2007. Proceedings of the Indiana Academy of Science (116):158–172

LAND TYPE ASSOCIATION DELINEATION AND SPATIAL ANALYSIS FOR THE HOOSIER NATIONAL FOREST IN SOUTHERN INDIANA

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ABSTRACT. A GIS approach was used to delineate Land Type Association (LTA) map units for the Hoosier National Forest (HNF) area. It was assumed that the spatial distribution pattern of Ecological Land Type (ELT) and Ecological Land Type Phase (ELTP) map units provide a theoretical foundation for LTA unit delineation. A semi-automated approach using visual detection of areas of different ELT patterns followed by multivariate statistical analysis and clustering was used for LTA delineation. This resulted in four LTAs for the Brown County Hills subsection (Pleasant Run unit of HNF) and six LTAs for the Crawford Upland subsection (Lost River, Patoka River and Tell City units of the HNF). Differentiating criteria included, in the general order of most frequent use, patterning of ELTPs and soil survey units, landforms, bedrock type, dominant tree species occurrence, and disturbance processes. LTA boundary identification was based on physiographic boundaries such as stream channels or watershed boundaries (ridges). All units are nested within boundaries of subsequent upper and lower hierarchical units (Subsection ↔ LTA ↔ ELT ↔ ELTP). Spatial statistics on ELT, ELTP, soils, erosion, and elevation are reported to highlight differences between LTAs. Mapped LTA units will help to apply effectively those management activities that require a spatially specific application, such as controlled fire and selection cuttings, or recreational planning. Map units also will provide a valuable tool for a researcher allowing to improve sampling strategy and have a solid ecological foundation in interpretation of results. Maps can outline areas with different biological and/or ecological potentials.

Keywords: Ecological classification, GIS, landscape analysis, land type mapping, forest ecosystems

One of the critical components of decision making in natural resource management is ecological information. An ecological classification (ECS) framework allows identification of land areas with similar properties at different scales for the purpose of management, research and education. This framework is hierarchical: the smaller map units compose larger units ("bottom-up" approach) or are created by subdividing the next larger unit ("top-down" approach), and nested: boundaries of smaller units do not cross those of larger units. The USDA Forest Service adopted a policy of ecosystem management on 4 June 1992 that applied to national forests and grasslands research programs. Later, an Ecological Classification and Mapping Task Team (ECOMAP) was formed to develop a consistent approach to ecosystem classification and mapping at multiple geographic scales. Other agencies such as the USDA Soil Conservation Service and The Nature Conservancy also contributed to the development of the framework, and it was adopted as the National Hierarchical Framework of Ecological Units (NHFEU) in 1993 (ECOMAP 1993). Bailey's classification of US ecoregions (Bailey 1980) was accepted as upper levels of ECS at the global scale (domains, divisions and provinces) and mapped (Keys et al. 1995). Regional scale (sections) was described and mapped in 1994 (McNab & Avers 1994).

Subsections in Indiana that represent next lower level in ECS follow Homoya's natural regions of Indiana (Homoya et al. 1984). In 1993, a multifactor ecological classification described ecological land types (ELT) and ecological land type phases (ELTP) for the Brown County Hills (BCH) and Crawford Upland (CU) subsections of the Hoosier National Forest (HNF) in southern Indiana (Van Kley 1993), based on vegetation, soils and physiography. The leading environmental factors that were correlated to variation in vegetation composition were aspect, soil A-horizon depth, slope position, and soil pH. Thus, vegetation is believed to be related to a moisture and nutrient gradient which is influenced by

the above mentioned factors. Van Kley (1993) identified 12 ELTPs for the BCH and 15 ELTPs for the CU subsection. He also described seven ecological plant species groups for the Brown County Hills and eight groups for the Crawford Upland subsection.

An important step in bringing ecological theory into application is mapping ecological classification units on the landscape. This study defines and describes Land Type Association units (local level) for the BCH and CU subsections within the HNF purchase boundary. When mapped, LTA units reflect information on medium-scale influences of local disturbance regimes, biological productivity and resiliency, hydrologic patterns and functions within each unit. Such information is readily available for a manager to be used in planning, and managing natural resources at the local scale. Using map units in managerial activities and research will help to build further knowledge of local ecosystems and improve their management. Mapping LTA units will help to apply effectively those management activities that require a spatially specific application, such as controlled fire or selection cuttings. Recreational planning is another example of possible use of mapped ecological units at fine to medium scale. Parker & Whitcomb (2002) demonstrated an application of mapped LTAs in studying patterns of dispersed campsites on the Chippewa National Forest.

Map units also provide a valuable tool for a researcher allowing to improve sampling strategy and have a solid ecological foundation in interpretation of results. Maps can outline areas with different biological and/or ecological potentials. LTA map units can be used for example to assess and rank the quality of Indiana bat habitats (DeMeo 2002).

Since LTA boundaries are independent of political or property lines, in most cases these LTA units will extend beyond the purchase boundary and should be considered as an intermediate step to mapping all LTAs within respective subsection boundaries.

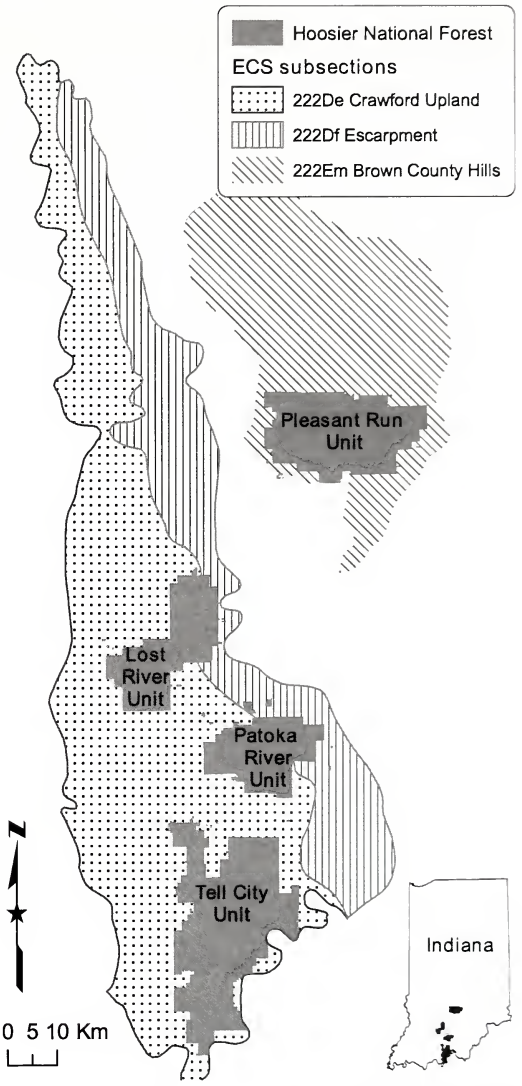

Figure 1.—A map of study area. Four Hoosier National Forest units and Ecological Classification System subsections are shown on the map.

