Analyzing Landscape Structural Change Using Image Interpretation and Spatial Pattern Metrics

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Abstract: This research integrates remote sensing and landscape ecology metrics to quantify land use/land cover change at the Wilson's Creek National Battlefield, Missouri. Aerial photography and IKONOS pan-sharpened data were used to develop land cover classification maps for the 1940s, 1960s, and 1990s. Post-classification change detection and landscape ecology metrics techniques were used to analyze habitat classes, while a threat vector analysis assessed residential migration pressure toward the park. Landscape patterns revealed that "natural" land cover classes (e.g., oak/hickory forest) have been affected by human influences through the regularization of their boundaries. The study area has experienced tremendous residential growth because of nearby towns such as Springfield and Republic. This growth has impacted the park environment and an analysis reveals that the park faces multi-directional threats from these developments.

INTRODUCTION

A landscape is defined as a heterogeneous land area composed of a cluster of interacting ecosystems and typically has several types of elements (patches) that represent regions that have the same habitat class and relatively homogenous environmental conditions (Forman and Godron, 1986). Changes in a landscape alter the structure (spatial components of the distinctive ecosystems or patches present) and function (interaction among the spatial elements) of the ecological mosaic over time. These changes are a result of complex interactions between physical, biological, economic, political, and social forces. Most landscapes have been influenced by human land use, and the resulting mosaic is a mixture of natural and human managed patches that vary in size, shape, and arrangement (Turner et al., 1989). Nearly all landscapes, even those perceived as "natural" by contemporary standards, have potentially been influenced by humans in the past, and growing concerns over the loss of biodiversity have encouraged land managers to look for better ways of managing these landscapes.

To quantitatively assess landscape change and their causes, a suite of metrics is often computed. These metrics can be derived at patch (defined for individual patches), class (characteristics of all patches in a given class), and/or landscape level (integrated over all patch types or classes over the extent of the data). Patch metrics are perhaps more useful for analyzing single patches for specific purposes (e.g.,

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habitat studies, reserves delineation, and edge effects). However, when analyzing land use/land cover (LULC) change as the most important process of landscape transformation, class metrics provide the important elements needed to describe the general patterns as well as the changes within the landscape.

It is a well-recognized fact that remote sensing data offer a wealth of information on the landscape (Turner et al., 2001). When viewing a satellite image or an aerial photograph, many elements can be identified, which when combined characterize the physical aspects of the landscape. Some of these elements—including variations in shape, size, texture, patterns, and association—have formed the basis of aerial photo-interpretation. The integration of landscape metrics with remotely sensed data allows the quantification of these groups of elements into measurable variables. However, for assessing landscape dynamics, the challenges before remote sensing analysts lie in how to infer process from static snapshots that is meaningful from an ecological perspective. The key to unraveling landscape dynamics from temporally discrete data is to link spatial metrics and landscape patterns to ecological and environmental processes for analyzing the causes and consequences of the change.

This research focuses on the conceptual and methodological implementation of integrating change detection methods and spatially distributed landscape metrics to monitor landscape dynamism over a 60-year period at the Wilson's Creek National Battlefield (WICR) in Missouri. Furthermore, the information was used to derive potential threat vectors based on land use change over the six decades.

BACKGROUND

In 1994, the United States National Park Service (NPS) established the Prairie Cluster Long Term Ecological Monitoring (LTEM) Program as one of the 11 prototypes to develop natural resource monitoring within NPS. The Prairie Cluster LTEM program currently serves six parks located in four Midwestern states and a primary focus of the program is to develop and implement monitoring protocols for resources affected by active management and/or external park threats (NPS/NBS, 1994).

Park ecosystems are affected by changing land use outside park boundaries as well as internal management actions. Agricultural, residential, and industrial developments are prominent land uses adjacent to these parks with some of them experiencing rapid development at their boundaries. Due to their size, 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 and Kaufman, 1996). Third, populations in isolated patches suffer from genetic inbreeding and accelerated rates of genetic drift (Benedict et al., 1996).

Increases in 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 the NPS is to develop methods for providing information to support natural resource management decisions that will protect and improve the survivability of the landscape including populations of plant and animal communities that are analogous to a time period pre-dating the influence of human settlement (Witcher et al., 2001). 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.

STUDY AREA

WICR is located 10 miles south of the city of Springfield, Missouri, on the boundary between Greene and Christian counties in the southwestern corner of the state (Fig. 1). The park was established by Congress on 22 April 1960 to preserve and commemorate the Civil War's Battle of Wilson's Creek, and encompasses 1,750 acres including approximately 75% of the historic battlegrounds (NPS, 2000). The battlefield is significant as the site of the first major battle west of the Mississippi River and retains unusually high integrity relative to other Civil War battlefields. It is the location where General Nathaniel Lyon, the first Union General, was killed in the Civil War. Lyon's death focused national attention on the potential loss of Missouri to the Confederacy.

WICR lies within a karst area along Wilson's Creek approximately 2 miles upstream from its confluence with the James River and is within the upper portion of the 1,460 square mile James River watershed. The watershed terminates at Table Rock Lake near Branson, Missouri, and is an economically important resource to the region. The park is downstream from the city of Springfield, Missouri (2000 population census 140,494), which discharges 42.5 million gallons of treated sewage effluent each day. During low- flow periods an estimated 80% of the water flowing through WICR is treated sewage effluent.

Vegetation and water quality have been the most studied natural resources at WICR primarily because they have typically been the most visible to the public, and are the key to a visitor's understanding of the battle and enjoyment of the facilities. Threatened and endangered species include the *Lesquerella filiformis* (Missouri bladderpod), which is the most studied plant within the park, and the *Myotis sodalist* (Indiana bat), whose population is located within the park (NPS, 2000). There are also approximately 1,100 acres of disturbed land that park personnel are trying to restore to oak savanna or historic fields that were present during the battle. Approximately 500 acres of the park are infested with exotic plant species, while pollution from external sources is adversely affecting the water resources within the park. To evaluate overall stream quality, aquatic insects are monitored annually, and from these studies Wilson's Creek is considered to be in "fair" condition.

