LAND COVER CHANGES (1815 TO 2007)
IN THE CENTRAL MISSOURI RIVER HILLS

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In Partial Fulfillment
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Master of Arts

by
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The undersigned, appointed by Dean of the Graduate School, have examined the thesis entitled:

LAND COVER CHANGE (1815 to 2007)
IN THE CENTRAL MISSOURI RIVER HILLS

Presented by Kevin Hunt

A candidate for the degree of Master of Arts in Geography

And hereby certify that in their opinion it is worthy of acceptance.

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I would first and foremost like to thank my parents, Kenneth and Susan Hunt, for their determined encouragement and love that has made much of my journey through graduate studies and research possible. My father, from the beginning inspired my curiosity of the process and science behind landscapes and much of the early knowledge I gained has been the foundation to accomplishing this thesis. My interest and familiarity in the study area comes from having been raised in the Central Missouri River Hills of Boone County, Missouri. As a firsthand witness of land cover changes in the Central Missouri River Hills I hope that this research can be used for further research and improve land use management of this important ecoregion in the Midwest.

This thesis would not be possible without the support and confidence of Mark Cowell, my graduate advisor. With his guidance I was able to succeed in my research from beginning to end in under a year. The faculty, staff, graduates and undergraduates made the geography department at the University a wonderful place to be over the past six years during both my undergraduate and graduate careers.

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ABSTRACT

The legacy of land use can influence landscape dynamics for centuries, potentially altering subsequent plant species composition, nutrient cycling and hydrology. To understand how previous land use has affected landscape patterns in the now predominantly forested central Missouri River Hills, this study assesses the magnitude of land cover change between four dates: the onset of European American settlement (circa 1815), near the period of maximum agricultural land use (1939), and through recent episodes of farm abandonment and reforestation (1968 and 2007).

The River Hills, characterized by fertile loess soils and located on the western edge of the eastern deciduous forest, have undergone substantial changes over the past two centuries. In the early nineteenth century, 10% was open canopy woodlands and 90% was closed canopy forest. By 1939 forest accounted for just over 37% of land cover, which then rebounded to 61.5% of the total landscape by 2007. Patch metrics indicate that individual forest patches are decreasing in number while increasing in size, as formerly isolated patches coalesce and increase connectivity; the reverse trend has been true of fields. Land that was forested in 1939 tended to persist as forest to 2007, with newly regenerated forest accreting to existing patches mainly on steep slopes. These patterns of land cover change provide context for understanding contemporaneous changes in forest structure and composition, and can be used to guide management of this comparatively large zone of forest habitat in an otherwise predominantly agricultural region.

Chapter One

Introduction

Landscape ecologists study historical land use as a means to understand land cover changes and their many ecological consequences. One-third to one-half of earth's ice free terrestrial surface has been directly changed and transformed by humans and these land use practices may influence subsequent plant species composition, nutrient cycling, hydrology and even climate (Vitousek 1994; Fitzpatrick et al. 1999; Houghton and Goodale 2004). An early student of these human influences was Henry Thoreau, the nineteenth century author, and naturalist who observed his local New England landscape in great detail. He paid particular attention to plant succession, and recognized that the human history of a landscape was important to understanding the present vegetation. His journal of October 16th 1860 noted: "Our wood-lots, of course, have a history, and we may often recover it for a hundred years back, though we do not...Yet if we attended more to the history of our lots we should manage them more wisely (Foster 2002)." Thoreau's perspective came from a period of peak demand for agricultural land in New England, which was followed by subsequent decline in intensity during the mid-nineteenth century (Foster 2002). Thoreau's observations pre-date the similar focus that landscape ecologists bring today on the long-term impacts that human land use can produce.

In many regions, the anthropogenic legacies on the environment are greater than natural disturbances (Foster 2002). Many patches of forest in the landscapes of the eastern half of the United States have a prior history as pasture, woodlot, or tilled cropland that shapes the present vegetation and succession in distinct ways (Motzkin et al. 1999). Understanding local land use histories clarifies the extent to which humans have altered ecosystems and ecological processes.

New England encompasses the northeast corner of the eastern deciduous forest of the United States (Figure 1.1), and was mostly forested prior to European settlement. By 1770, as seen in Figure 1.2, the region had been densely settled and much of its forest was being converted to agricultural land. Forest landscapes in the eastern United States have experienced a longer history of European settlement than in the west. A study of land cover change conducted in southern New England observed the progression of change. Prior to European settlement the region was primarily forest, then forest was mostly cleared following settlement into the nineteenth century. Agriculture declined in the second half of the nineteenth century while forest recovered through natural succession and today forest cover dominates the landscape (Golodetz and Foster 1996; Hall et al. 2002).

The upper Midwest, like New England, is a region that is within the eastern deciduous forest (Figure 1.1), but was settled later, mainly in the mid-nineteenth century (Figure 1.2). A study of southern Wisconsin's historical land cover changes compared periods before European American settlement in 1850 to recent land cover in 1993 (Rhemtulla et al. 2007). They found that in southern Wisconsin there was rapid conversion from forest and savanna to cropland from 1850 to 1935, while little change occurred during the rest of the twentieth century. Southern Wisconsin's croplands continue to dominate the landscape with little reforestation occurring, in contrast to the forest recovery occurring in parts of New England.

The land cover changes that have taken place in many regions like New England and the upper Midwest also affect landscape configuration. The nature and significance of historic land cover change can be identified by classifying the landscape into patches that share similar characteristics. As patches change through time, research may identify areas where forest composition and structure have shifted within the matrix. A landscape in a constant cycle of disturbance is often characterized by continual change in its composition (Romme 1982; Romme and Knight 1982).

New England and Midwest have both been affected in many ways by the arrangement of patches of land cover types. The spatial pattern of disturbance has been shown to have lingering influences on subsequent ecosystem functions (Foster et al. 1998). These legacies can produce effects such as habitat fragmentation, and can have negative consequences on habitat conditions and ecological diversity (Saunders 1991). The occurrence of particular species at a location is often an indicator of adaptation to prior disturbance history (Foster et al. 2003). Understanding patch configuration may help conservation management efforts in preserving ecological diversity and further the understanding of ecological functioning of a landscape.

This study presents a comparison to these previously documented patterns in New England and Wisconsin by examining the Missouri River Hills on the western edge of the eastern deciduous forest. The central Missouri River Hills represent a historically forested region. Immigration to the Missouri River valley began in full in the early nineteenth century, spurred by prospects of virgin forests and fertile farmlands that were documented by the United States-sponsored expedition of the Missouri River by explorers Lewis and Clark from 1804 to 1806 (Meyer 1965). In the decades following

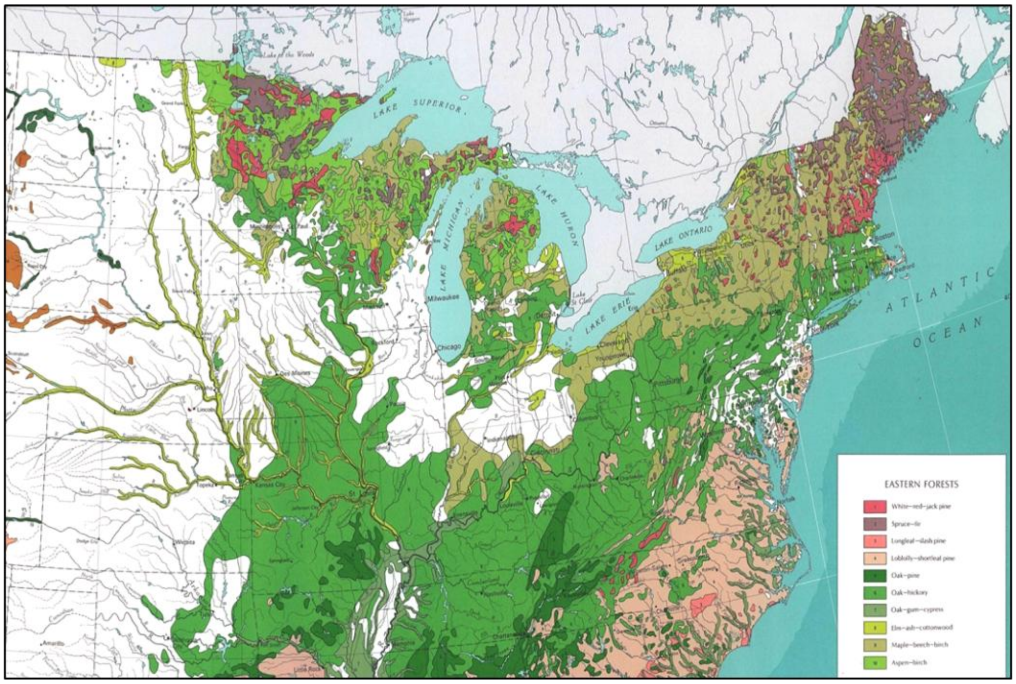

Figure 1.1 Forest types of the eastern United States, as delineated by the National Atlas of the United States (United States Department of Interior Geological Survey 1970).

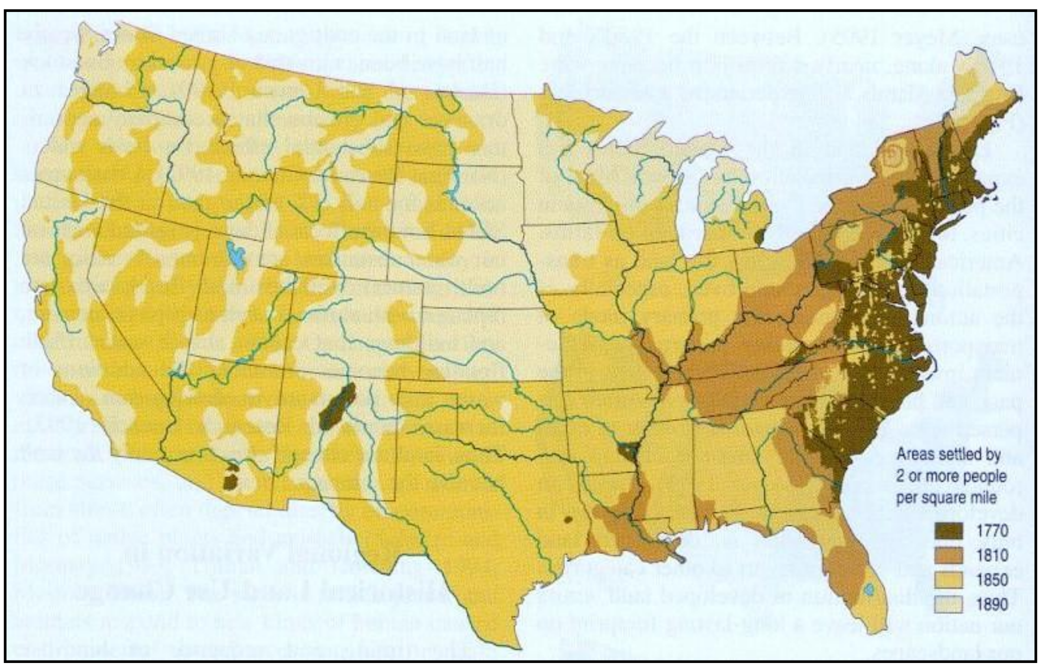

Figure 1.2 This image shows the settlement and population density of the United States over time. The Midwest was characterized by rapid population growth in the nineteenth century. Henry Thoreau lived from 1817 to 1862. These changes would have had a dramatic effect on land use and land cover of the landscape. From "Status and Trends of the Nation's Biological Resources," Volume 1 (Mac 1998).

this expedition the population in the state of Missouri increased from less than 70,000 in 1820 to more than 1.1 million in 1860 (Meyer 1965). The forests and prairies that occupied much of these areas were cleared as a consequence of population growth and associated demands for forest resources and farmland.

Federal policy often influenced early settlers' land use practices. Many pioneers cleared their land in keeping with laws like the Homestead Act, which allowed individuals to acquire federal lands in the west, with the condition that it be "improved" (Homestead Act 1862). There were also opportunities to sell timber logged locally as fuel to steamboats along Midwestern rivers. At these trade posts continuous fires were kept to advertise to passing steamboats (Perlin 1991). In the second half of the nineteenth century, railroads cut across the Midwest and in many circumstances the land along these lines were fully utilized for agriculture and forest resources (Scott 1979). These factors and others contributed to the rapid deforestation of the Missouri River Hills and most Midwestern forests by the early twentieth century.