METHODS

Study area.—The study area, located in south-central Indiana, included four units of the Hoosier National Forest situated within the Brown County Hills and Crawford Upland subsections according to the eastern United States classification (McNab & Avers 1994) (Fig. 1). The area is underlain by Paleozoic sedimentary bedrock (Gutshick 1966). Parent material of this area is early-to-middle Mississippian age siltstones and shales of the Borden group (Schneider 1966). Prevailing soils of this area are acid silt loams formed from weathered bedrock and small areas of loess (Homoya et al. 1984). Typical relief consists of uplands dissected by creeks with steep slopes and narrow hollows.

Van Kley (1993) developed an ecological

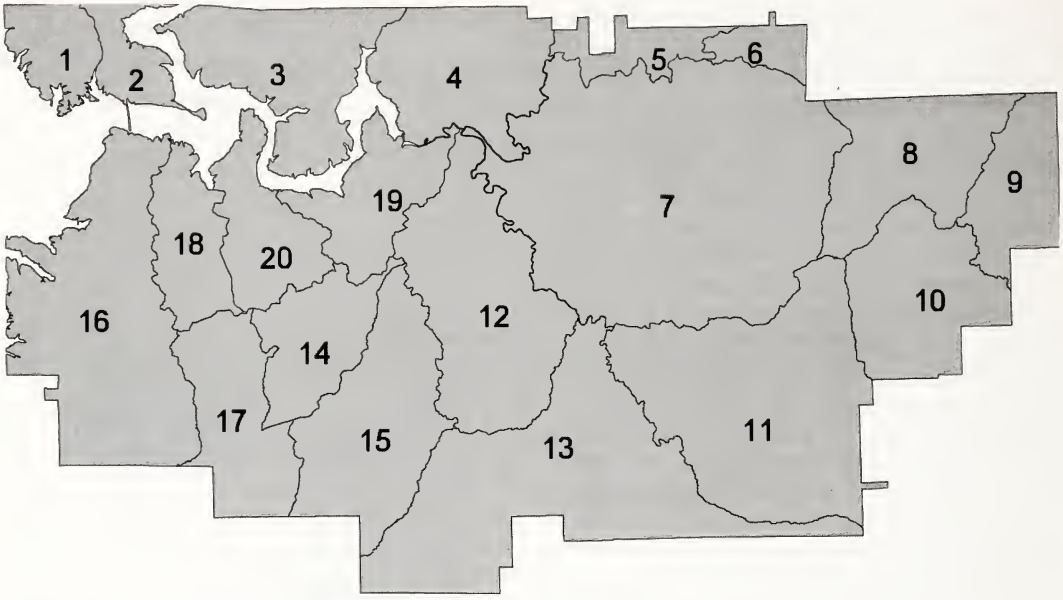

Figure 2.—LTA subunit boundaries for the Hoosier National Forest area. Numbers refer to temporary unit labels in analysis.

classification for the forest that includes 12 ELTPs for the Brown County Hills subsection and 15 ELTPs for the Crawford Upland subsection. Important factors affecting the classification were landscape physiography and soil parental material at the ELT level and physiography, A-horizon depth, and vegetation at ELTP level. ELT map units for the HNF were delineated using GIS tools (Shao et al. 2004).

Methodology.—LTA delineation was made using ELTP maps produced by Zhalnin (2004). It was assumed that natural features of the landscape such as watershed boundaries or streams are appropriate LTA boundaries. Therefore, at the first stage we visually analyzed the ELTP map and defined areas different in ELTP spatial pattern and separated by natural landscape boundaries (streams or ridges) to establish boundaries of LTA subunits (Fig. 2). Areas covered with large water bodies were excluded. The next step was to analyze each subLTA with the Patch Analyst extension for ArcView GIS (Rempel & Carr 2003) for differences in ELTP spatial pattern. Mean Patch Size (MPS) and Mean Proximity Index (MPI) were selected from a variety of spatial metrics suggested by the program as metrics that most reflected spatial differences between subLTAs according to our previous study (Zhalnin et al. 2002). Mean Patch Size is a mean area of each ELTP unit within each LTA. Mean Proximity Index uses the nearest neighbor statistics and is a measure of the degree of isolation and fragmentation of map units within each ELTP class. Each metric was calculated for each ELTP class separately. Next, we used multivariate statistics analysis (Principal component analysis, PCA, and Detrended Correspondence Analysis, DCA) to group subLTAs into final LTA units. In addition, other sources of information (GIS layers) were used to identify specific areas and incorporate them into the LTA classification, such as a bedrock map (USGS data layer), the STATSGO and SSURGO soil maps (NRCS Soil Survey data layers), and the map of distribution of chestnut oak (*Quercus prinus*) in the HNF area, interpolated from 511 sample points collected in the field. More detailed description of delineation testing procedure can also be found in USDA General Technical Report NE-294 (Zhalnin et al. 2002). The entire LTA map was converted into polygon version and grid GIS layer, and projected in the Universal Transverse Mercator (UTM) coordinate system and North American Datum of 1927 (NAD 27) to correspond to other GIS data layers within USGS Forest Service database. All GIS work was done in AcView GIS

3.3(ESRI 2002). PC-ORD statistical package was used for multivariate statistical analysis of metrics (McCune & Mefford 1999).

Naming of LTA units.—Names of LTA consist of a numerical designation of a respective subsection (e.g., 222Em for the BCH subsection), subsequent number of LTA, and a verbal description. LTAs were described according to canopy species prevailing within an LTA, prevailing moisture conditions (based on moisture gradient within an LTA), and landscape forms typical for the LTA.

Spatial metrics within LTAs.—Spatial metrics were calculated for ELTPs and ELTs within each LTA unit using the Patch Analyst application in ArcView to characterize individual units. Shannon's Diversity Index (SDI) and Shannon's Evenness Index (SEI) were used to describe ELTP and ELT diversity of the landscape. They are useful for estimating landscape value and comparing different LTAs. SDI and SEI are calculated using the following formulas:

$$SDI = -\sum_{i=1}^{m} (P_i \cdot \ln P_i) \quad (1)$$

$$SEI = \frac{-\sum_{\ln m}^{m} (P_i \cdot \ln P_i)}{\ln m}, \quad (2)$$

where P_i is a proportion of landscape occupied by ELTP or ELT i, and m is a number of ELTPs or ELTs present in the landscape.

SDI index is sensitive to occurrence of rare land types: the higher SDI value, the more unique ELTPs or ELTs occur within the LTA. SEI measures the other aspect of landscape diversity—the distribution of area among ELTP or ELT patches. As the evenness index approaches "1," the observed diversity approaches perfect evenness, when LTA is characterized by environmentally homogeneous landscape with equally sized ELTPs or ELTs. Soil and erosion information was obtained from respective GIS layers (SSURGO data layers) for each LTA map unit. An Area Weighted Erosion index (AWEi) was calculated to estimate the degree of soil erosion within LTAs using the following formula:

$$AWEi = \frac{E1 \cdot A1 + E2 \cdot A2 + \cdots + En \cdot An}{A1 + A2 + \cdots + An} \quad (3)$$

where En is an Erosion Class defined by the Soil Survey Manual (1993) and An is the area occupied by a corresponding soil Erosion Class. Higher values represent higher degree of erosion.

