Using the past to plan the future: Retrospective assessment of landscape and land-use change in the Clear Creek watershed, Iowa

by

Andrew Pierce Rayburn

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Program of Study Committee:
Lisa A. Schulte, Major Professor
Phillip Dixon
Thomas Isenhart
Mimi Wagner

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Graduate College
Iowa State University

This is to certify that the master’s thesis of

Andrew Pierce Rayburn

has met the thesis requirements of Iowa State University

______________________________
Major Professor

______________________________
For the Major Program
For my father, Regan Lee Rayburn
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CHAPTER 1. GENERAL INTRODUCTION

INTRODUCTION

While acknowledging the presence and effect of Native Americans upon historic American landscapes (Prior 1991, Manning 1995), it is no exaggeration to state that the vast majority of native landscapes in the Midwestern United States have been transformed by anthropogenic land uses, especially agriculture and pasture, since settlement by Euro-Americans in the early to mid-1800s (NASS 2004). This general trend is especially true in the state of Iowa, where between 80-90% of the pre-settlement landscape has been converted from a mosaic of prairies, forests, and wetlands to production landscapes associated with corn, soybeans, and livestock forage (Farrar 1981, Burkart et al. 1994). This dramatic conversion has had, and continues to have, significant impacts on both terrestrial and aquatic resources, including habitat for flora and fauna (Farrar 1981, Jackson and Jackson 2002), soil stability and erosion (Burkart et al. 1994), local and regional hydrologic systems (Neely and Baker 1989, Isenhart et al. 1997), water quality (Rabalais et al. 2002, IDNR 2004), and the aesthetic quality of rural landscapes (Kaplan and Austin 2004). Opportunities to mitigate potentially negative impacts associated with this landscape conversion exist, but in theory should be addressed at the landscape scale (Mitsch et al. 2001, Jackson and Jackson 2002, Lindenmayer and Franklin 2002) and should take into account the influence of historical trajectories of landscape change on present and future ecosystem properties (Anderson et al. 1996).

Because landscape change in the anthropogenically modified Midwestern United States reflects the interconnected relationship between the people and the land, it is
appropriate to examine the phenomena from both ecological and social perspectives. In order to evaluate landscape change within a study area in eastern Iowa, I integrated a variety of historic data sources in a GIS environment in order to compute changes in landscape composition and configuration, stream sinuosity, and housing density (metrics which relate to both people and the land on which they live; Vitousek 1994, Theobald 2001, Urban and Rhoads 2003, Hietal et al. 2004). I also sought to delineate remnant patches of native habitat that have persisted to the present, despite dramatic changes in the surrounding landscape.

Although my preconceived notion of Midwestern agricultural landscapes were that they were largely static in space and time, my research reveals that substantial landscape change has taken place within the study area over the last 150 years. My results suggest that forest cover has been increasing within the study area since the beginning of the 20th century, while crop cover has been declining since at least 1940. Furthermore, urban cover (as well as housing density) has been steadily increasing since 1940, echoing broader trends in urbanization throughout the Midwestern U.S. (Theobald 2001). In addition, as one component of a larger suite of anthropogenically-induced, hydrological modifications of the landscape, I observed a dramatic decline in the sinuosity of the main stream channel in the study area in the mid-1900s.

The changes I detail in land cover, stream sinuosity, and housing density have important implications in both ecological and social realms, and the remnant habitat patches that I delineated may serve as important conservation targets. The results of my research will hopefully inform future management and conservation efforts within the study area, such as identifying highly modified stream segments that may be targeted for restoration. Furthermore, my results may be used to establish baselines of change by which future
landscape changes may be evaluated, which are essential tools for ecosystem management (Swetnam et al. 1999, Bolliger et al. 2004). Overall, my research indicates the dynamic nature of the landscape within the study area over the last 150 years and suggests that the evolution of the landscape will continue into the future.

THESIS ORGANIZATION

From 2004-2006, I conducted two studies related to landscape within the Clear Creek watershed (IA); the first study (chapter two) examines changes in land cover, stream sinuosity, and housing density from 1940-2002, while the second study (chapter three) focuses on changes in forest cover from 1840-2002, as well as the delineation of remnant forest patches from two temporal scales (1840-2002 and 1940-2002).

