Landscape Ecology vol. 2 no. 1 pp 45-61 (1988)
SPB Academic Publishing, The Hague

Land-use changes in Illinois, USA: The influence of landscape attributes on current and historic land use

Louis R. Iverson
Illinois Natural History Survey, Champaign, Illinois 61820 USA

Keywords: Illinois, geographic information system, landscape ecology, soil, land use, presettlement vegetation, land-use change, fractal dimension

Abstract

The Illinois Geographic Information System was used to compare the soil and landscape attributes of the State with its historic vegetation, current land use, and patterns of land-use change over the past 160 years. Patch structural characteristics among land types in four geographic zones were also compared. The assessment of patch characteristics revealed a highly modified State with most land patches controlled by human influences and relatively few by topographic and hydrologic features. Correlation and regression analyses determined the relationships of land type and abundance within each of *50* general soil associations to properties of the soil associations – typically slope, texture, organic matter, productivity index, and available water-holding capacity. The distribution of the historic vegetation of the State and its current deciduous forests and nonforested wetlands related moderately ($r^2 \geq 0.44$) to various landscape attributes. Urban and other highly modified land types were less closely related.

Introduction

The identification of the formative processes, both historical and present, that are responsible for the existing pattern of a landscape is a central theme of landscape ecology (Risser *et al.* 1984). Although both natural processes and those generated by people influence landscape pattern, in recent decades, human-generated processes have been the dominate force in determining the North American landscape pattern. The various attributes of the landscape, *e.g.*, soils, topography, microclimate, obviously played a major role in determining the natural vegetation that developed on the landscape (Major 1961). Factors influencing landscape pattern, however, behave somewhat differently, in a hierarchal manner and across varying spatial and temporal scales (Urban *et al.* 1987). Nevertheless, landscape attributes are important in explaining the human-derived land uses because naturally favorable attributes often dictate our selection of particular landscapes for a specific land use. The interaction among all of these formative processes, therefore, is responsible for the extensive heterogeneity of landscapes today (Forman and Godron 1986).

Geographic information systems (GIS) can greatly assist us in assessing relationships between land use or vegetation types (hereafter called land types) and the characteristics of the soils and overall landscape (hereafter called landscape attributes). Hett (1971) used this approach to assess land-use changes for three counties in Tennessee. Iverson and Risser (1987) used it to detect bias and assess accuracy in the wetlands records of the General Land Office for the early 1800s, and to determine land-use changes at a high level of resolution for

Table 1. Historic vegetation, current land use, and land-use changes in Illinois between 1820 and 1980.

Class, use, and change	Area (ha)	Percent of State
A. 1820 Vegetation map (after Anderson 1970)		
Forest	5,598,720	37.67
Prairie	8,760,750	58.95
Water	501.580	3.38
B. 1980 Land-use map (U.S. Geological Survey data, after Anderson 1977)		
Urban, residential	388,940	2.65
Urban, commercial	119,560	0.81
Urban, industrial	51,860	0.35
Urban, transportation	54,180	0.37
Urban, mixed	7,160	0.05
Urban, other	59,620	0.41
Cropland/pastureland	11,777,350	80.20
Orchards, groves, vineyards	9,350	0.06
Confined feeding operations	4,080	0.03
Other agricultural land	5,740	0.04
Shrub/brush rangeland (includes prairies)	4,870	0.03
Deciduous forest	1,371,080	9.34
Coniferous forest	38,520	0.26
Mixed forest	18,500	0.13
Streams and canals	25,800	0.18
Lakes	16,490	0.11
Reservoirs	123,100	0.84
Great Lakes	404,122	2.75
Forested wetlands	66,510	0.45
Nonforested wetlands	19,870	0.14
Strip mines, quarries, and gravel pits	42,950	0.29
Transitional areas	74,330	0.51
Prairies (from White 1978)	931	> 0.01
C. 1820 to 1980 change (overlay of **A** and **B**)		
Forest to agriculture	4,009,190	27.30
Forest to urban	220,540	1.50
Forest still remaining	1,069,190	7.28
Prairie to forest	388,210	2.64
Prairie to agriculture	7,767,700	52.90
Prairie to urban	455,540	3.10

several Illinois counties. Simplified access and the development of intelligent GIS systems capable of interpreting results will greatly enhance their usefulness in landscape ecology studies and in the management of natural resources (Coulson *et al.* 1987; Robinson and Frank 1987).

Illinois, in the heart of 'Corn Belt, USA' is over 80% cropland/pasture (Table 1) and has seen massive land-use changes over the past 160 years. Only 11% of its area remains in Kuchler's (1964) potential natural vegetation (Klopatek *et al.* 1979), compared to 66% for the conterminous United States. Beyond that, only 0.045%, or 7,000 ha, of its total land remains in a relatively undisturbed, natural state (White 1978). Only 19% of Illinois forests and about 0.01% of the original prairies of 1820 remain, and most of the conversions have been to agriculture (Table 1). Based on selected county evaluations, an estimated 59–72% of Illinois wetlands were also lost during this period (Iverson and Risser 1987).

Changes in land use continue to occur in Illinois. **A** change-detection process using satellite imagery for two counties in southwestern Illinois found a 12% conversion of forest to nonforest and a 7% reconversion from nonforest to forest between 1978 and 1984 (Iverson and Risser 1987). Reversals in the trend of clearing for agriculture resulting from efforts to reduce soil erosion have recently been noted (R. Oliver, Soil Conservation Service, personal communication regarding 1985 Food Security Act Conservation Reserve Program in Illinois).

The objectives of this paper are to document changes in land types over the past 160 years in Illinois, to compare them with landscape attributes, and to decipher relationships between them. In this way, we can learn more about the importance of various attributes in the creation of landscape patches and the resulting heterogeneity of the landscape. The increased understanding of the landscape will enhance our capabilities for wise management of our resources.

Methods

Geographic information system processing

All analyses were conducted using data from the Illinois Geographic Information System (IGIS), operated by the Illinois Department of Energy and Natural Resources (IDENR), and located at the Illinois Natural History Survey (INHS) in Champaign. The system resides on two Prime computers. The primary GIS software is ARC/INFO, a vector-