RESULTS

LTA delineation.—Delineation procedure is explained on the example from the Pleasant Run Unit of the HNF within the Brown County Hill subsection. We defined 20 subunits that were naturally separated within the landscape (subLTAs, Fig. 2) in the first stage. Subunits 5, 6, 8, 13, 16, 17 and 18 were excluded from the further analysis for the following reasons: units 5 and 6 were added to unit 7, since they are small parts of larger units that lie outside the HNF boundary and visually resemble unit 7. Unit 8 has a unique pattern of ELTP spatial distribution. Units 13 and 16, as well as 17 and 18 represent two LTAs that have a distinctive difference from the rest of the area due to the pattern of limestone soil occurrence.

The ultimate reasonable number of LTAs for the Pleasant Run unit of the Hoosier National Forest is 4–5 units according to the LTA unit size suggested in National Hierarchy (Cleland et al. 1997). Three of the subunits were reserved for areas that have distinctive features. The delineation of remaining two LTAs was based on multivariate statistics results. PCA of Mean Patch Size revealed that in general subunit variability forms two clusters: first—subLTAs 1, 2, 9, 10, 12, 14, and 15; second—subLTAs 3, 4, 7, 11, 19, and 20. Subunit 19 was an "outlier" on the graph, but still can be considered closer to group 2 than to group 1 (Fig. 3, top). Groups from DCA were less distinctive: group one—2, 3, 11, 12, 15, and 20; group two—7, 9, 10, 14, and 19. Subunits 1 and 4 were not closely associated with the rest of the subunits (Fig. 3, bottom). Results of multivariate analysis of Mean Proximity Index using PCA statistics suggest two clusters: group one—9, 10, and 14; group two—1, 2, 3, 4, 7, 11, 15, and 20. Subunit 19 was again an "outlier" on the graph (Fig. 4, top). DCA method shows two clusters: group one—1, 2, 3, 4, 7, 11, 12, 15, 19, and 20; group two—9, 10, and 14 (Fig. 4, bottom). Groups determined by these analyses were used to delineate two additional LTAs. The

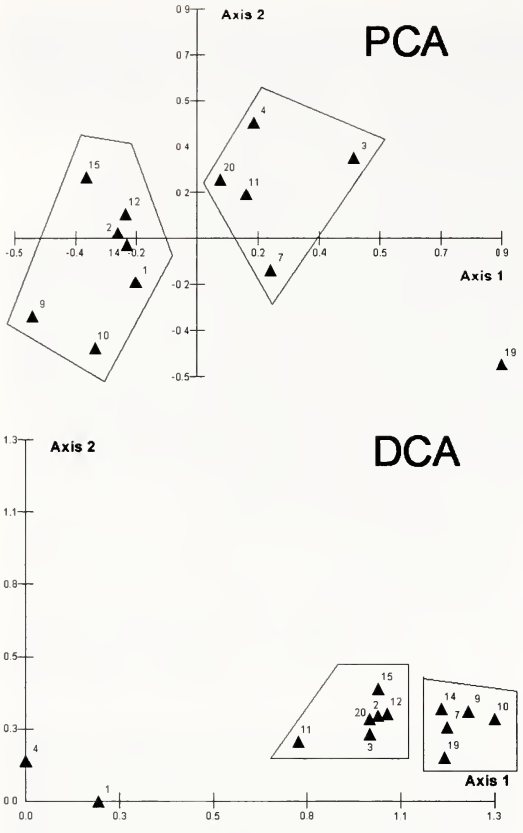

Figure 3.—Results of PCA (top) and DCA (bottom) statistics for LTA subunits within the Pleasant Run Unit of the Hoosier National Forest, the Brown County Hills subsection. Axes represent mean area size variability of 12 ELTPs among subunits.

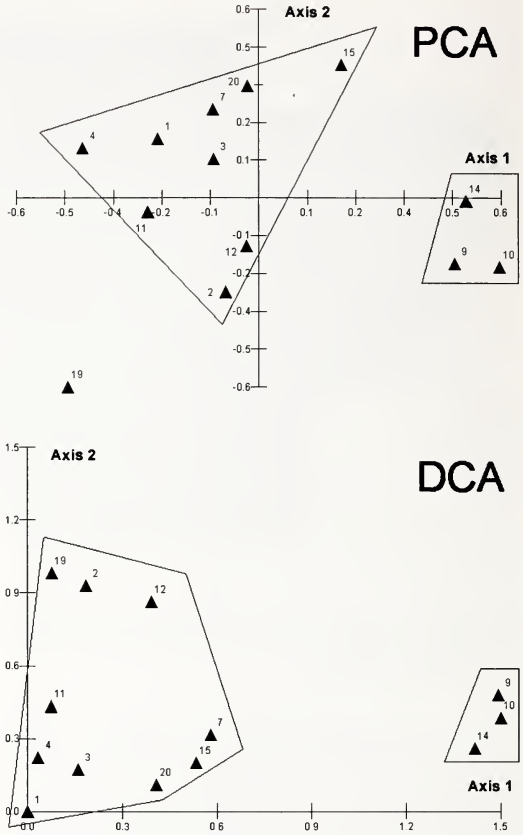

Figure 4.—Results of PCA (top) and DCA (bottom) statistics for LTAs within the Pleasant Run Unit of the Hoosier National Forest, the Brown County Hills subsection. Axes represent mean proximity index variability of 12 ELTPs among subunits.

same approach was used for delineation of LTAs within the Crawford Upland subsection.

As a result of visual and statistical analysis, four LTAs are described for the BCH subsection (the Pleasant Run unit of HNF, Fig. 5) and six LTAs are described for the CU subsection (Lost River, Patoka River and Tell City units of HNF, Fig. 6) as follows: *Brown County Hills subsection:* 1) LTA 222Em01, Mixed Oak Dry-Mesic Upland Hills; 2) LTA 222Em02, Chestnut Oak Dry-Mesic Upland Hills; 3) LTA 222Em03, Oak-Maple Mesic Upland Plateau; 4) LTA 222Em04, Oak-Maple Calcareous Mesic Upland Hills. *Crawford Upland subsection:* 1) LTA 222De01, White Oak Dry-Mesic Upland Hills; 2) LTA 222De02, Chestnut Oak Dry Upland Hills; 3) LTA 222De03, Oak-Maple Calcareous Upland Hills; 4) LTA 222De04, Oak-Maple Wet-Mesic Dissected Plateau; 5) LTA 222De05, Mixed Oak Dry Upland Hills; 6) LTA 222De06, Post Oak Dry Upland Hills.

