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Change detection and landscape metrics for inferring anthropogenic processes in the greater EFMO area

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Abstract

Remote sensing offers an important means of detecting and analyzing temporal changes occurring in our landscape. This research used remote sensing to quantify land use/land cover changes, and landscape metrics to track ecological impacts of such changes at the Effigy Mounds National Monument (EFMO), Iowa, USA. Aerial photography spanning a period of six decades, IKONOS pan-sharpened (1 × 1 m) data, and input from the US National Park Service were used to develop land cover classification maps for the 1940s, 1960s, and 1990s. A post-classification algorithm was applied to derive land cover changes, and landscape metrics were used to analyze specific habitat classes. Overall changes in natural vegetation between 1940s and 1990s at EFMO showed interchangeable shifts whereby the canopies of some areas of deciduous forests and bottomland woodlands thinned out, whereas others transited from croplands in the 1940s to full growth forest in the 1990s. Similar patterns were observed for cropland and pasture, where the total area of cropland declined while that of pasture increased, albeit with a decline in the number of patches. Land cover changes around EFMO reflect the impacts of management decisions made in response to shifts in agricultural and economic policy while, within EFMO, the areas of "natural" vegetation are well maintained and devoid of any significant human activity.
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Keywords: Change detection; Landscape metrics; EFMO area

1. Introduction

Biophysical materials and anthropogenic features are often subject to rapid change. To fully understand the physical and human processes at work, it is important that such changes be detected and quantified accurately (Jensen & Narumalani, 1992). Remote sensing offers an important means of detecting and analyzing temporal changes, and since the early 1970s, satellite data have been commonly used for short-term (decade or less) change detection studies (Jensen et al., 1993). Ecologists increasingly recognize that a full understanding of ecosystems should be based on the analysis of their functioning over long time scales (Oldfield et al., 2000). However, the use of remote sensing for long-term change studies provides considerable challenges because of the lack of easy availability, and the geometric and thematic fidelity of the data. For example, Axelsson et al. (2002) relied on ancillary data sources such as historical records to study changes in five mixed deciduous forests between 1866 and 1999. Despite these shortcomings, the long-term monitoring of landscape spatial pattern, in addition to biophysical variables, can lead to the detection of a greater range of processes of landscape modification (Lambin & Strahler, 1994).

Many change detection investigations tend to focus on a general description of the vegetation and may present satellite data as a qualitative tool for studying specific ecosystems (e.g., Carlson & Sanchez-Azofeifa, 1999; Sader et al., 1990). Rainis (2003) suggests that in addition to studying the composition of land use types, their spatial distribution and arrangement also need to be considered for monitoring changes. Herzog and Lausch (2001) proposed the use of landscape metrics that address landscape patterns and are based on analyzing the geometry and spatial arrangement of land use/land cover patches. For several decades, quantitative measurements of landscape pattern (called metrics or indicators) have been used to link ecological and environmental processes with patterns found in

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the landscape (Bunnell, 1997; Krummel et al., 1987; O'Neill et al., 1988; Prabhu et al., 2001). Resource managers require spatial and temporal information in order to make decisions that will have lasting ramifications on the landscape. Consequently, mapping the landscape through time, incorporating spatial relationships, and quantifying its structure are critical components of any study that analyzes a changing landscape.

To assess landscape dynamics, the challenge for remote sensing analysts is in the inference of processes from static snapshots that would be meaningful from an ecological perspective. The integration of landscape ecology and remote sensing/geographic information science may provide the key to unraveling landscape dynamics from temporally discrete data through the use of landscape metrics: i.e., patch and landscape statistics viewed as longitudinal data (Crews-Meyer, 2002). The primary purpose of our research was to explore and recommend both conceptual and methodological implementation of landscape metrics integrated with a conventional change detection method to monitor landscape dynamism or change. This research used remote sensing to quantify land use/land cover changes, and landscape metrics to track the ecological impacts of such changes at the Effigy Mounds National Monument (EFMO), Iowa.

1.1. Adjacent land use monitoring of National Park service units in the Mid-west

In 1994, the United States National Park Service (NPS) established the Prairie Cluster Long Term Ecological Monitoring (LTEM) Program as 1 of the 11 prototypes to develop natural resource monitoring within the NPS. The LTEM program currently monitors the status and trends of natural resources in six parks located in four Midwestern states. A primary focus of the program is to develop and implement monitoring protocols for resources affected by active management and/or external park threats. The NPS desires a technique to measure past and future trends in adjacent land use to provide a regional context for trends observed within park boundaries.

Park ecosystems are affected by changing land use outside park boundaries as well as internal management actions. Many are experiencing agricultural, residential and industrial developments at or near their boundaries. Small parks are particularly susceptible to outside influences such as degradation of water quality, loss of wildlife corridors and colonization sources, invasion of exotic species, and visual intrusions. In addition to the loss of adjacent prairie habitat, park ecosystems are also affected indirectly by increasing fragmentation and isolation of remnant grasslands. The effects of fragmentation are threefold. First, many species may require large, intact parcels of grassland for survival and reproduction, and as remnants decrease in size, these area-sensitive species are progressively extirpated locally (Herkert, 1994). Second, as remnants become more isolated, the probability of colonization/re-colonization of a patch decreases with distance from another patch (Kaufman & Kaufman, 1996). Third, populations in isolated patches suffer from genetic inbreeding and accelerated rates of genetic drift (Benedict et al., 1996).

Increased fragmentation of natural areas will also have a negative effect on threatened and endangered species, grassland birds, and butterfly assemblages found within the park, as well as contribute to proliferation of exotic invasive species. The goal of NPS is to develop methods for providing information to support natural resource management decisions that will protect and improve the sustainability of the populations of plant and animal communities that are representative of the period of significance as specified in each park's enabling legislation (typically to a time period pre-dating the influence of human settlement). By quantifying and documenting changing land use patterns within and adjacent to the parks, important ancillary information can be provided for monitoring the stability of terrestrial and aquatic prairie ecosystems.

The overall objective of this research was to map the vegetation change in the greater EFMO area over a period of 60 years and analyze possible anthropogenic impacts based on image interpretation and landscape metrics. Specific objectives include:

- Spatial identification and quantitative assessment of land use changes from natural or semi-natural vegetation types to non-native vegetation over a period of 60 years.
- Examine potential causes of these changes.
- Analyze landscape metrics for selected vegetation types.

2. Study area

Northeastern Iowa represents an environment of overlapping plant ecotypes. The eastern hardwood forests merging with the grasslands of the west have created a mosaic of forests, savannas, and prairie. Early survey records reveal that northeastern Iowa was a heavily forested region interspersed with oak savannas and prairie openings. The prairie openings extended into the forest area along ridge tops with smaller openings being found on south facing bluff edges maintained by shallow soil, higher temperatures and drier conditions. Today, the steep hillsides are dominated by climax stands of maple–basswood and oak–hickory vegetation communities with small goat prairies found on drier sites. Within the floodplains of the Mississippi and Yellow Rivers, Paint Creek, and Bloody Run Creek, lie nearly 100 acres of ponds and lakes making for valuable wetland resources.