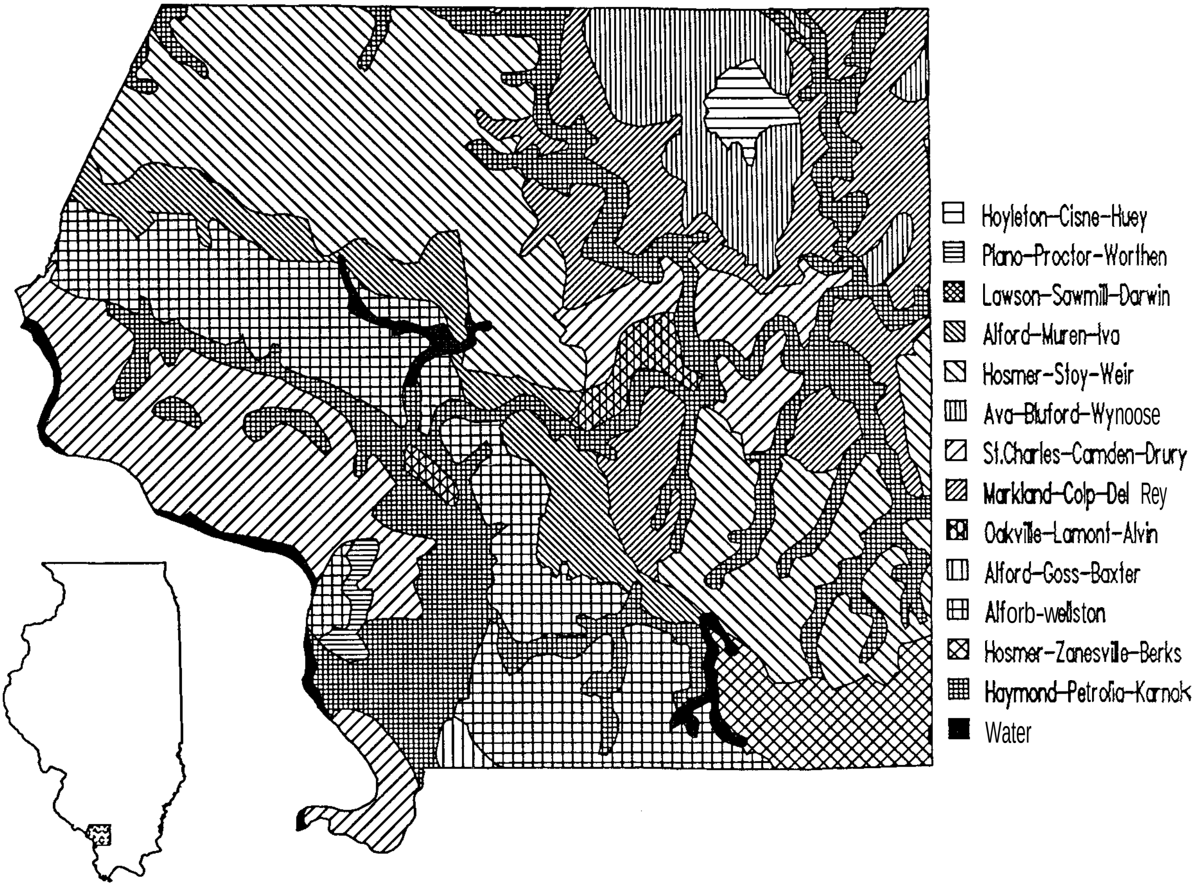

Fig. 1. General soil association map for Jackson County, Illinois. Water and 13 of the 50 soil associations found in Illinois are represented. Scale: the north-south height of the county is 39 km, and the north-south height of the State of Illinois (inset) is 640 krn.

based system developed by Environmental Systems Research Institute (ESRI) of Redlands, California. For this investigation, three statewide data sets were overlaid to provide a basis for comparing landscape attributes with historic vegetation, current land use, and changes in land use (*i.e.*, land types) over the past 160 years.

A primary statewide data set used in this analysis was a digitized version of the General Soil Association map of Illinois (Fehrenbacher *et al.* 1984), with a resolution of approximately 120 ha and a total of 2,820 polygons for the State. (The soil association map for one county is presented in Fig. 1). This data set provided the landscape attributes used in comparisons with two land type data sets: historic vegetation and current land use.

A map depicting forest and prairie distribution (historic vegetation) about the year 1820 has been published (Anderson 1970). This map had a resolution of approximately 500 ha and a total of 765 polygons; at this resolution, small forest and prairie patches could not be mapped. When this map was superimposed on the General Soil Association map, a comparison of historic vegetation and landscape attributes could be made.

The statewide soils map was also compared to present land types by overlaying it with the United States Geological Survey (USGS) Land Use Data and Analysis (LUDA) data base of current (automated from 1972 to 1980 aerial photography) land use for Illinois. With a ground resolution of 16 ha for nonurban uses and 4 ha for urban uses (Anderson 1977), and the higher resolution and more dissected nature of land types, over 53,000 polygons were represented in the LUDA data set. The combination of soils information and LUDA data al-

***Table* 2.** Soil attributes used in analysis, their abbreviations, and the range of values found across the State. Data were calculated by weighting the soil attribute by the proportion of soil series found in a particular association.

Attribute	Description	Range
S10	Percent sand, 0–25 cm (0–25 inches)	2.0–72.0
S50	Percent sand, 100–127 cm (40–50 inches)	2.0–90.0
C10	Percent clay, 0–25 cm	6.0–38.0
C50	Percent clay, 100–127 cm	9.0–51.0
AW	Available water to 152 cm, cm	12.0–33.0
OM	Percent organic matter in surface horizon	1.2– >65.0
Perm	Permeability, 1 = rapid, 6 = very slow	1.9–5.3
Drain	Natural drainage class, 1 = well, 5 = very	1.0–5.0
Solum	Thickness of **A** & B horizons, cm	66.0–152.0
PI	Productivity index, 0–160 scale	68.0–155.0
Slope	Maximum slope in association (%)	2.0–65.0

lowed us to investigate the relationships between landscape attributes and present-day land types.

When the LUDA land-use map and the historic vegetation map were superimposed, a map depicting changes in land use could be prepared as exemplified in Fig. 2 for Jackson County, Illinois. This map, prepared for the entire 14.5 million ha of Illinois, was then superimposed on the General Soil Association map to assist in analyzing the relationships between landscape attributes and the kinds of land-use changes that have occurred historically.

The thematic maps described above will have inherent (source map) and operational (encoding and GIS processing) errors because of the extreme complexity and varying scales of the original maps and because of the superimposition of maps (Berry 1987; Walsh *et al.* 1987). I attempted to minimize these errors by using and relying on sophisticated and proven vector software and the detection of map errors by State-agency personnel and a consultant firm. Nonetheless, my purpose here was to understand general landscape relationships over a large area and not to convey information about individual small parcels of land.

Landscape attributes used for comparisons with land types included percent sand and clay at two depths, available water to 152 cm (60 inches), percent organic matter, permeability, drainage class, thickness of soil solum, productivity index, and maximum slope (Table 2). Productivity index values integrate several soil characteristics and can be roughly equated to yield (bushels of corn per acre (Odell and Oschwald 1970)). Over 450 soil series are represented within the 50 soil associations in the Generalized Soil Association map of Illinois (Fehrenbacher *et al.* 1984). Since soil-attribute data are reported at the series level, association attributes were calculated by weighting the soil series attribute according to the proportion of each major soil series found within the association. The weighting procedure follows the equation

$$\text{Association attribute} = \frac{P_1 * Att_1 + P_2 * Att_2 \; \ldots + P_n * Att_n}{P_1 + P_2 \; \ldots\ldots = P_n}$$

where P_1 is the proportion of the association occupied by series #1 and Att_1 is the attribute of series #1. These calculations were made only on soil series occupying at least 8% of the association. In this way, one value for each attribute of each association was calculated for entry into the regression and correlation analyses.

Patch structural characteristics

Four LUDA quadrangles (1:250,000 scale) occupying varying physiognomic regions of Illinois and accounting for about **31%** of the land area of the State were evaluated for various patch characteristics, including patch number, size, and perimeter and fractal by land use. The Paducah quadrangle occupies the southernmost portion of the State and is the most highly forested portion including the Shawnee National Forest. The Decatur quadrangle resides in the central, highly agricultural region of the State. The Quincy quadrangle occupies a west-central position and is characterized by dissected forest-agriculture regions. The Chicago quadrangle has a very large urban component.

The ARC/INFO software, in conjunction with Minitab statistical software, was used with each of 12 land-use classes to calculate total patch number, mean patch area and perimeter, perimeter-to-area ratio, and fractal dimension according to the formula

$$\log P = 1/2\, d \log A$$

where P is patch perimeter, A is patch area, and d is the fractal dimension (Mandelbrot 1983; Gardner *et al.* 1987; Krummel *et al.* 1987). The fractal dimension was estimated by doubling the slope of the regression line betweeen log A and log P. The fractal is a measure of the complexity of patch perimeter and ranges from 1.0 to 2.0, with 1.0 representing a perfect square or circle and 2.0 representing a very complex perimeter of the same area. Krummel an3 his colleagues (1987) found that the fractal dimension of disturbed patches tended to be lower (*i.e.*, disturbed patches had smoother perimeters) relative to natural features, and that smaller patches tended to have lower fractals.

