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Landscape structure and change in a hardwood forest-tallgrass prairie ecotone

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Abstract

Temporal changes in land use, vegetation cover types, and landscape structure were examined in a hardwood forest-tallgrass prairie ecotone in northern Oklahoma using a Geographic Information System. Our objective was to examine relationships between human activity, changes in land use and vegetation cover type, and landscape structure in rural landscapes between 1966 and 1990. Cover types in most of the high density rural population landscape in this study require more intensive inputs and management, which resulted in a landscape with lower diversity, higher homogeneity, and greater patch fragmentation compared to the low density rural population landscape. Both native grasslands and forests were less fragmented in the low density rural population landscape whereas forests were increasingly fragmented in the high density rural population landscape. Native grasslands were less fragmented than forests for all years in both the low density rural population and high density rural population landscapes. Our study suggests conservationists should focus their concerns on fragmentation and losses in biological diversity that accompany increased human activity in densely populated rural landscapes that surround urban centers. Extensively managed landscapes dominated by native vegetation that are under less pressure from expanding human influence are in less peril.

Key Words: geographic information system, landscape structure, urbanization, vegetation cover type

Agricultural development of the Great Plains since the 1870's has caused a dramatic decline of tallgrass prairie, with the reduction of area occupied by this ecosystem exceeding any other in North America (Samson and Knopf 1994). Large, extensively managed blocks of native vegetation have been fragmented into smaller blocks of intensively managed introduced pastures and cropland. Urban sprawl into rural landscapes may exacerbate these changes in land use and vegetation cover type thereby further altering landscape structure and diversity. Replacing natural vegetation with managed systems of altered structure often reduce ecosystem diversity on a regional scale (Krummel et al. 1987, McNeeley et al. 1990). Such anthropogenic changes have caused concern about preserving and managing for biological diversity (Grove and Hohmann 1992, Urban et al. 1992, West 1993).

Although scientific literature contains extensive research on the effects of urbanization and fragmentation of contiguous forests, research is lacking in native grasslands (Samson and Knopf 1994) and grassland-forest ecotones (Risser 1990). Ecotones provide valuable insight to the complex dynamics of ecosystems including temporal changes in landscape structure and function (Wiens et al. 1985, Hardt and Forman 1989). Although ecotones are dynamic and typically have high community diversity (Risser 1990, Johnston et al. 1992), anthropogenic influences on change have not been well documented.

Changes in landscape structure may affect a wide variety of ecological processes (Turner 1989); but, relatively little is known about how components of landscape change over time (Baker 1992). Therefore, descriptions of changing landscape patterns form an important component of our understanding of ecological dynamics necessary to integrate the often conflicting demands of wildlife habitat, recreation, agriculture, and development. We chose 2 landscapes that differed in rural population density to test the hypothesis that human activity alters cover types and structure of landscapes in rural areas. Specifically, we hypothesized that 1) high density rural population and low density rural population landscapes differ in temporal change in land use, vegetation cover types, and landscape structure; and 2) structure of native grasslands have changed more than forests because of greater human activity in native grasslands.

Study Site

Our study was centered around suburban Tulsa, Okla., and the surrounding rural areas in northeastern Osage and southern Washington Counties. We selected 2 U.S. Fish and Wildlife Service Breeding Bird Survey routes, 024 (Collinsville) and 026 (Bartlesville) (Fig. 1) (Baumgartner and Baumgartner 1992), to represent the suburban to rural transition lying within the ecotonal area of the Cherokee Prairie grassland formation and oak-hickory savanna of the Cross Timbers (Bruner 1931, Soil

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Breeding Bird Survey Routes

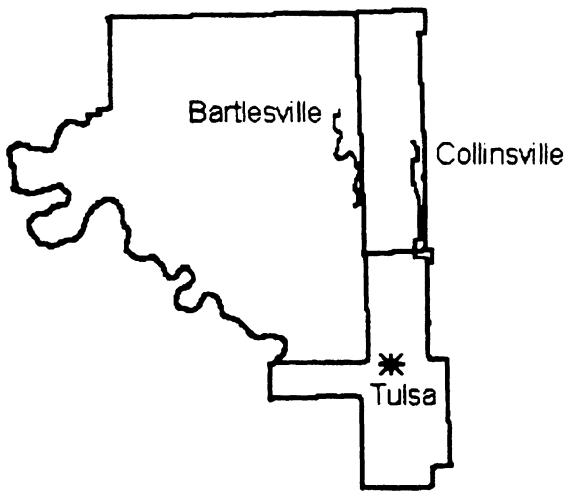

Fig. 1. The 2 U.S. Fish and Wildlife Service Breeding Bird Survey routes located in northern Oklahoma used for the study area.