EFMO covers an area of 2526 acres and is located in this driftless (non-glaciated) area of northeastern Iowa (Fig. 1). It lies in a geologically unique area of erosional topography

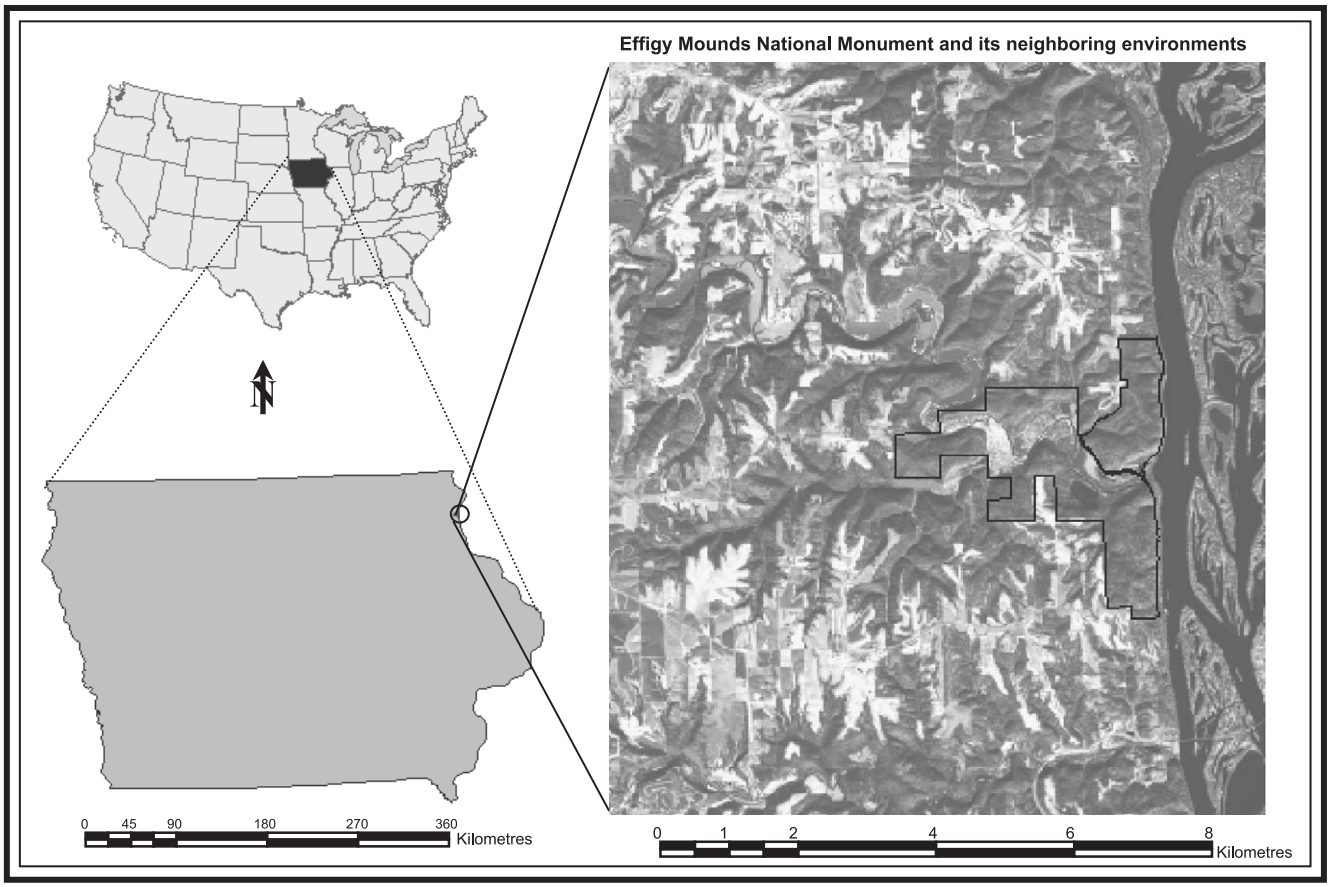


Fig. 1. Location of Effigy Mounds National Monument, Iowa in the conterminous United States. The IKONOS image dated 18 October 2001 shows the entire study area with the park boundary delineated.

drained by an intricate system of rivers and streams. Erosional forces have cut through a plain leaving high divides and precipitous bluffs towering up to 500 ft above adjacent waterways. Nearly 1200 acres of the monument are forested by rapidly maturing stands of mixed hardwood species, while approximately 80 acres of old field openings are being managed as recovering or restored prairie. An area of about 20 acres has been treated as part of an oak grove or savanna restoration project for the restoration of nearly 50 acres of oak savanna.

The monument represents an important link in a complex of protected areas that preserve many of the values characteristic of this region. Much of the nearby Mississippi River bank and island area is protected by the Upper Mississippi River National Wildlife and Fish Refuge, a 261-mile-long preserve that extends from Wabasha, MN, to Rock Island, IL. Situated between the currently developed EFMO monument units and the Sny Magill unit is Pikes Peak State Park, which preserves several effigy mounds, as well as bluff tops much like those of the monument. Management efforts for the monument focus on the protection and preservation of the burial mounds, control of exotic species, and restoration of the cultural landscape associated with the mound building era.

3. Materials and methods

3.1. Data sources and pre-processing

Aerial photography for the 1940s and 1960s was obtained from the United States Department of Agriculture's-Agriculture Stabilization and Conservation Service (USDA-ASCS). 1:20,000 scale black-and-white aerial photographs acquired in September 1940, October 1961, and August 1964 and archived by USDA-ASCS Aerial Photography Field Offices served as the historical data sources. Data for the 1990s included Digital Orthophotograph Quarter Quadrangles (DOQQs) obtained from the United States Geologic Survey (USGS). Since the mid-1990s the USGS has produced black-and-white (and occasionally color) DOQQs that meet National Map Accuracy Standards (NMAS) at a scale of 1:12,000. Photographic and terrain distortions have been removed, and the resulting images are georeferenced to the Universal Transverse Mercator (UTM) coordinate system.

To ensure a standardized digital format for all aerial photography (1940s and 1960s) used in this research, the University of Wisconsin-Environmental Remote Sensing Center (ERSC) was contracted to create digitally mosaicked

orthophotographs from the historic aerial photos. The process followed USGS standards whereby a digital orthophoto was created by scanning the aerial photograph transparencies (diapositive) with an image scanner. Each scanned photograph was rectified to an orthographic projection by processing each image pixel through photogrammetric space resection equations (Fuhr et al., 1999; Habib, 2002). The process required, as input, ground control points (GCPs) acquired from ground surveys or developed in aero-triangulation, conjugate photo-coordinates of ground control, camera orientation parameters, and a digital elevation model (DEM; USGS, 1996). The rectified digital images were contrast stretched, mosaicked, and had a horizontal positional accuracy of $<+5$ m. The 1990s DOQQs were used as baseline data and the orthophotos of the 1940s and 1960s were registered to them. A geometric fidelity of $+1$ pixel was maintained in the multi-temporal registration process to avoid pseudo-changes being recorded.

To aid in the interpretation process, a high-resolution, pan-sharpened (1×1 m) IKONOS satellite image, acquired in October 2001 was used. The pan-sharpened image contained color and tonal information that was considerably superior to the 1990s black-and-white DOQQs, and aided the interpretation process in cases where there was confusion between land cover categories (e.g., maple–cottonwood versus deciduous forests).

