An Ecological Classification System for the Central Hardwoods Region: The Hoosier National Forest

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Abstract: This study, a multifactor ecological classification system, using vegetation, soil characteristics, and physiography, was developed for the landscape of the Hoosier National Forest in Southern Indiana. Measurements of ground flora, saplings, and canopy trees from selected stands older than 80 years were subjected to TWINSPAN classification and DECORANA ordination. Physiographic and soil measurements were regressed on groundflora DECORANA scores. Strong relationships were observed between vegetation and slope aspect, soil A- horizon depth, slope position, and soil pH. The landscape was divided into ecological land units on the basis of these relationships. Twelve ecological units were identified for the Brown County Hills subsection, and fifteen units were identified for the Crawford Upland subsection of the Hoosier National Forest. These ecological units ranged from floodplain forest along large streams to dry forest on southwesterly slopes dominated by species such as blueberry (*Vaccinium vacillans*), common greenbriar (*Smilax rotundifolia*), and chestnut oak (*Quercus prinus*). This classification will aid researchers, naturalists and forestland managers as they deal with complex issues such as resource management and biodiversity.

As a result of growing pressures on forest lands to provide multiple products and amenities, there has been much recent interest in ecological classification systems (ECS) to aid in making ecologically sound management decisions. Ecological classification uses the interrelationships between components of ecosystems such as vegetation, soils, and physiography as the basis for classifying sites across the landscape (Barnes et al. 1982). On federal lands, legislation including the National Environmental Policy Act (1970), the Federal Land Policy and Management Act (1976), and the National Forest Management Act (1976) requires the use of ecological information in decision making (Barnes et al. 1982). Currently, the philosophy of the USDA Forest Service emphasizes an ecosystem approach to land management. To meet such challenges, many ecological classification systems have been developed for various regions of the United States in recent decades.

There have been several approaches to ecological site classification in the United States. The first, habitat typing, originated in eastern Washington and northern Idaho, where R. Daubenmire developed a system containing 22 habitat types (Daubenmire and Daubenmire 1968). Habitat type classifications group sites on the basis of climax or potential natural vegetation: vegetation that would be present on a site in the absence of significant disturbance (Pfister and Arno 1980). Climax vegetation was believed to integrate all of the physical and environmental variables which contribute to a site (Daubenmire 1980). Groundflora vegetation, in particular, has been useful in identifying classification units (Cajander 1926, Daubenmire and Daubenmire 1968, Coffman and Willis 1977, Barnes et al. 1982, Spies and Barnes 1985, Host 1987).

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Numerous habitat type systems have been developed. By 1977, 41 classifications were completed or in progress in the western US (Pfister 1977). Many more have been completed since, including Coffman (1980) for the northern Lake States, Alexander et al. (1986) for the Medicine Bow National forest, Wyoming, Cooper et al. (1987), who refined the work of Daubenmire and Daubenmire (1968) in northern Idaho, and Girrard et al. (1989) in South Dakota.

Classifications based primarily on climax vegetation are problematic in the eastern and central states because of the extensive disturbances which these ecosystems experienced following settlement. In the Central Hardwoods, less than one percent of the presettlement old growth forest remains (Parker 1989). Species composition is related to disturbance, chance immigration, successional stage, and other historical factors in addition to environmental site variables. Historical factors are more influential on a disturbed landscape and vegetation on such landscapes may poorly reflect site differences. Moreover, the dramatic environmental gradients associated with elevation changes and the corresponding dramatic influence on vegetation that occur in the montain regions of the west do not occur in the eastern and central states; composition differences are often more subtle.

Another approach is that of Smalley (1979, 1980, 1984) who developed forest site classification systems based mainly on physiography and soils. Woody vegetation was summarized for each classification unit or landtype; however, it is not clear whether each landtype supports a distinct vegetation community (Van Lear and Jones 1987).

Barnes et al. (1982) describe a multifactor approach to ecological classification in which vegetation and environmental data such as soils and physiography are simultaneously integrated to form ecological classification units. Such systems tend to be more accurate than those based on one component of the ecosystem alone. Systems using the multifactor approach have been developed for the Ottawa National Forest in upper Michigan (Jordan (1982), the Cyrus H. McCormick Experimental Forest in upper Michigan (Pregitzer and Barnes 1984), the Sylvania Recreation area in Michigan's upper peninsula (Spies and Barnes 1985), the Savannah River Plant in the southeastern coastal plain (Van Lear and Jones 1987), and the Kickapoo River watershed in southwestern Wisconsin (Hix 1988). A multifactor ecological classification has also been developed for the Manistee-Huron National Forest in lower Michigan (Host 1987) and systems are being developed for the Hiawatha National Forest in Michigan's upper peninsula and for the Wayne National Forest in southern Ohio.

The objective of this study was to develop a multifactor ecological classification system based on soils, physiography, and vegetation for the Hoosier National Forest in southern Indiana within the Central Hardwoods Region. This system can be used as both a research framework and as a management tool and will be applicable to adjacent public and private lands as well as to the Hoosier National Forest.

METHODS

Study Area

Southern Indiana occurs within the 100 million acre (40 million hectare) Central Hardwoods Region of the east-central United States (Clark 1989). Within the Central Hardwoods, the Hoosier National Forest is located across two of the Natural Regions of Indiana: the Highland Rim and the Shawnee Hills (Homoya et al. 1984). These Natural Regions are further divided into Subsections (Homoya et al. 1984). The Pleasant Run Unit of the Hoosier National forest is located in the Brown County Hills Subsection of the Highland Rim while the remainder of the forest is located in the Crawford Upland Subsection of the Shawnee Hills (Figure 1).