Conservation Service 1981). The Cherokee Prairie extends as a long, narrow strip, 240 km southward from the Kansas state line with a width ranging from 48 to 96 km throughout most of its length. The area is better adapted to support grasses than forests because of climate and underlying geology (Harlan 1957). The Cross Timbers lie west of the Cherokee Prairie and the Lower Arkansas Valley, extending 288 km southward from Kansas with a width of 80 km. The region is a transitional oak forest with interspersed grasslands (Bruner 1931, Gray and Galloway 1959).

Survey routes varied in their proximity to Tulsa, a major metropolitan area in northern Oklahoma with an estimated population of 361,628 (U.S. Department of Commerce 1990). The Collinsville route is located in Washington County and the Bartlesville route is located in Osage County. Human population density of Washington and Osage County in 1990 was 3,340 km^{-2} and 520 km^{-2}, respectively. In addition, rural population density of Washington and Osage County in 1990 was 10.3 km^{-2} and 4.9 km^{-2}, respectively. Rural population is defined by the U.S. Department of Commerce (1990) as residing in communities of less than 2,500 people. Hence, from this point forward, the 2 landscapes will be discussed as high density rural population or low density rural population.

Methods

Data Collection

We used aerial photography for 1966, 1973, 1980, and 1990 as the data set for addressing the relationships between human activity (i.e. population density) and changes in land use, vegetation cover type, and landscape structure. Black and white aerial photographs were obtained from the U.S. Department of Agriculture, ASCS, Aerial Photography Field Office, Salt Lake City, Ut. Photographs were 60.96 × 60.96-cm enlargements with a representative fraction of 1:7,920. We used portions of photography that covered breeding bird survey routes (40.2 km in length) and 0.8-km on each side of the route boundary. The resulting coverage was approximately 6,430 ha for each route.

Topographic quadrangel maps, photo inspected in 1976, showed the natural and man-made features of the land at 1:24,000 scale and were obtained from the Oklahoma Geological Survey, Norman, Okla. The quadrangles indicate both geographical coordinates and specific features such as vegetation, water, roads, and towns. These maps were used for both geo-registration of the photography and to aid in photo-interpretation.

Features identified on each photograph included: breeding bird survey route, roads, buildings and houses, oil and gas facilities, land use, and vegetation cover types. Land use and vegetation cover types were interpreted based on the classification scheme of Stoms et al. (1983) (Table 1). All interpreted polygons of interest were traced on overlying acetate and the results of supervised photo interpretation for 1966, 1973, and 1980 were compared to those from the 1990 photography.

Table 1. Classification system used to map land use and vegetation cover types (adapted from Stoms et al. 1983).

Land use and cover type	Description
Developed area	Land occupied by residential, industrial, or other human structures and non-agricultural activities. Also includes transportation and utility facilities
Roads	Black top, gravel, dirt roads and driveways
Water	Ponds, lakes, streams, and rivers
Cropland	Land cultivated for row crops and cereal grains but excluding grazing lands
Pasture land and hay meadows	Includes pasture land (seeded, grasslands used for grazing by cattle, sheep, goats, and horses) and hay meadows
Native grassland	Native grasslands with less than 10% cover by shrubs or trees
Deciduous forest	Vegetation dominated (>10%) by cover of broadleaf hardwoods. Mostly post oak (*Quercus stellata*) and blackjack oak (*Q. marilandica*)
Brush-treated land	Native vegetation subjected to herbicides, fire, or chaining to control woody brush encroachment
Bare ground	Land with less than 5% vegetative cover

Completed polygons were digitized using a digital scanner. Scanned images were edited, rectified, and vectorized using LTPlus (Line Trace Plus, version 2.22) and imported into the Geographic Information System GRASS (Geographic Resource Analysis Support System) (Shapiro et al. 1992). Vector maps were then patched together to form the complete route, labeled, and converted to a raster map with 5-m resolution.