Statistical analysis

The three combinations of soil and land type (soil associations overlaid with historic vegetation, current land use, or land-use changes) were treated identically in a number of statistical analyses. Summarizations were made of each land type by soil associations, *i.e.*, the number of hectares for each soil association and land type combination were calculated and incorporated into the Systems Analysis Service (SAS) statistical software for personal computers (Systems Analysis Service Institute, Inc. 1985). Percentages of each land type were then calculated by soil association, and landscape attributes associated with that land type were matched with the appropriate land-type percentage. Correlation analyses (PROC CORR) were performed by comparing the percent of each soil association occupied by each land type to the landscape attributes. Since some attributes would not be expected to behave linearly with respect to land-use percentages, log-transformed landscape attribute data were also correlated to the percent land type occupied per soil association. Regression analyses (PROC REG) were carried out using the percentage as the dependent variable and the landscape attributes (or the log-transformed landscape attributes) as the independent variables. A stepwise regression (maximum R^2 improvement) selected the subset of variables that best related to land type.

To further assess relationships between land types and land attributes and to satisfy the assumption that independent variables are uncorrelated, principal component analysis (PROC FACTOR) was performed on the data to reduce 11 attribute variables to five principal components. These five components were then regressed to percent of each land type as before. Assessment of the correlation matrix between raw attribute data and the components allowed for biological interpretations of the components. In an additional regression analysis designed to increase accounted variance, cross-products and second and third power polynomials were added to the regression variable pool along with the original five components. Efforts were made to minimize multi-colinearity by removing highly intercorrelated variables and by using the maximum R, improvement program (PROC REG-MAXR) so that only one of a pair of correlated variables was used in the model. The maximum-attained R^2 values resulting from the best six variable models were recorded for comparison with the five factor models attained previously.

Results and discussion

The analyses summarized above clearly describe the extremely high rates of agricultural conversion in Illinois over the past 160 years (Table 1). Currently 10 million ha (69.5%) of Illinois is in cropland (U.S. Department of Commerce 1983). Seventeen of the 50 soil associations, accounting for 41.2% of the State, are now 90% or more in cropland or pastureland. Only two associations, totalling just 0.9% of the State, have less than 40% cropland or pastureland. Most of the soils in cropland yield abundant amounts of corn or soybeans during average or better rainfall years (Illinois Agriculture Statistics Service 1987). Yet, an estimated 372,250 ha have been deemed ‘marginal’, *i.e.*, they are excessively prone to erosion and should be placed into permanent vegetative cover (Illinois Department of

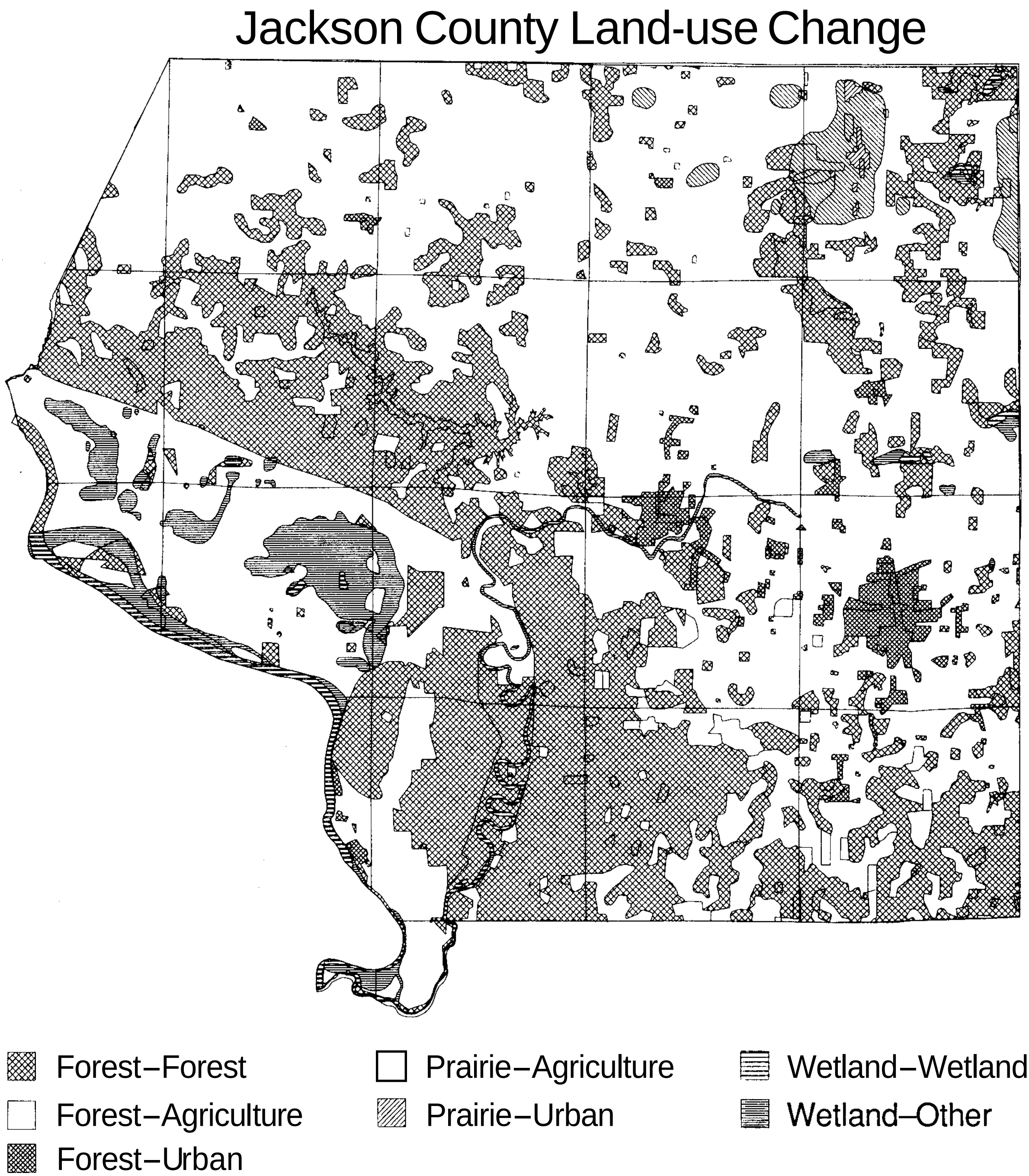

Fig. 2. Changes in land use in Jackson County, Illinois, from 1820 to 1980

Agriculture 1985). Economic factors during earlier periods contributed to excessive cropland conversions, but incentives like the federal Conservation Reserve Program are now in place and these apparently promote the reversion of marginal cropland to more permanent land covers.

Each of the 50 soil associations was found to have undergone large changes in land types during the past 160 years. These changes varied according to the landscape attributes characteristic of the soil

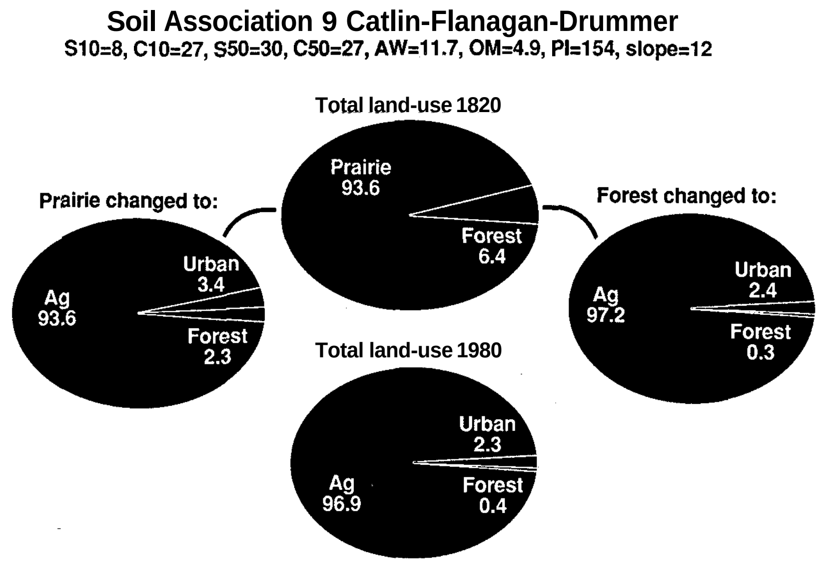

Fig. 3. Land use in 1820 and 1980 for the Catlin-Flanagan-Drummer general soil association, and the changes that occurred in the prairie and forest land during the 160-year interim. Landscape attributes for this association are also given.