LITERATURE CITED


ABSTRACT

Over the last 150 years, anthropogenic land use has resulted in extensive modification of Midwestern agricultural landscapes. Landscapes historically interspersed with prairies, forests, and wetlands are now dominated by a highly productive, though largely homogeneous, matrix of agriculture. This land conversion has had a significant impact on both terrestrial and aquatic resources, as exemplified by dramatic losses of native habitat, and hypoxia in the Gulf of Mexico. Opportunities to improve the ecological integrity and functioning of modern industrial agricultural landscapes exist, but require detailed spatial data on current resource patterning and an understanding of the causes and extent of historic landscape change. We use GIS and statistical analyses to assess landscape change in the Clear Creek watershed (IA) among four time periods (~1940, 1963, ~1980, and 2002). We focus our analysis on three metrics derived from aerial photos that have important implications in both ecological and social realms—land cover composition and configuration, stream sinuosity, and housing density. Agricultural land within the watershed, including row-crops and small grains, decreased by 2773.4 ha (~10%) from 1940-2002, mirroring state and national-level declines in farms and farmers over the last 60 years, and mean crop patch area decreased by 4.9 ha. Forest cover increased by 618.8 ha (~2.3%) and mean forest patch area increased by 3.7 ha, while the number of forest patches declined by
Given the ecological and social importance of forests in both the historical and present-day watershed, this increase in area and decline in fragmentation may have important implications for watershed conservation. Urban cover increased by 1743.1 ha, and both urban and rural housing density increased during the study period. While the majority of new homes are concentrated within the fringe of urban areas in the eastern portion of the watershed, urban expansion continues to be a driving force of landscape change in the watershed. Mean main channel stream sinuosity decreased by 0.17 from 1940-1963, and this decline in sinuosity persisted until 2002. Ancillary data from the region suggest that the majority of streams and rivers in Iowa were straightened prior to 1970, although minor modifications continue. Overall, our results indicate the dynamics of land use in the watershed, and may be used to parameterize hydrological models or in the development of future land use scenarios. These results are already forming the basis for restoration planning by a local watershed coalition group.

INTRODUCTION

Anthropogenic land use has historically resulted in extensive landscape modification that continues as a result of increases in both population and per capita resource consumption. The predominant form of landscape modification has been conversion of natural lands to agriculture (Ramankutty and Foley 1999). Within the United States, approximately 50% of the conterminous land is used either for crops or grazing (USDA 2000). Within the Mississippi River Basin, 65% of the land is farmland while 25% is harvestable cropland (Turner and Rabalais 2003). In Iowa, landscapes historically dominated by a mosaic of prairies, savannas, woodlands, forests, and wetlands have been transformed
into landscapes dominated by row-crop agriculture. More than 80% of the landscape in the
majority of Iowa’s counties has been converted to production of soybean, corn, and forage
for livestock (Burkart et al. 1994), as is the case for much of the U.S. Midwest (NASS 2004).

This unparalleled land conversion, while yielding a highly productive system of
agriculture in Iowa and throughout the agricultural Midwest, has had a significant impact on
both terrestrial and aquatic resources. As less than 10% of Iowa’s native vegetation remains
(Farrar 1981), native plant and animal communities are restricted to small and often isolated
remnants (Jackson and Jackson 2002). Loss of top soil through erosion—a major factor in
the high rates of sedimentation found in Iowa’s aquatic ecosystems—has been estimated to
be as high as 11.2 metric tons/hectare/year in agricultural regions of the Midwest (Burkart et
al. 1994). This is in sharp contrast to rates of erosion reported in undisturbed perennial
systems such as forest and grasslands, which are as much as 95% lower (USSCS1983).

Local and regional hydrologic systems have been significantly modified through lowered
rates of infiltration, increased surface runoff, sedimentation, nutrient and other agricultural
chemical pollution, widespread construction of surface and subsurface drainage systems, and
wide-ranging channelization of waterways, all of which have contributed to problems of
water flow and quality (Neely and Baker 1989, Isenhart et al. 1997). Two hundred and
eleven water bodies in Iowa are currently listed on the Impaired Waters List (IDNR 2004),
and Iowa watersheds in general are significant contributors to the hypoxic zone in the Gulf of
Mexico (Rabalais et al. 2002a, 2002b).

Significant opportunities to improve the overall health and functioning of agricultural
landscapes exist, including restoration of native plant communities and modification of
agricultural production systems to incorporate greater functional diversity. In order to
achieve the greatest efficacy, these opportunities should be evaluated at landscape scales rather than at the level of individual farms or on preservation of small, isolated patches of residual land (Mitsch et al. 2001), and they should be attentive to where these landscapes have been in the past. In this research, we seek to provide such assessment through integrated study of landscape and land use history within the Clear Creek watershed of Johnson and Iowa Counties, Iowa.

**Importance of a Landscape Approach**

Rationale in support of a landscape approach to sustainable land management spans both ecological and social perspectives. From an ecological perspective, the landscape is the scale at which ecological resilience may be achieved (Mitsch et al. 2001, Lindenmayer and Franklin 2002, Groves 2003). Historical conservation efforts have primarily focused on the establishment of reserves within a matrix of working lands—lands managed for food, fiber, or fuel production (Lindenmayer and Franklin 2002). Though reserves are an essential component of any comprehensive conservation strategy, there is a growing realization that maintaining the Earth’s life support systems, including biodiversity preservation, water purification, soil genesis, and climate regulation, cannot be achieved in reserves alone (Lindenmayer and Franklin 2002). With regards to regions dominated by agricultural production, although ecological goals are not achievable in all locations at all times, both goods and ecosystem services can be produced through attentive design of agricultural systems over landscapes (Jackson and Jackson 2002).