The River Hills in Boone County, Missouri exhibit a history of forest recovery generally similar to that seen earlier in New England. In contrast, however, the region's deep loess soil was fertile and ideal for farming. The earliest settlers cleared the forests and used the region for agricultural products like corn, tobacco and hemp (Nigh and Schroeder 2002). As cultural and economic conditions changed to reduce dependence on local crop production and consumption, some farms were abandoned and forest recovery ensued. The photographs in Figure 1.3 show an example of the twentieth century reforestation occurring in the River Hills region. The photographs were taken in

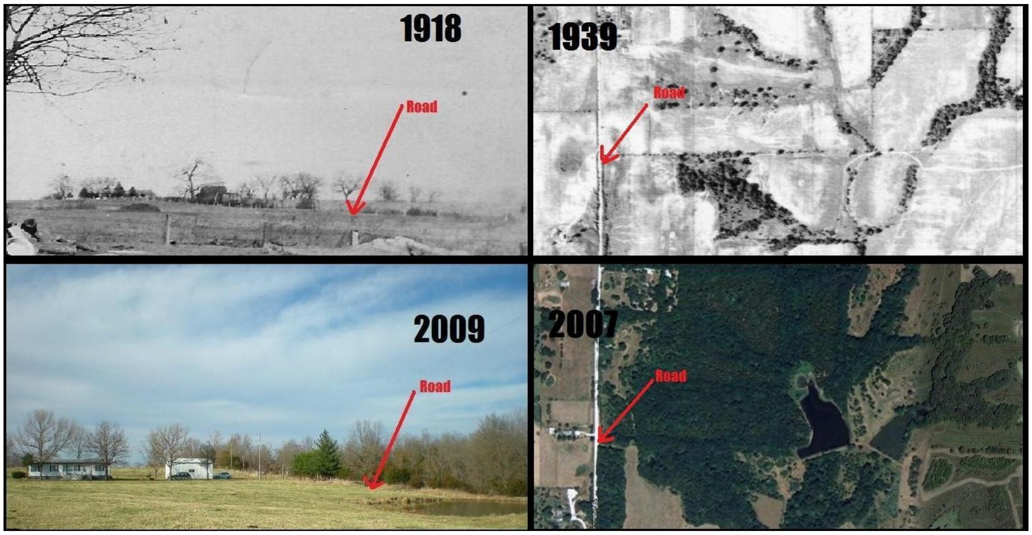

Figure 1.3 Historical changes in land use have dramatically changed the land cover of the Midwest. In this figure, a 1918 photograph (upper left) shows a river hills landscape that was completely dominated by farmland. By 2009, a photograph of the same area shows a heterogeneous landscape mixed with pasture in the foreground and dense forest established along the right side of the road. The right side of the figure shows two aerial photographs depicting the changing landscape of the same local River Hills area. In 1939, twenty-one years after the first photograph was taken, the landscape was dominated by fields. The subsequent ingrowth of large patches of forest is evident in the 2007 aerial. The 1918 and 2009 photographs, on the left, come from the personal collection of the author, Kevin Hunt, and the photos on the right are from 1939 (AAA) aerials and 2007 (NAIP) orthophotograph.

the same location over a ninety-one year interval. The paired aerial photographs show the corresponding landscape-scale change.

This research documents patterns of land cover change that occurred since the start of European American settlement within the Central Missouri River Hills. Understanding the progression of change will improve our knowledge of current landscape composition and patterns while potentially improving future land use management.

Chapter Two

Study Area

Missouri is at the crossroads of several ecoregions. The United States Environmental Protection Agency divides central Missouri into four level III ecoregions (Figure 2.1): the Central Irregular Plains, Interior River Valleys and Hills, Ozark Highlands and Western Corn Belt Plains (Omernik 1987; EPA 2009). The juxtaposition of ecoregions in central Missouri include prairie to the north, Ozark forest to the south and the corridor of River Hills forest in between. The River Hills ecoregion, as described in Nigh and Schroeder's Atlas of Missouri Ecoregions (2002), is an area that encompasses the belt of deeply dissected hills and bluffs bordering the Missouri River's floodplain. The hills consist of occasionally very thick loess mantles. Land cover in the region included oak savanna and woodland, oak and mixed-hardwood forests, and occasional prairie and glade openings (Nigh and Schroeder 2002), but the bluff forests have been documented as dominated by comparatively mesophytic species such as maple and basswood (Kucera and McDermott 1955). The region was first settled by European Americans in the early nineteenth century (Meyer 1965). The river villages of Rocheport, Huntsdale, McBaine, Easley, Wilton, Hartsburg and exurbs of Columbia presently populate the River Hills of Boone County in central Missouri (Figure 2.2).

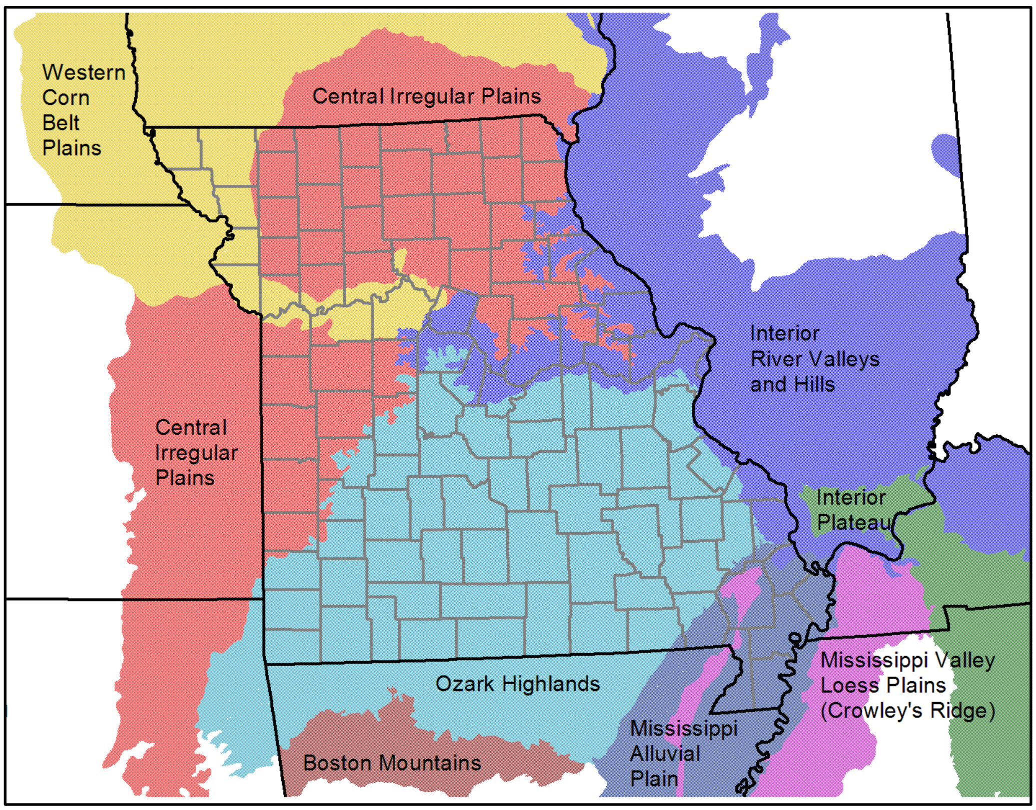

Figure 2.1 EPA Level III ecoregions of Missouri, USA (MOHAP 2009b).

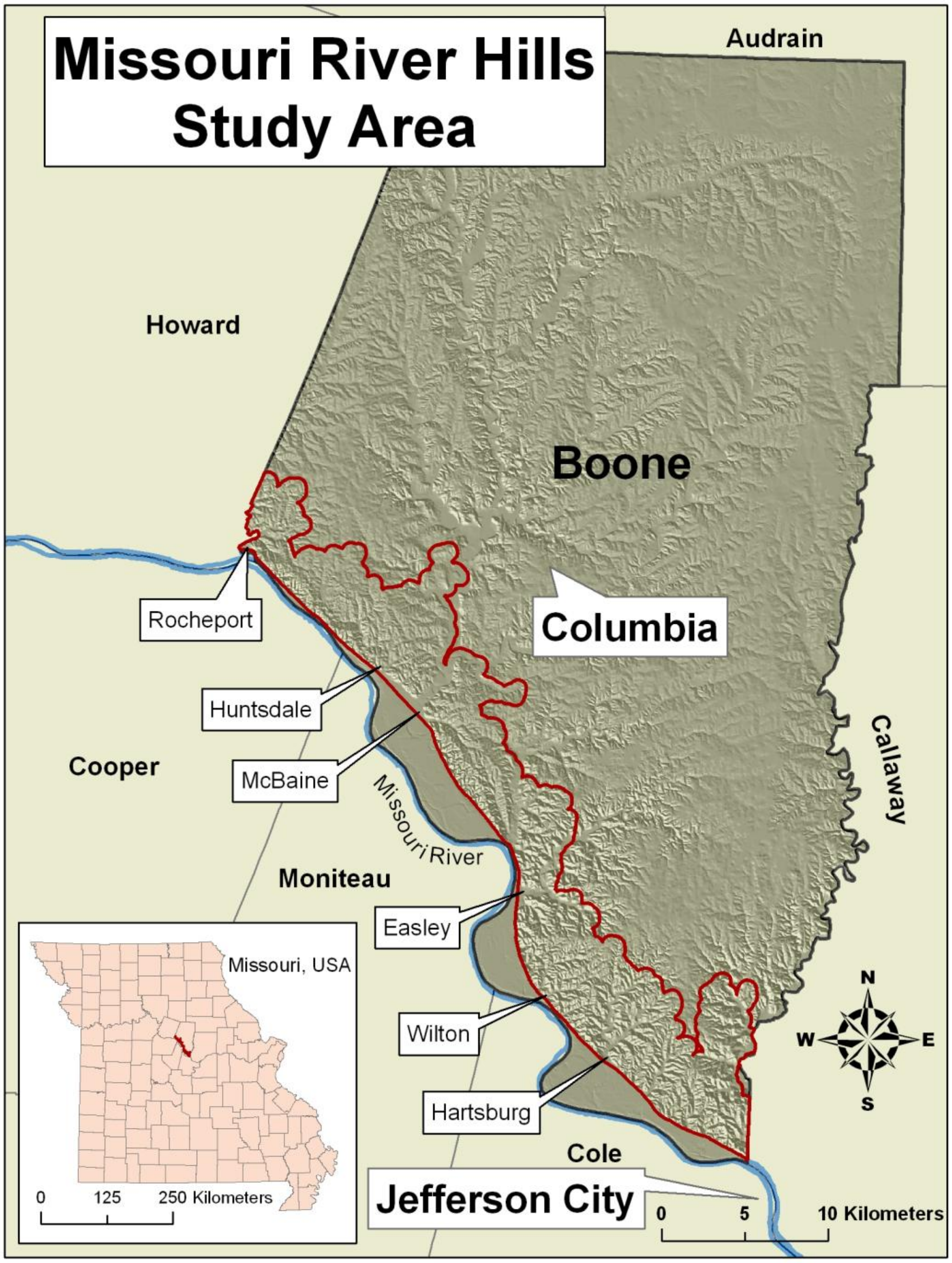

Figure 2.2 The Missouri River Hills study area and places within Boone County.

Landscape

The landscape of the region is dominated by steep forested loessal hills underlain by Mississippian and Ordovician limestone (Nigh and Schroeder 2002). The Missouri River Hills act as a final forest corridor along the belt of hills and bluffs as the landscape transitions from the eastern temperate forest to the prairies of the Great Plains (Figure 2.3). There are often dramatic changes in elevation (Figure 2.4), as much as 60 to 90 meters along the bluffs bordering the river floodplain, tapering to the less dissected landscape of the clay pan till plains to the north and east (Nigh and Schroeder 2002). The River Hills primarily consist of Menfro soil which can be very deep and is a well drained and moderately permeable soil series. It is found on uplands along the shoulders and back slopes of the River Hills (USDA 2001). The Missouri river generally flows north to south along Boone County's western border, which is caused by a curve in the river's general flow (Figure 2.5). This is known as the Grand Bend where the upstream area to the west arcs southward through central Missouri before it continues flowing primarily east towards the Mississippi River. Along this bend many of the bluffs face west creating northern and southern sloped ravines. The bluffs are dissected by several streams, as seen in Figure 2.5, which in Boone County include Moniteau Creek, Perche Creek, Little Bonne Femme Creek, Bonne Femme Creek and Cedar Creek. The climate ranges from an average temperature of -2° Celsius in January and 25° Celsius in July with an annual precipitation of 102 centimeters (NOAA 2009).