3.2. Image interpretation

A vegetation classification scheme based on National Vegetation Classification Scheme (NVCS) "Formation" level was used to classify the land use. Anderson et al. (1998) and Grossman et al. (1998) have expanded the NVCS to "Alliance" and "Association" levels. Classification categories were derived from the NVCS and tailored using local knowledge to eliminate or collapse categories. Currently, the NVCS does not address built features (e.g., roads, urban areas) satisfactorily, so descriptions from Anderson et al. (1976) were used for these categories. Because of the difficulty in interpreting certain key objectives (exotic pasture, native pasture, prairie) considerable ancillary input was provided by NPS personnel and incorporated into the classification scheme. A final land cover classification scheme comprised of twenty-three categories was determined at EFMO (Table 1).

On-screen digitizing with a minimum mapping unit of 1 ha was used to delineate the land use/land cover, and because image interpretation is a highly subjective discipline, it often requires the analyst to be familiar with local geography, land use history, classification scheme, and end user needs. Often several visits to a study area may be required to accomplish this. Unfortunately, the funding resources were restricted and such in situ visits were not performed.

The image interpretation was performed backwards in time—i.e., the 1990s DOQs were interpreted first with the aid of the pan-sharpened IKONOS data and LTEM staff input. An elimination process was followed by first classifying the "obvious" features of the landscape (e.g., roads, railroads, farmsteads/agricultural buildings, urban areas and rivers). Then the process focused on delineating croplands, pastures, and forest patches with more than 60% canopy cover. When attempting to differentiate between pasture and cropland, some useful information included visual texture of vegetation and land, feature shape, evidence of slope, presence of row crops or tillage marks, and erosion patterns that were evident in plots being used for continuous livestock pasturing. The spatial relationship of a field to the road network, sorting pens, holding pens, and buildings were additional indicators of its use. Associative information pertaining to the shape of pastures and their location relative to roads, farmsteads, woodlands, and waterways was useful for differentiating between row crops and pasture lands.

Once the agricultural matrix, road network (from *Topologically Integrated Geographic Encoding and Referencing* (TIGER) files) and urban areas were delineated, certain small tracts of prairie, woodlots, and other land uses remained to be classified. To facilitate the interpretation of key land use categories such as grazed prairies, prairie hayfields and grazed or degraded woodlands, areas that appeared to be natural vegetation (e.g., prairie, savanna) were labeled "Potential Natural Vegetation", and NPS personnel provided the feedback and clarifications to classify these areas.

Upon completion of each time period, draft maps were produced for dissemination to LTEM staff, park staff, and local experts to help determine map accuracy. Formal accuracy assessments were not performed because of the high costs involved with in situ data acquisition. The final land use/land cover classification maps (for example, Fig. 2) for the three time periods were derived and utilized in the post-classification change detection algorithm.

3.3. Change detection

When performing change detection, it is important to consider various sensor system and environmental parameters. Ideally, sensor system parameters such as spatial, temporal (e.g., anniversary dates), spectral, and radiometric resolutions should be held constant when feasible. In addition, variations in environmental characteristics such as atmospheric and soil-moisture conditions, and vegetation phenology should be minimal. However, few change detection studies could meet such stringent criteria even under controlled experiments. Consequently, it is necessary to adapt the available data in order to extract the best possible information from the given resources. In this study, because the land cover was manually interpreted, most of the sensor and environmental issues of change detection did not have any significant ramifications in modifying the interpreted cover type.

The post-classification change detection algorithm (Jensen et al., 1993) was used to determine differences between the three time periods. Using this method, image-maps for

Table 1
Classification scheme and respective descriptors of the land cover categories used for the effigy Mounds National Monument

Land cover class and code	Description
Upland forests/woodlands (>25% trees)	
Forested Hillside Prairie (FHP)	South- to southwest-facing slopes that were originally open oak woods, but now are forested. Map to 0.10 ha.
Silver Maple–Cottonwood Forest (FMC)	Floodplain along the Mississippi and Yellow Rivers. Silver maple dominates. Cottonwood, elm, and ash may be present
Nursery (FMP)	Commercial nursery operation including mixed cultivated trees and shrubs
Savanna/Woodlands (FSW)	>25%<60% Tree canopy with grass and forbe ground cover
Coniferous Forest (FED)	>60% Tree canopy
Deciduous Forest (FWO)	Deciduous trees. Canopy cover is >60% Includes White Oak, Red Oak, Shagbark Hickory, Sugar Maple, American Elm, Basswood
Shrublands (>25% shrubs)	
Upland Shrublands	
Upland Scrub (SUS)	Upland areas of recent clear cuts, edges of fields. One or more of the following species may be present; sumac, dogwood, black locust
Bottomland/Floodplain Forests/ Woodlands/Shrublands	
Bottomland Woodland (FBW)	Bottomland tree stands with areas >25% and <60% canopy cover
Bottomland Forest (FRH)	Bottomland tree stands with areas >60% canopy cover
Bottomland Shrub (SWL)	Occur along the Yellow and Mississippi river. This type is an early successional stage that occurs on recently flooded riparian areas
Herbaceous (>25% canopy cover)	
Upland Herbaceous	
Native Prairie Plantings (HRP)	Restored prairie and other private and commercial native prairie plantings in and around the park
Native Prairie (HNP)	
Pasture (HPG)	Fields used for grazing and haying
Croplands (HCF)	Annual crops such as corn and soybeans
Bottomland/Flood Plain Herbaceous	
Bottomland Cropland (HBC)	Bottomland fields currently in production
Marsh (HRB)	Shallow water communities in Mississippi and Yellow River floodplains
Open water (non-vegetated)	
Farm Ponds (OFP)	Farm ponds and stock dams for agricultural use
Marsh Ponds (OMP)	Ponds contained in wetland areas
Rivers and Streams (ORS)	Rivers and Streams of mappable width
Land use	
Residential (LRS)	Buildings and land for residential use
Commercial (LCM)	Buildings and land for commercial use (e.g. visitor center)
Farmsteads and Agriculture Buildings (LFB)	Farmsteads, buildings, and adjacent lands for agricultural use
Roads and Railroads (LRR)	Roads and Railroads and their rights-of-ways

two or more dates can be compared on a pixel-by-pixel basis to pinpoint any changes that may have occurred between the time periods. The change that was extracted for the three time periods was represented in a series of change detection matrices that depicted (a) "from–to" land cover classes, (b) the total area of change between the classes, and (c) specific color representation of change for select classes. Selected classes were draped on the aerial photographs to highlight the spatial locations of where these changes had occurred. While the change detection technique quantified several facets of the change (including its spatial location), it did not reveal changes in the geometry and fragmentation of the land cover classes. Therefore, a suite of landscape metrics were calculated that provided an overall perspective of the class level changes in the landscape.

3.4. Derivation of landscape metrics

A landscape is defined as a heterogeneous land area composed of a cluster of interacting ecosystems that is repeated in similar form throughout (Forman & Godron, 1986). Changes in a landscape are a result of complex interactions between physical, biological, economic, political and social forces, and the resulting landscape mosaic is a mixture of natural and human-influenced patches that vary in size, shape, and arrangement (Turner et al., 1989).