From the social perspective, the landscape is the scale at which most humans perceive and interact with the land (Nassauer 1989). Both urban and rural populations of the Midwest
Corn Belt base their aesthetic evaluations of the landscape on the distribution of farms and fields, conservation elements such as buffer strips or windbreaks, houses, and aquatic features including lakes, ponds, and streams (Nassauer 1989). The landscape property of configuration is as important as composition in visual quality assessments—heterogeneous agricultural landscapes are seen as more aesthetically pleasing than homogeneous ones—and oftentimes in farm stewardship assessments (Nassauer 1989). The landscape may be more critical in urban or urbanizing regions, such as Iowa (Radeloff et al. 2000a), because the extent of urbanites’ interaction with rural areas is often transitory and frequently confined to transportation networks (Flad 1997). Lastly, the landscape is the scale at which most conservation planning occurs (Weins et al. 2002, Groves 2003).

**Importance of a Historical Perspective**

In the last decade, ecologists and conservation practitioners have recognized the importance of history in understanding and managing current and future ecosystems (Andersen et al. 1996, Foster et al. 1998, Foster et al. 2003). Detailed study of the past can provide insights into ecosystem structure and resilience to disturbance akin to ‘experimental manipulations’ (Davis 1989, Franklin and McMahon 2000), but often at a much lower economic and social cost—landscape level manipulation is often too expensive to carry out or is not socially justifiable.

The history of a landscape has strong and enduring influences on current ecosystem properties related to both landscape structure and function, such as ability to cycle nutrients or resilience to human and natural disturbance (Andersen et al. 1996). Data from eight Long Term Ecological Research (LTER) sites across the Eastern United States show that a land use
history of settlement, agriculture, and logging has persistent effects on ecosystem structure and function at multiple scales—from stand to landscape levels (Foster et al. 2003). Differences in land use history have been shown to control modern vegetation patterns; for instance, the age and size structures of present-day forests are often strongly tied to the time since agricultural abandonment or the last occurrence of logging (Foster et al. 2003). A study by Bellemare et al. (2002) in western Massachusetts found persistent compositional differences between the vegetation of primary forests and post-agricultural secondary forests; the distribution of vegetation in the secondary forests reflected an agricultural past although reforestation had already occurred. Such landscape legacies, especially related to past agricultural land use, can also have enduring effects on soil properties, with resultant effects on ecosystem dynamics related to soil characteristics. A short list of such effects includes homogenization of upper soil layers through plowing, depletion of soil C and N, decreased speed of soil development, shifts in soil microbial populations, and decreased resistance to invasion by exotic species (Foster et al. 2003). Because of the potential for past land use to significantly influence both the present-day structure and function of a landscape, the legacy of a landscape may impose important limitations for conservation and restoration practices.

Past conditions also provide benchmarks for evaluating the success of conservation planning and ecological restoration efforts, and conditions at key time periods can be used as restoration targets (White and Walker 1997, Wissmar 1997, Bolliger et al. 2004). Historical data are one of the most common sources of reference information for restoration projects (White and Walker 1997). They are being used as a basis for restoration in such widely varying regions and ecosystem types as the rivers and streams of the Pacific Northwest (Wissmar 1997), old-growth forests of the Pacific Northwest (Cissel et al. 1994), prairie-
forest ecotones in northeast Kansas (Kettle et al. 2000), interior rangeland ecosystems in the interior Columbia basin (Bunting et al. 2003), ponderosa pine savannas of the Southwest (Fulé et al. 1997), the pine barrens of northwest Wisconsin (Radeloff et al. 2000b), and the heathlands of Martha’s Vineyard (Motzkin and Foster 2002).

**Objectives**

Our goals in studying landscape change in the Clear Creek watershed (IA) were multifold. The first aim of this research is to provide a quantitative baseline for assessing present and future landscape changes, including connectivity of land cover types, watershed hydrology, and stream channel morphology. Developing historical baseline data is an essential tool for present-day and future ecosystem management (Swetnam et al. 1999, Bolliger et al. 2004)—such management is specific to the ecosystem in question and relies on site-specific reference information (Bolliger et al. 2004). For example, the results of a study by Schilling and Wolter (2000) that examined stream dynamics and land use data for an Iowa watershed are being used by watershed managers to prioritize restoration projects within Neal Smith National Wildlife Refuge.