The park also has an active prescribed fire program to mimic the natural fire regime that created much of the savanna landscape that was present at the time of the battle. Approximately 300 acres of vegetation are burned each year under the direction of well-trained fire management personnel. There are five caves located within the park totaling approximately 60 feet of undeveloped cave passages. Two of the caves have been surveyed and mapped, though all caves are closed to the public until

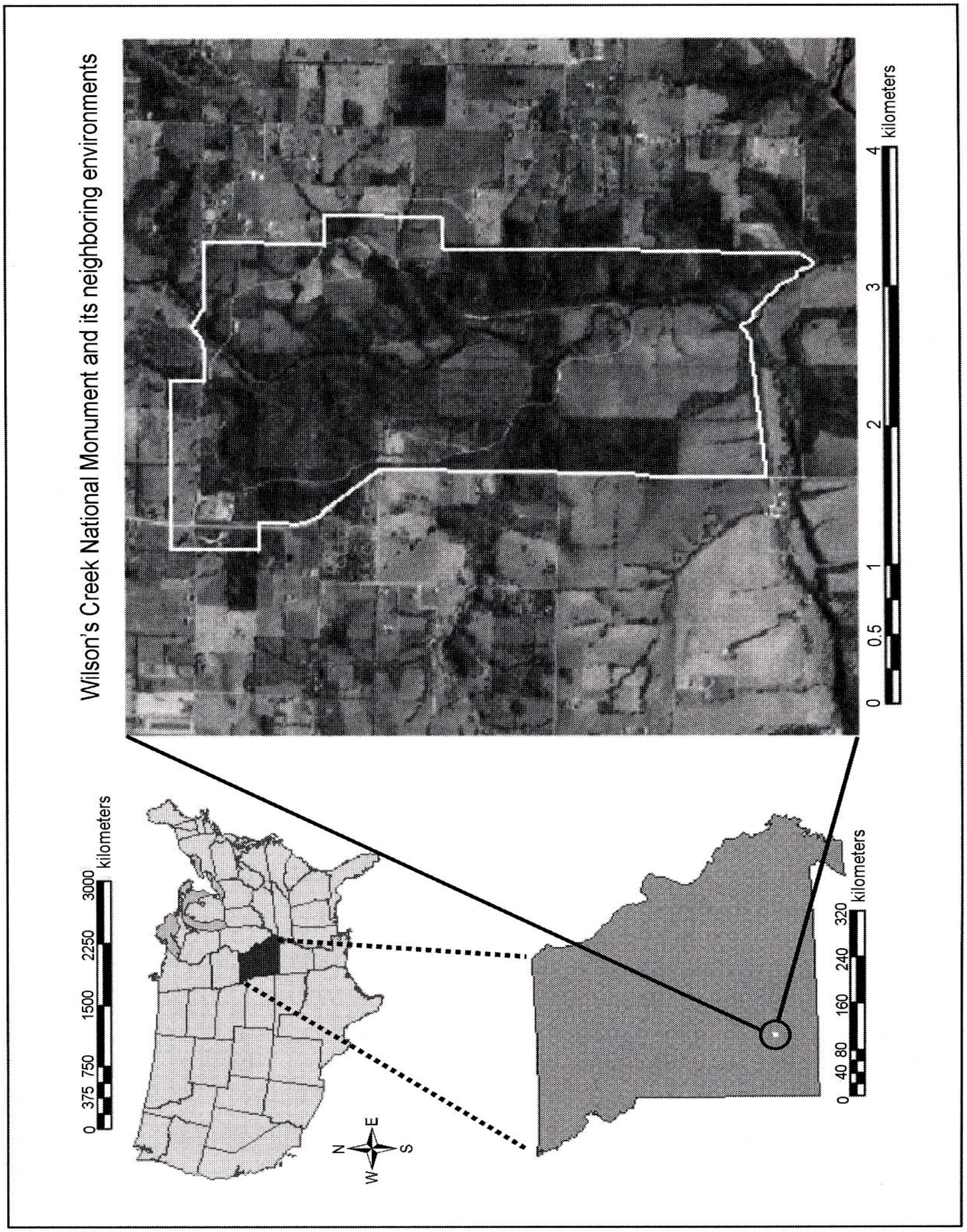

Fig. 1. Location of Wilson's Creek National Battlefield, Missouri in the conterminous United States. The IKONOS image dated 19 November 2000 shows the entire study area with the park boundary delineated.

a complete inventory of resources has been performed and an informed decision about their future management made. Finally, development in the surrounding areas of Springfield, Republic, and Battlefield has diminished available wildlife habitat, making the park a "haven" for various wildlife.

The primary issue affecting the park is the tremendous population growth in the surrounding region and its affect on the management of the park. As local governments expand their infrastructure to accommodate population growth, the result is an increase in development projects that have the potential to affect park resources. Recent examples include a proposed sewage treatment plant on the western boundary of the park, a proposed highway bypass near the park, a proposed residential development adjacent to the park, and a proposed Greenways trail from Springfield.

MATERIALS AND METHODS

Data Sources

Several sources of data were used to accomplish the objectives of this project. The three time periods for which land cover was to be interpreted were determined based on the availability of the aerial photography. Specific dates of the photos included September 1940, October 1961, August 1964, and the Digital Orthophoto Quadrangles (DOQs) were developed from photography acquired from March 1996 through June 2000. Photos were acquired at a nominal scale of 1:20,000. To aid the interpretation process, high-resolution, pan-sharpened (1 × 1 m) IKONOS satellite imagery, acquired in 19 November 2000 was used. In addition, NPS and PC LTEM personnel along with local residents provided considerable input.

Image Interpretation

Three "temporal snapshots" were used, pertaining to the decades of the 1940s, 1960s, and 1990s. Because multiple dates and even multiple years of photography were used to compile the mosaics for the study area, we refer to the specific decade in which the photography was acquired (i.e., 1940s, 1960s, and 1990s). Change detection requires that there be minimal variation in spatial, spectral, and radiometric resolution. However, when the mosaics were compiled, considerable effort was made to minimize variation in the black-and-white texture of the photographs between multiple dates within the same time period. In addition, because manual interpretation techniques were used, differences between the photographs would have minimal ramifications because the analyst would consider these impacts.

