	0	3	23	9	13	0.001	.
Cucumbertree (*Magnolia acuminata*)	5	18	3	34	12	0.001	*
Eastern hophornbeam (*Ostrya virginiana*)	28	28	2	6	12	0.001	.
Serviceberry (*Amelanchier sp.*)	3	3	19	9	12	0.001	.
Eastern redcedar (*Juniperus virginiana*)	43	25	4	0	12	0.001	*
Bitternut hickory (*Carya cordiformis*)	18	10	9	19	11	0.077	.
Sweetgum (*Liquidambar styraciflua*)	28	11	7	12	11	0.006	*
Winged elm (*Ulmus alata*)	33	25	1	3	11	0.001	*
Black walnut (*Juglans nigra*)	20	23	1	7	10	0.001	.

[a] Abbreviations of ecoregions and number of plots: Rim = Eastern Highland Rim (40 plots); Esc. = Cumberland Plateau escarpment (115); Plt. = Cumberland Plateau (216); Mtn. = Cumberland Mountains (67).
[b] Chi-square probability that the actual frequencies of occurrence of individual species among ecoregions are equal to the expected frequency determined for the area as a whole.
[c] Multinomial logistic regression probability (* denotes $P \leq 0.05$) that the presence of certain combined species discriminate among ecoregions.
Source: Griffith and others (1998).

Inclusion of black gum as a significant indicator species was surprising and probably was simply an artifact of the dataset because it occurred in all ecoregions at a relatively high level.

Several contributing factors are possible explanations for the reduced classification accuracy of several ecoregions, particularly the mountains and escarpment. The most important factor is lack of precise map delineation of some ecoregion boundaries, particularly the upper elevation location of the highly crenulated escarpment. Unlike boundaries of other ecoregions that have broad transition zones, the escarpment is generally sharply defined. Also, the small sample sizes for several ecoregions likely influenced model accuracy. In our test, the best results were obtained for the largest ecoregion, for which 233 plots were available for analysis. Finally, our biological indicator, tree species, may be an inexact integrator of environmental conditions. Inclusion of shrub and herbaceous species would likely increase classification accuracy.

Classification Within Ecoregions

Twenty-two species were present on >10 percent of the 216 plots in the plateau and were used to develop a logistic model for subdividing this ecoregion into northern and southern zones (table 4). Three of the 22 species, yellow-poplar, white pine, and shortleaf pine, occurred with unequal frequencies between the two zones, and two species, chestnut oak and American holly, were significant at a lower level ($P \leq 0.1$). An overall classification accuracy of 70 percent was achieved with a logistic model that included the three significant ($P \leq 0.05$) species. Two species, chestnut oak and American holly, which were not significantly associated with the two ecoregion zones, increased in importance ($P < 0.02$) in the presence of the other species. The presence of both these species increased the probability that a subject plot was situated in the southern zone of the plateau. The presence of two pine species, shortleaf and white, were strong indicators of plot classification membership in the northern zone. Individual classification accuracies were similar for the two zones: 70 percent for the south and 72 percent for the north.

These results suggest the plateau could be subdivided into northern and southern zones. If a latitude effect within the plateau ecoregion is real, perhaps resulting from climatic or physiographic differences, the boundary likely would not be at the location of our subdivision, 36° latitude, which we selected arbitrarily. Inclusion of shrubs and herbs has often increased classification accuracies of site-specific applications of indicator species, such as productivity evaluation (Hodgkins 1961); however, it is unclear if nontree species would be beneficial to classification over large geographic areas.

CONCLUSIONS

In this pilot study in the Cumberland Plateau region of Tennessee, we investigated the use of tree indicator species as a means of testing the delineation of ecoregions, which are ecologically dissimilar areas that likely respond differently to management. Using inventory data from > 400 permanent FIA plots established throughout the study area of > 4 million acres, we found that the relative frequency of occurrence of 14 tree species varied significantly in each of

Table 4—Arborescent taxa occurring on ≥ 10 percent of the total 216 sample plots occurring in two zones of the Cumberland Plateau ecoregion in Tennessee and their significance as potential indicator species

	Zone[a]			Indicator	
Arborescent taxa	South	North	All	Ind.[b]	Mul.[c]
	- -*percent of plots*- -				
Red maple (*Acer rubrum*)	94	94	94	0.994	.
White oak (*Quercus alba*)	93	96	94	0.773	.
Sourwood (*Oxydendrum arboreum*)	86	84	85	0.900	.
Black gum (*Nyssa sylvatica*)	83	81	82	0.843	.
Black oak (*Quercus velutina*)	65	69	67	0.761	.
Scarlet oak (*Quercus coccinea*)	63	60	61	0.779	.
Sassafras (*Sassafras albidum*)	63	52	57	0.317	.
Virginia pine (*Pinus virginiana*)	51	55	53	0.714	.
Yellow-poplar (*Liriodendron tulipifera*)	36	57	47	0.028	N
Chestnut oak (*Quercus prinus*)	55	39	47	0.074	S
Dogwood (*Cornus florida*)	39	52	46	0.157	.
Mockernut hickory (*Carya tomentosa*)	46	47	46	0.914	.
Pignut hickory (*Carya glabra*)	50	37	44	0.125	.
Shortleaf pine (*Pinus echinata*)	28	50	39	0.011	N
Post oak (*Quercus stellata*)	41	29	35	0.145	.
Eastern white pine (*Pinus strobus*)	16	40	28	0.001	N
Northern red oak (*Quercus rubra*)	28	26	27	0.739	.
Black cherry (*Prunus serotina*)	24	26	25	0.838	.
Southern red oak (*Quercus falcata*)	24	23	24	0.837	.
American holly (*Ilex opaca*)	28	17	23	0.102	S
Eastern hemlock (*Tsuga canadensis*)	16	24	20	0.190	.
Serviceberry (*Amelanchier sp.*)	15	22	19	0.228	.

[a] Latitude 36° arbitrarily divides the Cumberland Plateau ecoregion into southern (107 plots) and northern zones (109 plots), approximately at Crossville, Tennessee.
[b] Chi-square probability that the frequencies of occurrence of individual species between the two zones are not different from the expected frequency determined for the area as a whole.
[c] Multiple logistic regression probability (letter denotes $P \leq 0.05$) that the presence of certain combined significant species discriminates between the southern (S) and northern (N) zones of the ecoregion.
Source: Griffith and others (1998).

4 adjacent ecoregions. In addition, five other indicator species provided evidence of latitudinal differences in the largest ecoregion. In conclusion, our study provides evidence suggesting that the delineated ecoregions are discrete ecological units that should not be combined. Also, we demonstrated the potential value of indicator species for purposes other than their conventional use for evaluation of forest site quality.

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