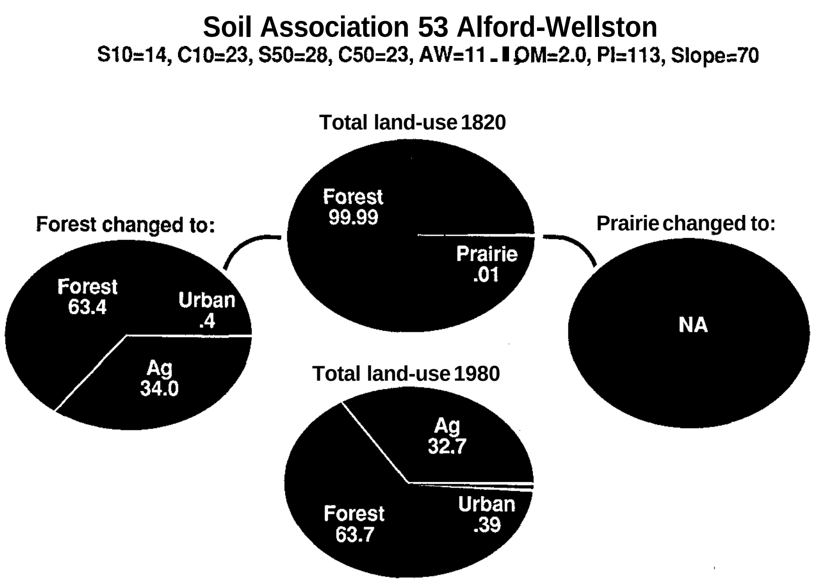

Fig. 4. Land use in 1820 and 1980 for the Alford-Wellston general soil association, and the changes that occurred in the prairie and forest land during the 160-year interim. Landscape attributes for this association are also given.

association. For example, the Catlin-Flanagan-Drummer association, a typical prairie soil from central Illinois, has characteristics highly suitable for agriculture (Fig. 3). In this case, the land forested in 1820 was largely converted to agriculture since the slope and texture characteristics provided no barriers to conversion. On the other hand, the Alford-Wellston association is found in highly sloping (up to 70°) forested regions in southern Illinois, a characteristic that tends to inhibit agricultural conversion (Fig. 4). In this case, only one-third of the land is now in agriculture. Figures can be generated for any soil association in Illinois and would generally fall between these two extremes.

Table 3. Patch attributes for four USGA 1:250,000 LUDA quadrangles in Illinois.

Land use	Percent	Patch number	Average patch size (ha)	Average patch perimeter (m)	Average perimeter/area	Fractal dimension
A Chicago (northeast Illinois); N = 2,542, area = 0.4 x 10^6 ha)						
Urban, residential	20.8	478	174.4	1,129	6.5	1.35
Urban, commercial	7.0	859	32.6	338	11.9	1.25
Urban, industrial	4.2	179	93.8	749	8.0	1.30
Urban, transportation	3.0	85	139.3	2,019	14.5	1.57
Cropland/pastureland	56.6	157	1,441.0	2,283	1.6	1.26
Deciduous forest	6.6	152	174.3	1,046	6.0	1.35
Evergreen forest	0.1	7	50.6	471	9.3	1.21
Mixed forest	0.0	1	21.7	295	13.5	–
All forest	6.6	160	167.9	1,016	6.1	1.35
All wetlands	0.6	23	96.5	730	7.6	1.28
All water bodies	0.7	106	26.3	385	14.7	1.11
Strip mines, quarries, and gravel pits	0.4	36	49.8	447	9.0	1.16
B. Decatur quadrangle (central Illinois); n = 2,660, area = 1.9 x 10^6 ha)						
Urban, residential	1.6	462	61.2	549	9.0	1.33
Urban, commercial	0.3	399	16.3	247	15.2	1.19
Urban, industrial	0.1	77	28.6	322	11.2	1.14
Urban, transportation	0.2	64	63.5	1,611	25.6	1.67
Cropland/pastureland	89.6	91	18,534.0	15,360	0.8	1.30
Deciduous forest	7.5	989	142.3	855	6.0	1.33
Mixed forest	0.0	2	59.6	466	7.8	–
All forest	7.5	991	142.2	855	6.0	1.33
All wetlands	0.0	8	92.1	743	8.1	1.42
All water bodies	0.6	124	94.1	962	10.2	1.38
Strip mines, quarries, and gravel pits	0.1	39	26.3	334	12.7	1.12
C. Quincy quadrangle (western Illinois; N = 1,678, area = 1.0 *x* 10^6 ha)						
Urban, residential	0.8	174	45.1	477	10.5	1.32
Urban, commercial	0.2	179	12.4	220	17.9	1.24
Urban, industrial	0.1	27	18.8	280	14.9	1.24
Urban, transportation	0.1	32	16.7	262	15.6	1.28
Cropland/pastureland	80.5	94	8,570.0	11,290	1.3	1.37
Deciduous forest	16.3	796	205.4	1,058	5.2	1.31
Evergreen forest	0.1	6	73.3	513	7.8	1.31
Mixed forest	0.0	1	105.6	760	7.2	–
All forest	16.4	803	204.3	1,054	5.2	1.31
All wetlands	0.6	37	166.9	1,075	6.5	1.34
All water bodies	1.3	106	124.9	1,342	10.8	1.48
Strip mines, quarries, and gravel pits	0.0	21	12.5	216	17.2	1.04
D. Paducah quadrangle (southern Illinois; n = 3,911, area = 1.2 x 10^6 ha)						
Urban, residential	1.3	411	35.3	395	11.2	1.27
Urban, commercial	0.4	211	19.4	267	13.7	1.12
Urban, industrial	0.2	109	22.3	287	12.8	1.07
Urban, transportation	0.3	57	62.5	1,047	16.7	1.59
Cropland/pastureland	66.8	432	1,777.0	4,120	2.3	1.30
Deciduous forest	23.6	1,254	216.5	1,119	5.2	1.27
Evergreen forest	1.4	284	55.0	505	9.2	1.20

Table 3. Cont

Land use	Percent	Patch number	Average patch size (ha)	Average patch perimeter (m)	Average perimeter/ area	Fractal dimension
Mixed forest	1.0	236	50.7	472	9.3	1.25
All forest	26.0	1,774	168.6	934	5.5	1.27
All wetlands	2.0	235	99.1	739	7.5	1.22
All water bodies	2.2	266	96.4	949	9.8	1.37
Strip mines, quarries, and gravel pits	0.8	97	98.0	633	6.5	1.05

Patch structural characteristics

Comparisons of patch characteristics among four regions of Illinois reveal distinct variations. Urban patches, not surprisingly, were much greater in size and number in the Chicago region than in the other regions (Table 3). The average size of Chicago residential patches, for example, were 3 to 5 times those of downstate urban regions. This difference is also reflected in the perimeter-to-area ratio and in the fractal data: the larger patches tended to have somewhat more complex perimeters but smaller perimeter-to-area ratios than the smaller downstate patches. Krummel *et al.* (1987) showed that smaller patches tend to have lower fractal dimensions. Many smaller cities in downstate Illinois have zoned off small rectangular blocks for commercial and industrial development, and these areas have very low fractal dimensions; residential areas, on the other hand, were larger and had more irregular-shaped patches as indicated by the higher fractal dimension.