Second, this research sought to delineate system thresholds, points at which system conditions and dynamics are dramatically altered, and the combination of biophysical and socioeconomic factors that drive systems toward such thresholds. Questions include: What were the ecological services provided by this landscape ~65 years ago? What has been lost? What has been gained? Was change more rapid during some periods than others? For example, the Andersen et al. (1996) study of landscape transformation in the upper Midwest found that landscape change was most pronounced during two different historical periods,
rather than being evenly distributed throughout the course of the study (1830-1990s). In providing a baseline for change, we expect to inform future conservation efforts within a watershed characterized by little remaining native habitat and intensive agricultural land use.

**Metrics**

In order to achieve the goals related to landscape and land use history, we focus on three simple metrics that integrate important ecological and social factors, and can be used in predictive modeling of ecosystem function: landscape composition and configuration, housing density, and stream sinuosity.

*Landscape composition and configuration*—There are many components of landscape composition and configuration; here we focus on land cover, or the biophysical elements that occur on a unit of land. The diversity of land cover types, patch sizes, and patch shapes—collectively known as landscape heterogeneity—relate to ecological complexity, which has broad implications for biodiversity (Lindenmayer and Franklin 2002) and the flow of materials (e.g., air, water, nutrients, sediments, fire) and organisms (Liu and Taylor 2002). Additionally, people strongly associate aesthetics with land cover composition and configuration—agricultural landscapes that are more heterogeneous in these elements are seen as more aesthetically pleasing in terms of scenic quality (Nassauer 1989). Changes in land cover have been identified as a primary effect of humans on natural systems (Vitousek 1994), and have important implications for water quality, an issue of critical importance within the Mississippi River Basin (Turner and Rabalais 2003, King et al. 2005, Schilling 2005).
Land cover changes are determined by complex sets of interactions of environmental and social factors, and social drivers of land cover change can be especially influential in regions where there is significant anthropogenic modification of the landscape and/or intensive land use (Hietal et al. 2004). In the U.S. Midwest, the development of industrial agriculture has strongly impacted environmental and social change over the last 75 years (Cochrane 1993). In the Clear Creek watershed, we expected to find that the diversity of land cover types and the size and shape of land units has dramatically changed with the growth of industrial agriculture. We expected that fewer land cover types would be represented, as grain crops have shifted to a two-year rotation of corn and soybeans and pastures have been increasingly replaced by other land uses as cattle operations have become more concentrated in recent decades. For example, cattle pastures declined by 14.5% from 1997-2002, while the number of cattle increased by approximately 2% (IBC 2006). We also expected that individual land units would show an increase in size and simplification in shape with the consolidation of land holdings and the move towards corporate ownership (Keeney and Kemp 2004).

**Housing density**—The conflict between the desire for one’s own piece of nature and sprawl is emergent in our society, and is reflected by dramatic increases in housing density within the U.S. from 4.1 homes/km² in 1940 to 12.7 homes/km² in 2000 (USCB 2004a). As a physical representation of human settlement patterns, trends in housing density can serve as a useful indicator of broader trends in urbanization (Brown et al. 2005). Changes in housing density are driven in part by changes in population, but also by changes in household number, which in some cases may increase faster than population and may even increase in regions where population declines (Liu et al. 2003). For example, the U.S. population
increased by more than 50 million people from 1980 to 2000 (Alig et al. 2004), and by 2010 the population is projected to reach approximately 300 million people (USCB 2004b). At the same time, the number of U.S. households increased from 34.9 million in 1940 to 105.5 million in 2000, with the number projected to increase to 114.8 million by 2010 (Day 1996).

In recent decades the ecological importance of housing development has been recognized as a result of the continued urbanization of exurban, rural, and nonmetropolitan areas (Theobald 2001, Kaplan and Austin 2004, Hammer et al. 2004). Since the 1970s, both rural and exurban regions have been experiencing substantial in-migration from urban core areas (the so-called “flight to the countryside,” Kaplan and Austin 2004) as a result of amenities associated with these landscapes (McGranahan 1999, Kaplan and Austin 2004). As of the year 2000, the area converted to exurban housing (one house/4-16 ha) in the U.S. was almost ten times that converted to urban land (greater than one house/4 ha) (Theobald 2001).