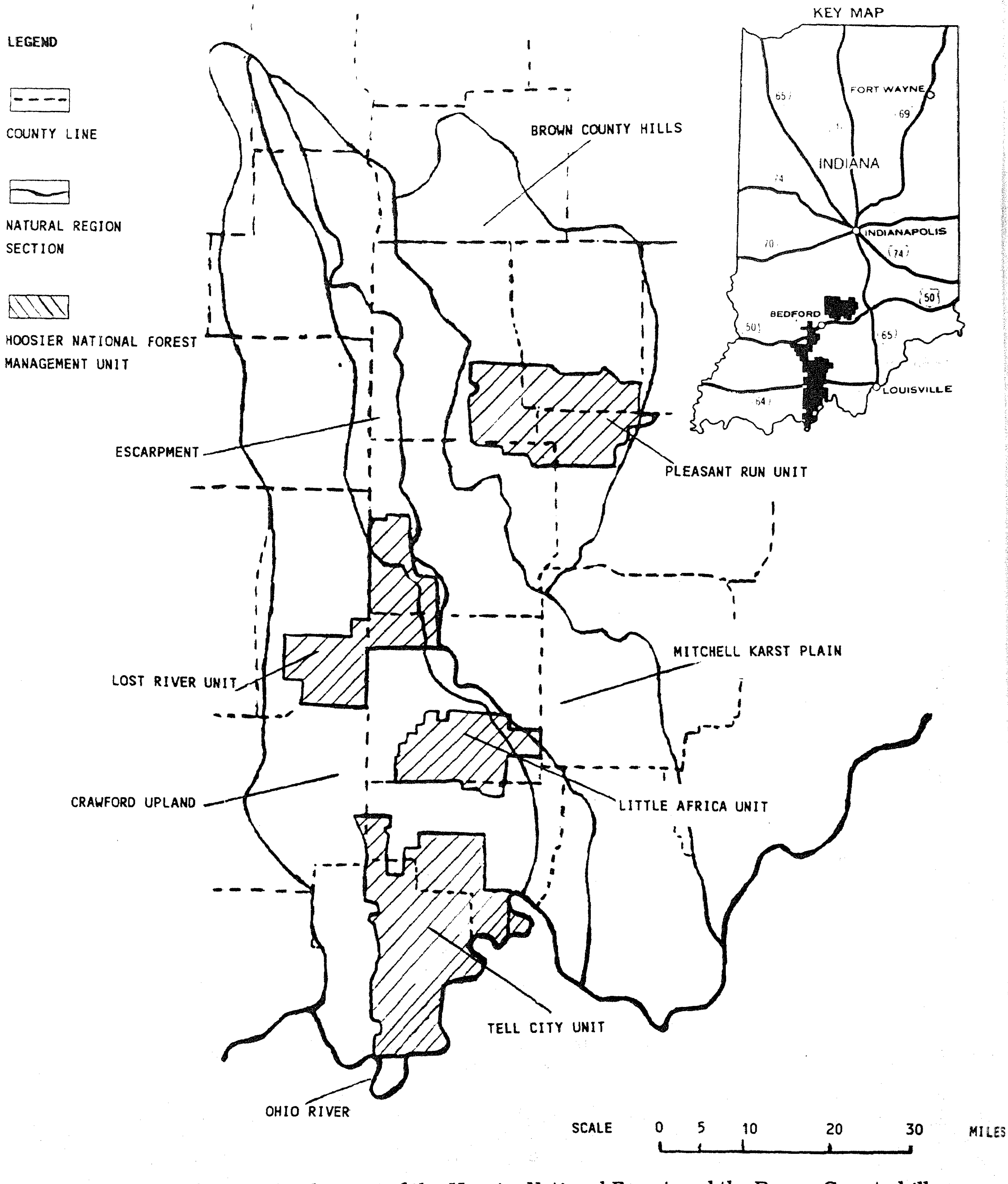

Figure 1.—A map showing the districts of the Hoosier National Forest and the Brown County hills, Mitchel Karst Plain, Escarpment, and Crawford Upland Subsections.

The Brown County Hills Subsection is underlain by mainly Mississippian age siltstones and shales. Soils are chiefly acid silt loams formed from weathered bedrock and a small amount of loess (Homoya et al. 1984). A limestone vein runs along the Mount Caramel Fault through the west side of the region. Deeply dissected uplands, steep slopes, and narrow hollows are typical topographic features of the area.

The Crawford Upland Subsection is characterized by rugged hills with acid silt loams formed in sandstone and loess, and occasional sandstone cliffs and outcrops. The eastern portion is composed of Mississippian sandstone while Pennsylvanian sandstone occurs at the higher elevations in the west (Homoya et al. 1984). While most soils are sandstone-derived, outcrops of shale and thin bands of limestone, calcareous sandstone or calcareous shale can occur throughout the section.

The Escarpment is the transition zone between the Crawford upland and the Mitchel karst plain to the east. (Figure 1). The upper slopes are similar to the Crawford Upland, but the lower areas may contain limestone-derived soils or karst topography (Homoya et al. 1984). Together, the Crawford Upland and Escarpment Subsections encompass the Lost River, Little Africa, and Tell City units of the Hoosier National Forest.

Forests were largely cleared from these landscapes in the late nineteenth and early twentieth centuries for subsistence agriculture. Currently forests cover most of the region with stands generally less than 100 years old. Much of the Brown County Hills Section is publicly owned with the Pleasant Run unit of the Hoosier National Forest, Brown County State Park and Yellowwood State Forest together providing the largest concentration of public land in Indiana.

Classification Hierarchy

The classification presented here is hierarchical, with the upper levels (Domain, Division, and Province) being derived from the ecoregions of Bailey (1989) and the Natural Regions of Indiana (Homoya et al. 1984) forming the middle levels of the hierarchy (Figure 2). The purpose of this study was to develop the lowest two ecological classification levels, the ecological unit groups and the ecological land units.

Data Collection

To minimize effects of historical disturbance on vegetation, all stands listed as greater than 80 years of age in the USDA Forest Service's VIMIS database were selected as potential sample sites. Stands were categorized into 10 land types on the basis of physiography (Table 1). Replicated stands were randomly selected from the pool of stands in each land type, plotted on USGS 1:24000 topographic maps, and field-checked for evidence of excessive disturbance. Reasons for rejection included stumps, underplanting, excessive early successional species, and excessive heterogeneity of physiography within the site. The Brown County Hills and the Crawford Upland\Escarpment Sections of the Hoosier National Forest were sampled and analyzed independently.

During the summers of 1989 to 1992, 66 and 144 stands (Table 1) were sampled in the Brown County Hills and the Crawford Upland/Escarpment Sections respectively. Four subplots were randomly established at each site (Figure 3). Each subplot included a series of nested plots for vegetation sampling. Diameter at breast height (dbh) was recorded for each tree greater than 10cm dbh on a 500m^2 circular plot, while the number of stems of shrubs and saplings less than 10cm dbh but greater than 1m high were tallied for each species in a 100m^2 circular plot. The percentage cover of groundflora species (herbs, vines, and small shrubs) in the 4m by 4m plot was estimated. Raw cover estimates were converted to an octave scale (Gauch 1982) before analysis. Tree seedlings less than 1m high were also counted on each 4m by 4m plot.

A soil pit at the first subplot and bucket augers at the remaining subplots were used to develop a