A vegetation classification scheme based on U. S. federal government standards was used to classify land use. These standards approved to the National Vegetation Classification Scheme (NVCS) "Formation" level and documents such as Anderson et al. (1998) and Grossman et al. (1998) have expanded upon 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 manmade features (e.g., roads, urban areas) satisfactorily and descriptions from Anderson et al. (1976) were used for these categories. Because of the difficulty in interpreting certain key objectives (oak-hickory forest or woodland), considerable ancillary input was provided by NPS personnel and incorporated into the classification scheme. Consequently, the classification was iteratively modified and finalized for 19 land use categories found at WICR (Table 1).

On-screen digitizing was used to delineate the land use/land cover. 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. The development of an accurate classification also depended on substantial and vital feedback of the Prairie Cluster LTEM personnel.

The image interpretation was performed backwards in time—i.e., the contemporary data were interpreted first in order for the image analyst to become familiar with the study area. The 1996–2000 DOQQ mosaic was analyzed and compared with the IKONOS multispectral data to aid the interpretation. Interpretation of features followed an elimination process by first classifying the "obvious" features of the landscape (e.g., roads, railroads, farmsteads/agricultural buildings, urban areas, and rivers). Further classification addressed areas of croplands, pastures, and forest patches with more than 60% canopy cover. In order to differentiate between pasture and cropland, photointerpretation elements such as vegetation texture, feature shape, slope indicators, presence of row crops or tillage marks, and erosion patterns were used. Association and shape elements such as the spatial relationship of a field to the road network, sorting pens, holding pens, and buildings often provided more clues about the use of a plot of land. The location of pastures relative to roads, farmsteads, woodlands, and waterways were particularly useful. Upon completion of each time period, draft maps were produced for dissemination to Prairie Cluster 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 classifications were derived without extensive ground surveys with a minimum mapping unit of 1 hectare.

Change Detection

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

After each date of aerial photography (and the IKONOS data) was interpreted, the post-classification change detection method was used to determine changes between three time periods including 1940s–1960s, 1960s–1990s, and 1940s–1990s. Post-classification change detection is the most commonly used method of change detection (Jensen et al., 1993). When image-map products for two or more dates are produced, they 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

Table 1. Land Use Classification Scheme

Land cover class and code	Description
FORESTS/WOODLANDS (> 25% trees)	
Upland forests/woodlands	
Oak / hickory forest complex (FHC)	Similar to oak / hickory forest that include pockets of glades
Oak-hickory woodland (FHW)	Similar to oak / hickory forest, primarily deciduous canopy cover 25-60%.
Oak / hickory forest (FOH)	Canopy cover is> 60%, trees mostly deciduous common species include white, black and post oaks, mockernut, and bitternut hickories.
Nursery (FMP)	Tree species that are cultivated
Upland woodland complex (FUW)	25% -60% tree canopy. Composition similar to oak / hickory forest with areas of glade included
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: cedars, sumac, honey locust.
Bottomland/Floodplain Forests/Woodlands/Shrublands	
Bottomland woodland (FBW)	Bottomland tree stands with areas with 25% -60% canopy cover; frequent species include oaks, slippery elm, and sycamore
Riparian forest (FRH)	Bottomland tree stands with areas >60% canopy cover
HERBACEOUS (>25% Canopy Cover)	
Upland herbaceous	
Croplands (HCF)	Annual crops such as corn and soybeans
Pasture (HPG)	Fields used for grazing and haying.
Pasture with trees (HTP)	Canopy cover < 25%. Areas of exotic, cool-season grasses interspersed with trees.
Restored savanna/prairie (HSP)	Restoration areas within the park, some areas have few mature trees due to recent restoration
OPEN WATER (non-vegetated)	
Farm ponds (OFP)	Farm ponds and stock dams for agricultural use
Rivers and streams (ORS)	Rivers and streams of mappable width
LAND 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.
Industrial (LRI)	Power generation and municipal water treatment facilities
Roads and Railroads (LRR)	Roads and railroads and their rights-of-ways
Residential (LRS)	Buildings and land for residential use

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. In addition, these selected classes were draped on the aerial photographs and IKONOS single band to highlight the spatial locations where these changes had occurred.

Landscape Metrics

Our focus was on analyzing temporal change using 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 that showed maximum change over the three time periods and computed four class-level metrics including class area (CA), number of patches (NP), area weighted mean patch size (MPS), and area weighted mean patch fractal dimension (MPFD) for the three time periods.

Class area is a measure of landscape composition and describes how much of the landscape is comprised of a particular patch type. Number of patches of a particular land use type is a simple measure of the extent of subdivision or fragmentation of the patch type. It conveys no information about area, distribution, or density of patches. If total landscape area and class area are held constant, then number of patches conveys the same information as patch density or mean patch size. Patch size is an important characteristic of the landscape when analyzing community structure, based on the fact that larger patches generally hold a greater number of species than smaller patches (Lavers and Haines-Young, 1993). Often, the frequency distribution of patch sizes is skewed toward a few large patches, surrounded by many smaller patches (Turner et al., 2001). Under these conditions, area weighted averaging of patch size is a more useful method than the simple average of patch size. Mean patch fractal dimension has been used in ecosystem change analysis to quantify the complexity of patch shapes on a landscape (Krummel et al., 1987; O'Neill et al., 1988; De Cola, 1989; Lam, 1990). It is a measure of the degree of human disturbance on the landscape. The premise is that natural boundaries such as those for vegetation have more complex shapes than those that are a result of human activity, such as agricultural fields. As human disturbance increases the fractal dimension of a patch decreases.

Derivation of Threat Vectors Representations

WICR has operated under a 1977 master plan, and since then the park and its surroundings have changed significantly (NPS, 2002). The population of the Springfield metropolitan area grew from 207,704 to 240,593 between 1980 and 1990 and increased to 281,767 by 1995. The population of Greene County (northeast) increased from 152,928 to 218,095 between 1970 and 1995, while that of Christian County grew from 15,124 to 38,433 in the same period (NPS, 2002). The impact of the population growth and encroaching suburban development around the park would undoubtedly be harmful for the park habitat. Regional planners predict that approximately 20,000 acres of undeveloped land in the Springfield area would be converted to housing and 65,000 people are expected to move into the area between 2000 and 2020. As the regional population grows, residential development on former agriculture fields would become visually prominent from areas within the park. This development could potentially intrude upon historical context of the park and have an adverse effect on the scenic as well as natural resources within the park.