Because rapid exurban development affects a larger area than densely settled areas of urban sprawl along the metropolitan fringe, Brown et al. (2005) suggest that it represents a different category of sprawl (“rural sprawl”), with development increasingly delinked to urban centers and driven by access to rural amenities. Rural sprawl is facilitated in the Midwestern U.S. because there are few limitations in terms of extensive public lands, topography, or water availability, and existing road networks are extensive (Radeloff et al. 2005). The number of homes in the U.S. Midwest increased by more than 14 million units, or 146%, between 1940-2000 (1940: 9,831,111 housing units; 2000: 24,146,080 housing units); approximately one-third of this growth occurred in non-metropolitan counties, which contributed to rural sprawl (Radeloff et al. 2005).
Increases in exurban development in the Midwest represent the continued expansion of rural sprawl into land that was formerly native habitat or that was used for agriculture (Theobald 2001). The effects of such switches from agricultural to more urban environments on water quality are currently unclear, although stream biotic integrity has been shown to be negatively correlated with urban land use (Synder et al. 2003) and increasing urbanization has been shown to result in degraded water quality (Milter et al. 2004). Increasing urbanization has important implications for biodiversity, as habitat composition, structure, and connectivity is completely altered (Liu et al. 2003, Theobald 2004, Radeloff et al. 2005). Recent work from forested environments in northern Wisconsin shows decline in bird diversity associated with increases in housing density (Chris Lepczyk, University of Wisconsin-Madison, personal communication). Conroy et al. (2003) reports that increasing human population and urban sprawl in the Southern Piedmont region can be expected to result in changes in both ecological integrity and the production of ecological goods and services, such as losses in both water quality and water availability, native habitats, and biological diversity, as well impacts on air quality and increasing forest fragmentation. From the social perspective, increasing housing density can result in a loss of rural aesthetics is increasingly transformed and fragmented by new housing construction (Kaplan and Austin 2004). Further, land parcelization presents a difficult challenge for natural resource managers: increased numbers of land owners need to be reached in order to promote positive land practices (Freeman et al. 2003). Concomitant with national trends, we expected that housing density within the Clear Creek watershed would initially decrease (coinciding with an expansion in farm size after World War II) before increasing in more recent decades as a result of increasing urban and exurban development.
Stream sinuosity—Stream sinuosity is an indicator of the amount of curvature in a stream channel (i.e., the degree to which the stream meanders) and directly influences water quality, water quantity, and biodiversity (FISRWG 1998, Barbour et al. 1999). The sinuosity of natural streams is controlled by factors such as the gradient of the stream and the degree of homogeneity of bank and substrate particles (Leopold et al. 1964). Most streams are naturally sinuous because the shape allows for even expenditure of energy present in moving water, creating a condition of near equilibrium, which is disrupted by anthropogenic modification (Leopold et al. 1964, Bulkley 1975).

Streams with a higher degree of sinuosity contain better water quality due to the greater number of filtration areas and greater time allowed for filtration (Barbour et al. 1999). In addition, more sinuous streams have lower slopes, flow velocity, stream competence, and stream power, all of which are drivers of erosion, sediment transport, and sediment deposition (Bulkley 1975, FISRWG 1998). More sinuous streams are less prone to severe flooding and are better able to absorb surges resulting from storm events (Barbour et al. 1999), which is extremely important in both agricultural and urban landscapes. The number of microhabitats for fish, invertebrates, and plants tend to be higher in more sinuous streams as bends in streams provide refugia during storm events and filtration areas reduce pollutant loads (Barbour et al. 1999). Further, more sinuous streams provide more interesting recreational opportunities and aesthetic experiences for people (FISRWG 1998).

Changes in stream sinuosity are an important component of landscape change in Midwestern landscapes, since they often accompany shifts from non-agricultural to agricultural land use and can have implications for a host of ecological and social factors. The vast majority of Midwestern streams have undergone some degree of anthropogenic
modification within the last century, and the straightening of formerly sinuous streams is a common practice within the agricultural landscapes that typify the region (Urban and Rhoads 2003). Large-scale efforts to channelized Iowa streams began in earnest in the late 1800s, in an effort to facilitate the drainage of agriculture land, and over 3,000 miles of rivers and streams in Iowa have been straightened to date (Bulkley 1975, Menzel 1983). Within the Clear Creek watershed, we expected to find that stream sinuosity has decreased over time, as wetlands have been drained, waterways have been channelized, and stream flow regimes have been altered.

MATERIALS AND METHODS

Study Area

The study area is composed of the Clear Creek watershed (27,520 ha) within Iowa and Johnson counties in eastern Iowa (Fig. 1.1). The watershed is dominated by anthropogenic land uses, with 60% of land cover in row-crops, 19% in pasture/hay, and approximately 15-20% in urban and suburban settlement (Vogelmann et al. 2001). Prior to settlement by Euro-Americans in the mid-1800s, the vegetation in the watershed was dominated by prairie, interspersed with forests, savannas and wetlands (Anderson 1996). The watershed lies on the Southern Iowa Drift Plain, a pre-Illinoian glacial landscape characterized by steeply rolling hills and well-developed drainage (Prior 1991). Soils are moderately to highly erodible, and include silty clay loams, silt loams, or clay loams formed in loess and till (Schilling and Wolter 2000). The mean annual temperature of eastern Iowa is approximately 10° C, and mean annual precipitation is approximately 89 cm (NOAA 2005). The municipalities of Coralville, Iowa City, and North Liberty are partially contained
within the eastern half of the watershed. Beginning in 1998, the Johnson County Soil and Water Conservation District identified Clear Creek as a priority watershed and initiated the Clear Creek Watershed Enhancement Project (CCWEP), the mission statement of which is “neighbors working together to restore the natural resources, control flooding, and foster economic development to enhance our watershed community” (Anonymous 2003). Parcelization of land ownership and exurban development characterize recent years, and has resulted in conflicts between rural and urban values (Keith Schilling, Iowa DNR, personal communication). Because of poor water quality within Clear Creek (Neely et al. 2003, Keith Schilling, DNR, personal communication), rapid land use changes within the watershed, and activity on the part of the CCWEP, Clear Creek was added to the state list of impaired streams in 2004 (IEC 2006).