LTA descriptions for the Brown County Hills subsection.—*LTA 222Em01, Mixed Oak Dry-Mesic Upland Hills:* This LTA is located in central part of the Pleasant Run (PRN) unit, extending from the northern to the southern purchase boundary, and is the largest LTA in the BCH subsection (Fig. 5). Dry ridge and dry slope ELTPs 10 and 20 of this LTA are dominated in some parts by *Quercus alba* (northwestern corner of PRN unit above the Monroe Lake) or *Quercus prinus* or both. In the southwestern part, this LTA borders LTA 222Em04, Oak-Maple Calcareous Mesic Upland Hills, and a few calcareous ELTPs 13 and 23 may occur along that border. In the south-

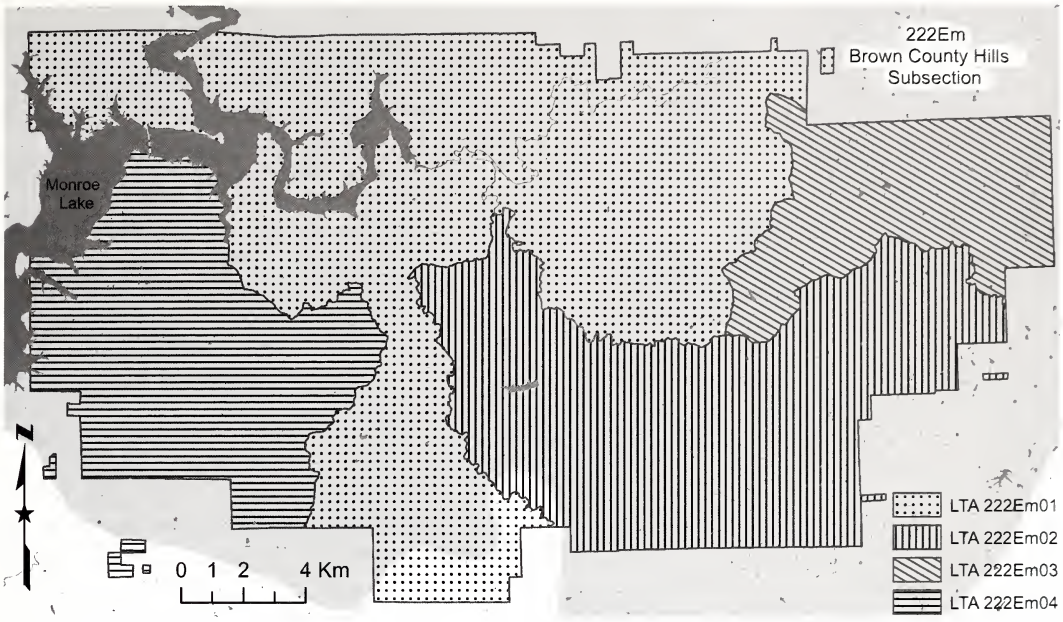

Figure 5.—Land Type Associations (LTA) of the Brown County Hills subsection (Pleasant Run unit of the Hoosier National Forest). LTA boundaries are restricted to purchase boundaries of the Hoosier National Forest.

eastern part, this LTA borders LTA 222Em02 (Chestnut Oak Dry-Mesic Upland Hills). The southern part of this LTA may justify separating from the northern in the area of Hickory Ridge Road as more information is obtained on characteristics of the region to the south of PRN Unit purchase boundary.

LTA 222Em01 has a mean elevation of 208 m with the highest point at 284 m and the lowest at 164 m (Table 1). It has the largest area (21,116 ha) and the highest proportion of dry slope ELTP 20 (32.5%) among all LTAs of the BCH subsection (Table 2). In general, the dominate ELTPs were dry slope ELTP 20, mesic slope ELTP 22, and mesic ridge ELTP 12 (32.5, 27.9, and 9.3%, respectively). The dry slope ELTP 20 has the largest mean area among all BCH subsection LTAs (6.66 ha). Shannon's Index of Diversity was 1.89 for ELTPs and 1.21 for ELTs (the latter is highest in the BCH subsection).

This LTA has the largest percentage of soils in Erosion Class 1 and least percentage in Erosion Class 2 (85.7 and 6.8%, respectively, Table 3) indicating relatively slight disturbance of soils in this area. The Area Weighted Erosion index (AWEi) is 1.07, the smallest among the BCH LTAs. The major soil survey map units within this LTA are Brownstown-Trevlac-Kurtz silt loams, 20–70% slopes; Brownstown-Gilwood silt loams, 25–75% slopes; Wellrock-Brownstown-Trevlac silt loams, 6–20% slopes which cover 27.4, 16.7 and 9.6% of the area, respectively.

LTA 222Em02, Chestnut Oak Dry-Mesic Upland Hills: This LTA is located in southeastern part of the PRN Unit and characterized by deeply dissected uplands underlain by siltstone, shale, and sandstone. From the south this area borders the outwash plain of the East Fork of the White River. The typical topography is represented by exposed hills, mesic ravines, and river floodplains. Dry ridge and dry slope ELTPs 10 and 20 of this LTA are dominated by *Quercus prinus*, and sites with *Q. alba* as a dominant species are uncommon. The current spatial pattern of these two species may be in differences of their response to past disturbance or differences in relation to ecological factors, namely soil moisture and nutrient content. In general, this area is known to be on the border of the *Q. prinus* natural range, apparently due to climatic conditions, and also may contribute to the intricate spatial variation of these species.

LTA 222Em02 has a mean elevation of 222

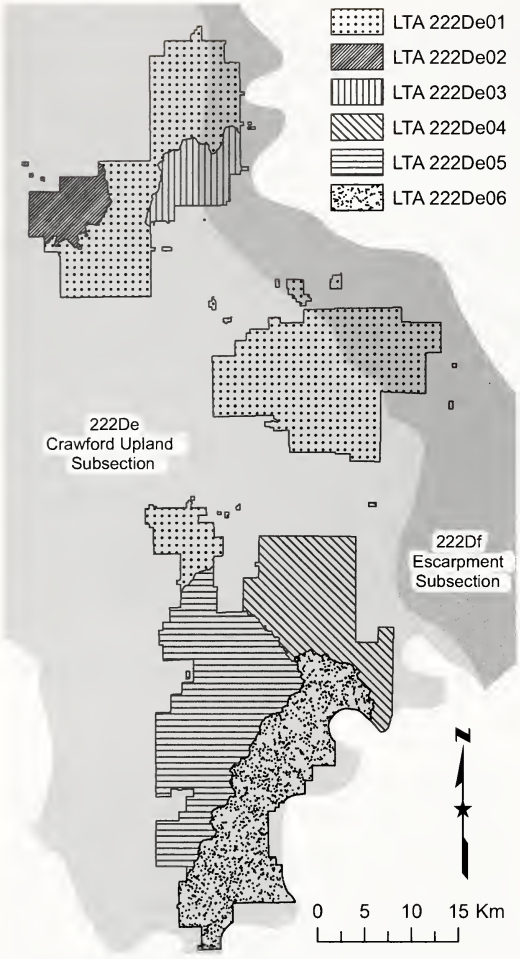

Figure 6.—Land Type Associations of the Crawford Uplands subsection (Lost River, Patoka River and Tell City units of the Hoosier National Forest). LTA boundaries are restricted to purchase boundaries of the Hoosier National Forest.

m with the highest point at 273 m and the lowest at 173 m. It has the second largest area (11,627 ha) and the highest proportion of broad floodplain ELTP 42 and ELTP 43 (13.3 and 8.2%, respectively) among all LTAs of the BCH subsection due to the adjacent East Fork of the White River. The dominate ELTPs within this LTA are mesic slope ELTP 22, dry slope ELTP 20 and mesic broad bottomland ELTP 42 with 28.0, 25.8 and 13.3% of the area, respectively). The mesic slope ELTP 22, wet-mesic bottomland ELTP 41, and floodplain ELTPs 42 have the largest mean area among all the BCH subsection LTAs with 4.95, 5.80, and 35.96, respectively (Table 2). This LTA has the largest proportion of area and the largest mean size of bottomland ELT 4 (29.5% and 31.75 ha, respectively). Shannon's Index of Diversity was 1.86 for ELTPs and 1.13 for ELTs (Table 1).