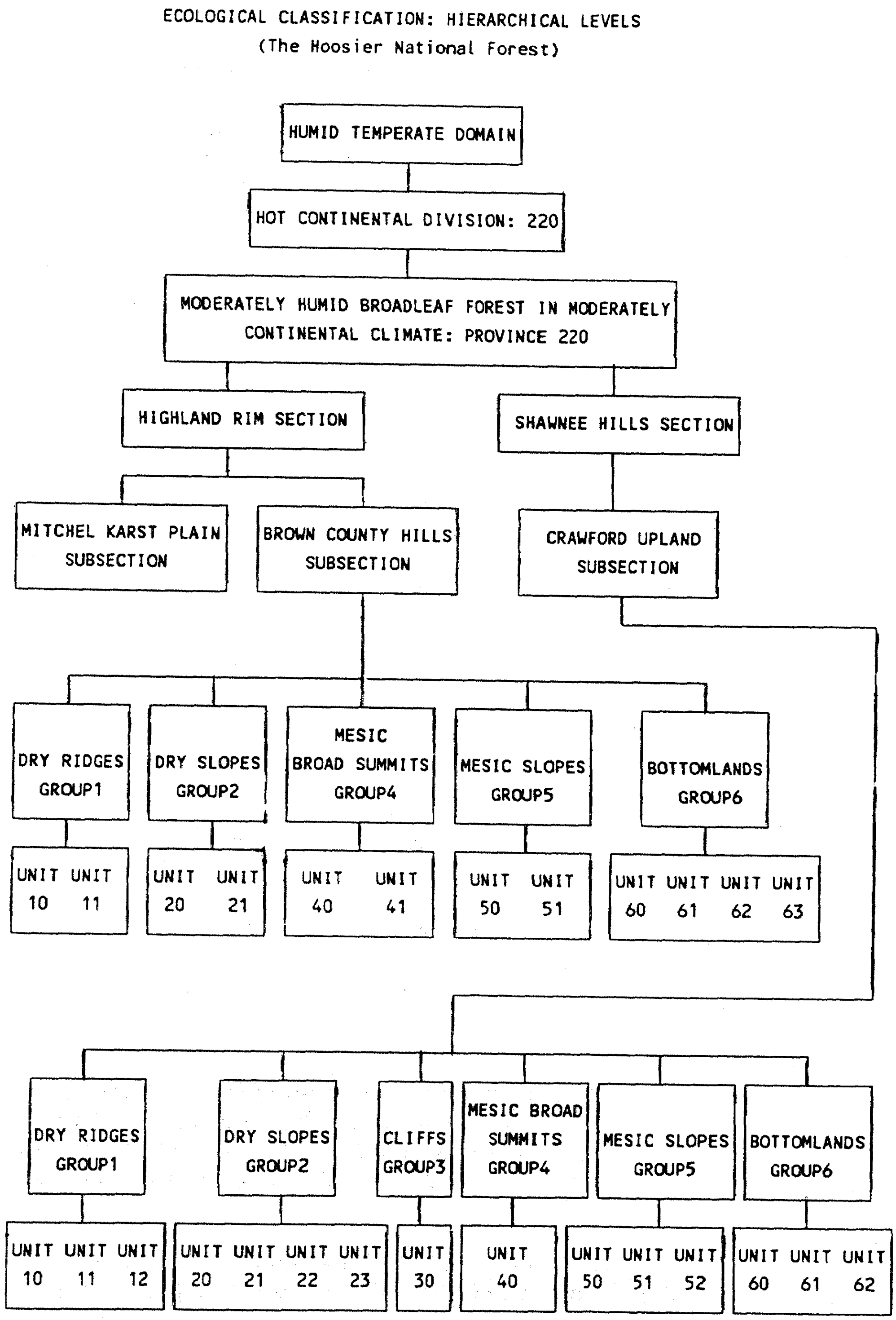

Figure 2.—Classification hierarchy for an ecological classification system of the Hoosier National Forest. The upper levels of the hierarchy (Domain, Division, and Province) derive from the ecoregions of Bailey (1989), while the middle level (Section, Subsection) derive from Homoya et al. 1984).

Table 1.—Ten landtypes based on physiography which were used to stratify the landscape for sampling. BC stands and CU stands are the number of stands sampled for each landtype in the Brown County Hills and Crawford Upland respectively.

Land type	Description	BC Stands	CU Stands
1	Narrow ridges between 30 and 150 feet in width.	12	12
2	Broad, sloping ridges > 150 ft wide, between 8 and 15 % slope.	1	10
3	Broad, flat ridges > 150 ft wide and < 8% slope.	3	4
4	Gentle slope, less than 15%.	5	13
5	Moderate northerly slope: (315° - 135°, 16-30 %.).	6	22
6	Moderate southerly slope: 136° - 314°, 16-30 %).	6	33
7	Steep northerly slope: (315° - 135°, over 30 %).	9	13
8	Steep southerly slope: 136° - 314°, over 30 %).	10	13
9	Major riparian area: (> 200 ft wide).	6	12
10	Minor riparian area: (< 200 ft wide).	8	10

detailed soil profile description. Measurements including depth of the O, A, and B horizons, the depth when present of the E, B_t, B_x, and C horizons, the depth to gray drainage mottles, the pH (tested in the field) for each horizon, the (texture estimated in the field) for each horizon, the percentage coarse fragments in each horizon, the depth of the solum to bedrock or a root-restricting layer, and parent material were recorded.

Physiographic measurements including slope gradient (in percentage), aspect (degrees azimuth), slope shape, relative slope position on a scale of 1 to 100, and elevation in meters above sea level were recorded at each subplot.

Data Analysis

The multivariate ordination technique known as Detrended Correspondence Analysis (DECORANA, Hill 1979a), an improvement of reciprocal averaging ordination, was used to arrange sites along

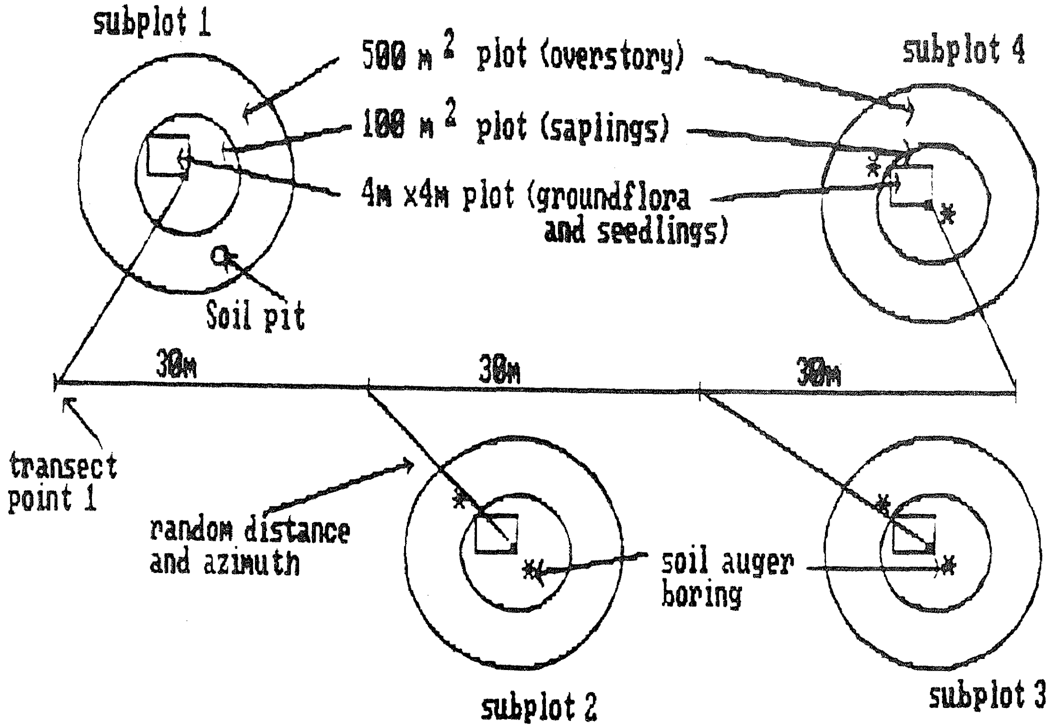

Figure 3.—A diagram of the design used to sample reference sites for an ecological classification system on the Hoosier National Forest.

two or three axes on the basis of the presence and coverage of groundflora species in each site. Sites with similar species composition are close to each other in ordination space but dissimilar sites are separate.