Landscape metrics act as the quantitative link between landscape patterns and ecological or environmental processes. They can be derived for one of three levels: patch level (defined for individual patches), class level (characteristics of all patches in a given class), and the landscape level

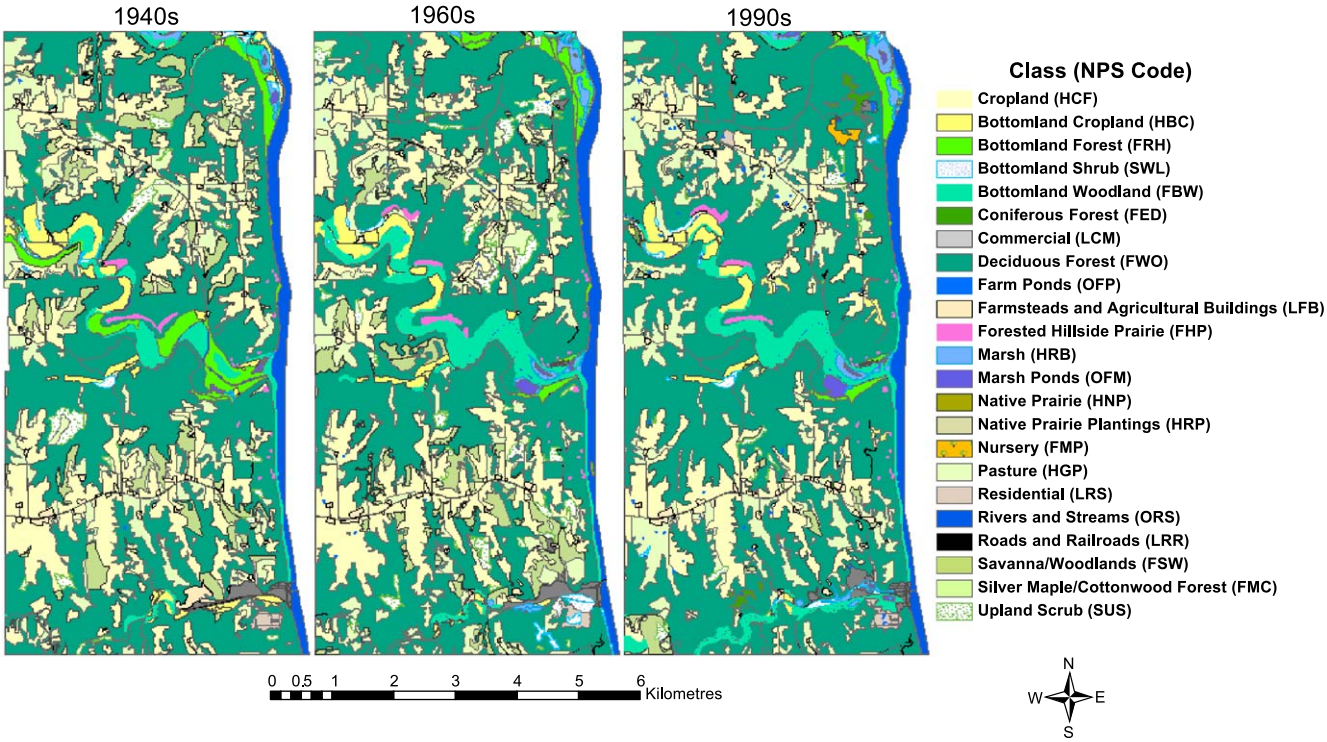


Fig. 2. Land use/land cover classification maps for the 1940s, 1960s, and 1990s derived from the image interpretation process.

(integrated over all patch types or classes over the extent of the data). Patch metrics are too disaggregated and can be more useful when analyzing single patches for specific purposes (e.g., habitat studies, reserves delineation, edge effects; Cunningham, 2000). However, when comparing a single landscape structure, over different periods of time, class metrics provide important elements that describe general patterns within the landscape.

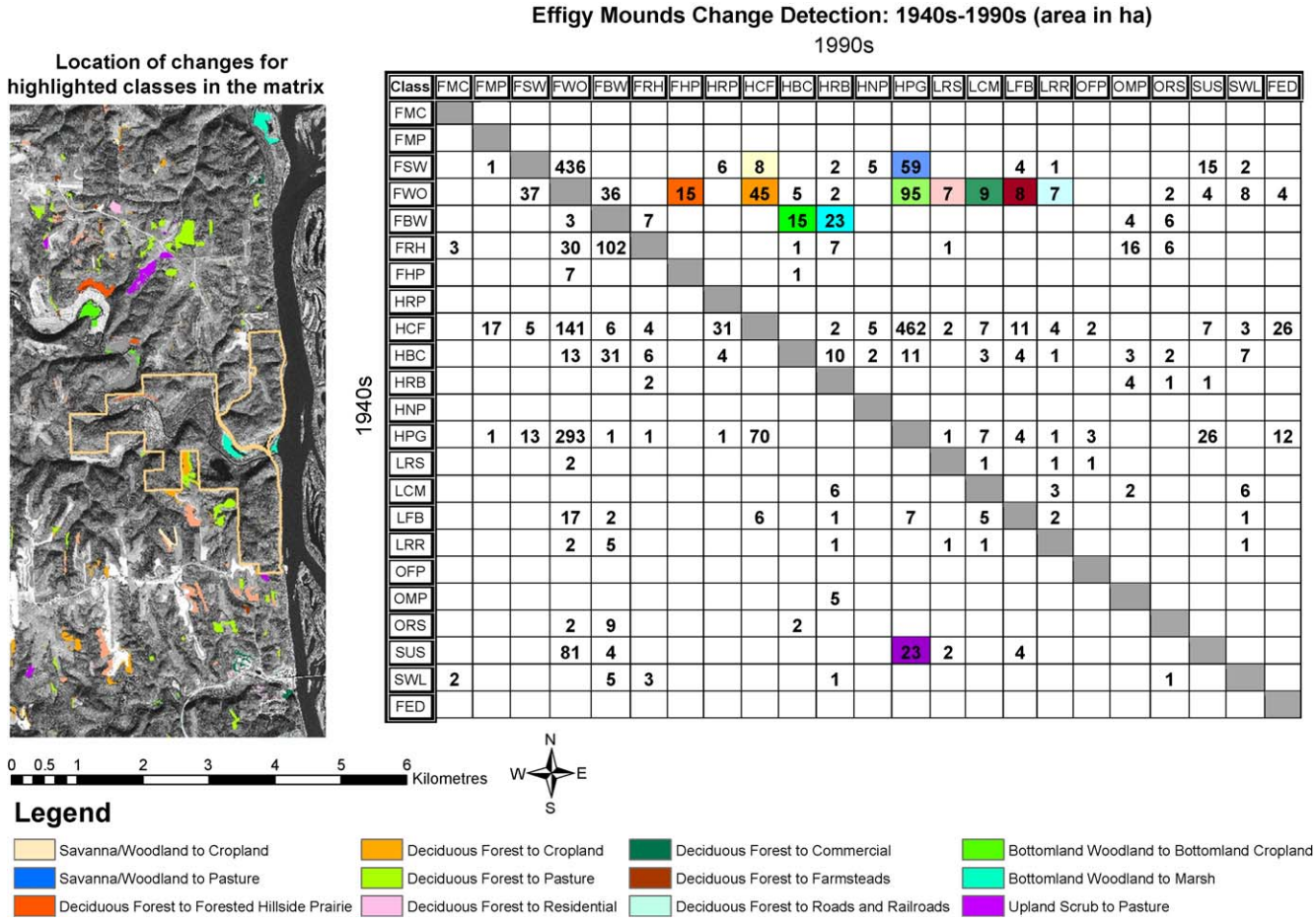
Our focus was on analyzing the temporal change of the class level metrics, which are integrated over all the patches of a given type (class). This integration may be accomplished by simple averaging, or through a weighted-averaging scheme for biasing the estimate to reflect the greater contribution of large patches to the overall index. The analysis was directed toward a few habitat classes which showed maximum change over the three time periods and included computation of four class-level metrics including class area, number of patches, mean patch size, and area weighted mean patch fractal dimension for the three time periods. While digitizing, care was taken to keep the aerial photographs at a scale 1:2000 for each time period. In addition, the cell size was kept constant at 1 m for calculating the landscape metrics keeping in mind that any variations in the scale of digitization and cell resolution would affect our analysis of landscape pattern, especially mean patch fractal dimension. A 3×3 window was used so that an eight-cell patch neighbor rule could be used for determining patch membership.