Representations of threat vectors based on the growing residential pressure towards the park boundary were modeled for a period of 60 years. The study area was divided into 1 mile buffers from the park boundary, for a distance of 3 miles, and the buffer was segmented into 8 vectors drawn at 45° angles to represent compass directions. Residential growth pressure for each segment was calculated using the following formula, thus producing normalized values:

$$\text{Residential pressure (at each segment) \%} = \frac{\text{Total residential areas in a segment (hectare)}}{\text{Total area of that segment (hectare)}} \times 100. \qquad (1)$$

RESULTS AND DISCUSSION

Results

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 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.

Change detection results for WICR for 1940s–1960s show that major changes, especially with reference to natural vegetation include: (a) net gain in bottomland woodland and upland woodland complex and oak/hickory forest; (b) increase in farm ponds; (c) increase in residential and pasture land; and (d) a decrease of oak/hickory woodland because of thinning canopy in oak/hickory forest. Between the 1960s and 1990s large areas (89 hectares) of oak/hickory woodlands had increased in canopy and were therefore classified as oak/hickory forest in the later date. There was also a tremendous increase in residential area from the 1960s to 1990s (339 hectares), at the expense of natural vegetation such as upland woodland complex, pasture with trees, upland scrub, oak/hickory forest, and oak/hickory woodland. Some losses of natural vegetation (e.g., oak/hickory forest and woodlands) were due the expansion of roads and railroads, as well as farmsteads and agricultural buildings in the area. There was a 34% decline (1,625 hectares) in cropland mainly due to conversion to pastureland, while some pasture in turn was re-colonized by upland woodland (206 hectares), shrub (169 hectares), and oak/hickory forest (153 hectares).

Overall changes in natural vegetation from the 1940s–1990s at WICR showed interchangeable shifts, whereby some areas of oak/hickory forest and oak/hickory woodlands had thinned-out canopies, whereas others changed from pasture in the 1940s to full-growth forested areas in the 1990s (Fig. 2). A major change was the tremendous rise in residential area—from 37 hectares in the 1940s to nearly 2,200 hectares in the 1990s, indicating the growth effects of Springfield and Republican. Pasture experienced a net gain in each of the study periods because of large-scale conversion of croplands. These changes as well as those from "natural" land cover are depicted by different colors in the change detection matrix (Fig. 2), with the corresponding spatial locations being presented in the change detection map (Fig. 3).

1990s (columns) / 1940s (rows)

Class	FMP	FUW	FBW	HTP	HSP	HCF	HPG	LRS	LCM	LFB	LRR	OFP	ORS	SUS	FOH	FHC	FHW	LRI
FMP							13	53	25		1							
FUW															6		2	
FBW		9					18							6	40			
HTP		104					93	81	7	4	1	3		58	141			6
HSP																		
HCF		83		65	39		1791	278	20	9	9	4		73	105			2
HPG	12	246		128	51	13		1128	144	39	30	19		166	409		5	25
LRS									9									
LCM																		
LFB		5		1	2		62	170	4		1			4	11			
LRR		6		1			20	11	15	1				2	10			
OFP							3	3										
ORS		1	9				4							2	4			
SUS		28		23			42	45	3						95			
FOH		115		14			126	102	5	2	2	2	14	66		2		
FHC															4			
FHW		109	3	18	1		83	53	5	3	2	1	2	55	182	3		
LRI																		

Fig. 2. Post-classification change detection matrix (1940s–1990s) quantifying the amount of change in hectares. Colors of selected classes indicate "from-to" change categories based on "natural" vegetation.