Data Analysis

Within the Geographic Information System, changes in land use and vegetation cover types over the last 24 years were examined. Landscape analysis was performed using the raster landscape ecological spatial analysis package within GRASS (Baker and Cai 1992). This package was developed for quantitative analysis of landscape structure. The raster landscape ecological programs were used to generate landscape measures of mean patch size, fractal dimension, richness, Shannon diversity index, dominance index, contagion, angular second moment, and contrast.

Mean patch size is the mean area (ha) of patches in the sampling area and serves as an index of fragmentation. It is calculated for all patches in the sampling area by dividing sample area size by the number of patches (Baker and Cai 1992). As patches become smaller because of fragmentation, mean patch size decreases. Fractal dimension is a measure of fractal geometry or patch shape complexity of a landscape (Mandelbrot 1983, Krummel et al. 1987). Fractal dimension was calculated by regressing polygon area against perimeter length for each landscape patch. Values for fractal dimension range from 1 to 2. Landscapes dominated by simple patterns (circles and squares) have low fractal dimension values while landscapes dominated by complex or convoluted patterns have high fractal dimension values (Krummel et al. 1987).

Shannon's diversity index combines richness and evenness. Richness refers to the number of patch attributes present in the sampling area and evenness refers to the distribution of area among different patch types (Turner 1990a, 1990b). Richness and evenness are the compositional and structural components of diversity, respectively (McGarigal and Marks 1994). Larger values for Shannon's diversity index indicate a more diverse landscape (O'Neill et al. 1988). The dominance index is based on the Shannon-Weaver diversity index (Shannon and Weaver 1962) but emphasizes deviation from evenness. The dominance index measures the extent that specific land uses (or vegetative cover types) dominate the landscape (O'Neill et al. 1988). Large dominance index values indicate a landscape dominated by 1 or few cover types while low dominance index values indicate a landscape with many cover types represented in approximately equal proportions (Turner 1990a).

Three texture measures were calculated for the regional landscape which included contagion, angular second moment, and contrast using eight-neighbor analysis to quantify the adjacency of similar patch types. Contagion measures the extent to which cover types are aggregated or clumped in contiguous patches (O'Neill et al. 1988). A landscape with well interspersed patch types will have a lower contagion compared to a landscape with poorly interspersed patch types (McGarigal and Marks 1994). Angular second moment is a measure of landscape homogeneity. Larger values for angular second moment indicate more homogeneity (McGarigal and Marks 1994). Contrast measures local variation present in the landscape (Baker 1994).

Comparisons between 1966 and 1990 were made between Collinsville and Bartlesville to assess the effects of human activity on vegetation cover types and landscape structure. Mean patch size and fractal dimension were also determined for native grasslands and forests within both Collinsville and Bartlesville to assess the effects of human activity on structure of these cover types.

Results and Discussion

Effects of Human Activity

Temporal Changes in Cover Types

Developed areas increased markedly in the high density rural population landscape (Collinsville) whereas developed areas decreased in the low density rural population landscape (Bartlesville) between 1966 and 1990 (Table 2). Therefore, these landscapes provided excellent study areas for investigation of the effects of human activity in rural landscapes on vegetation change and landscape structure. Because the high density rural population landscape was located near Tulsa, it experienced a greater amount of human influence over the past 25 years compared to the low density rural population landscape and resulted in different temporal changes in vegetation cover types.

Table 2. Temporal changes in vegetation cover types (ha) and percent change from 1966 of high density rural population and low density rural population landscapes in a hardwood forest-tallgrass prairie ecosystem in northern Oklahoma for 1966, 1973, 1980, and 1990.