Forman and Godron (1986) offer substantive discussions of the effects of patch size on energy and nutrients, and on species diversity. Size of a patch is an important characteristic of the landscape while analyzing community structure, based on the fact that larger patches generally hold a greater number of species than smaller patches (Lavers & Haines-Young, 1993). The smaller the fragmented blocks, the more the density of a population decreases and the risk of species extinction grows (Farina, 1998). Consequently, if mean patch size is analyzed in conjunction with other metrics such as the number of patches, it can be used to measure fragmentation.

Mean patch fractal dimension has been used in ecosystem change analysis to quantify the complexity of patch shapes on a landscape (De Cola, 1989; Krummel et al., 1987; Lam, 1990; O'Neill et al., 1988). It has been used as a measure of degree of human disturbance on the landscape. The premise is that boundaries of natural land cover types often have complex shapes than those cover types that are a result of human activity (e.g., agricultural fields.) As human disturbance increases, the fractal dimension of the landscape decreases (De Cola, 1989; Krummel et al., 1987; O'Neill et al., 1988; Turner & Ruscher, 1988). Patch fractal dimension is very critical in linking the landscape pattern to ecological processes.

4. Results and discussion

Change detection products can be used to illustrate and explain the changes that occurred over the given time period; however, it should be emphasized that these are derived from



Class	FMC	FMP	FSW	FWO	FBW	FRH	FHP	HRP	HCF	HBC	HRB	HNP	HPG	LRS	LCM	LFB	LRR	OFP	OMP	ORS	SUS	SWL	FED
FMC																							
FMP																							
FSW		1		436				6	8		2	5	59			4	1				15	2	
FWO			37		36		15		45	5	2		95	7	9	8	7			2	4	8	4
FBW				3		7				15	23								4	6			
FRH	3			30	102					1	7			1					16	6			
FHP				7						1													
HRP																							
HCF		17	5	141	6	4		31			2	5	462	2	7	11	4	2			7	3	26
HBC				13	31	6		4			10	2	11		3	4	1		3	2		7	
HRB						2													4	1	1		
HNP																							
HPG		1	13	293	1	1		1	70					1	7	4	1	3			26		12
LRS				2											1		1	1					
LCM											6						3		2			6	
LFB				17	2				6		1		7		5		2					1	
LRR				2	5						1			1	1							1	
OFP																							
OMP											5												
ORS				2	9					2													
SUS				81	4								23	2		4							
SWL	2				5	3					1									1			
FED																							

Fig. 3. Selected land cover change for Effigy Mounds National Monument (EFMO) 1940s–1990s Colors on the image indicate "from–to" change categories based on "natural" vegetation and the same color is highlighted in the change detection matrix (1940s–1990s), which quantify the amount of change in hectares.

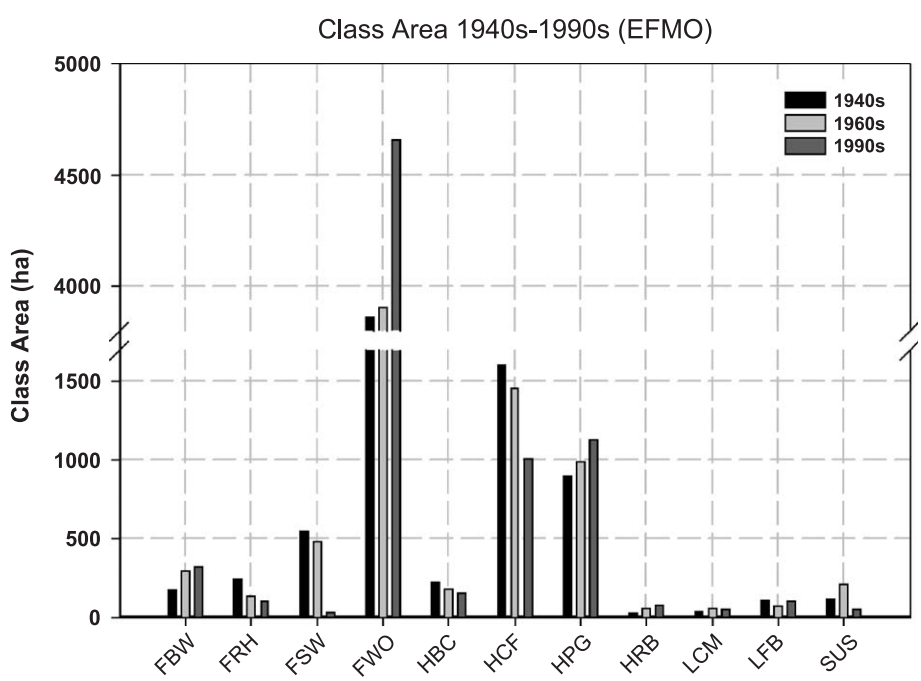


Fig. 4. Total area of different land cover classes at Effigy Mounds National Monument during each period.

single time-frame aerial photography—i.e., they are "snapshots" for given time periods. Change is a dynamic phenomenon and a continual detection and quantification of change is a virtual impossibility. However, examination of static map products derived at given time intervals provide valuable insights to the user on specific changes, trends, and a historical perspective (Fig. 3).

Change detection results for EFMO for 1940s–1960s show major changes, especially with reference to natural vegetation that include (a) net gain in bottomland woodland and marsh land, (b) increases in the number of farm ponds, and (c) a general gain of bottomland shrub resulting from a reduction in canopy cover likely the result of timber harvest (Fig. 4). Between the 1960s and 1990s, large areas (387 ha) of savanna woodlands experienced canopy closure and were, therefore, classified as deciduous forest in the later date. Some losses in the area of natural vegetation (e.g., deciduous forest, bottomland woodland) were due to the expansion of roads, farmsteads/agricultural buildings and railroads in the area. There was a 30% decline (394 ha) in cropland mainly due to conversion into pasture, while other pasture areas were, in turn, re-colonized into deciduous forest (194 ha).

Overall changes in natural vegetation between 1940s and 1990s at EFMO showed divergent trends. Some areas of deciduous and bottomland woodlands experienced a decrease in canopy cover, while other areas transitioned from croplands in the 1940s to forested areas in the 1990s (Fig. 3). A major change was the tremendous rise in the total area of farm ponds from 0.6 ha in the 1940s to nearly 161 ha in the1990s (Fig. 4) indicating changes in agricultural practices over the 60 year time frame. Bottomland forests were the most significantly impacted natural vegetation cover, losing nearly 60% of their acreage in the 60 years.