The transportation category (also including communication and utilities) was characterized by high perimeter-to-area ratios and high fractal dimensions (Table 3). Only the larger road networks are resolved at the 1:250,000 scale of mapping typical of LUDA, and these tend to be concentrated in urban regions into complex, narrow (high amount of edge), ‘spaghetti’ networks.

Cropland/pasture was the dominant land use in all four quadrangles and was most often the matrix within which all other polygons were islands. This finding was especially true in the Decatur quadrangle, where 89.6% of the land fell in that category and the average size for cropland polygons was huge (Table 3B). Because of this extraordinarily large polygon size, the perimeter-to-area ratios were extremely small.

When all forest classes were considered together, little variation in fractal dimension was found across quadrangles (1.27–1.35; Table 3). Forest patch size and density were greatest in the Quincy and Paducah quadrangles, where percent forest exceeded 16%. Of the three forest classes (deciduous, evergreen, and mixed), deciduous patches had much lower perimeter-to-area ratios and somewhat higher fractal dimensions relative to the other forest classes. These findings suggest that deciduous forests had more irregular boundaries. Most of the evergreen patches found in these areas were pine plantations planted from 1930 to 1950 on abandoned agricultural land. They were quite small in size and quite regular in shape, conforming to the zones where loess material was sufficiently deep on the uplands.

The Quincy quadrangle contained the highest average size of wetlands and water bodies because it encompasses portions of the very large Illinois and Mississippi rivers, as well as the many backwater lakes and wetlands in the floodplains (Table 3C). The Paducah quadrangle, on the other hand, has the highest density and overall percentage of wetlands and water bodies (Table 3D); remnant cypress swamps and floodplains along with high numbers of reservoirs and small farm ponds are responsible. The fractal dimensions of wetlands and water bodies tended to be relatively high since these habitat types often conform to natural, irregular boundaries rather than to human-dictated boundaries. The Chicago water bodies, which were dominated by much smaller and more regular-shaped glacial lakes, are the exception.

Surface mines, quarries, and gravel pits had the lowest fractal dimension of all land uses, with the exception of urban commercial and industrial land use in a couple of instances (Table 3). Land uses having very high human modification such as these tend to have very regular perimeters.

Mandelbrot (1977) indicated that land types controlled by topographic and hydrological patterns (as opposed to human-influences) could produce fractal dimensions greater than 1.5. Such dimensions would be expected for unmodified land types like forested wetlands or deciduous forest. Although wetlands and water fractals sometimes approaches 1.5, no forest type came close to that level of complexity (Table **3).** In Illinois, the low fractal dimensions of forests also reflect human impact. Forest perimeters are often straight lines adjacent to agricultural land. The complex 'natural' boundary does not exist, thus providing a lower fractal dimension. Only the transportation category, with its winding-road networks, exceeded fractals of 1.5. These values again confirm the tremendous amount of landscape modification produced by humans in all parts of Illinois.

Generally, fractal dimensions ranged from very low values on small, highly manipulated land parcels (surface mines, commercial or industrial districts) to intermediate on cropland or forest types, which have their boundaries influenced by a combination of natural and human phenomena, to high for wetlands and water bodies, which are generally more influenced by natural features, and finally to transportation networks, which have quite high fractals because of the 'spaghetti' nature of the networks resolved by the LUDA data.

Correlation analysis

Correlation analysis between the percent of each soil association in a land type and the attributes (or the log transformations of the attributes) of the landscape revealed an assortment of significant relationships (Table 4). In most but not all cases, the use of log-transformed attribute data strengthened the relationship slightly; however, the data are not presented since the transformed data yielded little additional information.

Because the 1820 map has only two vegetation classes, the correlation coefficients are the same (with opposite sign) (Table 4A). Organic matter percentages were highly correlated to the historic vegetation type, an indication of the direct effect of vegetation on soil formation. For example, the fibrous roots of prairie vegetation greatly increase organic matter content and soil productivity (Jenny 1941). Maximum slope in the association positively correlated highly with forested landscapes. Again, this finding is logical because dissected regions would be more sheltered against large fires sweeping across the plains (Burton *et al.* 1988). The positive correlation of historic prairies to the productivity index for crops is indicative of the fertile, organically rich nature of soil formerly in prairie vegetation.

Recent land uses, as ascertained from the LUDA data, are also correlated to certain attributes (Table 4B). Urban land categories have few statistically significant relationships to landscape attributes. At the broad scale permitted by the coarse resolution of the soil associations over the entire State, urban land uses occurred regardless of landscape characteristcs. Proximity to surrounding urban areas had an overriding influence in urban development because significant positive correlations were found between percent of urbanized land and the percentage of sand near the surface, as were negative correlations to solum thickness and available water (Table 4B). These correlations reflect the concentration of urban areas in the well-drained sandy soils of the Chicago-Lake Michigan region.

Cropland/pastureland percentages within each soil association correlated positively with productivity index and organic matter and negatively with slope. These correlations relate to the nearly 100% conversion of historic prairie to agriculture. These fertile and level prairie soils were ideally suited to agriculture following the development of the self-scouring plow in 1837. By 1870, nearly all prairie lands in Illinois had been converted to agriculture (Telford 1926).

Table 4. Correlation coefficients between the percentage of land-use type or change and landscape parameters over all of Illinois. See Table 2 for explanation of variables.

Class/Use/Change	S10	S50	C10	C50	**AW**	Solum	P1	Perm	Drain	OM	Slope
A. 1820 Vegetation map											
Forest	−0.01	−0.07	−0.27	−0.05	0.09	0.05	−0.43**	0.06	−0.24	−0.55**	0.50**
Prairie	0.01	0.07	0.27	0.05	−0.09	−0.05	0.43**	−0.06	0.24	0.55**	−0.50**
B. 1980 LUDA map											
Urban, residential	0.31*	0.22	−0.14	−0.06	−0.23	−0.34*	−0.27	−0.03	−0.04	0.03	0.01
Urban, commercial	0.31*	0.20	−0.08	0.00	−0.27	−0.36**	−0.24	0.01	−0.01	0.06	−0.05
Urban, industrial	0.23	0.24	−0.05	0.06	−0.30*	−0.21	−0.23	0.00	0.00	0.14	−0.14
Urban, transportation	0.33*	0.24	−0.11	−0.05	−0.25	−0.24	−0.16	−0.07	0.07	0.13	−0.21
Cropland/pastureland	−0.22	−0.11	0.22	0.15	0.09	0.15	0.52**	0.01	0.26	0.35*	−0.44**
Deciduous forest	0.00	−0.07	−0.10	−0.10	0.07	0.05	−0.35*	0.04	−0.27	−0.45**	0.52**
Coniferous forest	−0.02	*0.00*	−0.08	−0.09	−0.16	0.05	−0.35*	0.14	−0.06	−0.30	0.08
Forested wetlands	−0.02	−0.16	−0.10	−0.02	0.10	0.09	0.14	0.16	0.33*	0.05	−0.39*
Nonforested wetlands	−0.04	0.05	−0.47**	−0.32	0.46**	0.34*	−0.14	−0.44*	0.24	0.69**	−0.15
Strip mines, quarries, and gravel pits	0.12	0.25	−0.07	−0.14	−0.14	0.04	−0.31*	−0.05	−0.32*	−0.23	0.19
C. 1820–1980 Change											
Forest to agriculture	−0.19	−0.09	0.18	0.16	0.05	0.13	0.48**	0.05	0.26	0.28*	−0.42**
Forest to urban	0.35*	0.27	−0.11	−0.09	−0.25	−0.34*	−0.22	−0.08	−0.01	0.14	−0.06
Forest remaining	−0.02	−0.10	−0.08	−0.10	0.08	0.03	−0.35*	0.04	−0.29*	−0.44**	0.51**
Prairie to forest	0.09	−0.05	−0.29*	−0.08	−0.03	−0.10	−0.45*	0.07	−0.09	−0.50**	0.45**
Prairie to agriculture	−0.17	−0.12	0.21	0.13	0.10	0.16	0.42**	−0.04	0.19	0.31	−0.29*
Prairie to urban	0.32*	0.23	−0.14	−0.03	−0.28*	−0.38**	−0.30	−0.01	−0.05	0.01	−0.01

* = $P \leq 0.05$. ** = $P \leq 0.01$

Deciduous forest percentages were negatively correlated to organic matter and productivity index, and positively to slope (the inverse of cropland/pastureland relationships). Basically, nearly all arable lands have been converted to agriculture, and only highly sloping and/or infertile lands remain uncultivated and forested. Most of the coniferous forests in Illinois are plantations that were established largely on abandoned and fairly level upland farmland in the southern part of the State. They are also negatively related to the productivity index and to organic content.