Two Way Indicator Species Analysis (TWINSPAN) is a divisive polythetic classification based on repeated division of a reciprocal averaging ordination space (Hill 1979b). We used TWINSPAN to group sites into classes with similar species composition and species into groups which grow on similar types of sites. These groupings produced an ordered species-by-samples table, and formed the basis for ecological species groups as in Spies and Barnes (1985). Separate ordinations and classifications were used for the groundflora and overstory layers.

Aspect was Cosine-transformed according to Beers et al. (1966) resulting in a value that ranged from 0 (southwest) to 2 (northeast). Mean values for variables relating to physiography, soil horizon development, soil pH, soil depth, and soil texture were calculated for each sample stand.

Forward stepwise multiple regression (Hintze 1988) was used to relate linear changes in the environmental variables above to each DECORANA ordination axis. This approach for integrating ordination results with environmental variables follows "strategy two" of Ludwig and Reynolds (1988).

Sample stands were classified into ecological units on the basis of the groundflora vegetation type identified by TWINSPAN, and on the basis of the soil and physiographic variables most strongly correlated with the groundflora and overstory DECORANA ordination axes.

Indicator species (species that distinguish between two choices at each step of the key) derived from TWINSPAN, species groups also derived from TWINSPAN, and the main soil and physiographic variables were used to develop a field key (Figure 5). This key was used to field-test the ECS and to determine if the relationships identified were consistent and useful in the field. The key will also be used by forestland managers to identify ecological units.

RESULTS

A TWINSPAN classification of the Crawford Upland subsection reference sites on the basis of groundflora revealed eight vegetation types. Since communities were believed to mainly occur along a moisture gradient, the types were named floodplains, moist-mesic, mesic, cliffs, moderately dry, dry oak forest, dry clay post oak forest, and dry clay oak barrens. These groups were corroborated by the DECORANA results (Figure 4). Similar results were observed for the Brown County Hills, but the cliffs, dry clay post oak forest, and dry clay oak barrens were lacking.

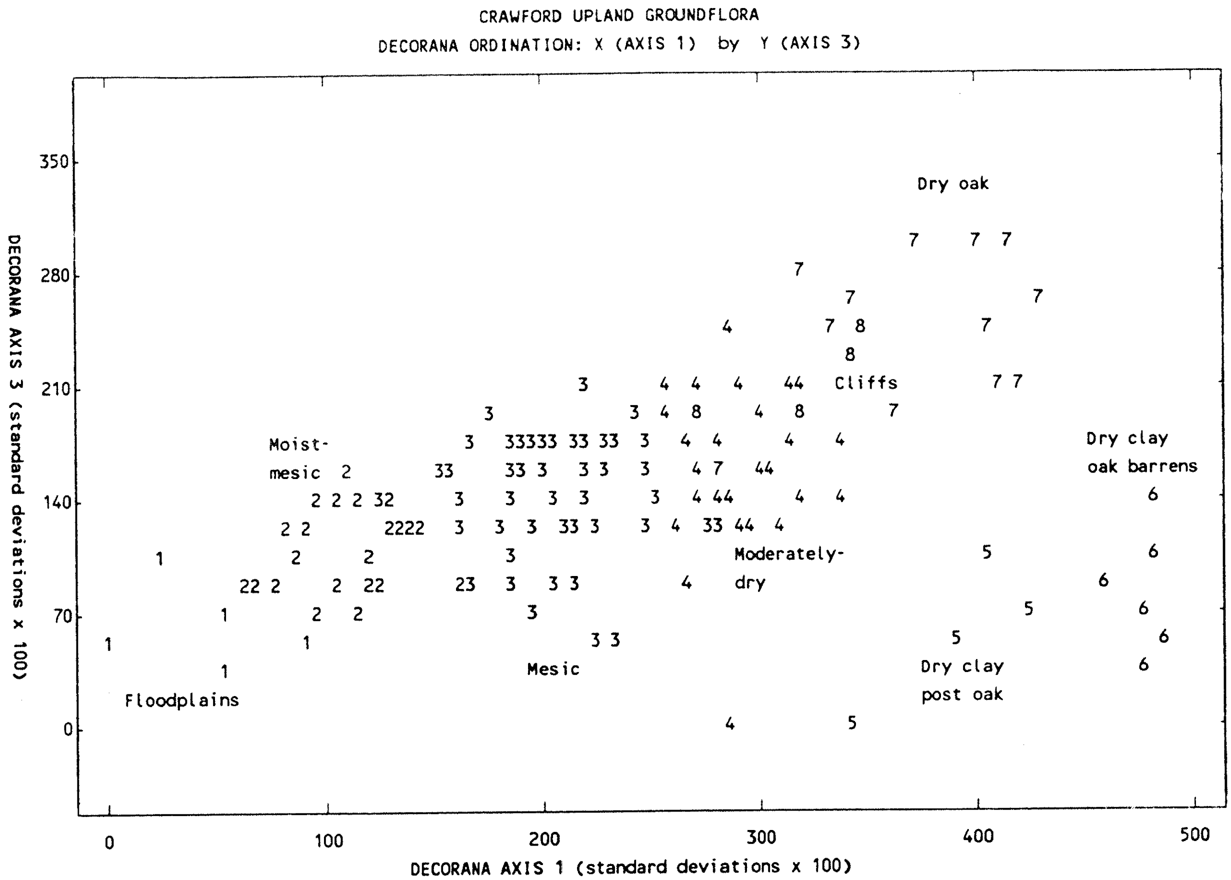

Figure 4.—The first and third axes of a DECORANA ordination of 144 stands from the Crawford Upland on the basis of groundflora. The numerals refer to classification units derived from TWINSPAN. Seven vegetation types (names) resolve on this graph, while type 8 (Cliffs) resolves on axis 2. Most of axis 2 was compressed as a result of variability associated with the cliffs and the floodplains.

Vegetation types were distinguished on the basis of species groups derived primarily from the species classification of TWINSPAN. Indicator species and species groups for the Brown County hills data set were similar for equivalent vegetation types in the Crawford Upland data set.

After selecting the site variables most correlated with axis one DECORANA ordination scores, a final stepwise regression model for the Crawford Upland included eight variables while the model for the Brown County Hills contained six (Table 2). R-squared was 0.74 for the Crawford Upland and 0.87 for the Brown County Hills. In both Subsections, the variables most correlated with axis

A KEY TO THE ECOLOGICAL LAND UNITS OF THE HOOSIER NATIONAL FOREST: KEY 1, THE BROWN COUNTY HILLS.