Index	Year				Change
	1966	1973	1980	1990	
	(ha)				-(%)-
High density rural population (Collinsville)					
Developed areas	16	7	25	24	50
Roads	88	92	101	87	-1
Water	53	76	58	71	34
Cropland	556	453	208	120	-78
Pasture land and hay meadows	676	672	850	999	48
Native grassland	1,432	1,601	1,546	1,508	5
Deciduous forest	449	294	398	377	-16
Brush-treated land	0	41	4	5	—
Bare ground	2	6	2	2	0
Low density rural population (Bartlesville)					
Developed areas	23	18	16	22	-4
Roads	108	94	121	118	9
Water	27	39	30	38	41
Cropland	25	41	12	13	-48
Pasture land and hay meadows	90	50	25	49	-46
Native grassland	1,375	1,308	1,120	1,117	-19
Deciduous forest	1,184	980	950	887	-26
Brush-treated land	397	616	877	878	121
Bare ground	20	7	10	8	-60

Land in the high density rural population landscape was subject to more intensive management practices, such as cropland and pasture land and hay meadows., than the low density rural population landscape. Cropland accounted for 17% of the area of the high density rural population landscape and only 1% of the low density rural population landscape in 1966. Both landscapes had a reduction in cropland between 1966 and 1990; however, the rate of loss in cropland was greater for high density rural population landscape compared to the low density rural population landscape (Table 2). Cropland in the high density rural population landscape was converted primarily to pasture land and hay meadows. Pasture land and hay meadows, which accounted for 21% of the area of the high density rural population landscape and only 3% of the low density rural population landscape in 1966, subsequently increased in the high density rural population landscape but decreased in the low density rural population landscape (Table 2). The increase in pasture land and hay meadows in the high density rural population landscape, which resulted from the conversion of native grassland, cropland, and forests, suggests the cover types on the high density rural population landscape require more intensive inputs and management compared to the cover types on the low density rural population landscape.

Deciduous forests accounted for 37% of the area of the low density rural population landscape and only 13% of the high density rural population landscape in 1966 (Table 2). Forests were converted primarily to brush-treated lands in the low density rural population landscape and to pasture land and hay meadows in the high density rural population landscape from 1966 to 1990. However, the rate of decline in forest was greater for the low density rural population landscape than the high density rural population landscape. Brush-treated lands accounted for 12% of the area of the low density rural population landscape and only 1% of the high density rural population landscape in 1966. Furthermore, area of brush-treated lands increased dramatically from 1966 to 1990 in the low density rural population landscape but not on the high density rural population landscape (Table 2).

Native grasslands were the dominant cover type on both landscapes in all years (Table 2). However, native grasslands changed little on the high density rural population landscape whereas native grasslands declined on the low density rural population landscape from 1966 to 1990. The decline in native grasslands along the low density rural population landscape may be misleading because native grasslands subjected to either herbicides or fire were photo-interpreted as brush-treated lands. Maintenance of tallgrass prairie dominance in this region requires fire or herbicides to prevent encroachment of woody species (Bragg and Hulbert 1976, Knight et al. 1994).

Temporal Changes in Landscape Structure

Landscape structure can be characterized by the composition and relative abundance of vegetation cover types and their spatial arrangement or geometry (Freemark et al. 1993). Because natural and anthropogenic disturbances alter landscape structure and may have important ecological implications (Turner 1990b), temporal changes in landscape structure must be considered in quantitative landscape studies (Dunn et al. 1990). Temporal changes observed in land use and vegetation cover types in our study resulted in altered landscape structure.

Mean patch size is generally large in areas of natural vegetation with minimal influence from human activities (Pickett and Thompson 1978). With increased human activity, mean patch size decreases because the landscape is generally subdivided into smaller patches (Forman and Boerner 1981). Measures of mean patch size in our study indicate the high density rural population landscape became more fragmented than the low density rural population landscape since 1973 (Table 3), and because mean patch size declined by 29% in the high density rural population landscape and only 7% in the low density rural population landscape from 1966 to 1990, landscape fragmentation was 4 times greater in the high density rural population landscape over the entire period. Human activities related to crop production and urban development also tend to simplify patch shapes which reduces fractal dimension (Krummel et al. 1987, O'Neill 1988). However, patch complexity as measured by fractal dimension was similar between landscapes and slightly increased in both landscapes after 1973 (Table 3). This suggests that natural disturbance regimes, including climate, may have influenced patch complexity to a larger degree than human activities.