Forested wetlands are found generally on poorly drained, nonsloping landscapes, and this relationship explains the significant correlation coefficients (Table 4B). The percentage of nonforested wetlands in each soil association was found to be positively correlated with available water, solum thickness, improved permeability and organic content and negatively correlated with the percentage of clay. The correlations with increasing permeability of the soil along with high available water reflects the occurrence of marshes on deep sand and peat soils, especially in the northeastern part of Illinois. Negative correlations of surface mines, quarries, and gravel pits with drainage class and productivity index reflect the excessively drained and infertile features of these sites.

Changes in land use since 1820 were assessed by comparing the percent of each soil association undergoing a particular conversion to the landscape attributes (Table 4C). The disappearance of forest has similar explanations as reported for current cropland, deciduous forestland, and urban uses, and these explanations are reflected in the correlations. Conversion of prairie to forest between 1820 and 1980 naturally occurred in Illinois in the absence of fire (Risser *et al.* 1981). **As** shown in the correlations, conversion occurred primarily on soils low in fertility and organic matter with high slope

Table 5. Regression results comparing the percentage of each land type or change in each soil association to landscape attributes. Based on 50 soil associations. See Table 2 for explanations of variables.

Class	Average percent per association	R^2	Regression equation (in order of entry)
A. Historical vegetation of Illinois			
Forest	43.8	0.61***	78.9 – 12.4 (OM) + 7.7 **(AW)** – 0.7 (PI) + 0.14 (Slope)
Prairie	56.2	0.61***	21.1 + 12.4 (OM) – 7.7 **(AW)** + 0.7 (PI) – 0.14 (Slope)
B. Current land use (1980)			
Residential	3.9	0.22**	18.4 – 0.19 (Solum) + 1.2 (OM) – 0.08 (PI)
Commercial	1.2	0.24**	6.1 – 0.07 (Solum) + 0.4 (OM) – 0.03 (PI)
Industrial	0.5	0.25**	2.5 + 0.3 (OM) – 0.14 **(AW)** – 0.01 (PI)
Transportation	0.4	0.17*	0.4 + 0.01 (S10) – 0.01 (Slope)
Cropland/pastureland	79.8	0.39***	38.5 + 0.48 (PI) – 2.9 **(AW)** – 0.18 (Slope) + 0.41 (Solum)
Deciduous forest	10.5	0.44***	15.6 + 2.4 **(AW)** – 3.5 (OM) – 0.20 (PI) + 0.17 (Slope)
Evergreen forest	0.5	0.30*	6.1 – 0.04 (PI) – 0.10 (C50) – 0.03 (S50) + 0.10 (C10)
Mixed forest	0.4	0.10	1.7 – 0.01 (PI)
Forested wetlands	0.4	0.25*	0.9 – 0.02 (Slope) + 0.25 (Drain) – 0.17 (OM)
Nonforested wetlands	0.3	0.83***	0.9 + 0.34 (OM) – 0.03 (PI) + 0.18 **(AW)** + 0.01 (S50)
Strip mines, quarries, and gravel pits	0.5	0.21*	1.1 – 0.19 (Drain) – 0.01 (PI) + 0.02 (Solum)
C. Land use change (1820–1980)			
Forest to urban	6.5	0.28**	27.4 + 2.33 (OM) – 0.32 (Solum) – 0.12 (PI)
Forest to agriculture	77.8	0.38***	40.1 + 0.46 (PI) – 3.05 **(AW)** – 0.16 (Slope) + 0.41 (Solum)
Forest to forest	13.5	0.44***	19.2 + 2.6 **(AW)** – 3.58 (OM) – 0.22 (PI) + 0.17 (Slope)
Prairie to urban	7.1	0.25**	35.7 – 0.37 (Solum) – 0.16 (PI) + 2.13 (OM)
Prairie to agriculture	80.5	0.26*	20.1 + 0.58 (PI) – 3.24 **(AW)** + 0.57 (Solum)
Prairie to forest	6.7	0.45***	43.1 – 0.16 (S50) – 0.18 (PI) – 0.21 (C50) – 1.67 (OM)

* = $P \leq 0.05$, ** = $P \leq 0.01$, *** = $P \leq 0.001$

angles and with small amounts of clay near the surface. Conversely, prairie conversion to agriculture occurred on landscapes characterized by level terrain, high productivity indexes, and high organic content. Conversion to urban uses were most prevalent on sites with sandy, shallow soils and lower productivity.

Regression analysis

Regression analysis further described relationships between landscape attributes and land types. Regression models were built from the raw attribute data (which had some intercorrelation among variables) and from five principal components of the data. Since the best variables were selected for maximum R^2 improvements, the number of variables entered into the selected model varied. Even though R^2 values were generally low, all models were significant at the 0.05 level except for mixed forest (Table 5A). These results indicate limited predictability for most land types at any particular point on the landscape; when scaled-up to the level of the entire State, however, the relationships hold fairly well, as indicated by the high level of significance for most of the regression equations (Table 5). Productivity index, organic matter, and available water were the most common variables entering into the raw-data models. Available water and solum thickness were common variables so that they were providing new information to the models, even though they generally did not individually correlate well to the land-type percentages (Table 4). The land type predicted most accurately was current nonforested wetlands with an R^2 of **0.83**

Table 6. Correlations to the first five factors resulting from principal component analysis

Abbreviated definition	Factor 1[a]	Factor 2[b]	Factor 3[c]	Factor 4[d]	Factor 5
S10	–0.80	0.22	0.31	0.19	0.00
C10	0.51	–0.65	0.17	–0.38	0.17
S50	–0.83	0.30	0.29	–0.13	0.16
C50	0.44	–0.71	0.09	–0.04	–0.51
AW	0.67	0.56	–0.42	0.02	0.01
SOL	0.60	0.45	–0.39	0.16	0.02
PI	0.68	0.32	0.16	–0.49	0.26
Perm	0.38	–0.79	0.10	0.29	0.33
Drain	0.72	0.10	0.28	0.55	0.14
OM	0.54	0.56	0.39	–0.09	–0.25
Slope	–0.43	–0.30	–0.72	–0.06	0.04
% Variance	38.0	25.0	12.0	8.0	5.0

[a] High productivity
[b] Rapidly permeable
[c] Low water availability and nonsloping
[d] Low productivity
[e] Unclear definition

related to organic matter, productivity index, available water, and sand fraction at a depth of 1 m. The remaining wetlands in Illinois are obviously on specific sites with a close relationship to the attributes of those sites.