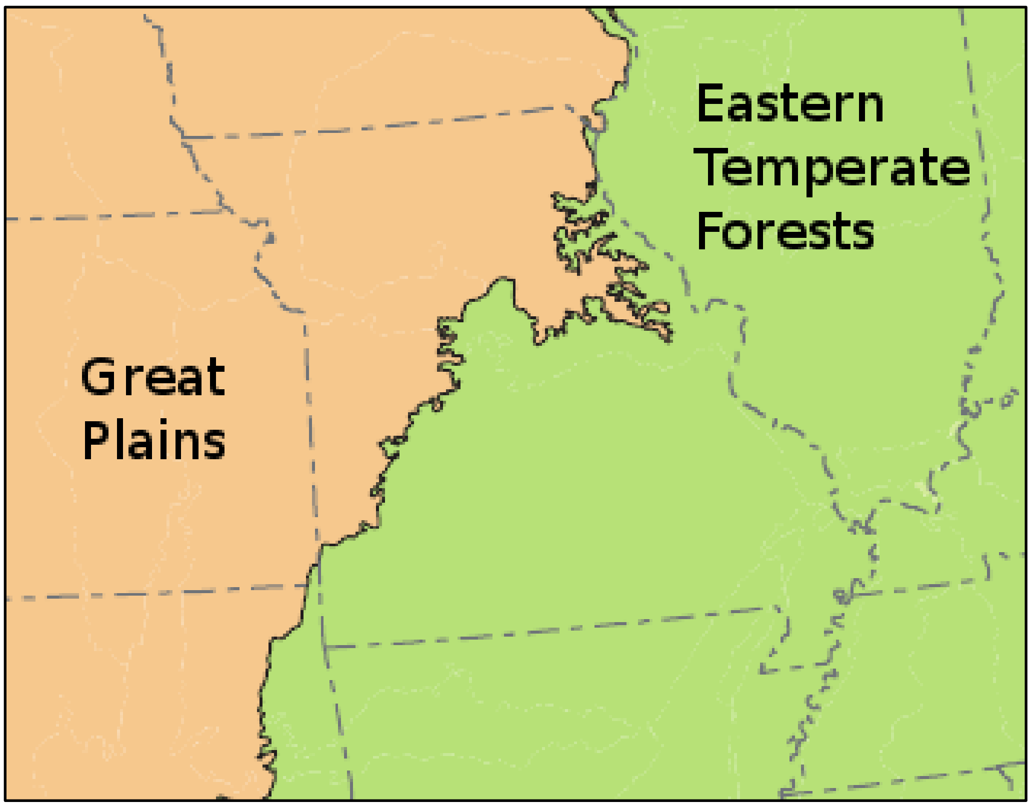

Figure 2.3 EPA Level I ecoregions of Missouri, which includes the Eastern Temperate Forests and the Great Plains (MOHAP 2009a).

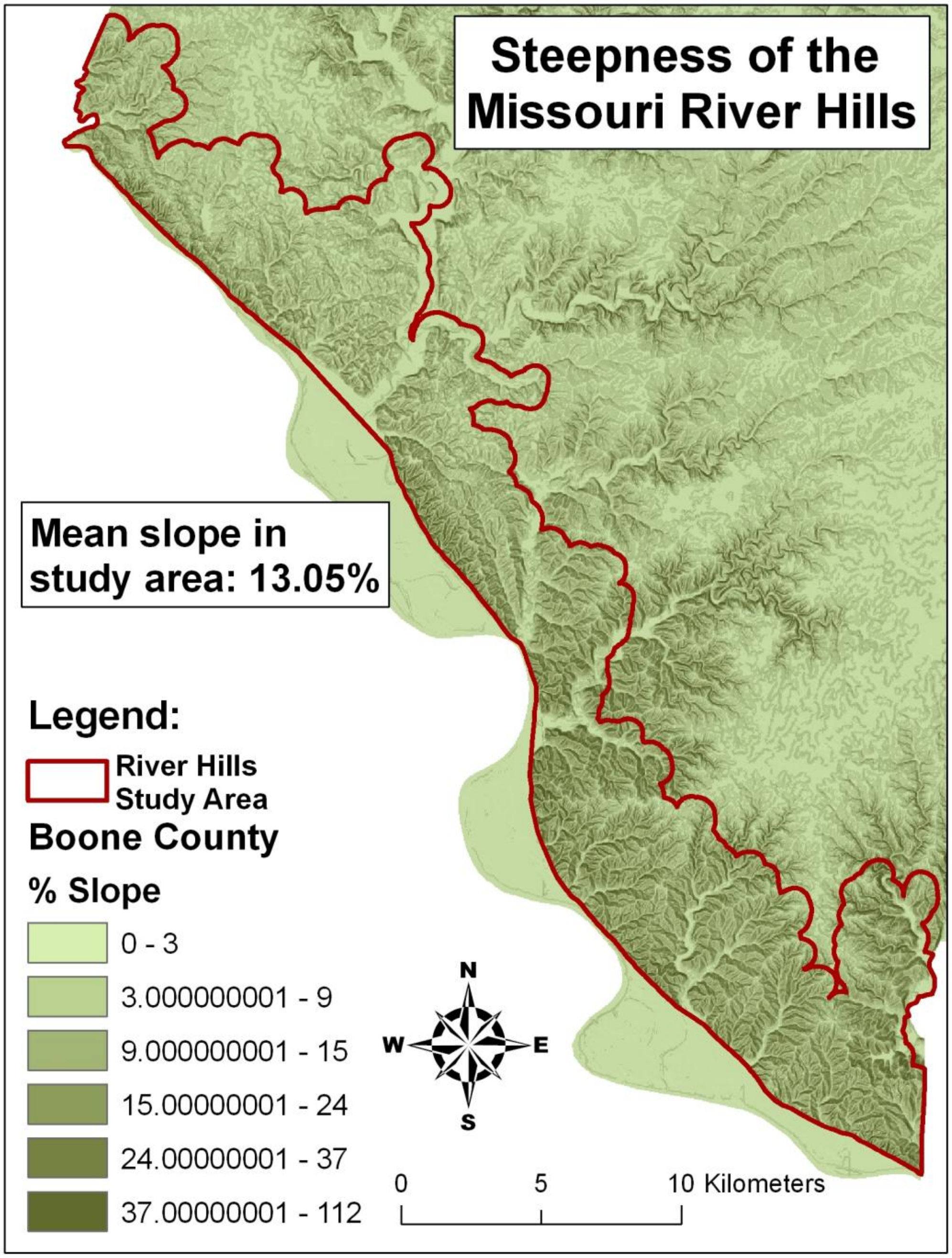

Figure 2.4 Slope percentages within the study area. The steepness was found with ten meter digital elevation model dataset of Boone County.

Figure 2.5 Landscape Features of Central Missouri.

This now primarily forested zone in a predominately agricultural region can provide important habitat, as individual requirements for many species of plants and animals are dependent on forests. There are seven federally listed rare or endangered species that include decurrent false aster (*Boltonia asteroids* var. *decurrens*), bald eagle (*Heliaeetus leucocephalus*), pink mucket (*Lamsilis abrupta*), gray bat (*Myotis grisescens*), Indiana bat (*Myotis sodalist*), Topeka shiner (*Notropis Topeka*) and running buffalo clover (*Trifolium stoloniferum*; Nigh and Schroeder 2002). Many other species are dependent on similar conditions as these protected species.

The Central Missouri River Hills landscape is divided into forest, old fields, fields, pastures, row crops and urban-dominated uses like roads, homes and suburbs. The Columbia Metropolitan area borders the northern two-thirds of the eastern edge of the area. This area is in greatest transition from rural to urban land use and the City of Columbia facilities like the waste water treatment plant and wetlands dominate sections of the study area like in the Perche Creek floodplain.

Forest Regions

The region's land cover in the early nineteenth century (Figure 2.6), as derived from U.S. General Land Office surveyor notes, places the River Hills at the northern limits of Ozark forest cover (Harlan 2008). Attempts to classify forest associations within the region by Lucy Braun (1950) and subsequent authors (Pell and Mack 1977; Dyer 2006) describe this region as Oak-hickory forest (Figures 2.7 and 2.8). However,

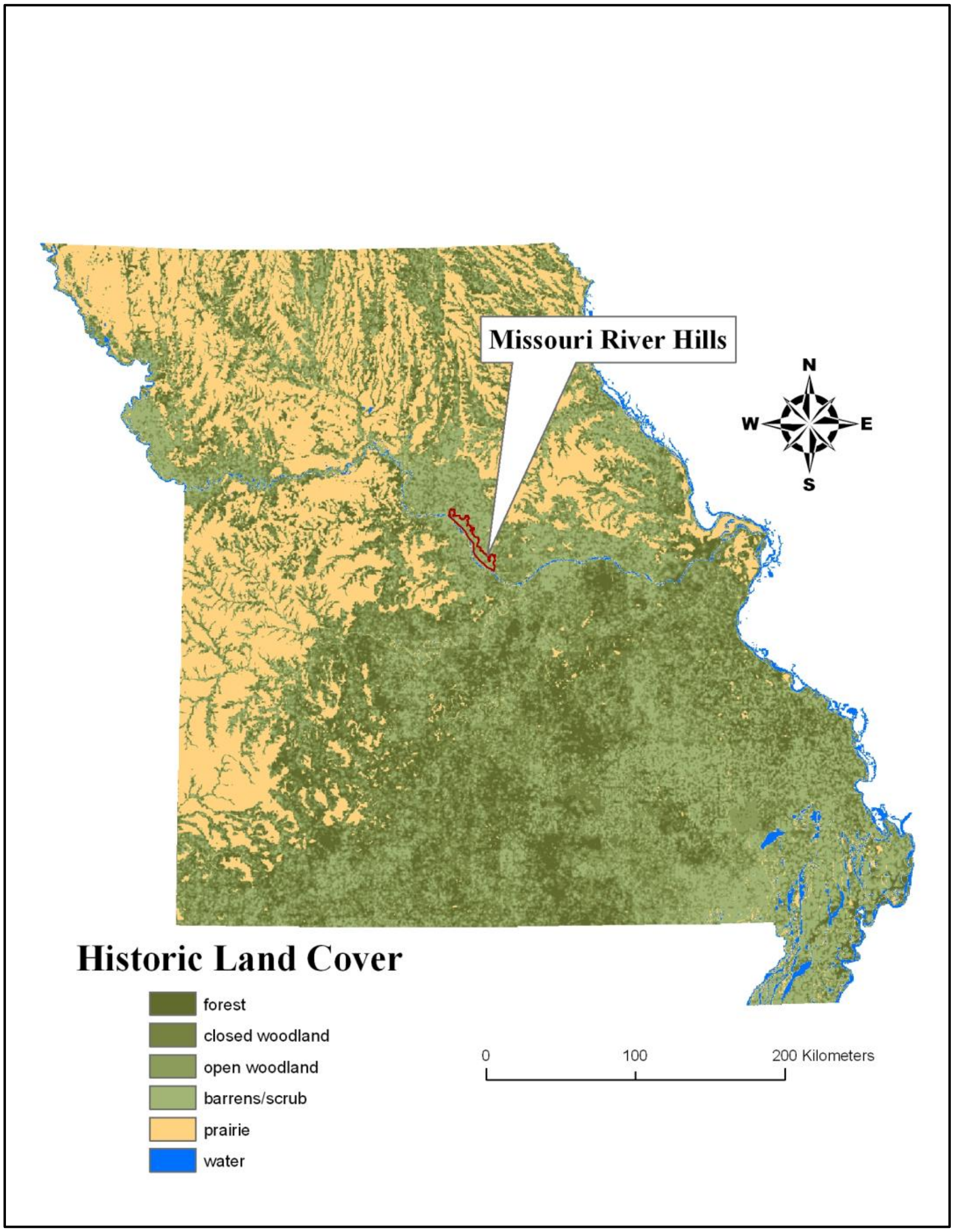

Figure 2.6 Historical Land Cover of Missouri circa 1815. Darker green areas represent denser forests while tan represents historic prairies (Harlan 2008).