**Data capture**

Our estimates of landscape change were derived from aerial photographs that spanned our time frame of interest, 1940-2002, at approximately 20-year intervals. Aerial photographs of the watershed were available as follows; Iowa County: 1940 (1:20000, black and white), 1963 (1:20000, black and white), 1979 (1:40000, black and white), 2002 (1:20000, false color IR), Johnson County 1937 (1:20000, black and white), 1963 (1:20000, black and white), 1983 (1:40000, false color IR), 2002 (1:20000, false color IR) (Appendix A). Aerial photographs were acquired from various sources (Appendix A), scanned at 600 dpi, and georectified in ArcGIS (version 9.1; ESRI 2004). Land cover, stream sinuosity, and housing density were then digitized in ArcGIS for each timestep (1940, 1963, 1980, 2002).
Land cover—Ten land cover classes were used, based on the degree to which landscape features were distinguishable from aerial photography (crop, grass, closed forest, open forest, urban, water, homesite, road, other, missing). Various criteria related to landscape pattern, texture, color, shape, and position were used to assign landscape elements to cover classes (Appendix B). The minimum dimensions of digitized landscape features were 10 m x 10 m. Each land cover polygon was assigned a confidence rating (1 [least confident] to 10 [most confident]), and polygons with a rating ≤ 7 were rechecked by a second observer to ensure consistency. Shared edges between all polygons were checked to ensure that divisions were based on real divisions in the landscape and not artificial divisions resulting from the digitizing process.

Housing density—Houses were digitized as point features, with points being centered approximately on the center of each individual house. Collections of buildings in the rural landscape were assumed to be farmsteads, and were treated as a single home site with the point being centered on the building identified as the house. Multiunit structures (e.g., apartments) were not digitized, since they could not be accurately identified from aerial photographs. To address the possibility that some houses were either missed or misidentified, all point data were rechecked by a second observer.

Stream sinuosity—Streams were digitized as polylines, with lines being placed approximately in the middle of stream channels. In infrequent cases where other landscape elements (e.g. forests, roads) obscured small portions of streams, efforts were made to digitize streams according to the position of landscape elements that could serve as a guide (such as riparian forests) or to simply connect known stream segments with a straight line (across the unknown portion). Individual stream segments were defined as running from
confluence to confluence. Stream segments were rechecked to ensure connectedness to adjacent segments, as well as for accuracy in relation to streams visible on aerial photographs.

Analysis

_Land cover_—In order to examine changes in land cover, a set of landscape statistics were calculated for each land cover class. Certain land cover classes (homesite, road, water, missing, and other) were excluded from analysis because they occupied a small percentage of the landscape. For the remaining classes (crop, grass, closed forest, open forest, urban), we calculated the number of patches, total class area (ha), proportion of the landscape (%), mean patch area (ha), total class edge (km), mean patch edge (km), and mean perimeter-to-area ratio using base ArcGIS tools and the VLATE extension (Lang and Tiede 2003). The periods of greatest change were identified for each landscape statistic for each land cover class.

_Housing density_—Housing density (homes/km²) was calculated for each time period over both the whole watershed and at a quarter-section resolution. Total housing density at the watershed-scale was calculated by dividing the number of housing units by the watershed area. Rural housing density was calculated by using 2002 urban land cover as a mask, followed by dividing the number of rural houses by the adjusted watershed area (rural area = total area – urban area). Urban housing density was calculated by dividing urban area by the number of urban homes. Quarter-sections, 0.65 km² land units based on the Public Land Survey of the United States (Stewart 1935), were chosen for finer resolution analysis since they represented a traditional parcel size for privately owned land in Iowa (n=138). For each
time period, mean housing density was calculated by taking the average of all quarter-section housing density values.

Total, urban, rural, and mean housing density were compared across all time periods, and the periods of greatest change in each statistic were identified. Digital maps of home site distribution (watershed resolution) and housing density (quarter-section resolution) for each time period were created in ArcGIS. A digital map was also created to visualize changes in quarter-section scale housing density from 1940-2002.