Equations for the historic vegetation types had high R^2 values with the variation accounted for by organic matter, available water, productvity index, and slope. These close relationships are expected from the simple correlations and they accurately reflect the interdependence of soil characteristics and vegetation types. Two major factors not included in these analyses were the impact of fires (natural or set by Native Americans) and the temporal-spatial variations of climate. Manual inspection of General Land Office maps for Illinois commonly reveals wider riparian forest strips on the leeward (eastern) side of streams, indicating greater advancement of fire on the windward (westward) sides. A close relationship between fire occurrence and proximity to stream valleys and other topographic fire barriers has been shown for other vegetation types (Givnish 1981). Inclusion of these variables would undoubtedly increase the variance accounted for in the regression models.

Other dependent variables with R^2 values above 0.35 included current cropland/pastureland and current deciduous forest (Table 5B), and changes in land use from forest to agriculture and from forest to forest (Table 5C). Obviously, a very high correlation was found between current forest or cropland/pastureland and the land-use change equivalent because almost all of current forest was historically forested as well. Similar to simple correlations, the positively correlated variables for forest tended to be negatively correlated for cropland, and *vice-versa.* The R^2 values would be expected to be higher in general if landscape position (proximity to water, etc.) were factored into the equations.

The principal component analysis resulted in the calculation of five noncorrelated factors from the 11 variables; these five accounted for a total of 88% of the variance (Table **6).** Analysis of the resulting correlation matrix facilitated assigning attributes to the factors: Factor 1 was highly correlated to many of the variables and was related to high productivity and high water-holding characteristics (low sand, high clay, high organic matter, deep solum thickness, poor drainage; hereafter called high productivity); Factor *2* was associated with rapidly permeable and low clay fraction sites that nevertheless had sufficient available water and organic matter (rapidly permeable); Factor 3 pertained to nonsloping sites with shallow, sandy soils having low water availability (low water availability and nonsloping); Factor 4 related to sites with very low productivity

Table 7. Regression results predicting percent in particular land uses based on the first five principal components. The R^2 shown in the right-hand column pertains to the R^2 attained from the best six-variable model which included the second and third polynomials and cross-products of the five factors.

Class	R^2	Regression model (in order of F inclusion)	R^2
A. Historical vegetation of Illinois			
Forest	0.55***	43.8 – 19.62 (3) + 8.43 (4) – 7.16 (1) – 4.67 (2)	0.63***
Prairie	0.55***	56.2 + 19.62 (3) – 8.43 (4) + 7.16 (1) + 4.67 (2)	0.63***
B. Current land use (1980)			
Residential	0.12*	3.9 – 1.36 (1) + 1.21 (3)	0.35**
Commercial	0.15*	1.2 + 0.54 (3) – 0.40 (1)	0.34**
Industrial	0.17*	0.5 – 0.32 (3) + 0.20 (5)	0.29*
Transportation	0.22**	0.4 + 0.17 (3) – 0.08 (1) + 0.07 (4)	0.27*
Cropland/pastureland	0.31***	79.8 + 5.91 (1) + 5.72 (3) – 3.75 (4)	0.43***
Deciduous forest	0.40***	10.5 – 7.66 (3) – 2.70 (1) – 1.95 (2)	0.46***
Evergreen forest	0.08	0.5 – 0.29 (2)	0.54**
Mixed forest	0.13	0.4 – 0.21 (1) – 0.18 (3)	0.40**
Forested wetlands	0.14	0.4 + 0.28 (3) + 0.15 (4)	0.42*
Nonforested wetlands	0.72***	0.4 + 0.54 (2) + 0.44 (5) – 0.28 (4)	0.90***
Strip mines, quarries, and gravel pits	0.12	0.5 – 0.16 (1) – 0.12 (3)	0.36**
C. Land use change (1820–1980)			
Forest to urban	0.18**	6.49 + 2.52 (3) – 1.88 (1)	0.38**
Forest to agriculture	0.26**	77.8 + 5.42 (3) + 5.13 (1) – 2.91 (4)	0.40***
Forest to forest	0.41***	13.3 – 8.02 (3) – 2.67 (1) – 2.14 (2) + 1.29 (4)	0.45***
Prairie to urban	0.15*	7.1 – 2.63 (1) + 2.43 (3)	0.35**
Prairie to agriculture	0.19*	80.6 + 6.37 (1) – 4.73 (4) + 4.72 (3) + 2.08 (2)	0.28*
Prairie to forest	0.44***	6.7 – 3.37 (3) + 2.83 (4) – 1.99 (1) – 1.20 (2)	0.52***

* = $P \le 0.05$, ** = $P \le 0.01$, *** = $P \le 0.001$

and poor drainage (low productivity); and Factor 5 was difficult to characterize and provided no clear definition, but featured lower subsoil clay and lower organic matter at the surface (unclear definition) (Table **6).**

The five principal components were then used as dependent variables for regressions predicting percent of land use, with resulting R^2 and equations calculated (Table 7). The R^2 values, except for transporation and mixed forest, were lower with the principal components compared to those using attribute or log of the attribute data (Tables 5 and 7). However, inclusion of the second- and third-power polynomials and the cross-products (interactions) of the factors resulted in regression models predicting substantially higher amounts of variance. However, the resultant complex equations were nearly impossible to interpret and are not presented here. Natural features (wetlands, deciduous forest, original forest and prairie) had higher associations with the landscape than did nonnatural land types like mines and urban areas. These results also draw attention to the nonlinear nature of some of the relationships and emphasize that significant portions of the variance are not accounted for by the variables evaluated. The inherent variation in natural and managed systems and the absence of such pertinent variables as proximity to streams, position on the landscape, topographic influences, and historical use and abuse of the land between 1820 and 1980 are two reasons for the low variance accounted. In addition, relatively low R^2 values may be attributed to errors in the GIS data that resulted from overlaying data of varying scales of resolution and accuracies (Walsh *et al.* 1987). The magnitude of this kind of error is unknown for this project, but it is likely to be substantial because of the three scales of resolution used in the analysis. For example, Walsh *et al.* (1987) found combined inherent and operational error to be as high as 83% for their examples of multiple-layer overlays.

The regression equations from the five principal components (excluding interaction and polynomial terms) show the importance of Factors 1 (high productivity) and 3 (low water availability and nonsloping) in explaining the percent of each land type (Table 7). Eleven of the 19 land types had Factor 3 as most important; 6 of the remaining 8 land types had Factor 1 as the most important. Factor 5 (miscellaneous) was not important for most land types. Factor 2 (rapidly permeable) was important for evergreen forest and nonforested wetlands, and Factor 4 (low productivity) was second in importance to several land types. As one might expect, Factor 1 (high productivity) was the most important variable in explaining percent of cropland/pastureland. It was also the main factor for several minor land uses having very poor predictability (Table 7). Factor 1 did not carry much weight on the historical vegetation model; low water availability, nearly level slopes, and low productivity factors were more explanatory if an area was originally in prairie or forest. The importance of Factor **3** (low water availability and nonsloping) may be overstated in the urban categories because of the domination of these types by the Chicago region.

Conclusions

Landscape attributes more closely influence the distribution of naturally derived land types than human-manipulated landscapes in Illinois. Such naturally derived land types as present-day nonforested wetlands and most deciduous forests generally conform to the landscapes more closely associated with the landscape attributes from which they developed. In these two examples, 44 to 83% of the variance in percent land type can be explained by the landscape attributes. Conversely, urban types, strip mines and quarries, and most of the evergreen forests in the State occur as a result of human activities. These types, therefore, do not have a close association with the landscape attributes measured (only 17 to 30% of variance accounted for by landscape attributes). The one exception to the generally poor association between artificially derived land types and their landscape attributes is cropland/pastureland. Much of Illinois is endowed with extremely fertile soils ideal for agriculture (59% of the State qualifies as 'prime' farmland) (Soil Conservation Service 1982). Nearly all of the best arable soils have been converted to cropland. **As** such, relatively higher amounts of variance can be explained in the relationship between the percentage of an association in cropland and the attributes that make for ideal farmland – high organic matter, low slopes, and high productivity indexes.