This LTA has the largest percentage of soils in Erosion Class 3 (5%). AWEi equals 1.25 which is the second highest among BCH LTAs. The dominate soil survey map units within this LTA are Brownstown channery silt loam (25–75% slopes), Gilwood-Wrays silt loams (10–25% slopes) Gnawbone silt loam (25–55% slopes) covering 26.8, 18.0 and 15.2% of the area, respectively).

LTA 222Em03, Oak-Maple Mesic Upland Plateau: This LTA is located in north-eastern part of the PRN Unit and characterized by wide and relatively level mesic ridges underlain by soils formed in 0.6–1 m of loess. Historically, this area was and still is heavily disturbed by agricultural practices and has the highest percentage of eroded soils among all LTAs of the PRN unit. Most exposed sites within ELTPs 10 and 20 of this LTA are dominated by *Q. prinus*; however, the majority of sites are dominated by *Q. alba*.

LTA 222Em03 has a mean elevation of 217 m with the highest point at 292 m and the lowest at 164 m. It has the smallest area of all LTAs (4735 ha) and the highest proportion of mesic ridge ELTP 12 (51.2%) among all LTAs of the BCH subsection. The dominate ELTPs within this LTA were mesic ridge ELTP 12, mesic slope ELTP 22, and mesic broad bottomland ELTP 42 with 51.2, 12.7, and 12.0% of the area, respectively). The dry-mesic ridge ELTP 11, mesic ridge ELTP 12, and mesic bottomland ELTP 40 have the largest mean area among all the BCH subsection LTAs (1.11, 34.14, and 2.23 ha, respectively). This LTA has the largest area proportion and largest mean size of ridge ELT 1 (51.8% and 29.56 ha). Shannon's Index of Diversity was 1.93 for ELTPs and 1.17 for ELTs (Table 3).

This LTA has the largest percentage of soils in Erosion Class 2 (50%), second highest percentage in Erosion Class 3 (4.7%). This LTA is the only one among those described that has 5.2% of the area covered by gullied soils (Erosion Class 5). AWEi is 1.81 and is the highest among the BCH LTAs. High percentages of erosion in this LTA are due to broad mesic plateaus that have been used extensively for agriculture. The dominate soil survey map

Table 1.—Elevation (meters) and diversity statistics of Land Type Association map units of the Brown County Hills subsection (the Pleasant Run unit of the Hoosier National Forest). SDI—Shannon's Diversity Index; SEI—Shannon's Evenness Index.

	LTA *222Em01*		LTA *222Em02*		LTA *222Em03*		LTA *222Em04*	
Elevation, m								
	Mode (Mean)	Max (Min)	Mode (Mean)	Max (Min)	Mode (Mean)	Max (Min)	Mode (Mean)	Max (Min)
	164 (208)	284 (164)	229 (222)	273 (173)	174 (217)	292 (164)	164 (210)	275 (164)
Landscape diversity								
	SDI	SEI	SDI	SEI	SDI	SEI	SDI	SEI
ELTP	1.89	0.74	1.86	0.78	1.93	0.80	1.95	0.76
ELT	1.21	0.88	1.13	0.81	1.17	0.84	1.16	0.84

units within this LTA are Brownstown-Trevlac-Kurtz silt loams (20–70% slopes), Stonehead-Trevlac silt loams (10–20%, eroded slopes), Stonehead silt loam (4–12% eroded slopes) covering 16.9, 16.2, and 14.0% of the area, respectively.

LTA 222Em04 Oak-Maple Calcareous Mesic Upland Hills: This LTA is located in eastern part of the PRN Unit and characterized by calcareous ELTPs. The eastern boundary of this LTA lies on the eastern edge of the Frog Pond Ridge then follows Hickory Ridge Road and goes south along Hunter Creek and Little Salt Creek. The majority of calcareous ELTPs occur in the area of the Frog Pond Ridge and Little Salt Creek. However, several ELTPs were detected in Allens Creek and Hardin Ridge State Recreational Areas on the slopes adjacent to Monroe Lake. Other locations may occur sporadically within the area in locations associated with Corydon or Crider soil series. Geologically, this area is within the transitional zone extending from the Norman Upland to the Mitchell Karst Plain. It may be similar to areas across Monroe Lake within the Mitchell Karst Plain subsection.

LTA 222Em04 has a mean elevation of 210 m with the highest point at 275 m and the lowest at 164 m. It has the area of 8498 ha and the highest proportion of calcareous mesic

Table 2.—Spatial metrics of Ecological Land Type Phase map units (area and %) by Land Type Association map units of the Brown County Hills subsection (the Pleasant Run unit of the Hoosier National Forest).

	LTA *222Em01*			LTA *222Em02*			LTA *222Em03*			LTA *222Em04*		
ELTP	Area, ha	%	Mean size, ha	Area, ha	%	Mean size, ha	Area, ha	%	Mean size, ha	Area, ha	%	Mean size, ha
10	757	3.6	1.12	332	2.9	1.12	18	0.4	0.73	305	3.6	1.15
11	60	0.3	0.91	39	0.3	0.95	12	0.3	1.11	4	0	0.85
12	1,955	9.3	4.95	1,481	12.7	6.38	2,424	51.2	34.14	773	9.1	7.09
13	15	0.1	3.81	—	—	—	—	—	—	454	5.3	16.8
20	6,869	32.5	6.66	2,998	25.8	4.12	378	8	2.08	2,694	31.7	5.55
21	148	0.7	1.07	47	0.4	0.83	58	1.2	0.8	90	1.1	1.64
22	5,884	27.9	4.33	3,252	28	4.95	602	12.7	2.33	2,296	27	4.74
23	1	0	0.02	—	—	—	—	—	—	298	3.5	11.91
40	412	2	1.81	357	3.1	2.15	171	3.6	2.23	138	1.6	1.71
41	926	4.4	4.35	580	5	5.8	373	7.9	4.15	415	4.9	4.23
42	1,119	5.3	4.1	1,546	13.3	35.96	566	12	21.78	386	4.5	3.09
43	1,304	6.2	5.64	950	8.2	25	103	2.2	12.9	180	2.1	89.77
Water	1,665	7.9	3.57	46	0.4	0.21	29	0.6	0.24	466	5.5	4.96
Total	21,116	100	4.13	11,627	100	4.52	4,735	100	5.04	8,498	100	4.58

Table 3.—Soil erosion statistics of Land Type Association map units of the Brown County Hills subsection (the Pleasant Run unit of the Hoosier National Forest). AWEi—Area Weighted Erosion index. Erosion class descriptions: 1—soils that have lost on the average less than 25% of the original A and/or E horizons; 2—soils that have lost, on the average 25 to 75% of the original A and/or E horizons; 3—soils that have lost, on the average 75% of the original A and/or E horizons; 5—gullied soils.