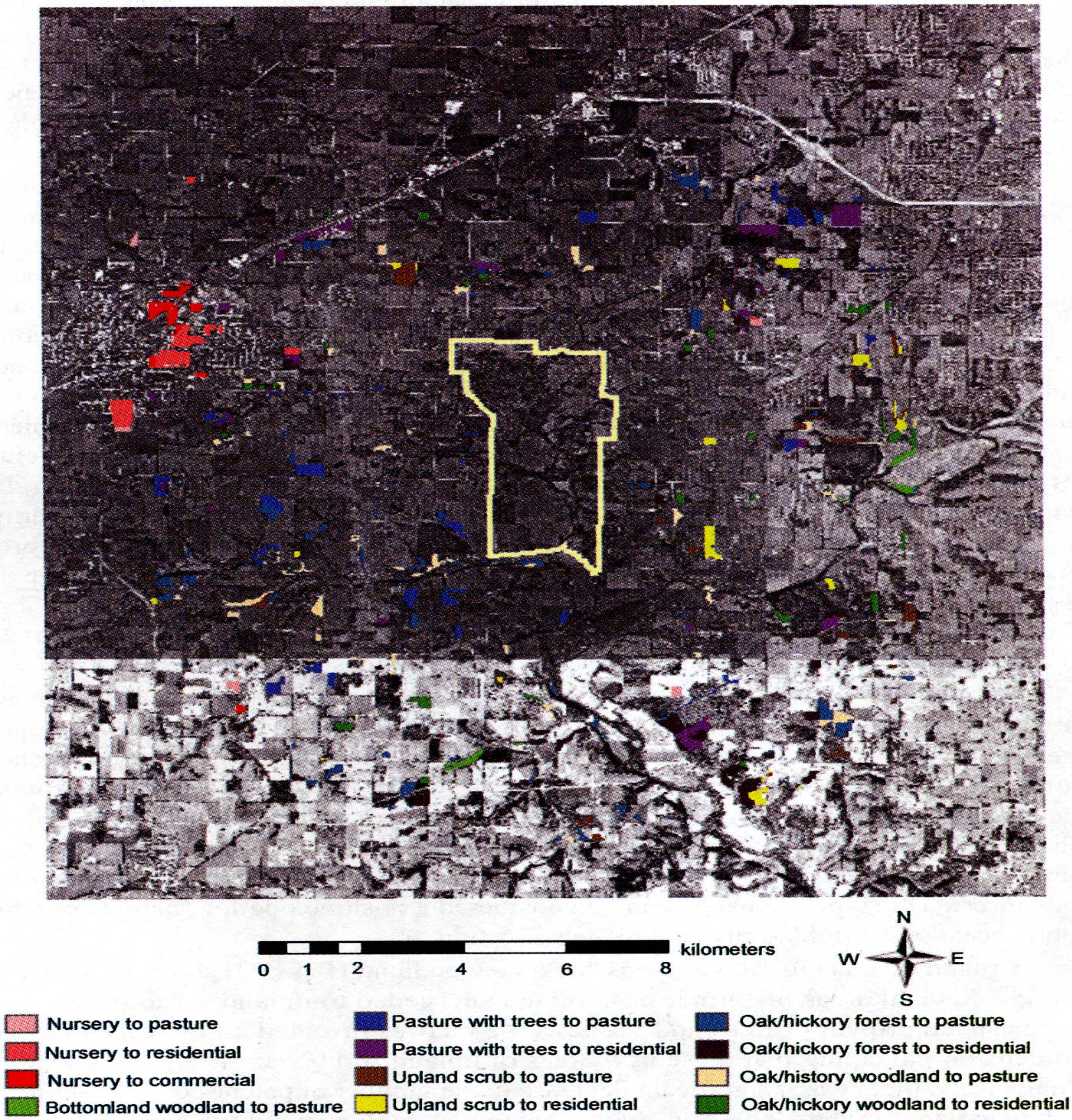

Fig. 3. Representation of selected land cover change for Wilson's Creek National Battlefield from 1940s–1990s. Colors on the image indicate "from-to" change categories based on "natural" vegetation and are the same colors highlighted in the change detection matrix (1940s–1990s).

While conventional change detection methods described changes in class area, their spatial locations, and interacting areal differentials (i.e., from-to) between classes, landscape metrics provide an insight into 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 United States. 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 others such as fractal dimension evaluate patch complexity and human influence on a given patch.

Land cover classes including oak/hickory forest, upland woodland complex, upland scrub, oak/hickory woodland, and residential showed high temporal change (Fig. 4) in their class area compared to other classes and are, therefore, examined in 3-D landscape pattern space (Figs. 5A–D). For example, oak/hickory forest experienced a net increase of 681 hectares over 60 years, although a much larger percentage of clearings occurred to pave the way for agriculture and residential. The temporal shifts for this cover type indicate it has become more fragmented (number of patches and mean patch size are declining while the latter decreased more compared to the number of patches; Fig. 5A). However, the sharp decline in mean patch fractal dimension indicates that the configuration of the boundaries of oak/hickory 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 anthropogenic 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 upland woodland complex cover type has experienced considerable increase in its area. Fragmentation of this cover type is difficult to observe between the 1940s and 1990s because there is an increase in the number of patches and mean patch size simultaneously (Fig. 5B). However, there is a significant decrease in fractal dimension of patches indicating increased human influence. When these data were examined in conjunction with the change detection matrix for this time period, it was noted that 246 ha of savanna/woodlands was converted to deciduous forest. This type of change can be considered a positive one for "natural vegetation" because it would imply canopy densification.

Upland scrub (Fig. 5C) and oak/hickory woodland (Fig. 5D) showed opposing trends. Several areas of former pastureland succeeded to upland scrub because of unrestricted growth of trees and bushes. The metrics revealed an increased fractal dimension indicating that these new areas of upland scrub were irregular in shape. Conversely, there was a significant decrease in the number of patches of the oak/hickory woodland. In the 1990s few patches remained, with some of the areas achieving higher canopy density and being classified as oak/hickory forest (182 ha between the 1940s and 1990s). However, the changes of ecological concern were those where some of the oak/hickory woodland was converted to residential and pastureland.

As mentioned earlier, substantial residential growth was observed over the 60 years. The landscape metrics reveal an increase in the number of patches and mean patch size, along with a decrease in mean patch fractal dimension (Fig. 6A). A

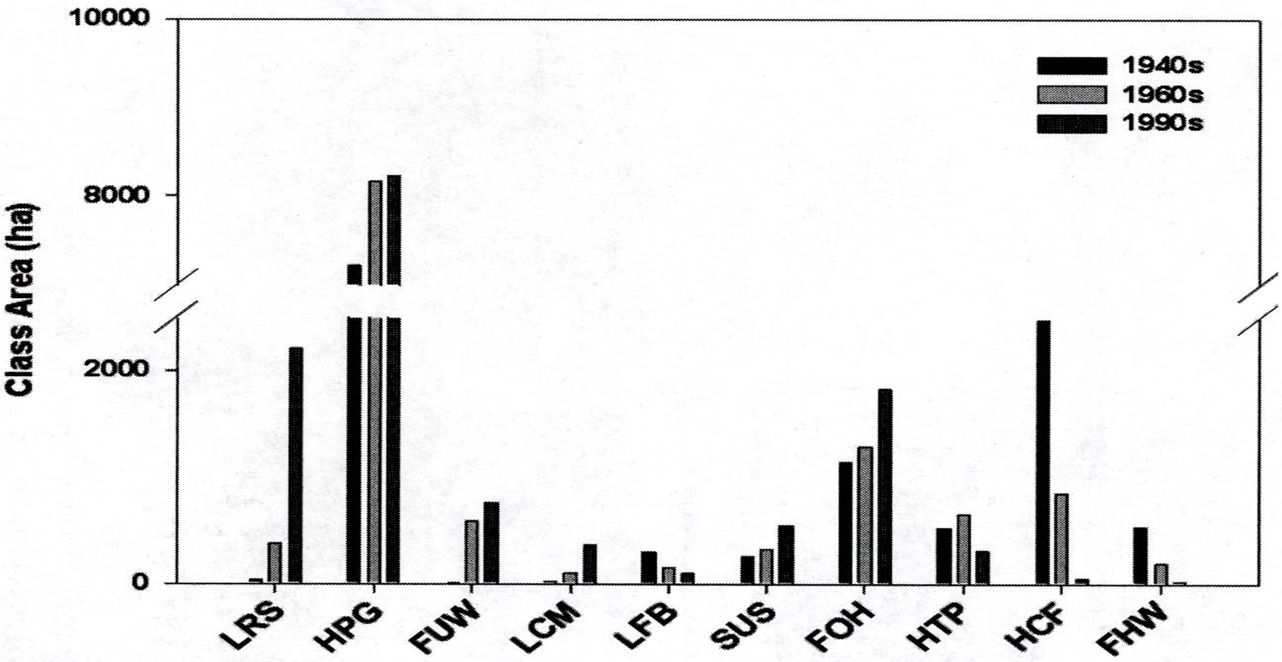

Fig. 4. Total area of different land cover classes at Wilson's Creek National Battlefield during the 1940s, 1960s, and 1990s.

time-sequence study of the neighborhood within a three-mile radius of the park boundary reveals the residential migration pressure towards the park, because of the growth of nearby cities like Springfield, Republican, and Battlefield (Figs. 6A–6C).