PART 1: KEY TO THE ECOLOGICAL GROUPS

1a) Site is located in the Brown County Hills section of the Highland Rim Natural Region (The Pleasant Run Unit of the Hoosier National Forest, Yellow wood State Forest, Morgan-Monroe State Forest, Brown County State Park or vicinity)...(2)

1b) Site is located in the Crawford Upland or Escarpment sections of the Shawnee Hills Natural Region (the Lost River, Little Africa, and Tell City Units of the Hoosier National Forest or vicinity) ...(KEY 2)

2a) Upland slope positions ...(3)

2b) Alluvial (bottomland) positions. Vegetation is variable but always mesic, moist mesic, or wet. Smilax rotundifolia is infrequent, rare or absent and dry-site indicators such as Carex picta, Vaccinium vacillans, Danthonia spicata, and Cunila origanoides are usually absent...GROUP 6: BOTTOMLANDS

3a) Summit or upper shoulder (ridgetop) slope positions. Slope gradient is not steep (<10%) ...(4)

3b) Backslope positions. Slope gradient is steeper than 10%...(5)

4a) Ridgetops generally narrower than 75m. Ridgetop is usually convex. Carex picta, Vaccinium vacillans and Smilax rotundifolia are usually common. Other members of the Carex picta ecological species group may be present ...GROUP 1: DRY DGETOPS

4b) Broad, flat ridgetops generally wider than75m. Ridgetop is flat or slightly convex with concave depressions possible. Topography may be gently rolling on larger landforms. Arisaema triphyllum, Galium triflorum, Claytonia virginiana, Osmorhiza claytoni, and Sanicula canadensis are common or abundant. Dentaria laciniata abundant. Overstory contains significant amounts of sugar maple and beech. Members of the Arisaema and Lindera ecological species groups are common...GROUP 4: BROAD MESIC RIDGETOPS.

5a) Aspect is generally southerly (135-315 degrees azimuth). Sites outside this azimuth range with the vegetation described below either have a thin A horizon or occur high on the slope. Mean soil A horizon depth is generally less than 6 cm. Carex picta, vaccinium vacillans and other members of the Carex picta group are present. Members of the Arisaema group, especially Dentaria laciniata may be present, but much less common than for 5b...GROUP 2: DRY SLOPES

5b) Aspect is generally northerly (between 315-135 degrees azimuth) or limestone is present. Mean soil A horizon depth is usually greater than 6cm. Arisaema triphyllum, Galium triflorum, Claytonia virginiana, Sanicula canadensis, Osmorhiza claytoni, and Dentaria laciniata are common or abundant. Other members of the Arisaema, Lindera, and occasionally the Asarum groups are present. Fagus grandifolia and Acer sacharum are common in the overstory of older stands... GROUP 5: MESIC SLOPES.

PART 2 :KEY TO THE ECOLOGICAL LAND UNITS

GROUP 1: DRY RI ,ETOPS

1a) Ridgetops with common or abundant parthenocissus quinquefolia. Conopholis americana is often present. Members of the Arisaema ecological species group may be present. Carex picta, vaccinium vacillans, and Smilax rotundifolia generally present but not abundant. Mean Soil A horizon depth is usually greater th 3.3 cm. ...UNIT 11: QUERCUS, ACER SACHARUM, PARTHENOCISSUS, MODERATELY DRY RIDGETOPS.

1b) Narrow ridgetops with abundant Smilax rotundifolia and Carex picta. Vaccinium vacillans, Cunila origanoides and other members of the Carex picta group are common. Members of the Arisaema group are rare or absent. Mean soil A horizon depth is less than 3.3cm. common. Quercus prinus may be dominant in the overstory...UNIT 10: QUERCUS, VACCINIUM, DRY RIDGETOPS.

Figure 5.—A field key for the Hoosier National Forest ECS which identifies ecological land units on the basis on indicato. species, soils and physiography. The first part identifies the correct section (the Brown County Hills) and identifies the ecological unit groups. The second part identifies the individual ecological units of group 1. Subsequent keys (not shown) identify the ecological units of the remaining groups.

Table 2.—Multiple linear regression models relating the dependent variable, groundflora vegetation (as summarized by DECORANA axis 1) to soil and physiographic variables for 66 stands in the Brown county Hills and for 144 stands in the Crawford Upland. (Tr aspect = cosine-transformed aspect: range 0-2, Geo = distance north of the latitude of Tobinsport, IN on the Ohio River).

	The Crawford Upland				
Independent variable	**Parameter estimate**	**t-value (b=0)**	**Prob. level**	**Sequential R-square**	**Simple R-square**
Intercept	429.078	9.01	0.000	-	-
Tr. aspect (0-2)	-44.644	-5.35	0.000	0.24	0.24
Slope gradient (%)	1.112	3.07	0.003	0.29	0.04
slope position (%)	0.977	5.87	0.000	0.50	0.29
Geo (miles)	-1.519	-5.18	0.000	0.55	0.06
A horizon pH	-38.053	-4.53	0.000	0.62	0.20
B horizon clay (%)	2.949	6.17	0.000	0.70	0.15
A horizon depth (cm)	-2.940	-2.31	0.022	0.72	0.43
B horizon depth (cm)	-0.476	-2.97	0.003	0.74	0.05
	The Brown County Hills				
Independent variable	**Parameter estimate**	**t-value (b=0)**	**Prob. level**	**Sequential R-square**	**Simple R-square**
Intercept	-6.359	-0.07	0.946	-	-
Tr. aspect (0-2)	35.872	3.76	0.000	0.11	0.11
Slope position (%)	-1.054	-4.77	0.000	0.55	0.46
Elevation (m)	-0.650	-2.17	0.034	0.67	0.47
A horizon pH	44.205	4.12	0.000	0.78	0.42
A horizon depth (cm)	10.522	4.54	0.000	0.80	0.45
Total solum depth (cm)	0.889	5.29	0.000	0.86	0.23

one were slope position, aspect, A horizon depth, and A horizon pH. B horizon clay was also correlated with axis one for the Crawford Upland. These were the main environmental variables considered when sorting the reference sites into ecological land units and in writing the field key (Figure 5).

The importance of aspect is underestimated in the models in Table 2 because these models include ridgetop and bottomland sites where the effects of aspect are negligible. For models in which only sloping lands are included, the simple r^2 for aspect is 0.40 for the Crawford Upland, and 0.43 for the Brown County Hills.

Soils on most site types were formed in sandstone or siltstone, often with a thin layer of loess. Soil textures were generally silt loams with silty clay loams in the B horizon of soils that possessed argillic horizons (Tables 4, 5). Soil texture differences were not important for distinguishing most ecological units. However, the percentage clay of the B horizon was important in the Crawford Upland for describing the contrast between sandstone cliffs, dry clay barrens and dry oak sites.

The Forest Ecosystems of the Hoosier National Forest

Six groups of ecological units (Table 3) were determined on the basis of physiographic position (whether a site was on a ridgetop, a cliff, a back-slope, or in a bottom) and on the basis of the whether a site had a mesic (type 4-7, figure 3) or a dry (type 1-3) vegetation type.

Table 3.—A list of the ecological units described for the Hoosier National Forest. (*) Units are described for the Crawford Upland and (^) the Brown County Hills only.