*Stream sinuosity*—Mean stream sinuosity was calculated at the watershed scale (i.e., for all stream segments at each time period) using Hawth’s Analysis Tools for ArcGIS (Beyer 2004). There was considerable variation in the number of stream segments digitized in each time period ($n_{1940} = 2360; n_{1963} = 2840; n_{1980} = 1062; n_{2002} = 598$). Based on these observations and on preliminary analyses, it was determined that meaningful analysis could be conducted only on the main stream channel. These differences in the number of stream segments was observed to be a byproduct of ephemeral streams within an agricultural landscape and variation in photo quality. Individual main channel segments were classified using common confluences for all time periods ($n=34$). This method allowed for an ecologically relevant way to standardized segments such that sinuosity of the individual segment composing the main stream channel could be compared across time periods. Sinuosity values were calculated for each main channel stream segment in each time period, and mean main channel sinuosity was compared across time periods. The period of greatest change in mean main channel sinuosity was then identified.

Due to variability in definitions of what constitutes a sinuous stream, as well as variability in the digitization of stream channels, we used a three-group classification scheme
to classify individual segments as sinuous \((s \geq 1.4, \text{ where } s = \text{sinuosity})\) semi-sinuous \((1.4 > s > 1.2)\), and non-sinuous \((s \leq 1.2)\). A sinuosity value of 1.3 was used as an approximate value for sinuous streams (FISRWG 1998). The number of sinuous, semi-sinuous, and non-sinuous stream segments in each time period were determined, and changes in these numbers were examined from 1940-2002. The periods of greatest change in the numbers of sinuous, semi-sinuous, and non-sinuous segments were then identified.

RESULTS

Land cover

*Crop*—The number of crop patches decreased by 5.5%, from 380 patches in 1940 to 359 patches in 2002. The proportion of the watershed occupied by crop cover decreased by 10.4%, from 68.0% in 1940 to 57.6% in 2002. Total crop area decreased from 18164.9 ha in 1940 to 15391.5 ha in 2002, a net decrease of 2773.4 ha (Fig. 1.2). Mean crop patch area decreased by 4.9 ha, from 47.8 ha in 1940 to 42.9 ha in 2002. Total crop edge decreased by 284.9 km, from 1379.3 km in 1940 to 1094.4 km in 2002. Mean crop patch edge decreased by 0.55 km, from 3.6 km in 1940 to 3.05 km in 2002. The mean P/A ratio of crop patches varied only slightly between 1940 and 2002 (Table 1.1).

*Grass*—The number of grass patches decreased by 4.9%, from 433 patches in 1940 to 412 patches in 2002. The proportion of the watershed occupied by grass cover decreased by 1.0%, from 19.8% in 1940 to 18.8% in 2002. Total grass area decreased from 5299.5 ha in 1940 to 5025.1 ha in 2002, a net decrease of 274.4 ha (Fig. 1.2). Mean grass patch area varied only slightly between 1940 and 2002 (Table 1.1). Total grass patch edge decreased by
13.3 km, from 87.3 km in 1940 to 74.02 km in 2002. Mean grass patch edge varied only slightly between 1940 and 2002, as did the mean P/A ratio of grass patches (Table 1.1).

*Closed forest*—The number of closed forest patches decreased by 21.1%, from 337 patches in 1940 to 266 patches in 2002. The proportion of the watershed occupied by closed forest cover increased by 2.3%, from 6.5% in 1940 to 8.8% in 2002. Total closed forest area increased from 1723.7 ha in 1940 to 2342.6 ha in 2002, a net increase of 618.8 ha (Fig. 1.2). The mean area of closed forest patches increased by 3.7 ha, from 5.1 ha in 1940 to 8.8 ha in 2002. Total closed forest edge increased by 68.4 km, from 508.6 km in 1940 to 577.0 in 2002. Mean closed forest patch edge increased by 0.7 km, from 1.5 km in 1940 to 2.2 km in 2002. The mean P/A ratio of closed forest patches varied only slightly between 1940 and 2002 (Table 1.1).

*Open forest*—The number of open forest patches increased by 4.6%, from 66 patches in 1940 to 69 patches in 2002. The proportion of the watershed occupied by open forest cover increased by 0.3%, from 1.0% in 1940 to 1.3% in 2002. Total open forest area increased from 275.3 ha in 1940 to 349.1 ha in 2002, a net increase of 73.8 ha (Fig. 1.2). Mean open forest patch area varied only slightly from 1940-2002 (Table 1.1). Total open forest patch edge increased by 51.3 km from 17.7 km in 1940 to 69.0 km in 2002. Mean open forest patch edge varied only slightly from 1940-2002 (Table 1.1). The mean P/A ratio of open forest patches decreased from 0.053 in 1940 to 0.036 in 2002, and changes in the mean P/A ratio of open forest patches also occurred in intermediate time periods (Table 1.1).