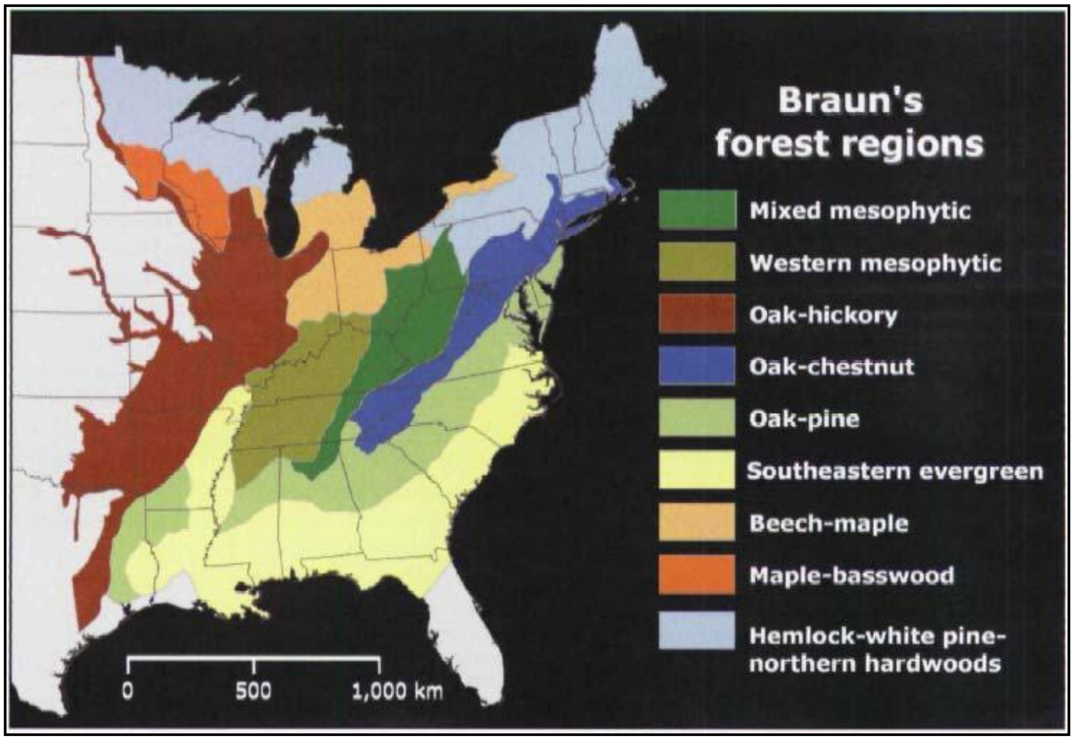

Figure 2.7 E. Lucy Braun's map of forest regions (Dyer 2006)

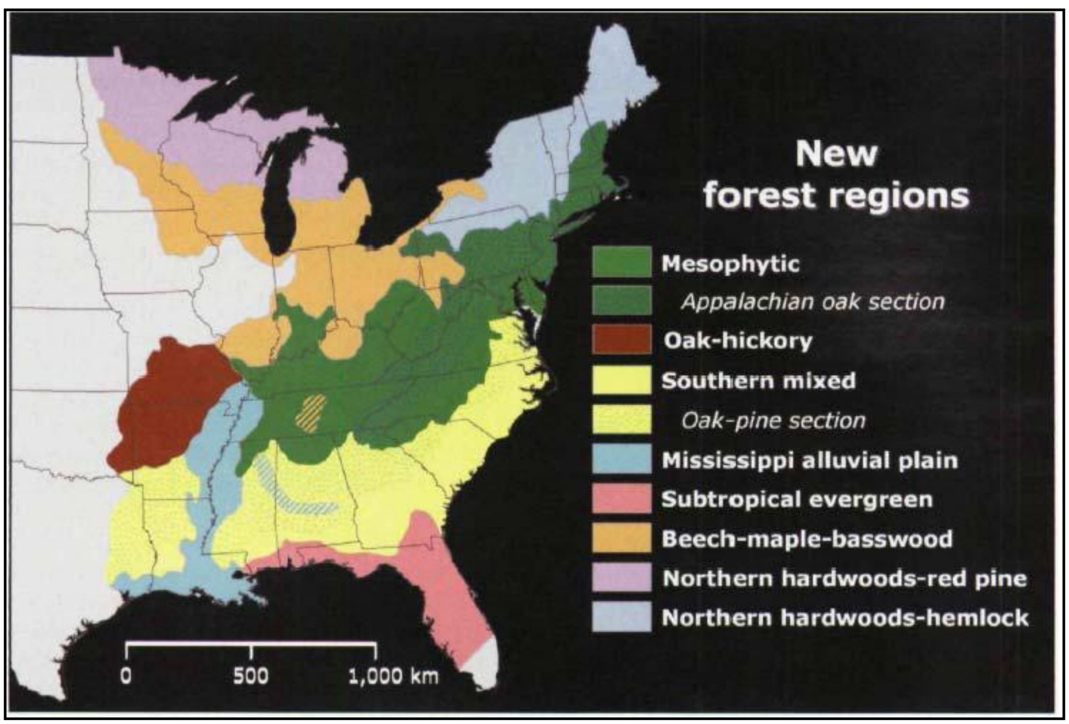

Figure 2.8 A revised map of eastern deciduous forest regions (Dyer 2006)

species associations within the River Hills are distinctive, as noted in the GLO records and later reports that referred to timber resources in Boone County as abundant in sugar maple and basswood (Industrial World and Commercial Advertiser 1880). Research conducted at Schnabel Woods, a River Hills forest that was acquired by the University of Missouri as a research site, confirmed these compositional patterns (Kucera and McDermott 1955). Schnabel Woods is located on the bluffs one mile south of McBaine, Missouri, and was described by Kucera and McDermott (1955) as an 'undisturbed' area. They reported that sugar maple (*Acer saccharum),* black maple (*A. nigrum)* and basswood (*Tilia americana)* dominated this stand, with red elm (*Ulmus rubra)* and white oak (*Quercus rubra)* also common. The most prominent understory species was *Ostrya virginia.*

Chapter Three

Methods

Land cover can be mapped using remote sensing or from historical documents. By classifying land cover, many observations about landscape patterns can be made (Foster and Motzkin 1998). To quantitatively approach historical land cover changes in the Missouri River Hills, primary and secondary sources were used to create land cover maps across four intervals: 1815, 1939, 1968 and 2007. The first interval, 1815, uses historical land cover maps previously created by Harlan (2008) from United States Public Land Surveyor notes. Aerial photographs were obtained for the other three intervals. The changing patterns of forest and field over these times were then analyzed to identify patterns of land cover conversions and changing landscape configuration.

The central Missouri River Hills study area was delineated using four parameters. Its primary extent was defined by the distribution of the Menfro soil series, which is a deep loess soil type characteristic of the River Hills (USDA 2001). This area was then buffered to 500 meters to create a single coherent region. The resulting area was clipped to the boundary of Boone County and to the KATY Trail State Park. The KATY Trail was used because it follows closely the edge of the Missouri River floodplain and serves as a clear boundary separating the floodplain environment from the adjacent bluffs. The resulting area is 24,545 ha in size.

Data Sources

The patterns of 1815 land cover were obtained from Harlan's (2008) analysis of early nineteenth century United States GLO surveyor field notes and earlier French and Spanish land survey documents (Figure 3.1). Harlan classified land cover types into six categories based on vegetation density: barrens/scrub (less 20% canopy cover), open woodland (20-50% canopy cover), woodland (>50-80% canopy cover), forest (>80% canopy cover), prairie and water.

The selection of aerial photographs to represent subsequent periods depended on availability, coverage and spacing of time intervals. Based on these criteria, three suitable dates were chosen for which to produce mosaics of photos for the study area: 1939, 1968, and 2007 (Table 3.1).

Table 3.1 Historic aerial photographs used to reconstruct land cover history.

Date	Source	Scale	Color
August 4, 1939	Agricultural Adjustment Administration (AAA)	1:20,000 inch	Panchromatic black and white
August 5, 1968	Farm Service Agency (FSA)	1:20,000 inch	Panchromatic black and white
Summer 2007	National Agriculture Imagery Program (NAIP)	1 meter resolution	Color

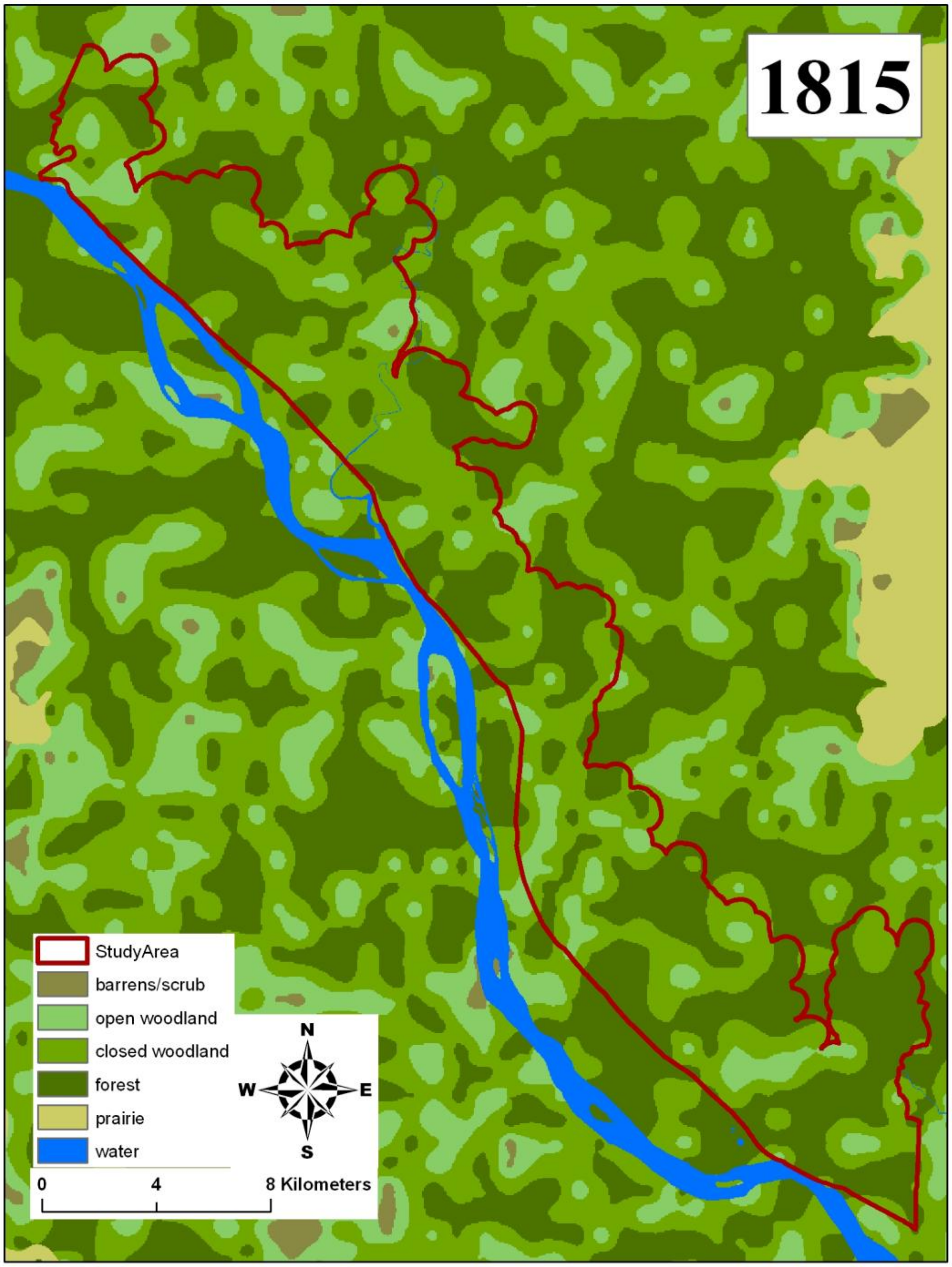

Figure 3.1 Historic Land Cover of the Central Missouri River Hills (based on Harlan 2008).

The first date consists of panchromatic black and white photographs from August 1939 flown by the Agricultural Adjustment Administration (AAA) at 1:20,000 inch scale (Figure 3.2). These original aerial photos were borrowed from the Soil and Conservation District of Boone County. Each individual 9” x 9” photo was scanned, georeferenced, and mosaiced. The second date, August 1968, is panchromatic black and white photographs flown by the Farm Service Agency (FSA) at 1:20,000 inch scale (Figure 3.3). Each individual 24” x 24” photo was scanned, georeferenced, mosaiced using the same procedures as the 1939 date. The aerial photographs flown in the summer of 2007 were the most recent orthorectified color photograph available from the National Agriculture Imagery Program (NAIP) at one meter resolution (Figure 3.4).

The 1939 and 1968 aerial photographs were prepared for image processing and classification using identical methods. Photos extending beyond the study area boundary were scanned to make sure complete coverage was achieved. There were 170 photos scanned for 1939 and 218 photos scanned for 1968. Each was scanned with grayscale, at 350 dpi and a 95% compression setting and were saved as a .jpeg file on a Colortrac SmartLCF x40 (2008) scanner.