The analyses performed here represent a large amount of sophisticated overlay processing of vectors by GIS. At least 150,000 polygons were created in the combination of soil association, land use, and historic vegetation maps over nearly 150,000 km^2 of Illinois. GIS also allowed rapid calculation of measures of patch dynamics, including fractal dimensions and perimeter-to-area ratios, and thereby provided a quick method for determining the complexity of the landscape as a whole or of the individual land types within the landscape. Comparisons among different localities could then be accomplished, with inference to landscape heterogeneity and human/natural influences. This study, therefore, illustrates how GIS technology can expedite scientific research.

Some of the conclusions of this study might have been logically inferred. We are not surprised, for example, to find that historical or natural land types are more highly related to landscape attributes than are human-manipulated landscapes. Indeed, we may be surprised that the relationships were no tighter for 'natural' land types. **As** noted earlier, errors in GIs-overlay resulting from varying resolution and accuracy on the base maps and the absence of such variables as proximity to streams and historical use and abuse of the land may well be responsible. For the first time, however, relationships between land types and landscape attributes have been evaluated over a large area. This study confirms that we might have expected, but it also points out that additional factors need to be considered.

Illinois is presently embarking on a plan to boost forests and forestry within the State (Illinois Commission on Forestry Development 1987) and, at the same time, reduce soil erosion (Illinois Department of Agriculture 1985). Results from this study are being incorporated into that plan whereby 'marginal' hectarage – land with high slopes and relatively low productivity indexes – will be targeted for reconversion to forests and encouraged through economic incentives. Without GIS technology, major problem areas would be much more difficult to locate. In reflecting on the long-term conversions that have occurred over the past century and a half, we now recognize that governmental programs and economic incentives pushed conversion to agriculture too far from the 1950s to 1970s. We are now in a period of retrenchment where 'marginal lands' cannot be profitably farmed with intensive row-crop agriculture. Even though this study shows that several land types are related to the attributes most suited for those particular land uses, we realize now that we could have done a better job of matching our land uses to the appropriate landscapes. We also could have done much better in preserving natural habitats for future generations. As we make future land-use decisions, we must be more cognizant of these facts so that such desirable landscape characteristics as ecosystem stability, biotic diversity, sustainable agricultural and timber production, recreation opportunities, natural disaster preparedness, and the protection of natural communities, wildlife habitat and aquatic resources can be developed and maintained.

Acknowledgments

Thanks to Paul G. Risser, Bruce Milne, John B. Taft, Anton G. Endress, and Audrey S. Hodgins for reading the manuscript drafts, and to Betty A. Nelson for the typing.

References

Anderson, J.R. 1977. Land use mapping and data compilation in U.S.G.S. *In* W.A. Dando and G.E. Johnson, editors. Innovations in land use management. pp. 9–19. University of North Dakota Press, Grand Forks, North Dakota.

Anderson, R.C. 1970. Prairies in the Prairie State. Transactions of the Illinois State Academy of Science 63: 214–221.

Berry, J.K. 1987. Computer-assisted map analysis: potential5 and pitfalls. Photogrammetric Engineering and Remote Sensing 53: 1405–1410.

Burton, P.J., Robertson, K.R., Iverson, L.R. and Risser, P.G. 1988. The ecology and restoration of North American prairies. *In* E.B. Allen, editor. The reconstruction of disturbed arid ecosystems. Westview Press, Boulder, Colorado. (in press).

Coulson, R.N., Folse, L.J. and Loh, D.K. 1987. Artificial intelligence and natural resource management. Science 237: 262–267.

Fehrenbacher, J.B., Alexander, J.D., Jansen, I.J., Darmody, R.G., Pope, R.A., Flock, M.A., Voss, E.E., Scott, J.W., Andrews, W.F. and Bushue, L.J. 1984. Soils of Illinois. University of Illinois College of Agriculture Bulletin 778, Urbana.

Forman, R.T.T. and Godron, M. 1986. Landscape Ecology. John Wiley & Sons, New York.

Gardner, R.H., Milne, B.T., Turner, M.G. and O'Neill, R.V. 1987. Neutral models for the analysis of broad-scale landscape pattern. Landscape Ecology 1: 19–28.

Givnish, T.J. 1981. Serotiny, geography, and fire in the pine barrens of New Jersey. Evolution 35: 101–123.

Hett, J.M. 1971. Land-use changes in east Tennessee and a simulation model which describes these changes for three counties. ORNL-IBP-71-8, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Illinois Agriculture Statistics, 1986. Illinois Department of Agriculture and United States Department of Agriculture National Agricultural Statistics Service Bulletin 86-1, Springfield.

Illinois Commission on Forestry Development. 1987. Forestry in Illinois: opportunities for action. Illinois Commission on Forestry Development, Springfield.

Illinois Department of Agriculture. 1985. T by 2000: a state plan for meeting 'T' or tolerable soil losses in Illinois by the year 2000. Illinois Department of Agriculture, Springfield.

Iverson, L.R. and Risser, P.G. 1987. Analyzing long-term vegetation change utilizing geographic information system and remotely sensed data. Advances in Space Research 7(11): 183–194.

Jenny, M. 1941. Factors of Soil Formation. McGraw-Hill Book Company, New York.

Klopatek, J.M., Olson, R.J., Emerson, C.J. and Jones, J.L. 1979. Land-use conflicts with natural vegetation in the United States. Environmental Conservation 6: 191–120.

Krummel, J.R., Gardner, R.H., Sugihara, G., O'Neill, R.V. and Coleman, P.R. 1987. Landscape patterns in a disturbed environment. Oikos 48: 321–324.

Kuchler, A.W. 1964. Potential natural vegetation of the conterminous United States. American Geographical Society Special Publication 36, American Geographical Society, New York.

Major, J. 1961. A functional factorial approach to plant ecology. Ecology 32: 392–412.

Mandelbrot, B.B. 1977. Fractals, form, chance, and dimension. W.H. Freeman and Company, San Francisco, California.

Mandelbrot, B.B. 1983. The fractal geometry of nature. W.H. Freeman and Company, New York.

Odell, R.T. and Oschwald, W.R. 1970. Productivity in lllinois soils. University of Illinois Cooperative Extension Service Circular 1016, Urbana.

Risser, P.G., Birney, E.C., Blocker, H.D., May, S.W., Parton, W.J. and Wiens, J.A. 1981. The true prairie ecosystem. Hutchinson Ross Publishing Company, Stroudsburg, Pennsylvania.

Risser, P.G., Karr, J.R. and Forman, R.T.T. 1984. Landscape ecology: directions and approaches. Illinois Natural History Survey Special Publication 2, Champaign.

Robinson, V.B. and Frank, A.U. 1987. Expert systems for geographic information systems. Photogrammetric Engineering and Remote Sensing 53: 1435–1441.

Soil Conservation Service. 1982. Basic statistics, 1977 national resources inventory. United States Department of Agriculture Soil Conservation Service Statistical Bulletin 686, Washington, D.C.

Systems Analysis Service Instite, Inc. 1985. SAS/STAT Guide for Personal Computers. Sixth editions. Cary, North Carolina.

Telford, C.J. 1926. Third report on a forest survey of Illinois. Illinois Natural History Survey Bulletin 16, Champaign.

United States Department of Commerce. 1983. Census of agriculture. Part 12. Illinois. United States Department of Commerce, Washington, D.C.

Urban, D.L., O'Neill, R.V. and Shugart, H.H. 1987. Landscape ecology. BioScience 37: 119–125.

Walsh, S.J., Lightfoot, D.R. and Butler, D.R. 1987. Recognition and assessment of error in geographic information systems. Photogrammetric Engineering and Remote Sensing 53: 1423–1430.

White, J. 1978. Illinois natural areas inventory technical report. Volume 1. Survey methods and results. lllinois Natural Areas Inventory, Urbana.