While the conventional change detection methods described changes in class area and the spatial location of such changes, landscape metrics will provide an insight to the impact of such change. O'Neill et al. (1996) used three-dimensional pattern space to analyze the landscape in three regions in the southeastern US. This method is powerful because it can also be used to assess the direction and magnitude of change through time. Metrics that describe landscape diversity and fragmentation include class area, number of patches, and mean patch size, while fractal dimension evaluates patch complexity (i.e., shape of a patch changing from a simple geometric shape to a highly convoluted, extremely complex type) and human influence on a given patch. In this research, the three-dimensional pattern space was defined by number of patches, mean patch size, and area weighted mean patch fractal dimension as the x, y, and z axes, respectively, to visualize the fragmentation and human influence for selected land cover categories.

Land cover classes including deciduous forest, savanna/woodlands, croplands, bottomland woodland, bottomland forest, and pasture showed very high temporal change (Table 2; Fig. 4) in their class area compared to other classes and are, therefore, examined in 3-D landscape pattern space (Fig. 5a–f). For example, deciduous forest experienced a net increase of 795 ha over 60 years although a much smaller percentage of clearings occurred to pave the way for agriculture, farm ponds, and agricultural buildings. The temporal shifts for this cover type indicates it has become less fragmented (number of patches are declining while their size is increasing; Fig. 5a). However, the decline in mean patch fractal dimension indicates that the configuration of the boundaries of deciduous forests is being affected by human influences, thus regularizing the patch shapes. Depending on the land cover class adjacent to forest patches, different effects may be observed in terms of ecological processes. If forest patches border upon open vegetation, such as production areas, the patch may be more susceptible to disturbances in its structure and become more regular in shape, thus decreasing the fractal dimension. Conversely, if forest patches are adjacent to succession areas, secondary re-growth may be accelerated, which will increase the fractal dimension.

By contrast, the savanna/woodlands cover type has experienced considerable decline. Fragmentation of this

Table 2
Landscape metrics of selected land cover categories for the three time periods

Year	No. of patches	Mean patch size	Area wt. mean patch fractal dimension
Deciduous forest			
1940s	83	46.518	1.389
1960s	88	44.369	1.376
1990s	47	112.592	1.370
Savanna/woodlands			
1940s	64	8.573	1.141
1960s	78	6.161	1.366
1990s	14	2.283	1.123
Bottomland forest			
1940s	15	16.167	1.208
1960s	14	9.890	1.209
1990s	9	11.104	1.197
Bottomland woodland			
1940s	35	5.027	1.175
1960s	43	6.927	1.354
1990s	48	6.647	1.168
Croplands			
1940s	128	12.565	1.338
1960s	87	16.745	1.143
1990s	77	13.110	1.120
Pasture			
1940s	169	5.321	1.153
1960s	171	5.789	1.365
1990s	137	8.240	1.162

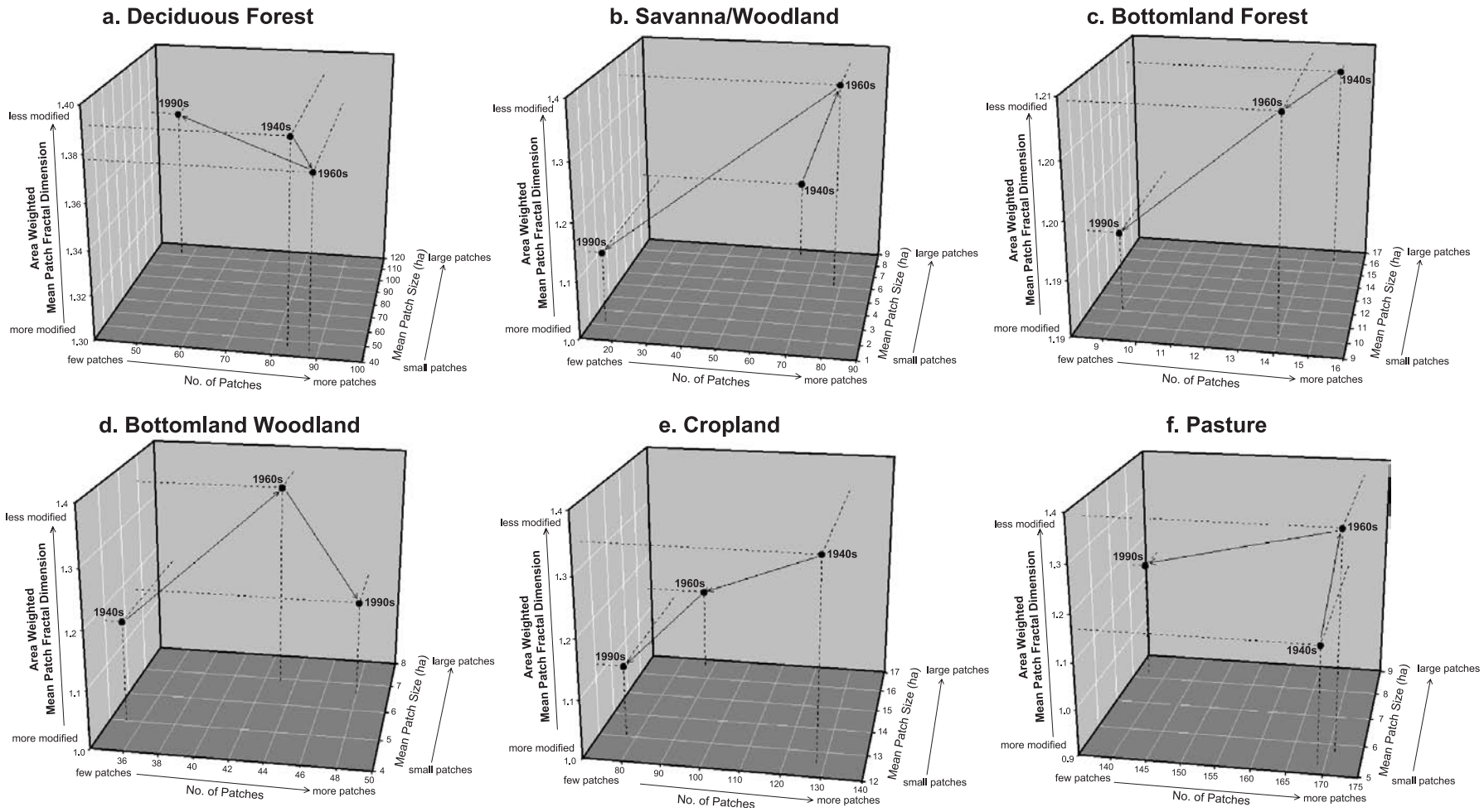


Fig. 5. Three-dimensional landscape metrics space for selected land cover categories showing the direction and magnitude of change from 1940s–1960s and 1960s–1990s.