GROUP 1: DRY RIDGETOPS

UNIT 10: QUERCUS, VACCINIUM, DRY NARROW RIDGETOPS.
UNIT 11: ACER SACCHARUM, QUERCUS, PARTHENOCISSUS, MODERATELY DRY NARROW RIDGETOPS.
*UNIT 12: QUERCUS STELLATA, VACCINIUM, DRY CLAY RIDGETOPS

GROUP 2: DRY SLOPES

UNIT 20: QUERCUS, VACCINIUM, DRY SLOPES.
UNIT 21: QUERCUS, ACER SACCHARUM, PARTHENOCISSUS, MODERATELY DRY SLOPE
*UNIT 22: QUERCUS STELLATA, VACCINIUM, DRY CLAY SLOPES
*UNIT 23: QUERCUS STELLATA, ERYNGIUM DRY CLAY OAK BARRENS

GROUP 3: CLIFFS

*UNIT 30: ACER RUBRUM, HYDRANGEA, SANDSTONE CLIFFS

GROUP 4: MESIC BROAD SUMMITS

UNIT 40: FAGUS, ACER SACCHARUM, ARISAEMA MESIC BROAD SUMMITS
UNIT 40L: DEGRADED MESIC BROAD SUMMITS
^UNIT 41: ACER SACCHARUM, ARISAEMA-JEFFERSONIA CALCAREOUS MESIC BROAD SUMMITS

GROUP 5: MESIC SLOPES

UNIT 50: FAGUS, ACER SACCHARUM, ARISAEMA, MESIC SLOPES
*UNIT 51: FAGUS, ACER SACCHARUM, ASARUM MOIST-MESIC SLOPES
^UNIT 51: ACER SACCHARUM, JEFFERSONIA MOIST-MESIC LIMESTONE SLOPES
*UNIT 52: ACER SACCHARUM, ARISAEMA-JEFFERSONIA CALCAREOUS MESIC SLOPES

GROUP 6: BOTTOMLANDS

UNIT 60: FAGUS, ACER SACCHARUM, ARISAEMA, MESIC STREAM BOTTOMS
UNIT 61: PLATANUS, ASARUM MOIST-MESIC STREAM BOTTOMS
UNIT 62: ACER SACCHARINUM, BOEHMERIA WET BROAD FLOODPLAINS.
^UNIT 63: ACER SACCHARUM, ASARUM-BOEHMERIA MOIST BROAD FLOODPLAINS

Groups were named with a moisture term and a physiographic description. Ecological units were named for one or two potential dominant overstory species, the species group most typical of the unit, a term describing soil moisture (mesic, moderately dry), and a physiographic description (Table 3).

The numbering system of the ecological unit groups (Table 3) expresses a gradient from high position dry sites (group 1) to low position moist sites (group 6). Ecological land units have a two digit number, the first digit representing the ecological group and the second, the ecological unit within the group. Unit numbers were chosen so that similar units from the Brown County Hills and the Crawford Upland had the same number. The numbering system is patterned after the one being used for the Hiawatha National Forest in upper Michigan (E. Padley, personal communication).

Twelve ecological units for the Brown County Hills and 15 for the Crawford Upland (Table 3) were identified on the basis of the basic vegetation types such as dry or moderately dry, (Figure 4) and on the basis of the environmental variables associated with these divisions. For example, among the mesic slopes (group 5) of the Crawford Upland, unit 50 (Table 3) consists of sites that have a mesic vegetation type, generally face north of 315°- 135° azimuth, have a moderately deep mean A horizon (at least 6 cm), and an A-horizon pH which is on average greater than 5.2. Unit 51 meets all of the criteria for unit 50 but includes additional species typical of more moist situations, is restricted to northeasterly aspects, has an A horizon depth of greater than 10cm, and usually occurs low on the slope or in an otherwise sheltered location. Unit 52 also meets most of the criteria for unit 50 but also has limestone or calcareous rock layers, pH greater than 6.0 in some soil horizons, and calciphilic species such as chinkapin oak and *Jeffersonia diphylla*. Important identifying characteristics are summarized for each unit in Tables 4 and 5.

The most xeric ecosystems (units 10 and 20) usually occur on convex knobs and the ends of narrow ridges (unit 10) and on southwest-facing upper slopes (Table 4). Groundflora is low in diversity and usually dominated by *Vaccinium vacillans* and *Smilax rotundifolia*. *Carex picta* is usually abundant on these sites in the Brown County Hills, but is rare in the Crawford Upland. Soil A horizon is thin (usually <5cm) and soil pH is low (<5.0). The current overstory is usually dominated by chestnut oak and, less commonly, white oak.

The moderately dry ecosystems (units 11 and 21) are transitional between the dry and mesic sites (Tables 4 and 5, Figure 4). Although species typical of both dry sites and mesic sites may occur here, groundflora is generally dominated by species including *Parthenocissus quinquefolia*, *Galium circaezans*, and *Toxicodendron radicans* which have a wide ecological range and occur across many site types (Table 3). Slopes on unit 21 generally face south, 135-315°. Current overstory in stands older than 80 years is dominated by a mixture of upland oaks and hickories, but understory tree saplings may contain a strong component of sugar maple and beech.

The mesic ecological units (Figure 4) occur on northerly slopes, lower southerly slopes, on the sides of narrow ravines (unit 50), in a few narrow headwater bottoms (unit 60), and on broad, flat ridges (>75m wide) where they are usually associated with fragipan soils (unit 40). Groundflora contains mesic species including *Lindera benzoin* and *Arisaema triphyllum*, and several *Galium* species. With the exception of unit 40, mean soil A horizon depth is generally more than 6cm, and mean soil pH is generally greater than 5.0 (Table 4). Current overstory usually contains a strong maple-beech component as do the understory tree saplings. Mesic slopes, unit 50, is perhaps the most common ecological land unit on the landscape.

Moist-mesic sites (Figure 4) usually occur on the alluvial soils of narrow and medium sized bottoms of intermittent and perennial first to third order streams (unit 61). This vegetation type may also occur on protected northeast slopes on lower positions or benches in the Crawford Upland and locally on limestone slopes along Frog Pond Ridge in the Brown County Hills (unit 51). Soils are rich; A horizon depth is usually deeper than 9cm. The groundflora are lush and diverse. In addition to species typical of mesic sites, rich-site species such as *Asarum canadense* and *Cystopteris protrusa* are common. The overstory may contain species such as black walnut, American sycamore, American Basswood, and black cherry as well as a strong component of sugar maple and beech.

Floodplain sites (unit 62) occur on deep alluvial soils associated with the floodplains of larger, medium and low gradient streams and rivers (4th order and greater). These sites experience regular seasonal flooding. Groundflora is commonlydominated by waist-high thickets of wet-site

Table 4.—A summary of 15 ecological units for the Crawford Upland and Escarpment Sections. Summarized environmental variables include aspect, A horizon depth (A DEPTH), A horizon pH (A PH) B horizon soil texture (B TEXTURE), and slope position (POSITION). Ranges represent a 95 percent confidence interval for the mean. Soil texture includes the two most common textures observed for the unit.