Threat Vector Analysis

Threat vector analysis revealed the direction of growing residential threat within a three-mile buffer zone from the park boundary. In the 1940s, no major threat due to residential growth was observed for the study area. Less than 10% of the land area was residential land use, and most of the segments had no residential cover (Fig. 7A). In the 1960s, significant residential development was observed in all directions, heading toward the park boundary (Fig. 6B). Even within a one-mile buffer of the park, development is evident. However, the residential proportion of land use remains low (less than 10%) in all directions except the WNW, where urban development from Republic (3 miles away) begins to manifest itself within three miles of the park boundary (Fig. 7B). From the interpretation of the 1990s aerial photographs and 2001 IKONOS imagery, a dramatic increase in residential areas is observed in all directions, with some of the development occurring adjacent to the park boundary (Fig. 6C). When the threat vector analysis is performed, several segments have between 30 and 50% residential areas (Fig. 7C). While two well-demarcated threat vectors can be established from the WNW and ENE because of the growth of Republic and Springfield, there is also an overall shift as additional segments both north and south of the park boundary begin to experience substantial developmental pressure.

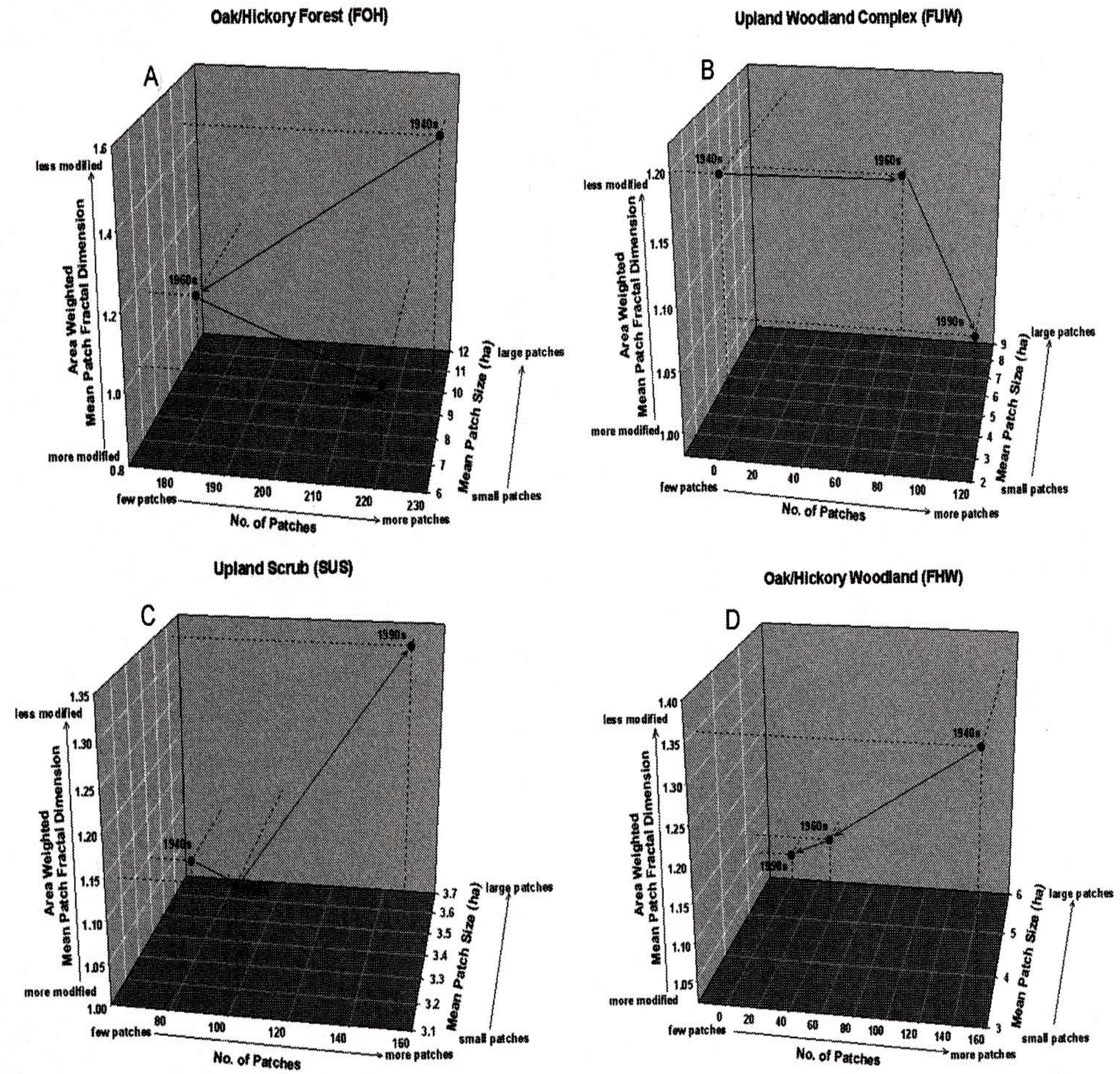

Fig. 5. Three-dimensional landscape metrics space for selected land cover categories showing the direction and magnitude of change for (A) oak/hickory forest, (B) upland woodland complex, (C) upland scrub, and (D) oak/hickory woodland from the 1940s–1960s–1990s.