The .jpeg files were then uploaded into Adobe Photoshop CS3 (2008) image editing software where the edges were cropped and the tone was equalized between all image files. The edited image was then uploaded into ArcMap 9.3 (2008) and georeferenced by attributing spatial points to the image using the 2007 orthorectified NAIP image as a base reference with at least three control points. The georeferenced images were then opened in ArcCatalog 9.3 where the resampling tool was run on each image to match resolution

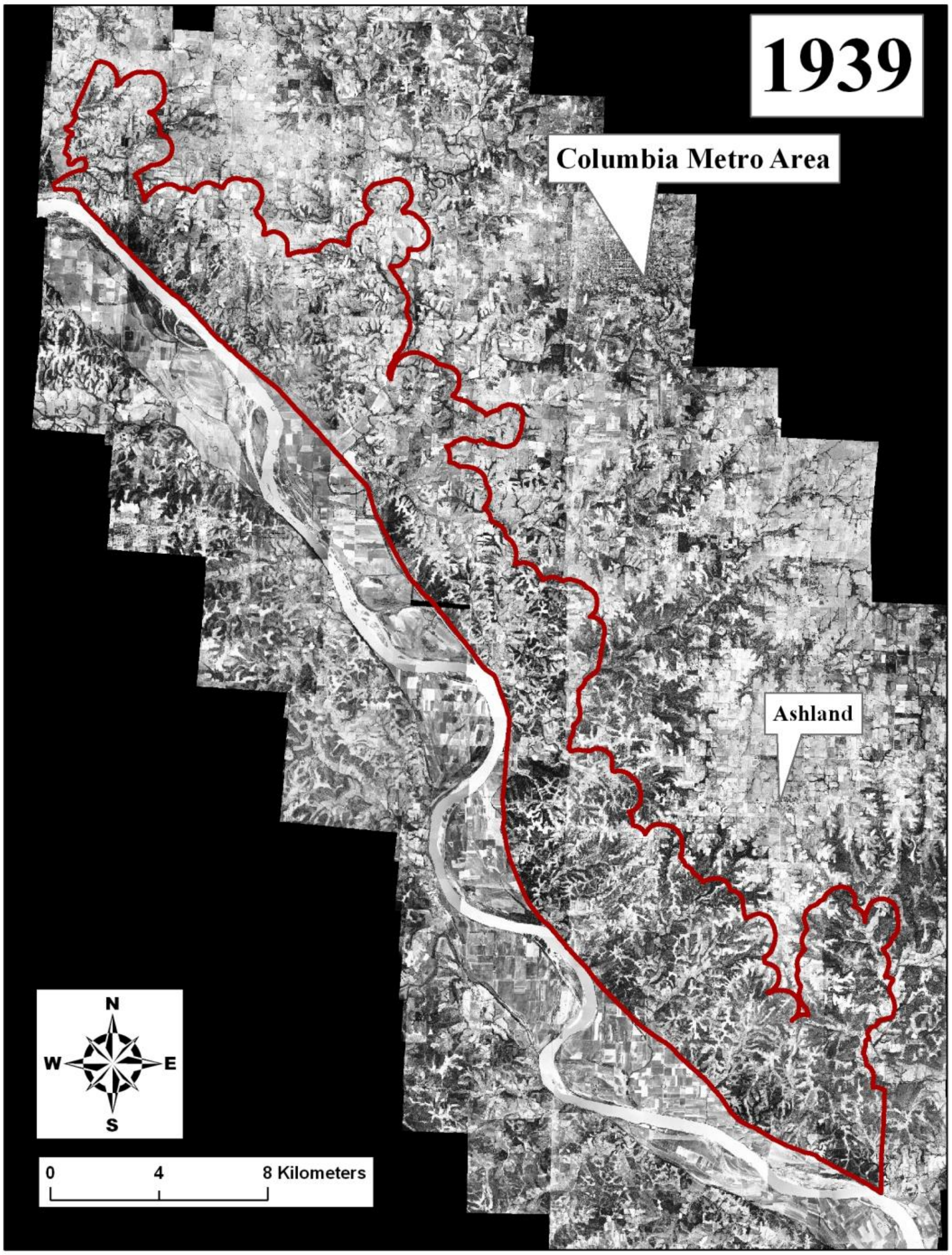

Figure 3.2 Aerial Photograph Mosaic of Boone County 1939 (AAA 1939).

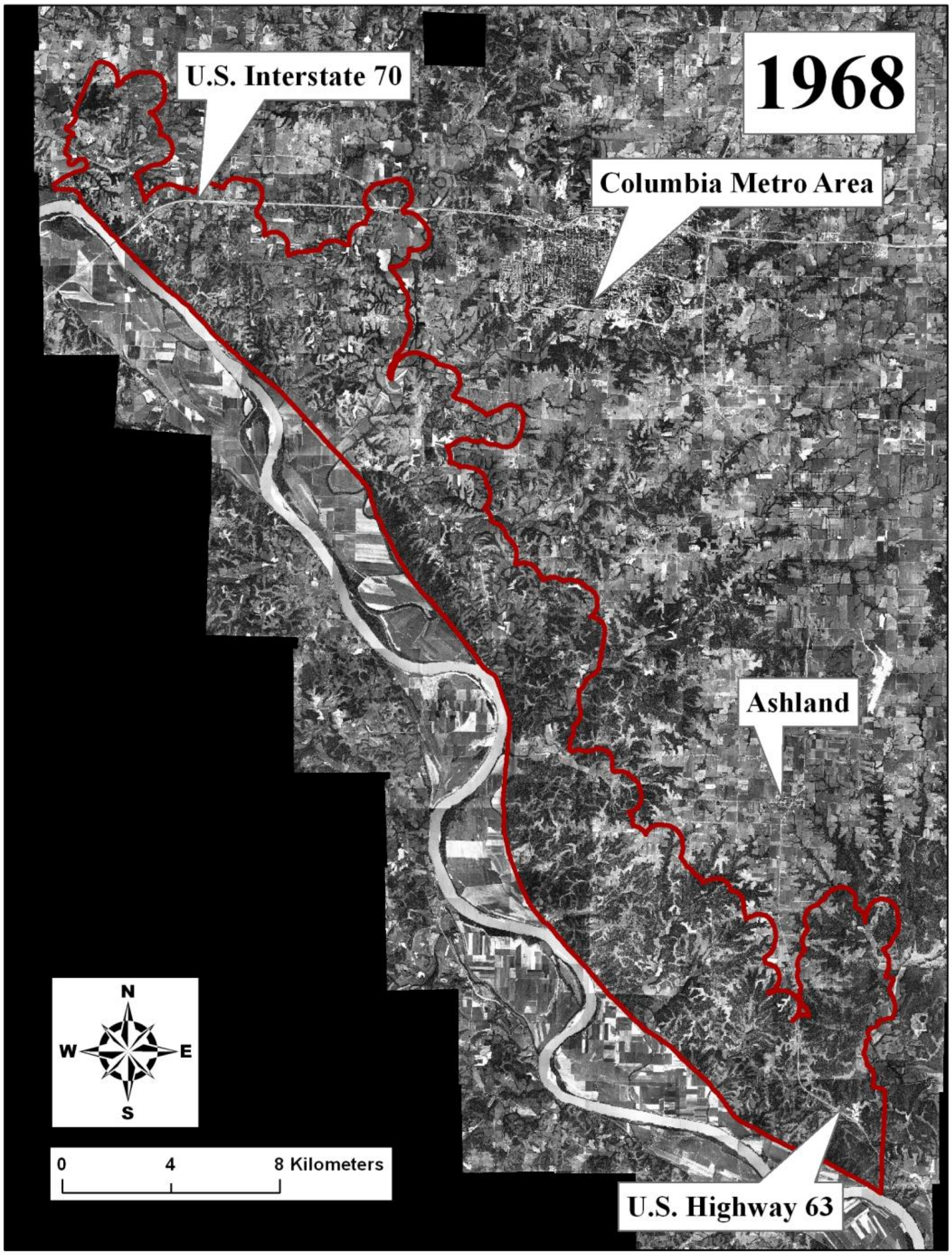

Figure 3.3 Aerial Photograph Mosaic of Boone County 1968 (FSA 1968).

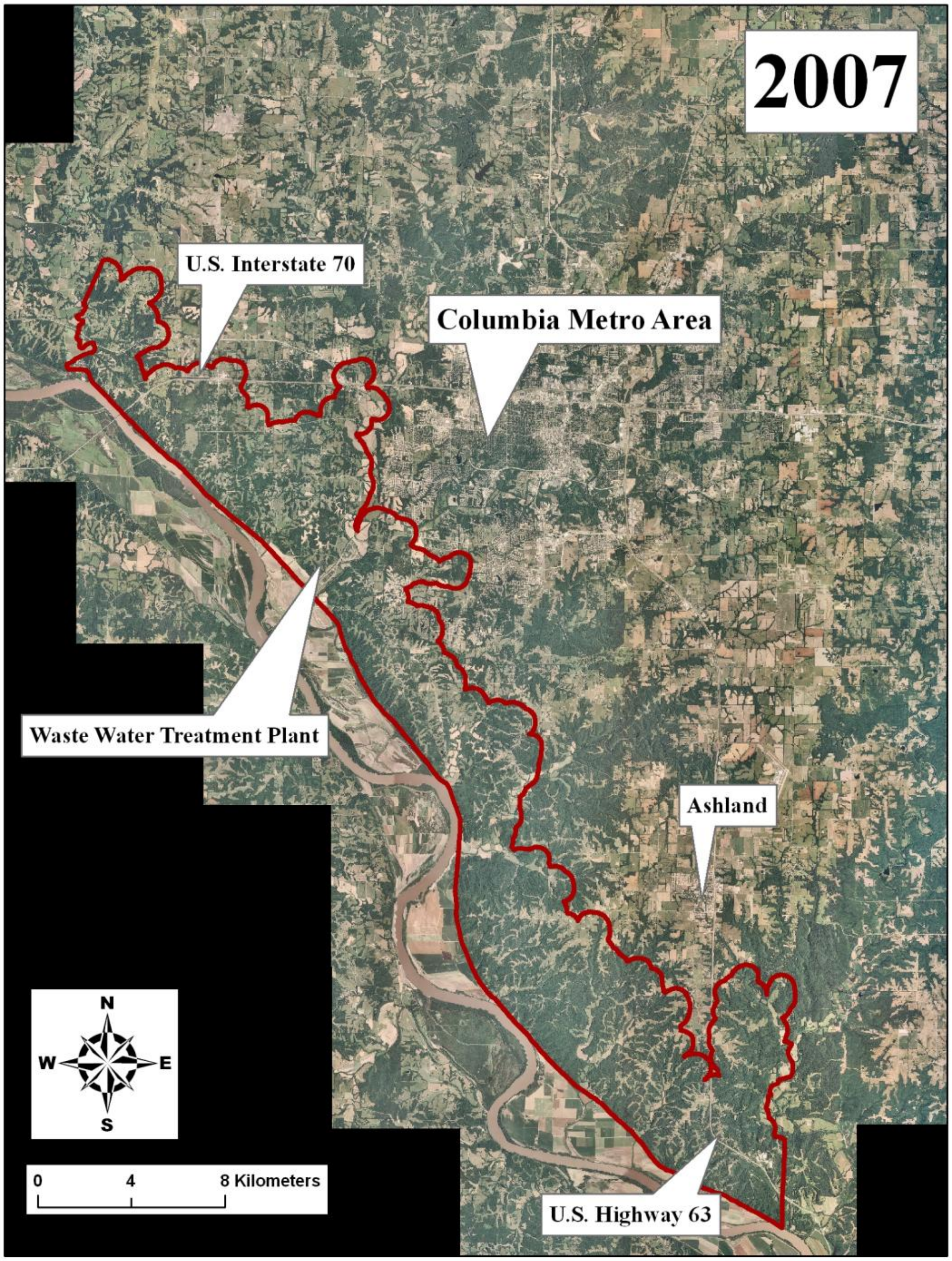

Figure 3.4 Aerial Photograph Mosaic of Boone County 2007 (NAIP 2007).

between images and prepare them to be mosaic. The mosaic process was run in ArcCatalog 9.3 for both 1939 and 1968 to merge all the images into one geodatabase file.

Each mosaic was subsequently exported to ERDAS Imagine (.img) files using ArcMap 9.3 (2008), and then uploaded into image processing software, ERDAS IMAGINE 9.3 (2008), to have their resolution set at 30x30 meter. This resolution was chosen to represent coarser aggregations of trees, rather than individuals, and to match the resolution of the digital elevation model. Each interval was then processed using a two class classification system for each interval (Table 3.2). Two classes were chosen to simplify the classification and to accurately process the black and white images. The two classes represented either forest cover or field, with the latter also including any other human land uses like agriculture, residential, commercial, industrial, transportation, utilities and bodies of water.

Following the classification process an accuracy assessment was completed in ERDAS IMAGINE 9.3 (2008). The classifications' accuracies were tested using a

Table 3.2 Two class land cover classification system

Land Cover Type	Classification Characteristics
Forest	Areas of forest cover larger than 30 x 30 meters
Field and Human Land Uses	Areas of agricultural, residential, commercial, industrial, transportation, utilities and bodies of waters

stratified 100 point random sampling of each land cover map. This assessment produces an overall accuracy percentile and kappa value statistics (Congalton and Green 1999).

Landscape metrics

The land cover maps produced for the four dates loaded into ArcMap 9.3 as raster grid files to be used for land cover change and landscape metric calculations. This study calculated landscape metrics of land cover transitions, landscape dimensions and patch persistence.

Land cover transitions were calculated to record rates of change between periods for areas converted from either forest to field, or field to forest. The transition rates were calculated using Equation 3.1:

Equation 3.1 Transition Equation

$$p_{ij} = n_{ij} / \sum_{j}^{n} n_{ij}$$

where p_{ij} = rate of transition from class i to class j and n_{ij} = number of pixels that underwent transition from class i to class j (Pastor et al. 1992).

Patch persistence is used to show different patterns in their temporal persistence of a cover type across a landscape (Grossman 2007). This study recorded which patches remained within that same cover type prior to 2007 (and since 1939), as outlined in Table 3.3. For example, if a patch was forest in 1939 and remained in this class during both in 1968 and 2007 it was termed “persistent.” If a patch had been converted from field to forest between 1968 and 2007, it was classified as “transient.” A patch that was a field in 1939 but converted to forest by 1968 and remained as forest in 2007 was termed “semi-persistent.” Maps of these three classes were calculated to identify landscape positions where such changes were occurring.

Table 3.3 Patch persistence classes are defined according to the duration of a given cover type within that patch.