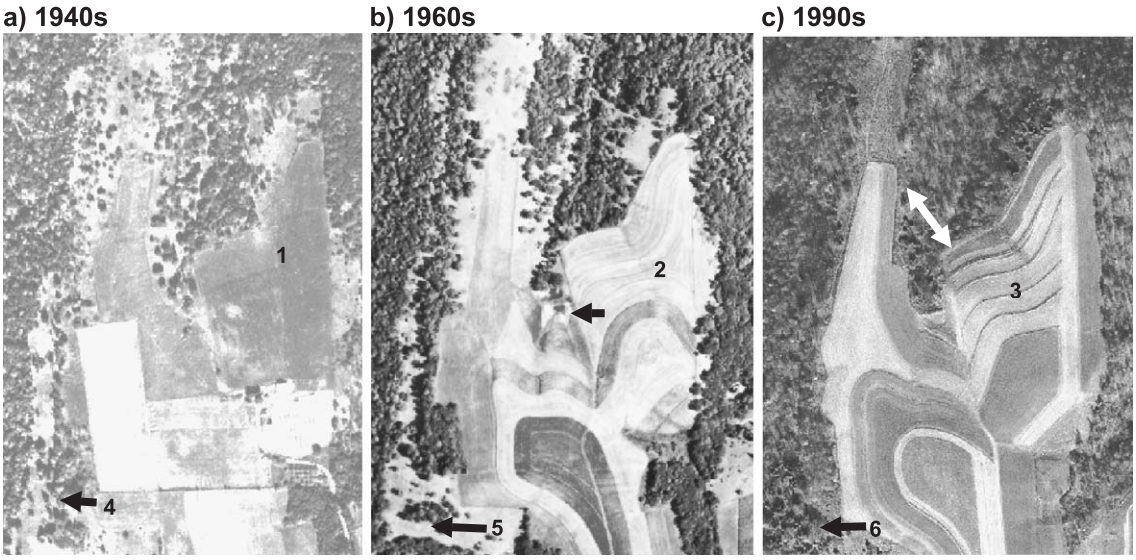


Fig. 6. Comparison of spatial change at an agricultural field lying adjacent to a deciduous forest boundary, between the three time periods. (a) In the 1940s the field is dominated by straight-line cultivation and surrounded by pasture (1). (b) In the 1960s, newer management practices are evident, i.e., contour tillage, field terracing and a new farm pond in the center of the scene (2). (c) The 1990s image shows matured contour farming practices within the well-defined (fenced) field (arrows) while scrub growth is evident in old pasture at the top of scene (3). Pasture vegetative succession to scrub is illustrated by the clean look of the (a) 1940s woodland pasture bordering the west side of the cultivated field (4). In the 1960s (b), that area has a rougher texture (5) and by 1990s (c) it is evident that scrub and mature trees have filled in the canopy (6).

cover type is implied between the 1940s and 1960s because there is a decline in the area, accompanied by an increase in the number of patches (Fig. 5b). The decline in all landscape parameters was observed for the 1960s to 1990s; however, when these data were examined in conjunction with the change detection matrix for this time period, it was noted that 436 ha of savanna/woodlands was converted to deciduous forest. This trend supports concerns of NPS management that open woods (savanna) maintained by periodic wildfire are being replaced by more dense forest types in the absence of fire.

Bottomland forest (Fig. 5c) and bottomland woodland (Fig. 5d) showed opposing trends. A general decline in all landscape parameters of bottomland forest was accompanied, in large part, by an increase in those parameters for bottomland woodland. When examined with relation to the change detection imagery, it was observed that bottomland forest canopies were thinning and becoming bottomland woodland in subsequent years. This trend was more evident between the 1940s and 1960s, where the number of patches of bottomland woodland increased along with the mean patch fractal dimension, indicating that several, irregular shaped patches were occurring in the landscape. Between 1960s and 1990s, these patches had a lower mean patch fractal dimension because the construction of roads and railroad in the southern portion of the study area had the effect of regularizing the boundary.

Similar patterns were observed for cropland (Fig. 5e) and pasture (Fig. 5f), with the exception that mean patch size had increased for both categories, implying a consolidation of patches. In general, the number of patches and total class area declined for cropland, while the areas of pasture increased, albeit with a decline in the number of patches. Changes in pasture and cropland can be affected by management decisions made in response to changing natural or economic environments. In general, farm operators control their livelihood in the best manner they can by responding to changing conditions including climate variation, commodities market cycles, government policy changes and subsidy revisions. Pasture and cropland are the largest of the assets contained in a farm business that can be allocated to different methods of production to affect yearly income. For example, if market conditions favor livestock production with higher income returns, farmers will divert lands currently used for row crop production to a pasture usage by planting forage varieties that offer more lucrative financial returns. In other cases, the USDA crop subsidies may offer land managers the opportunity to stabilize or increase net income, leading to the transformation of tillable land that was being used for pasture to be converted to the specific cash crops (e.g., corn).

5. Conclusion

When evaluating change across several decades, it is important to be aware of the impacts that alterations in governmental land management policy can have. Rindfuss and Stern (1998) state that land use changes often reflect abstract variables such as governmental policies, market mechanisms, social customs, land tenure rules, and distri-

butions of wealth and power. As described earlier, some of the changes in the EFMO area were indicative of precisely such issues (e.g., fire management policies and USDA strategies).

Further examples of such influences are revealed in the 1936 USDA policy that focused on decreasing soil erosion losses from agricultural lands in the US. Practices such as field reshaping for terrace formation combined with contour seedbed tillage and planting were some of the land management strategies implemented to slow the rate of water runoff and decrease topsoil losses (for example, Fig. 6). The USDA provided monetary incentives in the form of cost-share payments to land owners to offset their expenses for reshaping their fields, and this was partially responsible for a decrease in mean patch fractal dimension for croplands from 1940s to 1990s.

Another facet of the soil erosion control policy encouraged land owners to create water impoundments by building earthen berms in the path of precipitation runoff. Cash assistance payments were made when land operators cooperated with the USDA for these projects. Consequently, large numbers of farm ponds were constructed between the 1960s and 1990s in the vicinity of EFMO which were evident in the change detection assessment and the landscape metrics.

An additional manifestation of changes in policy pertains to the fact that in the early part of the 20th century, considerable logging of hardwood deciduous forests occurred in the northeastern portion of Iowa. Many of the plots and fields cut into the forests within the EFMO area and were easy to interpret from the 1940s aerial photography because of their distinctive regular shapes. In the later time periods, patterns of floral succession were evident—plant maturation to scrub (low or interrupted canopy $<60\%$ cover) and forest canopy ($>60\%$ cover) could be observed at the edges of some plots. In some areas, old forest cuts were completely recovered, while in other cases the deforested areas remained clear-cut because of cropping and pasturing land management practices. These landscape patterns, interpreted from the photographs, and described by the metrics provide an insight into the changing socio-economic processes and policies as well as the anthropogenic influences over the 60-year period. Within the park boundaries there has been very little change; however, its surrounding area has borne witness to varying intensities of land use transitions and modifications influenced largely by external drivers.

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References

Anderson, J. R., Hardy, E. E., Roach, T. T., & Witmer, R. E. (1976). A land use and land cover classification system for use with remote sensing data. *U.S. Geological Survey Profession Paper*, *vol. 964*. Washington, DC: U.S. Gov. Printing Office.

Anderson, M., Bourgeron, P., Bryer, M. T., Crawford, R., Engelking, L., Faber-Langendoen, D., Gallyoun, M., Goodin, K., Grossman, D. H., Landaal, S., Metzler, K., Patterson, K. D., Pyne, M., Reid, M., Sneddon, L., & Weakley, A. S. (1998). *International classification of ecological communities: Terrestrial vegetation of the United StatesThe National Vegetation Classification System: List of Types*, *vol. II*. Arlington, VA, USA: The Nature Conservancy (502 pp).