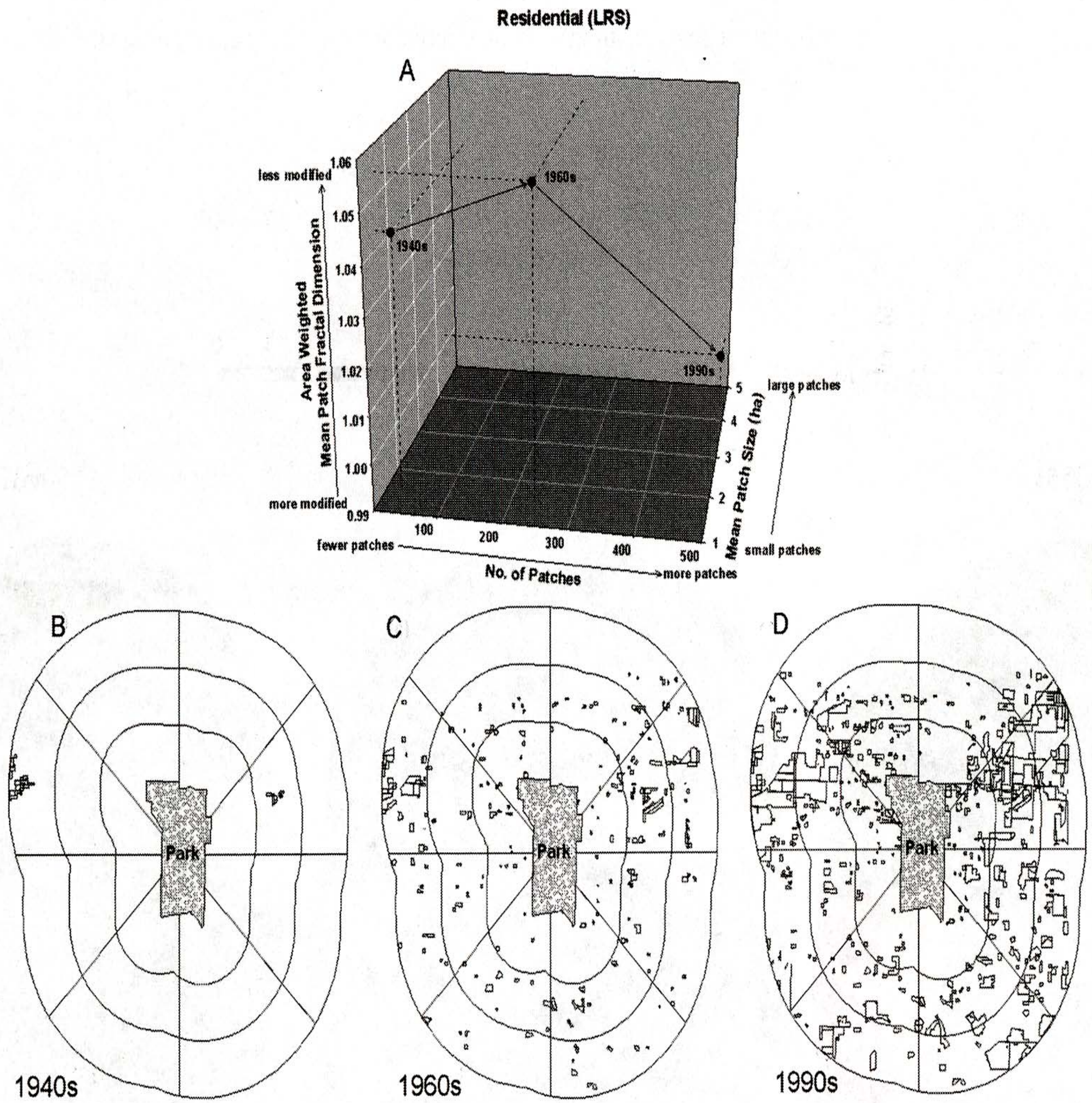

Fig. 6. Changes in "residential" land cover shown in (A) three-dimensional landscape metric representation, and the depiction of its spatial growth within a three-mile zone from the park boundary (at one-mile buffers) during the (B) 1940s, (C) 1960s, and (D) 1990s.