Persistence class	Duration
Transient	<39 years
Semi-persistent	39-68 years
Persistent	>68 years

Patch statistics were calculated for each time period using the Patch Analyst extension in ArcMap 9.3 (Rempel et al. 2009). Metrics generated were class area, number of patches, mean and median patch area, patch area standard deviation, largest patch, total edge, edge density, mean patch edge, mean perimeter-area ratio, area weighted mean shape index, mean shape index, area weighted mean patch fractal dimension, and mean patch fractal dimension (Table 3.4) Patch density and patch size are landscape metrics that have been of concern to conservation (Grossman 2007). Largest patch and patch area statistics were chosen because of conservation concerns centering on patch sizes for forest habitat (Grossman 2007 and Howell et al. 2007). Shape metrics like shape index and mean patch fractal dimension are used to understand shape complexity. Patch fractal dimension is used as an index of human interference on landscape pattern and has been shown to diminish with increasing human dominance of the landscape (Krummel et al. 1987 and Mladenoff et al. 1993).

Table 3.4 Landscape metrics and description (Elkie, Remple and Carr 1999)

Statistic Name	**Description**
Area Metrics	
Class Area	Sum of areas of all patches belonging to a given class.
Patch Density & Size Metrics	
Number of Patches	Number of patches for each individual class.
Largest Patch	The largest patch of a given class.
Mean Patch Size	Average patch area.
Median Patch Size	The middle patch size, or 50^{th} percentile.
Patch Area Standard Deviation	Standard deviation of patch areas.
Edge Metrics	
Total Edge	Perimeter of patches.
Edge Density	Amount of edge relative to the landscape area.
Mean Patch Edge	Average amount of edge per patch.
Shape Metrics	
Mean Perimeter-Area Ratio	Shape Complexity.
Area Weighted Mean Shape Index	Shape Complexity adjusted for shape size.
Mean Shape Index	Shape Complexity.
Area Weighted Mean Patch Fractal Dimension	Shape Complexity adjusted for shape size.
Mean Patch Fractal Dimension	Shape Complexity.

Chapter Four

Results

The Missouri River Hills experienced major land cover changes over the past two centuries. In 1815, the River Hills of Boone County were essentially all forested. By the second interval in 1939 forest accounted for just over forty percent of land cover, with much of the conversion from forest to field occurring in stream valleys of on the ridges of hills. By 1968, forest cover had rebounded to occupy nearly fifty percent of the landscape. This pattern of reforestation continued through 2007, when forest covered 61.5% of the total landscape. This recent forest recovery occurred mainly on steeper slopes.

Accuracy assessment

Classification of land cover from the aerial photographs for all three intervals had an overall accuracy of 98-99% with a kappa value of greater than .95 (Table 4.1). These high values suggest that the simple two-class classification used here captured the overall patterns of land cover well

Table 4.1 An accuracy assessment results from a random sample using ERDAS IMAGINE 9.3 (2008).

Aerial photograph Dates	Accuracy Percentage	Kappa Value
1939	98%	.9571
1968	98%	.9600
2007	99%	.9791

Land cover change

The Missouri River Hills experienced significant changes in land cover over the study period. From 1815 to 2007 the region shifted from majority forest to predominant agricultural use by 1939, and then back to majority forest in the late twentieth century (Figure 4.1). In 1815, the River Hills of Boone County were essentially all closed woodlands or forest representing ninety percent of the total landscape, with ten percent open woodlands.

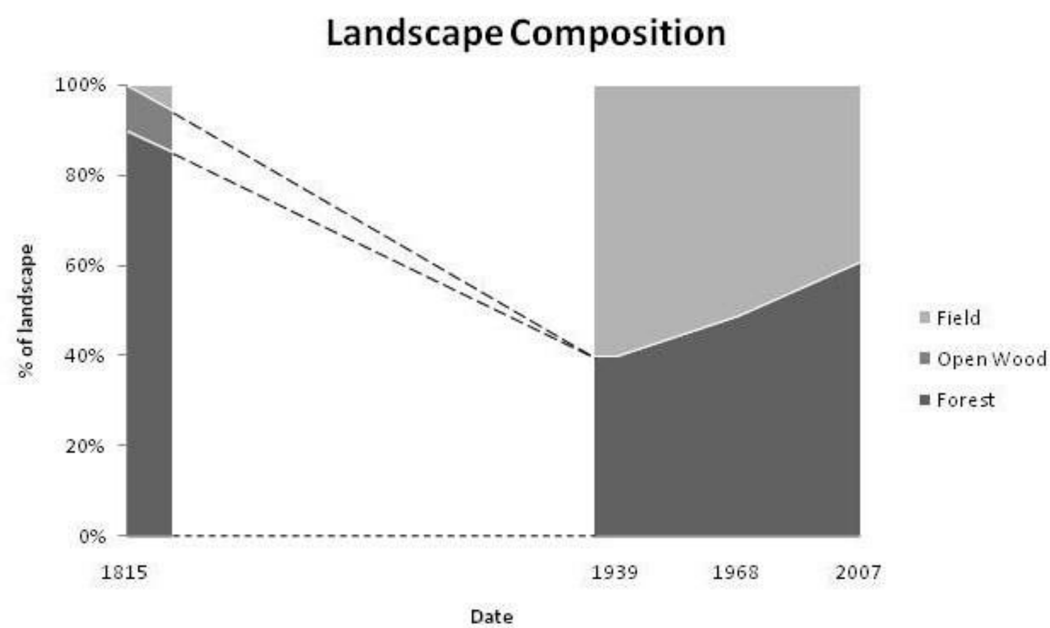

Figure 4.1 Landscape composition with respect to total percent of landscape occupied by each cover type. The blank area and dashed lines indicate an unknown period of land use for the study area.

The spatial distribution of these land cover changes is seen in Figure 4.2. In 1815, the map depicts a region covered by 90% forest and closed woodlands and 10% open woodlands. This forest-dominated landscape was converted to human land uses over the following century to 1939, with forest fragmented into patches (Figure 4.2b). From 1968 to 2007 (Figures 4.2c and 4.2d), forest regrowth led many of these forest patches to increase in area.

These patterns of land cover change were in part related to slope steepness. The mean slope of the study area is 13.0% (Table 4.2). Following settlement, the forest class occupies generally steeper sites like ravines (mean of 17.8% in 1939), while fields tend to be associated with flatter sites (mean of 10.2% in 1939), such as stream valleys, ridgelines or hills with mild slope. As the forest occupied more total area in 1968 and 2007, the average slope declined, suggesting forest was regenerating on some of the less severe topography. Over this time fields became even more confined to areas of flatter topography.

Table 4.2 Mean percentage slope of study area.

Date	Forest	Field
1815	13.0%	0%
1939	17.8%	10.2%
1968	16.7%	9.4%
2007	16.2%	7.7%

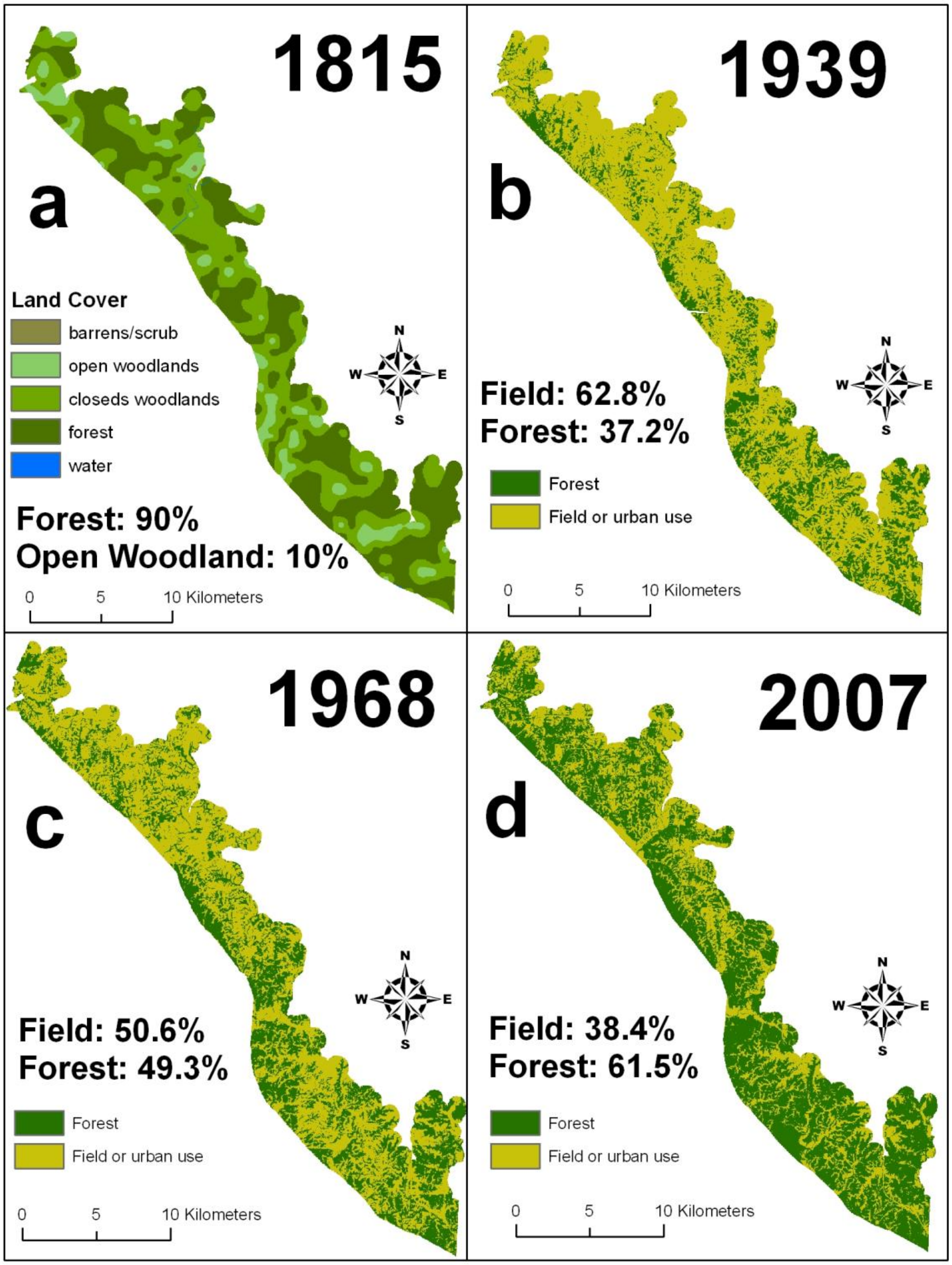

Figure 4.2 Landscape composition maps. The green areas represent forests and the yellow is fields or other human land uses for the periods of 1815 to 2007.

There was greater change of the overall landscape between 1939 and 1968 than between 1968-2007 (Table 4.3). During this first interval, forest area was increased as 21% of the landscape converted to forest from field, adding to a base of 28% that remained forest throughout that time. From 1968 to 2007, an additional 18% of the landscape became forested. Throughout these intervals, there were portions of the landscape that were cleared of forest, but at rates less than 10%.

Table 4.3 Land cover retention and conversion percentages.