Axelsson, A. -L., Ostlund, L., & Hellberg, E. (2002). Changes in mixed deciduous forests of boreal Sweden 1866–1999 based on interpretation of historical records. *Landscape Ecology*, *17*, 403–418.

Benedict, R. A., Freeman, P. W., & Genoways, H. H. (1996). Prairie legacies—mammals. In F. L. Knopf, & F. B. Samson (Eds.), *Ecology and conservation of great plains vertebrates* (pp. 149–167). New York: Springer-Verlag.

Bunnell, F. L. (1997). Operational criteria for sustainable forestry: focusing on the essence. *The Forestry Chronicle*, *73*, 679–684.

Carlson, T. N., & Sanchez-Azofeifa, G. A. (1999). Satellite remote sensing of land use changes in and around San Jose, Costa Rica. *Remote Sensing of Environment*, *70*, 247–256.

Crews-Meyer, K. A. (2002). Characterizing landscape dynamism using paneled-pattern metrics. *Photogrammetric Engineering and Remote Sensing*, *68*, 1031–1040.

Cunningham, S. (2000). Effects of habitat fragmentation on the reproductive ecology of four plant species in Mallee woodland. *Journal of the Society for Conservation Biology*, *14*(3), 758–768.

De Cola, L. (1989). Fractal analysis of a classified Landsat scene. *Photogrammetric Engineering and Remote Sensing*, *55*, 601–610.

Farina, A. (1998). *Principles and methods in landscape ecology* (p. 256). Dordrecht: Kluwer Academic Publishing.

Forman, R. T. T., & Godron, M. (1986). *Landscape Ecology* (p. 619). New York: Wiley.

Fuhr, D., Dudka, M., Gage, J., & Scarpace, F. (1999). New approaches to georectification and image mosaicing in digital airborne imaging for agriculture airborne data systems. Final report: National Aeronautics and Space Administration Commercial Remote Sensing Program Office.

Grossman, D. H., Faber-Langendoen, D., Weakley, A. S., Anderson, M., Bourgeron, P., Crawford, R., Goodin, K., Landaal, S., Metzler, K., Patterson, K. D., Pyne, M., Reid, M., & Sneddon, L. (1998). International classification of ecological communities: terrestrial vegetation of the United States. In *The National Vegetation Classification System: Development, Status, and Applications*, *vol. I*. Arlington, VA: The Nature Conservancy (126 pp).

Habib, A. (2002). Coordinate transformations. In J. D. Bossler (Ed.), *Manual of geospatial science and technology* (pp. 27–49). New York: Taylor and Francis.

Herkert, J. R. (1994). The effects of habitat fragmentation on midwestern grassland bird communities. *Ecological Applications*, *4*, 461–471.

Herzog, F., & Lausch, A. (2001). Supplementing land-use statistics with landscape metrics: Some methodological considerations. *Environmental Monitoring and Assessment*, *72*, 37–50.

Jensen, J. R., Cowen, D. J., Narumalani, S., Althausen, J. D., & Weatherbee, O. (1993). An evaluation of Coastwatch change detection protocol in South Carolina. *Photogrammetric Engineering and Remote Sensing*, *59*(4), 519–525.

Jensen, J. R., & Narumalani, S. (1992). Improved remote sensing and GIS reliability diagrams, image genealogy diagrams, and thematic map legends to enhance communication. *International Archives of Photogrammetry and Remote Sensing*, *6*(B6), 125–132.

Kaufman, G. A., & Kaufman, D. W. (1996). Ecology of small mammals in prairie landscapes. In F. L. Knopf, & F. B. Samson (Eds.), *Ecology and conservation of great plains vertebrates* (pp. 207–243). New York: Springer-Verlag.

Krummel, J. R., Gardner, R. H., Sugihara, G., O'Neill, R. V., & Coleman, P. R. (1987). Landscape pattern in a disturbed environment. *Oikos*, *48*, 321–324.

Lam, N. S. N. (1990). Description and measurement of Landsat TM images using Fractals. *Photogrammetric Engineering and Remote Sensing*, *56*, 187–195.

Lambin, E. F., & Strahler, A. H. (1994). Change-vector analysis: A tool to detect and categorize land-cover change processes using high temporal-resolution satellite data. *Remote Sensing of Environment*, *48*, 231–244.

Lavers, C., & Haines-Young, R. (1993). Spatial heterogeneity and new technology. In R. Haines-Young, D. Green, & S. Cousins (Eds.), *Landscape ecology and geographic information systems* (pp. 57–74). London: Taylor and Francis.

McGarigal, K., Marks, B. J., (1995). *FRAGSTATS: Spatial pattern analysis program for quantifying landscape structure*. General Technical Report PNW-GTR-351, USDA Forest Service, Pacific Northwest Research Station, Portland, OR.

Oldfield, F., Dearing, J. A., Gaillard, M. J., & Bugmann, H. (2000). Ecosystem processes and human dimensions—The scope and the future of HITE (Human Impacts on Terrestrial Ecosystems). *Pages Newsletter*, *8*, 21–23.

O'Neill, R. V., Hunsaker, C. T., Timmins, S. P., Jackson, B. L., Jones, K. B., Ritters, K. H., & Wickham, J. D. (1996). Scale problems in reporting landscape pattern at the regional scale. *Landscape Ecology*, *11*, 169–180.

O'Neill, R. V., Krummel, J. R., Gardner, R. H., Sugihara, G., Jackson, B., DeAngelis, D. L., Milne, B. T., Turner, M. G., Zygmut, B., Christensen, S. W., Dale, V. H., & Graham, R. L. (1988). Indices of landscape pattern. *Landscape Ecology*, *1*, 153–162.

Prabhu, R., Ruitenbeek, H. J., Boyle, T. J. B., & Pierce-Colfer, C. J. (2001). Between voodoo science and adaptive management: The role of research needs for indicators of sustainable forest management. In R. Raison, A. Brown, & D. Flinn (Eds.), *Criteria and indicators for sustainable forest management* (pp. 39–66). Willingford, UK: CABI Publishing.

Rainis, R. (2003). Application of GIS and landscape metrics in monitoring urban land use change. In N. M. Hashim, & R. Rainis (Eds.), *Urban ecosystem studies in Malaysia: A study of change* (pp. 267–278). Florida: Universal Publishers.

Rindfuss, R. R., & Stern, P. C. (1998). Linking remote sensing and social science: The need and the challenges. In D. Liverman, E. F. Moran, R. R. Rindfuss, & P. C. Stern (Eds.), *People and pixels: Linking remote sensing and social science* (pp. 1–27). Washington, DC: National Academy Press.

Sader, S. A., Stone, T. A., & Joyce, A. T. (1990). Remote sensing of tropical forests: An overview of research and applications using non-photographic sensors. *Photogrammetric Engineering and Remote Sensing*, *56*, 1343–1351.

Turner, M. G., O'Neill, R. V., Gardner, R. H., & Milne, B. T. (1989). Effects of changing spatial scale on the analysis of landscape pattern. *Landscape Ecology*, *3*, 153–162.

Turner, M. G., & Ruscher, C. L. (1988). Changes in landscape patterns in Georgia, USA. *Landscape Ecology*, *1*, 241–251.

U.S. Geological Survey (1996). Standards for digital orthophoto: Part 1. General. *National mapping program technical instructions* (9 pp) (Reston, VA).