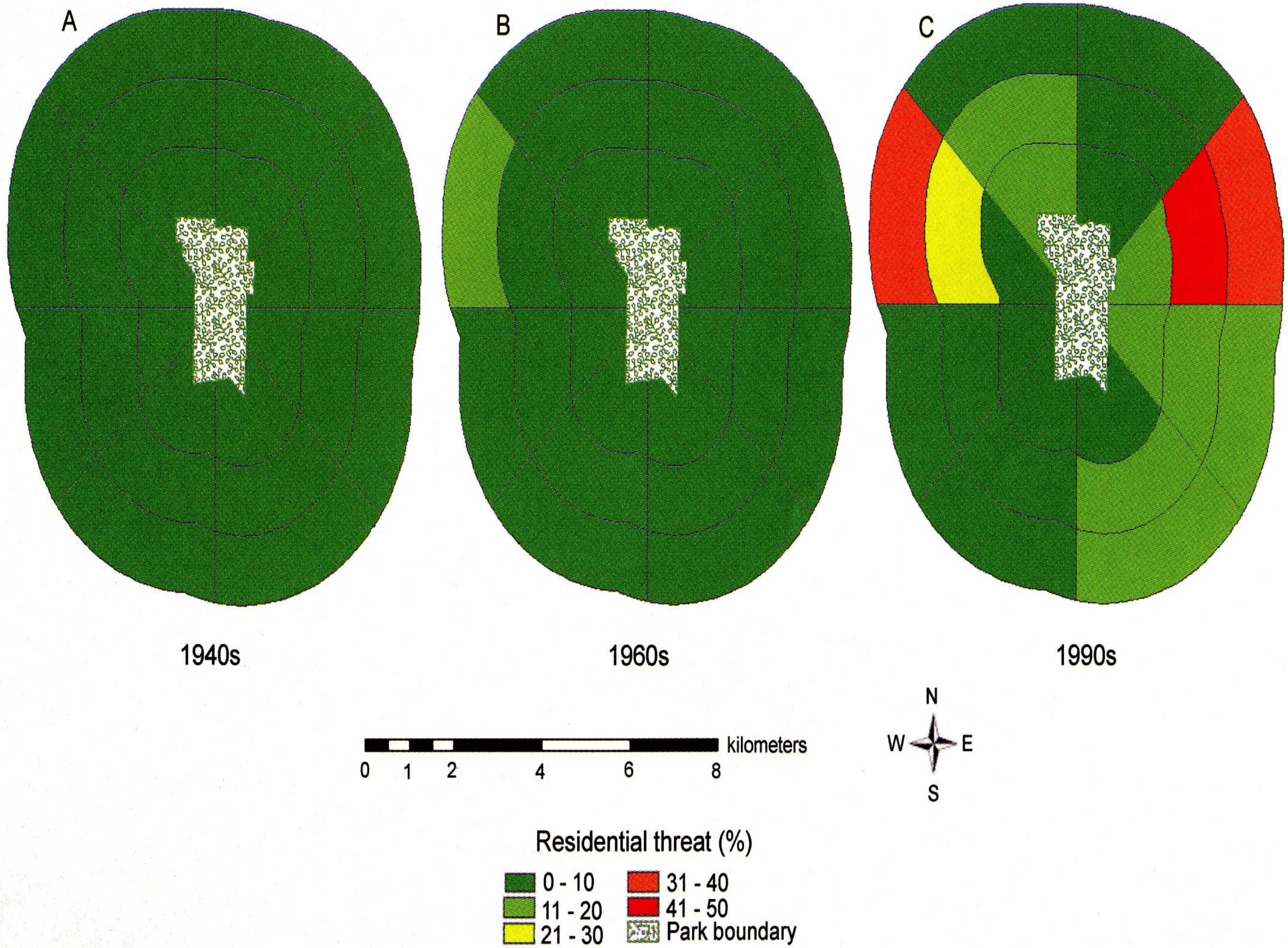

Fig. 7. A threat vector analysis based on the ratio of residential land growth in each segment during the (A) 1940s, (B) 1960s, and (C) 1990s.

Discussion

When evaluating change across several decades, it is important to be aware of alterations in governmental land management policy. For example, in 1936 the U.S. Department of Agriculture (USDA) introduced policy that focused on decreasing soil erosion losses from agricultural lands in the United States. Consequently, practices such as field reshaping for terrace formation combined with contour seedbed tillage and planting are some land management strategies that were implemented to slow the rate of water runoff and decrease topsoil losses. To implement soil erosion control policy, conservation strategies were advocated by the USDA to all agricultural communities, and monetary incentives in the form of cost-share payments to land owners were offered to offset their expenses for reshaping their fields. Another facet of the soil erosion control policy emphasized monetary encouragement to land owners to create water impoundments by building earth berms in the path of precipitation runoff by providing cash assistance payments when land operators cooperated with the USDA for the design phases of the projects. Consequently, large numbers of farm ponds are observed in the 1960s and 1990s at WICR.

Major landscape changes around WICR have been due to exponential urban development and residential growth in cities near the park (NPS, 2002). Recent growth in the Springfield metropolitan area has changed the character of land use patterns in the suburban areas of Springfield, Battlefield, and Republic. Large agricultural tracts increasingly are being subdivided into 10-acre residential home sites; as a result, the land area of Springfield has grown significantly. In 1961 WICR was approximately 10 miles from Springfield city limits. Now, however, metropolitan Springfield is as close as five miles from the park, and this changing land use pattern is visible and audible from within the park boundaries. For example, transportation improvements to serve this growing suburban population are bringing higher traffic volumes and associated noise to county road ZZ and highway 182, which respectively border the western and northern boundaries of the park.

Impact of the threat due to residential growth is being felt on the various natural, cultural, and aesthetic resources, as well as on the socio-economic environment, park access, and transportation. A variety of past, present, and foreseeable actions have affected the soil, wildlife, water quality, and historic sites related to the civil war and will continue to affect the resources within the park. For example, conversion of land for residential purposes results in widespread soil disturbance and increased soil erosion associated with displacement of native vegetation. Since the 1830s, urban development has affected approximately 46,000 acres of lands within the Springfield city limit, resulting in extensive removal, rearrangement, compaction, and paving of soils. Projected growth estimates indicate an additional 20,000 acres of land would be developed in the Springfield region by 2020, with the consequential impacts of soil compaction, porosity, and an increase in surface runoff rates toward the park (Springfield Planning and Development Department, 1998).

Projected residential development in this region is likely to increase the volume of storm water runoff discharged into Wilson's Creek by 35 to 40% between the year 2000 and 2020. Most of the Wilson's Creek watershed lies outside the boundary of the park in areas that had been intensively cultivated between the 1940s and 1960s, resulting in the degradation of water quality because of agricultural runoff. With the rapid pace of residential development, the storm water runoff transports urban contaminants, including petroleum products, and heavy metals into Wilson's Creek. Another source of past and potential contamination is Springfield's water treatment plant, which is located upstream from the park, where sewage spills have occurred in the past and may again in the future (NPS, 2000). The cumulative impact of these sources of contamination has reduced populations of aquatic vertebrates and invertebrates, and has resulted in occasional fish kills in Wilson's Creek.

The conversion of land for residential use has drastically reduced the extent of native vegetation and habitats. Such development has isolated small patches of vegetation that have been transformed by fire suppression and other factors from savanna woodland dominated by scattered oaks to dense forests dominated by exotic plants such as Osage orange and honey locust (Missouri Department of Conservation, 1986). Narrow corridors along the waterways continue to support riparian vegetation; however, the majority of wetland vegetation of the area has been destroyed by urban development (Dahl, 1990).

Residential growth has reduced the extent of native habitats available for wildlife. For example, ground- nesting birds and mammals are particularly sensitive to construction activities that may disrupt their reproductive and rearing cycles. Increasing mortality, competition, and predation of native wildlife have reduced their populations, and future projects (such as the construction of the Highway 60 bypass and urban construction of a projected additional 20,000 acres of open space by the year 2020) will continue to reduce and fragment the remaining wildlife habitat.

Unlike typical change detection procedures, this research focused on integrating the change detection results with landscape metrics. By incorporating input from PC LTEM personnel and local residents, a detailed and thorough land cover classification scheme was produced. The post classification change detection method provided information on the "from-to" conversion between land covers, while the landscape metrics explained the impact of human influence in and around the study area.

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