	LTA *222Em01*		LTA *222Em02*		LTA *222Em03*		LTA *222Em04*	
Erosion class	Area, ha	%	Area, ha	%	Area, ha	%	Area, ha	%
1	18,100	85.7	9,243	79.4	1,885	39.8	6,648	78.2
2	1,434	6.8	1,790	15.4	2,370	50.0	1,345	15.8
3	5	0.0	578	5.0	224	4.7	—	—
5	—	—	—	—	247	5.2	—	—
Water	1,583	7.5	23	0.2	11	0.2	510	6.0
Total	21,122	100	11,634	100	4,738	100	8,503	100
AWEi	1.07		1.25		1.81		1.17	

ridge ELTP 13 and mesic slope ELTP 23 (5.3 and 3.5%, respectively) among all LTAs of BCH subsection. The dominate ELTPs were mesic slope ELTP 22, dry slope ELTP 20, and mesic ridge ELTP 12 (with 31.7, 27.0, and 9.1% of the area, respectively). The dry ridge ELTP 10, calcareous mesic ridge ELTP 13, and floodplain ELTP 43 have the largest mean area among all BCH subsection LTAs (1.15, 16.80 and 89.77 ha, respectively). This LTA has the largest area proportion and largest mean size of slope ELT 2 (63.3% and 122.29 ha). Shannon's Index of Diversity was 1.95 for ELTPs (highest in BCH subsection) and 1.16 for ELTs.

The eroded area proportions of this LTA are similar to those of LTA 222Em02: 78.2% in Erosion Class 1 and 15.8% in Erosion Class 2 (Table 3). AWEi equals 1.17 and is the second smallest among the BCH LTAs. Dominate soil survey map units within this LTA are Brownstown-Gilwood silt loams (25–75% slopes), Wrays-Gilwood silt loams (6–20% slope), Crider silt loam (6–12% slopes, eroded) covering 41.5, 15.4, and 11.1% of the area, respectively. Other soils series, such as Caneyville and Corydon, derived from calcareous parent material also occur.

LTA descriptions for the Crawford Upland Subsection.—*LTA 222De01 White Oak Dry-Mesic Upland Hills:* This LTA occupies the central part of the Lost River unit, the entire Patoka River Unit and northwestern corner of the Tell City unit to the border between Crawford and Perry counties (Fig. 6). It is characterized by *Q. alba* dominated dry ridge and dry slope ELTPs 11 and 22. *Quercus prinus* was not found in this area during sampling. Wet-mesic slope ELTP 25 occurs commonly on northeastern nose slopes adjacent to wide wet-mesic floodplains within this LTA. Calcareous mesic ELTP 26 is scattered rather scarcely throughout this LTA and associated with patches of Crider-Caneyville soil series.

LTA 222De01 has a mean elevation of 209 m with the highest point at 297 m and the lowest at 133 m (Table 5). It is the largest (53,257 ha) and has the highest proportion of mesic ridge ELTP 13 and wet-mesic bottomland ELTP 41 (35.2 and 6.8%, respectively) among all LTAs of the CU subsection (Table 4). In general, the dominate ELTPs were mesic ridge ELTP 13, dry slope ELTP 22, and mesic slope ELTP 24 with 35.2, 18.6, and 14.3% of the area, respectively). Post oak dominated ELTPs 10, 20, and 21 as well as cliff ELTP 30 are absent from this LTA. The mesic ridge ELTP 13 of this LTA has the largest mean area among all the LTAs (17.54 ha). This LTA has the largest mean size of ridge ELT 1 (16.46 ha). Shannon's Index of Diversity was 2.12 for ELTPs and 1.13 for ELTs (Table 5).

This LTA has the largest percentage of soils in Erosion Class 2 (36.5%), and it is the only LTA that has 0.6% of the area occupied by gullied soils (Erosion Class 5). The Area Weighted Erosion Index is 1.61 (Table 6). Dominate soil survey map units within this LTA are Adyeville-Wellston silt loams (18–50% slopes), Wellston-Adyeville-Ebal silt loams (12–18% slopes, eroded), and Wellston silt loams (6–12%, slopes, eroded) covering 16.1, 14.0, and 11.6% of the area, respectively

Table 4.—Area of Ecological Land Type Phase map units (ha and %) by Land Type Association map units of the Crawford Upland subsection (Lost River, Patoka River and Tell City units of the Hoosier National Forest).

	LTA *222De01*			LTA *222De02*			LTA *222De03*			LTA *222De04*			LTA *222De05*			LTA *222De06*		
ELTP	Area, ha	%	Mean size, ha	Area, ha	%	Mean size, ha	Area, ha	%	Mean size, ha	Area, ha	%	Mean size, ha	Area, ha	%	Mean size, ha	Area, ha	%	Mean size, ha
10	—	—	—	—	—	—	—	—	—	3	0	1.48	7	0	1.15	45	0.2	1.15
11	826	1.6	0.86	103	2.1	0.79	79	1.3	0.9	267	1.6	0.81	639	2.4	0.84	433	1.9	0.84
12	444	0.8	0.78	20	0.4	0.77	95	1.6	0.87	143	0.9	0.81	190	0.7	0.83	200	0.9	0.83
13	18,733	35.2	17.54	1,524	31.2	15.87	1,347	22.2	8.27	4,626	28	12.57	7,043	26.8	12.14	6,692	29.3	12.14
20	—	—	—	—	—	—	—	—	—	7	0	7.09	—	—	—	182	0.8	8.32
21	—	—	—	—	—	—	—	—	—	186	1.1	16.89	111	0.4	9.22	630	2.8	9.22
22	9,907	18.6	6.63	1,137	23.2	4.96	1,454	23.9	9.32	2,639	16	6.72	7,032	26.7	6.72	4,113	18	6.72
23	2,118	4	2.11	20	0.4	1.66	334	5.5	4.46	1,522	9.2	5.64	577	2.2	3.39	523	2.3	3.39
24	7,638	14.3	3.61	1,056	21.6	5.44	1,230	20.3	5.86	2,645	16	4.93	6,917	26.3	5.53	5,366	23.5	5.53
25	4,543	8.5	9.6	125	2.6	5.95	463	7.6	10.07	1,865	11.3	11.44	294	1.1	11.77	413	1.8	11.77
26	113	0.2	2.45	—	—	—	232	3.8	6.11	92	0.6	13.09	1	0	1.05	58	0.3	1.05
30	—	—	—	—	—	—	—	—	—	109	0.7	4.95	96	0.4	8.77	79	0.3	8.77
40	793	1.5	1.16	35	0.7	0.65	48	0.8	0.89	282	1.7	1.8	707	2.7	2.32	269	1.2	2.32
41	3,606	6.8	5.63	310	6.3	2.77	393	6.5	7.14	801	4.9	3.83	938	3.6	6.47	1,075	4.7	6.47
42	3,882	7.3	11.98	549	11.2	28.89	381	6.3	14.13	1,105	6.7	12.01	1,487	5.7	33.05	2,465	10.8	33.05
Water	655	1.2	0.74	12	0.2	0.15	14	0.2	0.11	208	1.3	0.34	274	1	0.59	336	1.5	0.59
Total	53,257	100	5.18	4,891	100	5.02	6,071	100	5.27	16,498	100	4.93	26,312	100	5.21	22,878	100	5.21

Table 5.—Elevation and diversity statistics of Land Type Association map units of the Crawford Upland subsection (Lost River, Patoka River and Tell City units of the Hoosier National Forest). SDI—Shannon's Diversity Index; SEI—Shannon's Evenness Index.