Cover Type Transition	Interval 1 (1939-1968)	Interval 2 (1968-2007)
Field to field “retention”	41.67%	31.55%
Forest to forest “retention”	28.08%	42.24%
Field to forest “conversion”	21.14%	18.73%
Forest to field “conversion”	9.03%	7.01%

The patterns of land cover transitions from 1939 to 1968 are seen in Figure 4.3. This was a period when field retention was greatest, at over 41% (Figure 4.3a). These areas of field retention largely occurred in areas of low slope or sites otherwise better suited to farming. Forest retention over this period was 28% (Figure 4.3b). Land cover conversion occurred at lower rates; relatively little forested land was converted to fields

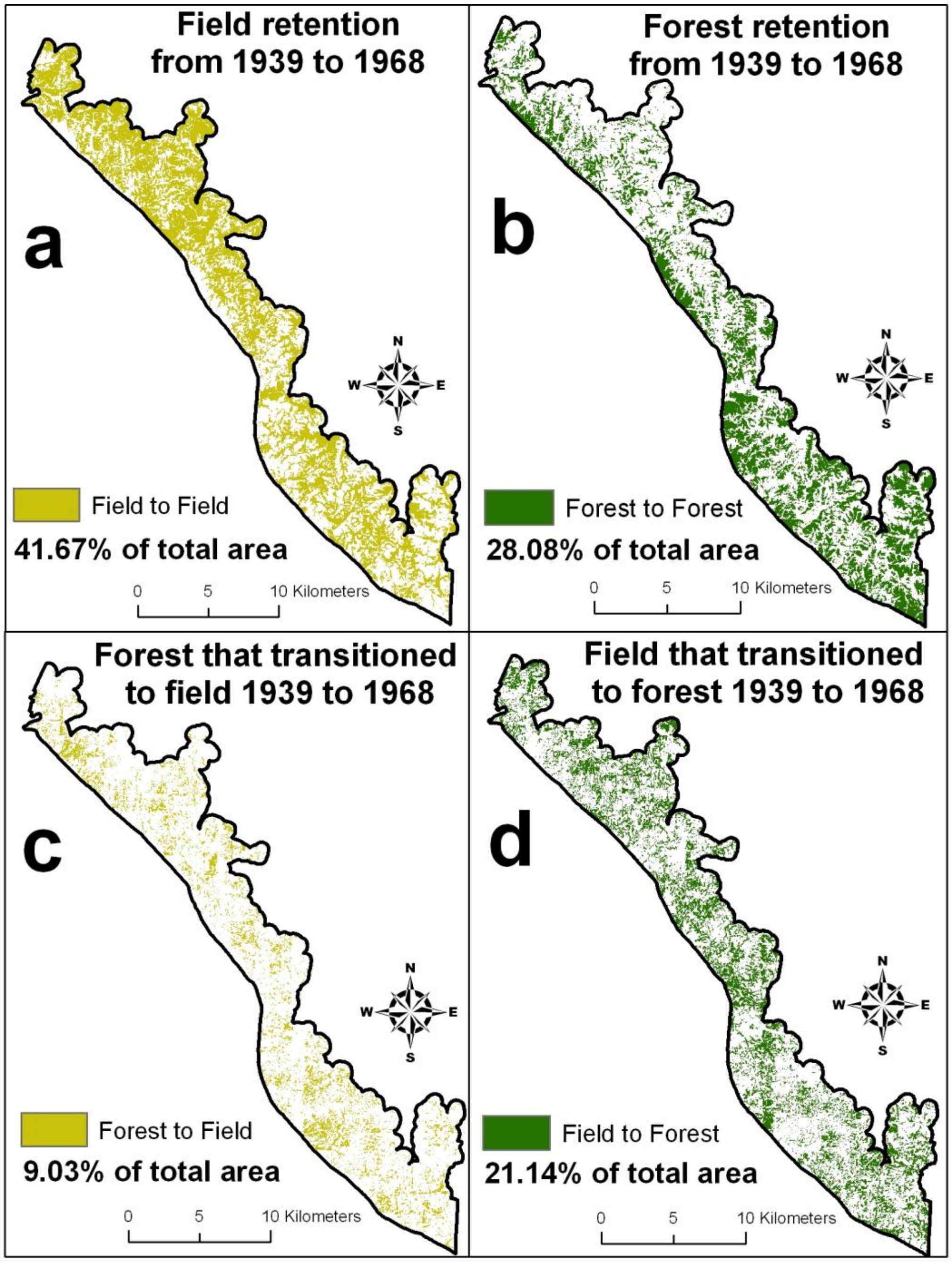

Figure 4.3 Land cover transitions, 1939-1968.

(9%; Figure 4.3c). Reforestation is evident, however, with 21% of the area converted from field to forest (Figure 4.3d).

Overall stability of land cover was somewhat higher between 1968 and 2007 (Figure 4.4). Reforestation continued, with 18.7% of the landscape transitioning from field to forest (Figure 4.4d). Other forest was converted to field over this time, at a rate of 7% (Figure 4.4c). Areas remaining field and forest were 31% and 42%, respectively.

Landscape metrics

Landscape metrics can give clues to the amount, quality and persistence of habitat patches across a region. Patch statistics documenting historic changes in the configuration of the central Missouri River Hills landscape are provided in Table 4.4. Forest area increased from 9,104 ha in 1939 to 12,063 ha in 1968, and to 15,081 ha in 2007. The number of forest patches decreased during all intervals, particularly after 1968. Mean forest patch size increased slightly between 1939 and 1968, but more than doubled between 1968 and 2007. The overall standard deviation of forest patch area decreased over the study period. The largest patch size and mean area-perimeter ratio of forest increased while total edge decreased, suggesting greater forest connectivity.

Patch statistics for fields indicate that the class area declined from over 15,000 ha in 1939 to just over 9,400 ha in 2007. The number of field patches doubled from around 2,000 patches to 4,200 during the period of 1939 to 1968, but then declined back to 2,700 in 2007. Field sizes decreased from a mean of 7.4 ha in 1939 to 3.5 by 2007. The largest patch size declined from over 9000 ha in 1938 to about 1500 ha in 2007.

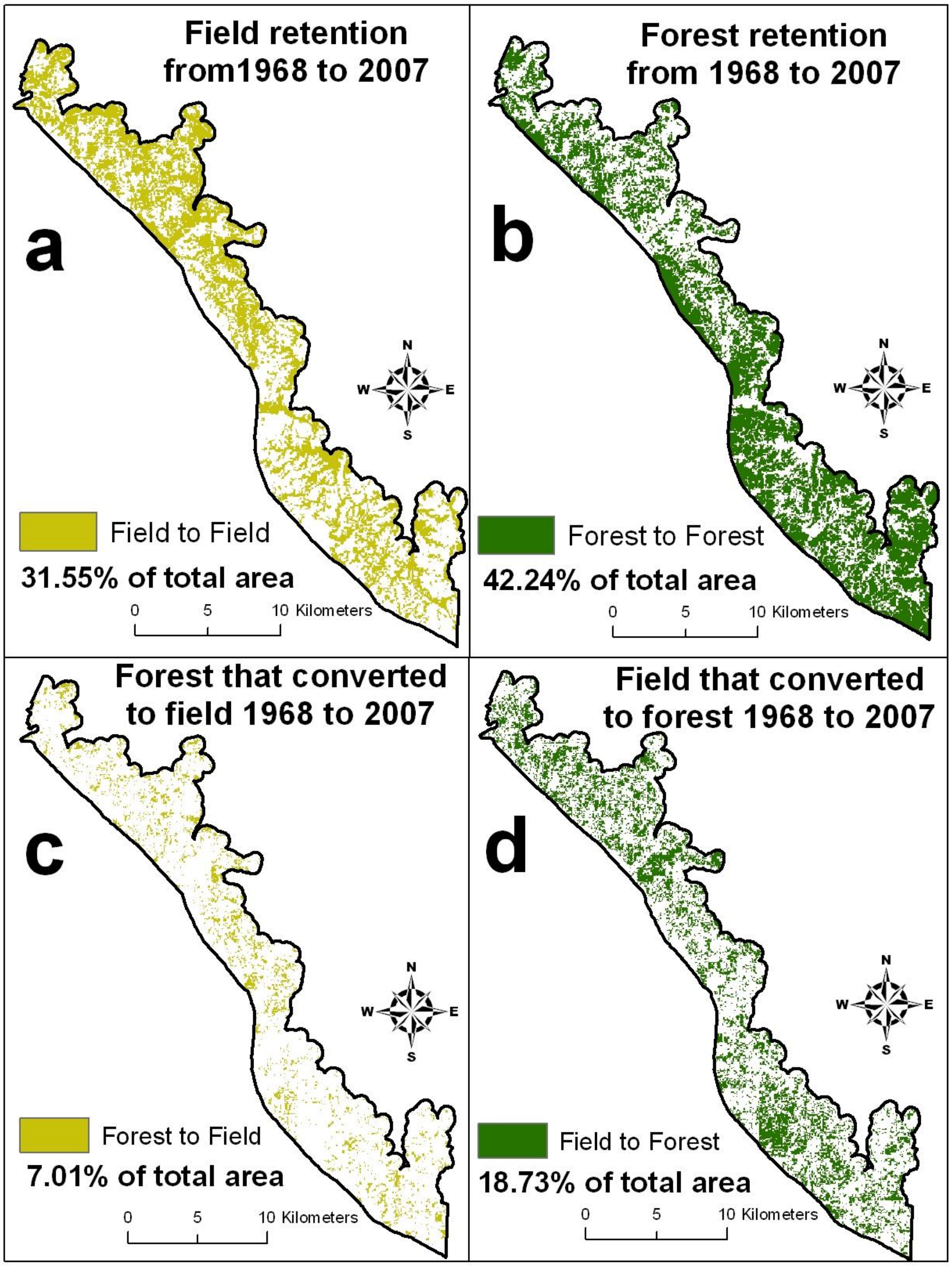

Figure 4.4 Land cover transitions, 1968-2007.

Table 4.4 Patch Statistics.

Statistics	Forest			Field		
Year	**1939**	**1968**	**2007**	**1939**	**1968**	**2007**
Area Metrics						
Class Area (ha)	9,104.2	12,063.1	15,081.9	15,377.7	12,392.3	9,425.9
Patch Density & Size Metrics						
Number of Patches	3,954	3,905	1,971	2,082	4,203	2,747
Largest Patch (ha)	351.1	1,066.5	3,954.1	9,785.2	3,553.7	1,554.3
Mean Patch Size (ha)	2.3	3.1	7.8	7.4	2.9	3.5
Median Patch Size (ha)	1.44	1.08	0.09	1.08	1.08	0.09
Patch Area Standard Deviation (ha)	188.2	387.3	122.7	2,400.0	720.8	44.9
Edge Metrics						
Total Edge (meters)	8,938,800	10,662,240	2,580,720	9,184,920	10,687,140	2,555,940
Edge Density (m/ha)	91.0	81.7	168.1	55.3	79.7	264.8
Mean Patch Edge (ha)	2260.7	2730.4	1309.3	4411.6	2542.7	930.4
Shape Metrics						
Mean Perimeter-Area Ratio (m/ha)	328.4	340.3	1070.7	347.9	352.9	1046.4
Area Weighted Mean Shape Index (ha)	5.6	9.3	14.5	31.7	18.2	11.5
Mean Shape Index	1.41	1.40	1.38	1.32	1.32	1.39
Area Weight Mean Patch Fractal Dimension	1.36	1.39	1.46	1.45	1.43	1.47
Mean Patch Fractal Dimension	1.30	1.30	1.40	1.30	1.30	1.40

Patch persistence patterns in the River Hills (Figure 4.5) illustrate that over half the landscape remained unchanged for at least the last sixty-eight years. Approximately one-fourth of the landscape remained as fields since 1939, and the same proportion of forest has been maintained for that duration. A somewhat greater proportion of the landscape (19%) reverted to forest in the most recent period than in the preceding one (16%). Locations of this forest recovery (transient and semi-persistent) appear to be most often found in steep ravines and around previously forested areas (Figure 4.6). There is little reforestation seen on the ridges of hills or in the valley floodplains (Figure 4.7). Areas of recent human disturbance, which occurred as 7% of the landscape in the recent period, and 3% previously, are seen with new transportation networks, utilities and residential areas.

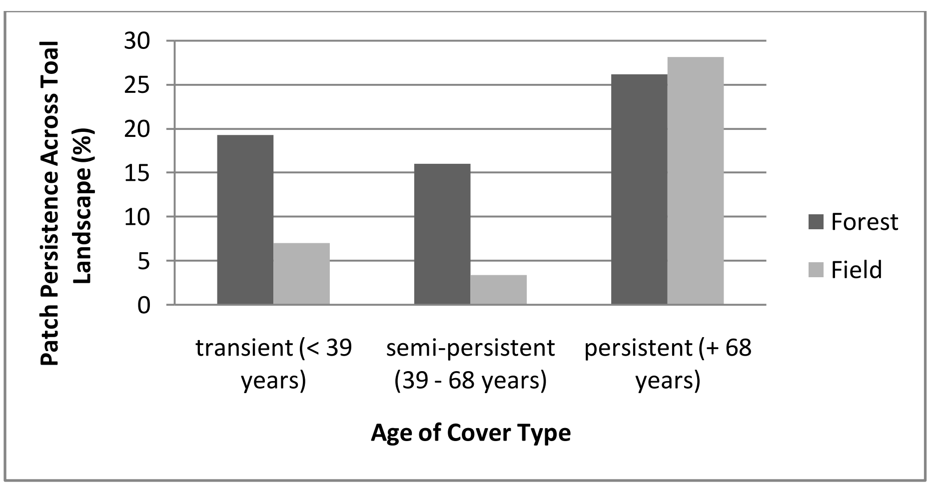

Figure 4.5 Patch Persistence Across Total Landscape by Cover Type.