Table 3. Measures of landscape pattern and percent change from 1966 of high density rural population and low density rural population landscapes in a hardwood forest-tallgrass prairie ecosystem in northern Oklahoma for 1966, 1973, 1980, and 1990.

Index	Year				Change
	1966	1973	1980	1990	-(%)-
High density rural population (Collinsville)					
Mean patch size (ha)	4.16	3.93	3.22	2.96	- 29
Fractal dimension	1.23	1.25	1.27	1.28	+ 4
Shannon diversity	1.43	1.39	1.33	1.28	- 11
Dominance	0.65	0.75	0.81	0.86	+ 32
Contagion	2.69	2.83	2.85	2.91	+ 8
Angular second moment	0.27	0.30	0.30	0.32	+ 19
Contrast	0.33	0.46	0.50	0.50	+ 52
Low density rural population (Bartlesville)					
Mean patch size (ha)	3.96	4.29	3.63	3.42	- 8
Fractal dimension	1.27	1.24	1.27	1.30	+ 2
Shannon diversity	1.21	1.29	1.29	1.31	+ 8
Dominance	0.93	0.78	0.78	0.83	- 11
Contagion	2.99	2.82	2.81	2.88	- 4
Angular second moment	0.35	0.30	0.29	0.29	-17
Contrast	0.41	0.35	0.35	0.42	+ 2

Human activity typically decreases diversity by increasing landscape fragmentation, homogeneity, and dominance (Davis and Glick 1978). Landscape dominance increased in the high density rural population landscape (Table 3) suggesting a general trend for the landscape to be dominated by fewer land uses or vegetation cover types (O'Neill et al. 1988). Landscape dominance decreased in the low density rural population landscape suggesting a general trend toward land uses or vegetation cover types represented in more equal proportions. In addition, angular second moment increased from 1966 to 1990 in the high density rural population landscape suggesting a homogeneous, less diverse landscape. In contrast, angular second moment decreased from 1966 to 1990 in the low density rural population landscape indicating a landscape becoming more heterogeneous suggesting an increase in landscape diversity. Although landscape diversity was 15% greater in the high density rural population landscape compared to the low density rural population landscape in 1966, landscape diversity declined by 11% in the high density rural population landscape while landscape diversity increased by 8% in the low density rural population landscape from 1966 to 1990 (Table 3). Overall, the high density rural population landscape became less diverse, but the low density rural population landscape became more diverse since 1966.

Our results suggest that in the absence of societal pressure to halt increased human activity in rural landscapes still dominated by native vegetation, fragmentation will continue and biological diversity will most likely degrade in an accelerated fashion. For example, avian community structure as an indication of biological diversity, diverged over time in the high density rural population and low density rural population landscapes because of different land use and agriculture practices associated with each landscape (Boren 1995). Temporal shifts in avian community structure were reflected in increasing prairie habitat and generalist habitat associated species in the low density rural population and high density rural population landscapes, respectively. More neotropical migrants were lost from the high density rural population landscape compared to the low density rural population landscape (Boren 1995). A decrease in landscape quality, especially with regard to increased landscape fragmentation, may account for the observed loss of neotropical migrants from the high rural population density landscape (Johnson and Temple 1986).

Structure of Native Grasslands and Forests

Human activity tends to simplify patch complexity and increase fragmentation of contiguous forests (Godron and Forman 1983). The fractal dimension indicates forest patches were more complex in shape compared to native grassland patches in the high density rural population landscape (Table 4), suggesting greater human impact in native grasslands than in forests. In contrast, native grassland fragmentation remained relatively unchanged while fragmentation of forest increased from 1966 to 1990 (Table 4). Therefore, extrapolation of relationships between urbanization, patch complexity, and fragmentation to other ecosystems may not always be appropriate.

Table 4. Measures of landscape pattern and percent change from 1966 of native grassland and forest of high density rural population and low density rural population landscapes in a hardwood forest-tallgrass prairie ecosystem in northern Oklahoma for 1966, 1973, 1980, and 1990.