	LTA *222De01*		LTA *222De02*		LTA *222De03*		LTA *222De04*		LTA *222De05*		LTA *222De06*	
Elevation, m												
	Mode (Mean)	Max (Min)	Mode (Mean)	Max (Min)	Mode (Mean)	Max (Min)	Mode (Mean)	Max (Min)	Mode (Mean)	Max (Min)	Mode (Mean)	Max (Min)
	207 (209)	297 (133)	140 (179)	248 (134)	220 (199)	287 (139)	189 (182)	272 (117)	201 (191)	266 (118)	129 (171)	268 (117)
Landscape diversity												
	SDI	SEI	SDI	SEI	SDI	SEI	SDI	SEI	SDI	SEI	SDI	SEI
ELTP	2.12	0.85	1.90	0.79	2.17	0.87	2.29	0.82	1.92	0.71	2.16	0.78
ELT	1.13	0.82	1.10	0.79	1.12	0.81	1.25	0.78	1.13	0.70	1.19	0.74

(Table 4). This LTA has also other soils series derived from calcareous parent material (1.2%) such as Crider, Caneyville, and Corydon.

LTA 222De02, Chestnut Oak Dry Upland Hills: This LTA is north of the junction of the White River East Fork and the Lost River within the Lost River unit. It is characterized by *Q. prinus* dominated dry ridge and dry slope ELTPs 11 and 22. Wet-mesic ELTP 25 and calcareous mesic ELTP 26 are absent from this LTA. LTA 222De02 has a mean elevation of 179 m with the highest point at 248 m and the lowest at 134 m. It has the smallest area (4891 ha) and the highest proportion of bottomland ELTP 42 (11.2%) among all LTAs of the CU subsection. The dominating ELTPs were mesic ridge ELTP 13, dry slope ELTP 22, and mesic slope ELTP 24 (31.2, 23.2, and 21.6%, respectively). Post oak dominated ELTPs 10, 20, and 21 as well as cliff ELTP 30 and calcareous ELTP 26 are absent from this LTA. This LTA has the largest area proportion of bottomland ELT 4 (18.8%). Shannon's Index of Diversity was 1.90 for ELTPs and 1.10 for ELTs.

This LTA has the largest percentage of soils in Erosion Class 1 (78.5%) that indicates the slightest degree of soil disturbance among all the CU subsection LTAs. AWEi equals 1.24 which is the smallest within the CU subsection. Dominating soil survey map units within this LTA are Wellston-Tipsaw-Adyeville complex, 18–70% slopes; Wellston silt loam, 6–12% slopes, eroded; Apalona silt loam, 2–6% (53.0, 10.2, and 8.0% of the area, respectively).

LTA 222De03 Oak-Maple Calcareous Upland Hills: This LTA is located to the east from the Sams Creek within the Lost River unit and characterized by abundant occurrence of calcareous ELTP 26 on steep slopes along the Lost River and Sulfur Creek. This ELTP was closely associated with Caneyville-Crider rock outcrops. LTA 222De03 has a mean elevation of 199 m with the highest point at 287 m and the lowest at 139 m. It has the area of 6071 ha and the highest proportion of dry-mesic ridge ELTP 12 (1.6%) among all LTAs of the CU subsection. The dominating ELTPs were mesic ridge ELTP 13 and calcareous mesic slope ELTP 26 (22.2 and 3.8%, respectively). Post oak dominated ELTPs 10, 20, and 21 as well as cliff ELTP 30 are absent from this LTA. The dry-mesic ridge ELTP 12 and dry slope ELTP 22 of this LTA have the largest mean area among all LTAs (0.87 and 9.32 ha, respectively, Table 4). This LTA has the largest area proportion of slope ELT 2 (61.2%). Shannon's Index of Diversity was 2.17 for ELTPs and 1.12 for ELTs.

This LTA has the second largest percentage of soils in Erosion Class 2 (34.7%). AWEi equals 1.38 and is the second smallest among LTAs of the CU subsection. Dominating soil survey map units within this LTA are Adyeville-Wellston silt loams, 18–50% slopes; Wellston-Adyeville-Ebal silt loams, 12–18% slopes, eroded; Wellston silt loam, 6–12% slopes, eroded (48.6, 20.1, and 9.4% of the area, respectively). This LTA also has the highest percentage of calcareous soils series such as Crider, Caneyville and Corydon (6.1% in total).

Table 6.—Soil erosion statistics of Land Type Association map units of the Crawford Upland subsection (Lost River, Patoka River and Tell City units of the Hoosier National Forest). AWEi—Area Weighted Erosion index. Erosion class description: 1—soils that have lost on the average less than 25% of the original A and/or E horizons; 2—soils that have lost, on the average 25 to 75% of the original A and/or E horizons; 3—soils that have lost, on the average 75% of the original A and/or E horizons; 5—gullied soils.

	LTA *222De01*		LTA *222De02*		LTA *222De03*		LTA *222De04*		LTA *222De05*		LTA *222De06*	
Erosion class	Area, ha	%	Area, ha	%	Area, ha	%	Area, ha	%	Area, ha	%	Area, ha	%
1	27,177	51.0	3,844	78.5	3,867	63.7	8,539	51.7	13,444	51.1	11,947	52.2
2	19,463	36.5	896	18.3	2,106	34.7	3,286	19.9	7,085	26.9	6,213	27.1
3	5,730	10.8	150	3.1	91	1.5	4,158	25.2	5,229	19.9	4,338	19.0
5	311	0.6	—	—	—	—	—	—	—	—	—	—
Water	595	1.1	6	0.1	10	0.2	528	3.2	559	2.1	392	1.7
Total	53,277	100	4,895	100	6,074	100	16,510	100	26,318	100	22,889	100
AWEi	1.61		1.24		1.38		1.73		1.68		1.66	

LTA 222De04 Oak-Maple Wet-Mesic Dissected Plateau: Located in the northeastern corner of Tell City to the north from Mill Creek, this area is characterized by rugged terrain and steep slopes along the meandering Little Blue River and its forks. Cliff ELT and respective ELTP are typical for this LTA. Only one dry clayey ELTP 20 dominated by post oak was found in this LTA and dry clayey ELTPs 21 are very few and occur in southern tip next to the LTA 222De06 (Post Oak Dry Upland Hills) and the Ohio River.

LTA 222De04 has a mean elevation of 182 m with the highest point at 272 m and the lowest at 117 m (Table 5). It has the area of 16,498 ha and the highest proportion of wet-mesic slope ELTP 25, dry-mesic slope ELTP 23, and cliff ELTP 30 (11.3, 9.2, and 0.7%, respectively) among all LTAs of the CU subsection. The dominating ELTPs were mesic ridge ELTP 13, dry slope ELTP 22 and mesic slope ELTP 24 (28.0, 16.0, and 16.0%, respectively). The post oak dominated dry ridge ELTP 10, dry slope ELTP 21, and dry-mesic slope ELTP 23 of this LTA have the largest mean area among all CU subsection LTAs (1.48, 16.89, and 5.64 ha, respectively, Table 4). This LTA has the largest proportion of cliff ELT 3 (0.7%) and the largest mean size of slope ELT 2 (50.62 ha). Shannon's Index of Diversity was 2.29 for ELTPs and 1.25 for ELTs (both indices are highest for the CU subsection).