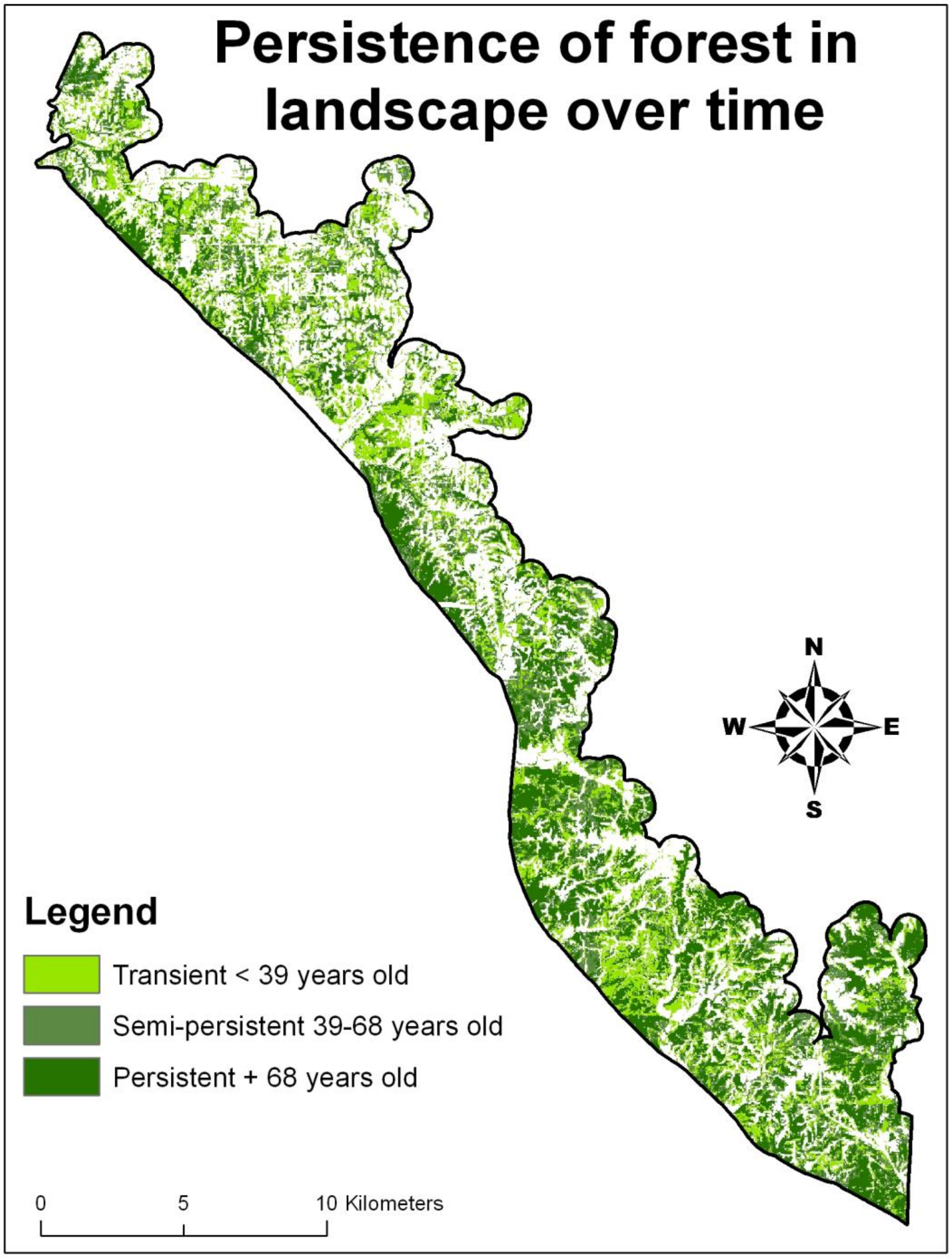

Figure 4.6 Forest patch persistence, 1939-2007.

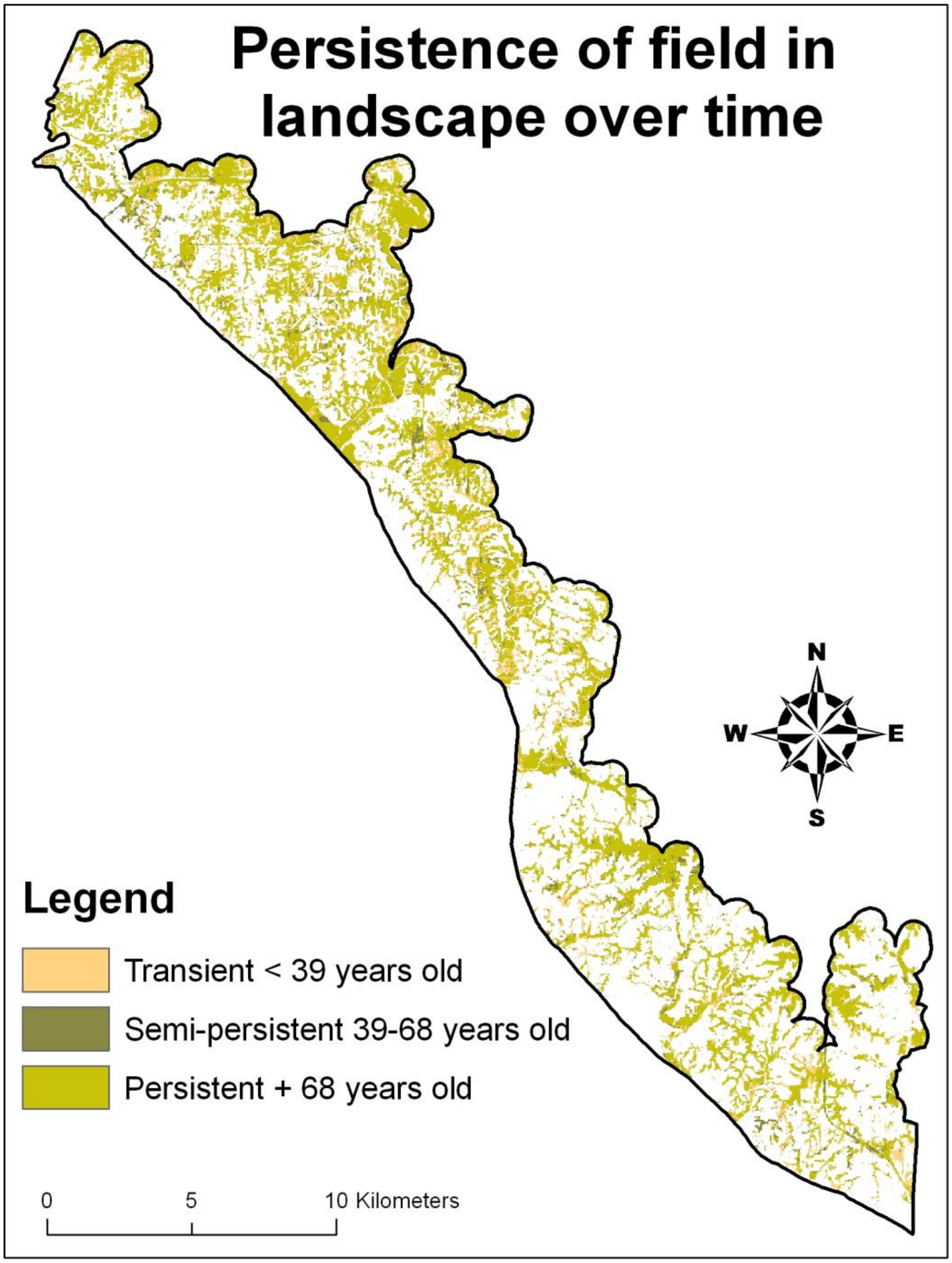

Figure 4.7 Field patch persistence, 1939-2007.

Chapter Five
Discussion

Midwestern forests are inextricably linked to human influences and these changes are evident in the contemporary landscape. The Missouri River Hills are no exception and share a similar settlement history with other Midwestern locations like southern Wisconsin in the upper Midwest. In southern Wisconsin, however, less than ten percent forest recovery occurred following the initial clearing of forest in the nineteenth and early twentieth centuries (Rhemtulla et al. 2007). The River Hills did not share that trend with Wisconsin as forest cover increased by over twenty percent during the last sixty-eight years. This trend in landscape transitions more closely resembles examples from New England where there has been significant reforestation since the mid-nineteenth century (Figure 5.1). The Missouri River Hills was intensely cleared following European American settlement, but like New England, deforestation has reversed. New England's historical landscape composition (Figure 5.1) has a similar "U" shape trend as seen in Figure 4.1 from the River Hills. Analysis of the study area depicts a region in the Midwest where a large forest habitat zone is growing and becoming more interconnected while situated in the predominately agricultural region of central Missouri.

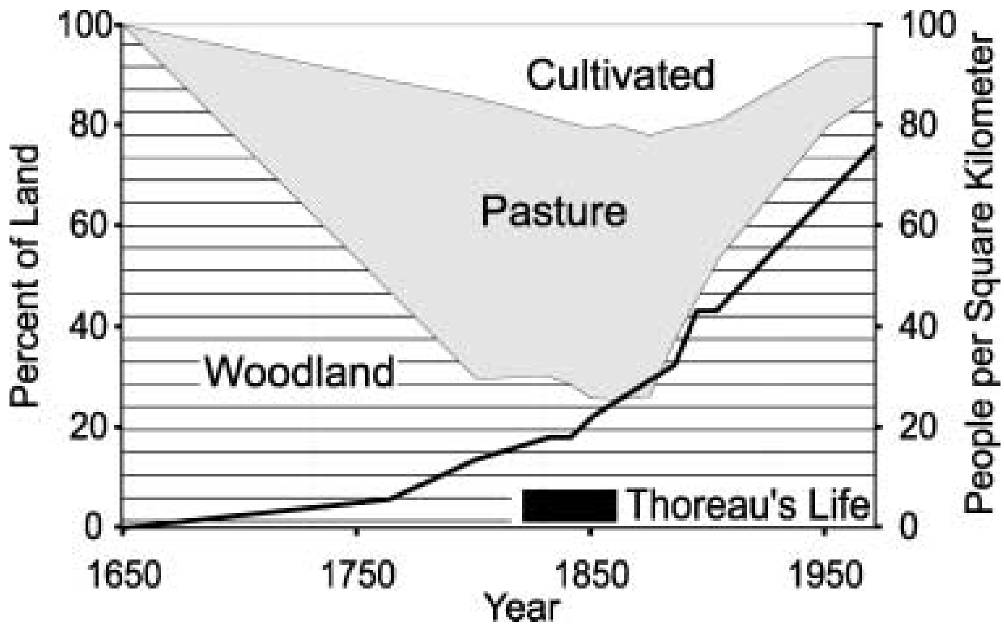

Figure 5.1 Historical land cover changes in New England. This graph notes the period when Henry Thoreau lived (Foster 2002).

Patch statistics indicate increasing forest connectivity across the Central Missouri River Hills landscape. The decreasing patch size could have many effects on species that prefer core habitat and less edge environments to survive. The increased forest connectivity is evidence that forest patch habitat is becoming more interconnected in some areas. This could have implications as the belt of River Hills can be used as a forest corridor through a predominately agricultural region. Corridors are appealing to conservation concerns because they provide a physical bridge linking patches of habitat (With 1997). Forest corridors have been assumed to increase species population persistence by providing for an exchange of individuals among a population that was historically connected but is currently fragmented (Turner et al. 2001). In contrast to the increasing forest habitat, there are many species associated with edges or open fields that may be diminishing as the area of fields decrease in size and numbers.

Despite changes, the Missouri River Hills was found to have had relatively persistent land cover during the twentieth century. In an upper Midwest study conducted in Wisconsin the landscape was found to be dominated by transient land cover types (Grossman 2007). In this particular example human disturbance like logging and natural disturbances like fire and insects shifted through the landscape much faster. In central Missouri, fields were the most persistent cover type and may be indicative of where ideal agricultural conditions are remaining fully utilized. Forests meanwhile were expanding into new locations usually with a steeper slope. Further research could examine these patches to determine successional pathways associated with these patterns of persistence.

Chapter Six

Conclusion

This study examined the Missouri River Hills to identify the land cover changes that have occurred from 1815 to 2007. This assessment has provided detail of the changes occurring in landscape composition that were driven by human land use for agriculture and the subsequent forest succession that occurred on abandoned farmland. This is the first quantitative observation of the land cover changes occurring in the western edge of the eastern deciduous forest. Similar trends were identified as with New England with farm abandonment and later reforestation beginning in the mid-nineteenth century (Golodetz and Foster 1996). The Missouri River Hills contrast with patterns occurring in some parts of southern Wisconsin, southern Illinois and other Midwestern regions that were characterized by little reforestation over the same period (Whitney 1994; Rhemtulla et al. 2007).

The land use practices in the River Hills are inherently a trade-off between ecosystem services with immediate benefits like timber resources or farmland, while at the same time potentially degrading long term ecosystem functions (Foley et al. 2005). During two centuries Missourians harvested timber, cleared land for agriculture and urbanized parts of the landscape. Realizing what occurred across the Missouri River Hills will allow for better management of the future landscape. As Henry Thoreau understood “Yet if we attended more to the history of our [wood] lots we should manage them more wisely.”

The land uses of the River Hills have altered the landscape composition due to clearing of forests for agriculture. This clearing and the plowing, especially on the steep and highly erodible loess soil of the River Hills created new gullies and altered hydrology of the region. Many of these steep areas are now experiencing forest recovery, but less topsoil remains.

Assessments of continuing land cover change will be needed to examine future directions of change in the Missouri River Hills. Many people living in the River Hills region are abandoning their farmlands and subsequently letting them convert to forests, which is a change from the intense use of land seen in 1939. It is possible that future suburbanization around Columbia will reverse this reforestation trend (Nigh and Schroeder 2002). Understanding these trends may help conservation efforts and the recovery of species habitat within the Missouri River Hills.

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