Unit	Aspect	A Depth	A PH	B Texture	Position	Selected indicator species
10	None	3.2 ± 2.7	4.6 ± 0.6	SiL SiCL	Summit (narrow)	*Vaccinium vacillans, Panicum dichotomum* *Quercus prinus, Danthonia spicata*
11	None	3.8 ± 1.5	5.2 ± 0.2	SiL SiCL	Summit (narrow)	*Parthenocissus quinquefolia* *Galium circaezans*
12	None	2.2 ± 2.2	5.0 ± 0.4	SiCL SiC	Summit (narrow)	*Psoralia psoralioides* *Quercus stellata*
20	Southwest (180°-270°)	3.7 ± 0.8	4.7 ± 0.3	SiL SiCL	Backslope (Upper)	*Vaccinium vacillans, Panicum dichotomum* *Quercus prinus, Danthonia spicata*
21	South (135°-315°)	3.8 ± 1.8	5.0 ± 0.2	SiL SiCL	Backslope	*Parthenocissus quinquefolia* *Galium circaezans*
22	South (135°-315°)	2.2 ± 2.2	5.0 ± 0.4	SiCL SiC	Backslope	*Psoralia psoralioides* *Quercus stellata*
23	North (160°-290°)	2.7 ± 2.7	5.5 ± 0.4 (C-PH >6.2)	SiC C	Backslope	*Andropogon scoparius, Liatris spp* *Quercus stellata, Quercus marilandica*
30	Variable	3.5 ± 3.1	4.6 ± 0.4	LS SL	Cliff	*Hydrangea arborescens, Kalmia latifolia* *Medeola virginica, Dryopteris marginalis*
40	None	4.7 ± 1.2	5.5 ± 0.9	SiL SiCL	Summit (broad)	*Arisaema triphyllum, Osmorhiza claytoni* *Galium triflorum, Galium Concinnum*
50	North (315°-135°)	7.2 ± 1.0	5.4 ± 0.2	SiL SiCL	Backslope	*Arisaema triphyllum, Osmorhiza claytoni* *Galium triflorum, Galium Concinnum*
51	Northeast (350°-100°)	16.8 ± 2.2	5.6 ± 0.5	SiL SiCL	Backslope (Lower)	*Asarum canadense, Cystopteris protrusa* *Impatiens spp., Solidago flexicaulis*
52	Variable	8.3 ± 5.0	6.3 ± 0.3	SiCl	Backslope	*Quercus muhlenbergii, Jeffersonia diphylla* *Lithospermum latifolia*
60	None	7.7 ± 3.3	5.1 ± 0.9	SiL SiCL	Bottom (headwater)	*Arisaema triphyllum, Osmorhiza claytoni* *Galium triflorum, Galium concinnum*
61	None	11.8 ± 2.8	5.8 ± 0.4	SiL L	Bottom (minor)	*Asarum canadense, Cystopteris protrusa* *Impatiens spp., Solidago flexicaulis*
62	None	17.1 ± 5.6	6.8 ± 0.3	SiL L	Bottom (major)	*Boehmeria cylindrica, Laportea canadensis* *Acer saccharinum, Acer negundo*

Table 5.—A summary of 10 ecological units for the Brown County Hills Subsection of the Hoosier National Forest. Summarized environmental variables include aspect, A horizon depth (A DEPTH), A horizon pH (A PH) B horizon soil texture (B TEXTURE), and slope position (POSITION). Ranges represent a 95 percent confidence interval for the mean. Soil texture includes the two most common textures observed for the unit.

Unit	Aspect	A Depth	A PH	B Texture	Position	Selected indicator species
10	None	2.6 ± 1.4	4.6 ± 0.4	SiL SiCL	Summit (narrow)	*Vaccinium vacillans, Panicum dichotomum* *Quercus prinus, Danthonia spicata*
11	None	4.9 ± 2.0	5.0 ± 0.2	SiL SiCL	Summit (narrow)	*Parthenocissus quinquefolia* *Galium circaezans*
20	Southwest (180°-270°)	2.7 ± 0.7	4.6 ± 0.3	SiL SiCL	Backslope (Upper)	*Vaccinium vacillans, Panicum dichotomum* *Quercus prinus, Danthonia spicata*
21	South (135°-315°)	4.9 ± 1.6	4.9 ± 0.4	SiL SiCL	Backslope	*Parthenocissus quinquefolia* *Galium circaezans*
40	None	5.3 ± 2.7	5.2 ± 0.7	SiL SiCL	Summit (broad)	*Arisaema triphyllum, Osmorhiza claytoni* *Galium triflorum, Galium Concinnum*
41	None	6.2 ± 2.0	6.5 ± 0.4	SiCL C	Summit (karst)	*Arisaema triphyllum, Osmorhiza claytoni* *Galium triflorum, Quercus muhlenbergii*
50	North (315°-135°)	6.4 ± 1.1	5.3 ± 0.4	SiL SiCL	Backslope	*Arisaema triphyllum, Osmorhiza claytoni* *Galium triflorum, Galium Concinnum*
51	Northeast (350°-100°)	10.5 ± 1.6	6.6 ± 0.4	SiL SiCL	Backslope (Lower)	*Asarum canadense, Cystopteris protrusa* *Impatiens spp., Solidago flexicaulis*
60	None	7.5 ± 6.0	5.0 ± 0.1	SiL	Bottom (headwater)	*Arisaema triphyllum, Osmorhiza claytoni* *Galium triflorum, Galium concinnum*
61	None	12.7 ± 4.4	5.3 ± 0.4	SiL L	Bottom (minor)	*Asarum canadense, Cystopteris protrusa* *Impatiens spp., Solidago flexicaulis*
62	None	5.9 ± 2.3	6.1 ± 0.4	SiL L	Bottom (major)	*Boehmeria cylindrica, Laportea canadensis* *Acer saccharinum, Acer negundo*
63	None	6.7 ± 2.5	5.6 ± 0.3	SiL L	Bottom (major)	*Amphicarpa bracteata, Acer saccharum* *Boehmeria cylindrica, Laportea canadensis*

species including *Boehmeria cylindrica* and *Laportea canadensis*. Overstory dominants include silver maple, green ash, American sycamore, and boxelder. Tree seedlings and small shrubs are rare in many stands.

A transitional phase between ecological units 62 and 61 (unit 63, Table 3) was observed on two reference stands in the Brown County Hills. These stands occurred on major flood plains but on slightly higher elevations such as on small terraces and levies. Vegetation contained floodplain species, but also many moist-mesic and mesic species such as *Asarum canadense* and *Lindera benzoin*. The overstory contained sugar maple, beech, and lowland oaks such as pin oak as well as silver maple, boxelder, and sycamore (Table 5).

Dry clay sites (units 12, 22, and 23) occurred only in the southern portion of the Crawford Upland. Units 12 and 22 are transitional between the moderately dry ecosystems (units 11 and 21) and the true oak barrens (unit 23, Table 4). Barrens usually occur on southwest slopes on clay soils derived from shale. PH was commonly low (<5) on the surface horizons, but increased with depth to at least 6.0. Limestone fragments were occasionally observed on and in the soil. Stunted post oak and blackjack oak dominated the overstory. The barrens openings were dominated by prairie grasses and forbs including *Andropogon scoparius* and *Eryngium yuccifolium*.

Large sandstone cliffs (unit 30) were only observed in the Crawford Upland (Table 4). Soils, where present, were formed in sandstone, variable in depth, and sandy loam or loamy sand in texture. PH was on average <5.0. Mesic species occurred in the rich forest at the base of the cliffs. Species including *Hydrangea arborescens* and *Medeola virginica* were common on ledges, cracks, and seepage areas on the cliffs themselves. Dry species such as *Vaccinium vacillans* commonly occurred in the zone immediately above the cliffs. Mountain laurel (*Kalmia latifolia*) commonly occurred both in the cliff zone and in the upper dry zone. Overstory was dominated by red maple. Sugar maple, beech, tulip tree, and northern red oak were common in the lower mesic zone, while black oak, white oak, and chestnut oak were common in the upper, dry zone. Rare species including *Tsuga canadensis*, *Magnolia tripetala*, *Betula alleghaniensis*, and *Dodecatheon meadia* have also been observed associated with this ecological unit.