This LTA has the largest percentage of soils in Erosion Class 3 (25.2%) and AWEi is 1.73, which is the highest erosion index within LTAs of the CU subsection. Dominating soil survey map units within this LTA are Tipsaw-Adyeville complex, 25–75% slopes; Wellston-Adyeville-Ebal silt loams, 12–18% slopes, eroded; Apalona silt loam, 6–12% slopes, eroded and severely eroded; Wellston silt loam, 12–18% slopes, severely eroded (23.2, 12.1, and 11.8% of the area, respectively). Corydon stony silt loam, with 20–60% slopes, is also present on this LTA (1.2% of LTA area).

LTA 222De05 Mixed Oak Dry Upland Hills: This is a landscape type that represents a transition from northern part of the Crawford Upland subsection to its southern part. It is located in the east-central part of the Tell City unit between Crawford county and Perry county line in the north and Middle Deer Creek in the south. It has a wide variety of ELTPs including Cliff ELTP 30 along Jubin and Oil Creeks. Calcareous ELTP 26 and dry clayey ELTPs 10, 20 and 21 are uncommon within this LTA.

LTA 222De05 has a mean elevation of 191 m with the highest point at 266 m and the lowest at 118 m. It has the area of 26,312 ha and the highest proportion of dry slope ELTP 22, mesic slope ELTP 24, mesic bottomland ELTP 40, and dry ridge ELTP 11 (26.7, 26.3, 2.7, and 2.4%, respectively) among all LTAs of the CU subsection. The dominating ELTPs were mesic ridge ELTP 13, dry slope ELTP 22, and mesic slope ELTP 24 (26.8, 26.7, and 26.3%, respectively). Post oak dominated

ELTP 20 is absent from this LTA. The wet-mesic slope ELTP 25, mesic bottomland ELTP 40, and floodplain ELTP 42 of this LTA have the largest mean area among all the CU subsection LTAs (11.77, 2.32, and 33.05 ha, respectively, Table 4). Shannon's Index of Diversity was 1.92 for ELTPs and 1.13 for ELTs.

AWEi is 1.68 that indicates relatively high proportion of eroded area in comparison with other LTAs. Dominating soil survey map units within this LTA are Adyeville-Tipsaw-Ebal complex, 20–50% slopes, very rocky; Ebal-Deuchars-Kitterman complex, 12–24% slopes, eroded; Apalona silt loam, 6–12% slopes, eroded and severely eroded (35.9, 13.2 and 12.4% of the area, respectively).

LTA 222De06 Post Oak Dry Upland Hills: It is located within approximately 8 km of the Ohio River and characterized by frequent occurrence of post oak dominated dry clayey ELTPs 10, 20, and 21 as well as a few cliff ELTPs 30 along the Ohio River banks. LTA 222De06 has a mean elevation of 171 m with the highest point at 268 m and the lowest at 117 m. It has the area of 22,878 ha and the highest proportion of post oak dominated dry slope ELTP 21, ELTP 20, and dry ridge ELTP 10 (2.8, 0.8, and 0.2%, respectively) among all LTAs of the CU subsection. The dominating ELTPs were mesic ridge ELTP 13, mesic slope ELTP 24, and dry slope ELTP 22 (29.3, 23.5, and 18.0%, respectively). The post oak dominated dry slope ELTP 20 and cliff ELTP 30 of this LTA have the largest mean area among all the CU subsection LTAs (18.17 and 15.80 ha, respectively, Table 4). This LTA has the largest mean size of cliff ELT 2 and bottomland ELT 4 (15.79 and 21.15 ha, respectively). Shannon's Index of Diversity was 2.16 for ELTPs and 1.19 for ELTs.

AWEi is 1.66 that is similar to LTA 222De05. Dominating soil survey map units within this LTA are Adyeville-Tipsaw-Ebal complex, 20–50% slopes, very rocky; Ebal-Deuchars-Kitterman complex, 12–24% slopes, eroded; Ebal-Deuchars-Kitterman complex, 12–24% slopes, severely eroded (30.5, 17.0, and 9.9% of the area, respectively).

DISCUSSION

The delineated LTA map is a first approximation and based on spatial variability among ELTP map units, soils, and geology within the study area. However, there are several limitations that should be considered when using this map. Delineated LTA map units were analyzed only within the purchase boundary of the HNF. Therefore, boundaries can be reconsidered in the future in relation to surrounding areas and the entire subsection, as more information is obtained. In addition, all spatial information represents each LTA only within the purchase boundary of the HNF and potentially can be different for the entire LTA area beyond those boundaries. Since only a small portion of the Escarpment subsection is occupied by the Lost River and Patoka River units of the HNF, this area is considered as part of the Crawford Upland subsection. The more precise delineation of the boundary between these subsections as well as LTA delineation within that part can be done when sufficient information on ELT and ELTP classification for the Escarpment subsection is collected. This study did not reveal any significant differences in ELTP, soil or geology pattern that would justify separation of that area.

Differentiating criteria used in LTA development for the HNF in Indiana include, in general order of most frequent use, patterning of ELTPs and soil survey units, landforms, bedrock type, dominant tree species occurrence, and disturbance processes. These criteria are specific for the study area and may be different from criteria used in other regions. For example, the differentiating criteria used in LTA development in the Lake States included, in order of most frequent use: surficial geology, composition or productivity of historic vegetation, hydrology, meso-climate, patterning of ELTs and ELTPs, bedrock type, hydrography, and disturbance processes (Jordan et al. 2001). Some criteria were the same but had a different importance, while others, such as glacial features or local climatic influence ("lake effect"), were not important. In general, most LTA projects are taking the same approach with geomorphology being an overriding differentiating criterion that is refined using soil and vegetation information.

As to boundary identification, the approach used in LTA delineation for the HNF was similar to approaches used in other regions and is based on physiographic boundaries (McFarlane et al. 2002; Zastrow et al. 2002). All units are nested within the boundaries of subsequent upper and lower hierarchical units

(LTA ↔ ELT ↔ ELTP). Normally the feature with the sharpest transitions between adjacent LTAs is used to draw boundaries.

Most other regions have used a "top to bottom" approach in delineating LTAs (McFarlane et al. 2002; Nigh & Shroeder 2002), due to the scale of delineation criteria (e.g., glacial geology) and also to the fact that delineated areas were already defined as units in other classification systems in use by various agencies (e.g., soil associations of USDA Natural Resources Conservation Service). The approach used in this study was primarily based on spatial distribution of smaller ecological units with an addition of information from other resource maps of coarser scale.

The current LTA maps should be considered as an initial version that will be periodically updated. Changes in understanding of relationships between biotic and abiotic components of LTAs as well as feedback from users and availability of new GIS data will lead to future revisions of LTA definitions and boundaries.

ACKNOWLEDGMENTS

We would like to acknowledge Ken Day, supervisor of the Hoosier National Forest, Patrick Merchant and Dave Weigel for their assistance. This project was funded by USDA Forest Service.

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Manuscript received 5 December 2006, revised 11 April 2007.