Index	Year				Change
	1966	1973	1980	1990	
					-(%)-
High density rural population (Collinsville)					
Native grassland					
Mean patch size (ha)	15.24	15.37	12.52	15.25	0
Fractal dimension	1.25	1.27	1.26	1.25	0
Forest					
Mean patch size (ha)	2.72	1.75	1.69	2.01	- 26
Fractal dimension	1.36	1.39	1.36	1.35	- 1
Low density rural population (Bartlesville)					
Native grassland					
Mean patch size (ha)	11.83	9.81	12.81	18.55	+ 57
Fractal dimension	1.35	1.29	1.35	1.41	+ 4
Forest					
Mean patch size (ha)	3.99	6.21	4.43	5.47	+ 37
Fractal dimension	1.25	1.24	1.24	1.31	+ 5

Native grassland patches were more complex in shape compared to forest patches in the low density rural population landscape for all years (Table 4), which we attribute to fire and other brush treatment practices. Disturbance patches created by prescribed burning can increase landscape heterogeneity and patch complexity because fire effects differ with respect to topography, fuel type, fuel load, climate, and season (Godron and Forman 1983, Biondini et al. 1989, Baker 1992, Urban 1994). In addition, fragmentation decreased in both native grasslands and forests in the low density rural population landscape from 1966 to 1990 (Table 4).

Table 5. Percentage of native grassland and forest on a relative basis adjacent to human impact areas for the high density rural population and low density rural population landscapes for 4 separate years.

Cover type	Year			
	1966	1973	1980	1990
	- - - - - - - - - - (%) - - - - - - - - - -			
High density rural population (Collinsville)				
Native grassland	25	28	50	48
Deciduous forest	13	7	35	38
Low density rural population (Bartlesville)				
Native grassland	36	34	44	47
Deciduous forest	40	46	32	47

In both high rural population density and low rural population density routes there was relatively little change in the complexity of patch shape in either native grasslands or forests over time (Table 4). In addition, native grasslands were less fragmented than forests for all years based on mean patch size in both landscapes. Because native grasslands were less fragmented than forests one would expect to find increased road and residential growth in the forests compared to the native grasslands. However, our data indicated that roads were developed randomly with respect to cover type in the landscape. Human impact areas, including residential development, were primarily located in native grasslands in the high density rural population landscape in 1966 (Table 5). However, forests were increasingly selected for human development from 1973 to 1990 (Table 5). This may account for the observed temporal increase in fragmentation of forests. However, human impact areas were more evenly distributed between native grasslands and forests for all years in the low density rural population landscape (Table 5). Forests were more fragmented than native grasslands for both landscapes as early as 1900 (Criner 1996), which indicates differences in fragmentation between cover types is most likely a function of geomorphologic processes such as soils and natural disturbance regimes including climate and fire (Godron and Forman 1983).

Conclusions

High density rural population and low density rural population landscapes differed in temporal change in vegetation cover types and landscape structure. Native grasslands were less fragmented than forests in both landscapes. However, we found landscape quality, as defined by increased landscape fragmentation and decreased landscape diversity, has recently eroded in a densely populated rural landscape. In contrast, landscape quality improved in a low density rural population landscape dominated by ranching enterprises. Differences in landscape quality between landscapes (high density rural population vs. low density rural population) can be attributed to differences in land use and associated management practices. Maintenance of the tallgrass prairie by extensive management practices including prescribed burning, herbicide application, and grazing management most likely accounts for the observed improvement in landscape quality in a low density rural population landscape whereas an increase in more intensive management practices associated with seeded pasture land and hay meadows accounts for an observed reduction in landscape quality in a high density rural population landscape. These and other similar landscapes likely will continue to diverge in landscape quality in the absence of societal pressure to halt the spread of human activity into rural landscapes dominated by native vegetation. Our study suggests conservationists should focus their concerns on fragmentation and losses in biological diversity that accompany increased human activity in densely populated rural landscapes that surround urban centers. Extensively managed landscapes dominated by native vegetation that are under less pressure from expanding human influence are in less peril.

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