DISCUSSION

To the best of our knowledge, this system is the first multifactor ecological classification system proposed for the Central Hardwoods states. Previous efforts were essentially based on soils and physiography (Smalley 1979, 1980, 1984) or were from the Lake states, (Barnes et al. 1982, Hix 1988, Host 1987), or the Southeast (Van Lear and Jones 1987). The study most similar to this one was Fralish's integration of overstory composition with environmental variables including aspect, soil depth, and slope position on the Shawnee Hills National Forest in southern Illinois (Fralish 1988). However, ecological classification units derived from these relationships have yet to be published.

The Hoosier ECS has many similarities with other multifactor classifications in the eastern US, particularly in the importance of topographic position, aspect, and other variables associated with a soil moisture gradient in determining potential vegetation. A classification of 11 site units in the Kickapoo watershed in southwestern Wisconsin (Hix 1988), like the Hoosier system, separates gently sloping and ridgetop sites from steeply sloping sites. Aspect and soil parent material were important in distinguishing sloping-land ecosystems. As in the Hoosier, vegetation communities followed a moisture gradient from dry southwesterly slopes dominated by oaks and hickories to more mesic northeasterly slopes where there was a strong sugar maple component. Van Lear and Jones (1987) describe a system for the Savannah River Plant in South Carolina which is based on a gradient of topographic position and a corresponding moisture gradient ranging from xeric upland sands to wet poorly drained stream bottoms. Likewise, Barnes et al. (1982) describe an Upper Michigan classification based on a moisture gradient ranging from exposed rocky ridges to dry sandy flats to sloping lands to wetlands. Depth of soil to bedrock, soil drainage, and aspect on sloping sites are major indicators. None of these systems list soil A horizon depth, one of the main soil variables for the Hoosier ECS, as an indicator. However, A depth was important in a southern Indiana study relating the site index for black and white oak to environmental variables (Hannah 1968).

Although time and budgets did not permit us to use an independent dataset from each subsection of the forest to verify the correctness of the ecological unit classification, the Brown County Hills and Crawford Upland data sets represent independent sample data taken from landscapes with similar climate, geology, soils, and physiography. The fact that the vegetation classifications and indicator species for the two data sets were very similar and that aspect, slope position, A-horizon depth, and pH were the environmental factors most highly correlated with DECORANA scores in both cases (Table 2) provides a degree of verification for the classification.

Field testing indicated that the ECS field key (Figure 5) and the interrelationships on which it is based were generally successful identifying ecological units throughout both sections of the forest on the basis of their soils, vegetation, and physiography. When identifying units, we generally gave equal weight to the vegetation, soil, and physiographic components. Only rarely were conflicts observed between the ecosystem components while identifying units.

Field testing of ECS also revealed the strengths of a multifactor approach. While groundflora indicators generally remained common and identifiable on previously mature stands that had been selectively harvested or clearcut in recent decades, identification of units on the basis of indicators was often unsuccessful for heavily disturbed sites such as those which had been farmed, eroded, or planted to pine. Soil and physiographic indicators alone were used to classify such sites. On the other hand, variables not included in the ECS field key such as subsurface water flow could occasionally result in a vegetation type different from that expected on the basis of the known environmental factors. Since vegetation integrates site factors (Daubenmire 1980), a strong presence of indicator species and diagnostic species groups could be used to override soil and physiographic indicators in such cases. On mature sites near steady-state, vegetation can be used alone to classify ecosystems as in the habitat type approach (Jones 1989).

Many sites in the Hoosier have been severely disturbed and eroded. Since A horizon depth was strongly related to vegetation (Table 2), it is likely that eroded sites will not return to their original ecological potential for some time. The current potential for such sites is of interest. A mesic site (unit 40, or 50) for example, could be degraded to something resembling a moderately dry or dry site (ecological unit 21 or 20), or to something completely different. Since the vast majority of the broad flat ridges on the Hoosier National Forest were severely disturbed in the past, a degraded version of unit 40—unit 40L—was designated. Future refinements may describe degraded sites for other ecological units as well.

The Hoosier ECS is flexible. We expect that it will continue to evolve and be refined in response to the experience of managers, researchers, and others who use it. The current hierarchy and numbering system makes it easy to add, merge, or split units without disrupting the rest of the system. It would also be easy to add a classification of an adjacent Natural Region Section such as the Mitchel Karst plain without disrupting the hierarchy.

ECS will be useful as a management tool and could be helpful in developing silvicultural recommendations. For example, Jones (1989) described a productivity continuum associated with ecological site units in South Carolina. Although the site indexes for key species for each Hoosier ecological unit have yet to be determined, differences in productivity most likely occur among these units. Moderately dry sites (units 11, 21) would probably be better sites for a silviculturalist to attempt to regenerate upland oaks than dry sites (units 10, 12, 20, 22, 23) where productivity is low, and mesic sites (units 40, 50, 51, 52) where productivity is high but competition with tolerant hardwoods such as sugar maple is severe.

ECS can also be used to identify potential rare species habitats. Rare species including *Betula alleghaniensis*, *Magnolia tripetala*, *Tsuga canadensis*, and *Dodecatheon meadia* are generally associated with sandstone cliffs (unit 30) when they occur. Yellowwood, *Cladrastis lutea*, is known from a few steep, northerly, mesic slopes (unit 50) in the Brown County Hills. Prairie grasses and forbes (the oak barrens community), a community of concern for the southern Crawford Upland, occurs on southwesterly slopes with clay soils where pH increases with depth (unit 43). Conservationists and managers attempting to locate, manage, or restore rare species such as these should look to these units as potential sites.

ECS can also serve as a research framework. Ecological units can be used to stratify the landscape ecologically into equivalent units that one can compare for different treatment groups. For example, one could evaluate the effects of potential overbrowsing by white-tailed deer in Brown County State Park where hunting is prohibited by comparing the groundflora composition of units within the park with the composition of the same ecological units outside the park where hunting is permitted.

In the future, verification and refinement of the system and the field key will continue. Productivity differences among ecological units will also be studied. Mapping of ecological units across the landscape of the Hoosier National Forest is the next major step in the development of this ECS. Mapping will function as a form of "operational verification" of the system; verifying that these units can indeed be mapped in terms of the vegetation, physiography, and soils relationships we have described. Mapping forms the heart of classification (Barnes et al. 1982) and will provide a basis for regional landscape planning and ecosystem management. Moreover, a map of ecological land units is the first step in developing management units that are also ecological units.

A decade ago, Barnes et al. (1982) stated that multifactor ecological classification had arrived in Europe and Canada and predicted that it would come to the US. It has now reached theCentral Hardwoods region. Because of the increasing need to understand the ecosystems we manage, demand for such systems and for an understanding of the basic vegetation-soil-physiography interrelationships of ecosystems will continue to increase. This study, as one of the first efforts, can therefore serve as a model for others in this region.

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