*Urban*—The number of urban patches increased by 144.4%, from 9 patches in 1940 to 22 patches in 2002. The proportion of the watershed occupied by urban cover increased by 6.5%, from 0.6% in 1940 to 7.1% in 2002. Total urban area increased from 152.4 ha in
1940 to 1895.4 ha in 2002, a net increase of 1743.1 ha (Fig. 1.2). Mean urban patch area varied only slightly from 1940-2002 (Table 1.1). Total urban edge increased by 51.3 km, from 17.7 km in 1940 to 69.2 km in 2002. Mean urban patch edge varied only slightly from 1940-2002, as did the mean P/A ratio of urban patches (Table 1.1).

*Period of greatest land cover change*—Here we focus on reporting the periods of greatest change in total area for each cover class, since changes in total area represent the most pronounced feature of landscape change associated with each land cover class. The period of greatest change in the total class area of both crop and grass cover was from 1940-1963, when crop cover declined by 1608.1 ha and grass cover increased by 579.8 ha. Changes in open forest cover were most pronounced from 1963-1980, when open forest cover declined by 330.0 ha. The most dramatic changes in both closed forest and urban cover occurred from 1980-2002, when closed forest cover increased by 425.8 ha and urban cover increased by 946.9 ha.

*Spatial arrangement of cover types*—Some spatial shifts in land cover types are visible within the watershed over the time frame of study. Maps of land cover distribution from each time step (Appendix F) show that crop cover dominated the western third of the watershed from 1940-2002, with grass cover increasingly in extent in the middle of the watershed during the study period. Urban and forest cover were more common in the eastern third of the watershed, and increases in urban cover from 1940-2002 are visually apparent.

**Stream sinuosity**

Digital maps of the stream network within the Clear Creek watershed illustrate the variability in the total number of stream segments from 1940-2002 (Fig. 1.3), underscoring
our decision to limit our analysis of stream sinuosity to the main stream channel. Although changes in main channel sinuosity are not visually apparent at the watershed resolution (see Fig. 1.4), mean main channel stream sinuosity decreased from 1.49 in 1940 to 1.32 in 2002 (Fig. 1.4, Appendix D). The period of greatest change in mean main channel sinuosity was from 1940-1963, when sinuosity declined from 1.49 to 1.27.

From 1940-1963, the number of sinuous \((s \geq 1.4)\) main channel segments decreased from 21 (61.8\%) to eight (23.5\%) (Fig. 1.5, Appendix C). In 2002, 10 (29.4\%) segments were sinuous, a decrease of 32.4\% from 1940. Only five segments (14.7\%) were non-sinuous \((s \leq 1.2)\) in 1940; 19 segments (55.9\%) were non-sinuous in 1963 and also in 2002. The number of semi-sinuous segments declined from eight (23.5\%) in 1940 to five (14.7\%) in 2002, suggesting that semi-sinuous segments were increasingly diverging towards becoming either sinuous or non-sinuous. Examples of three stream segments from in both 1940 and 2002 illustrate the degree to which many main channel stream segments declined in sinuosity during the study period (Fig. 1.6).

**Housing density**

The total number of houses in the watershed increased from 695 in 1940 to 3763 in 2002, an increase of 3068 (Fig. 1.7, Fig. 1.8). The number of urban houses increased by 2746, while rural houses increased by 322. The period of greatest change in the number of urban houses (+1388), rural houses (+119), and total houses (+1507) was between 1980 and 2002 (Fig. 1.7, Fig. 1.8, Appendix E).

At the resolution of the watershed, total housing density, urban housing density, and rural housing density increased from 1940-2002 (Fig. 1.7). Total housing density increased
from 2.60 homes/km$^2$ to 14.08 homes/km$^2$. Urban housing density increased from 16.36 homes/km$^2$ to 161.23 homes/km$^2$, while rural housing density increased from 1.55 homes/km$^2$ to 2.85 homes/km$^2$. The period of greatest change in both total housing density (+5.64) and urban housing density (+73.23) was from 1980-2002, while the period of greatest change in rural housing density (+0.69) was from 1963-1980. Contrary to expectations, all time periods witnessed an increase in rural housing density at the watershed scale.

Mean housing density at a quarter-section resolution increased from 2.97 homes/km$^2$ in 1940 to 15.13 homes/km$^2$ in 2002 (Fig. 1.7, Fig. 1.9, Appendix E). The period of greatest change (+6.25) in mean housing density was between 1980 and 2002, from 8.88 homes/km$^2$ in 1980 to 15.13 homes/km$^2$ in 2002 (Fig. 1.7, Fig. 1.9, Appendix E).

Digital maps of home site distribution and mean housing density from each time period illustrate that homes were increasingly clustered in and around urban areas (Fig. 1.8). Homes in rural areas often occurred in a grid-like pattern that echoed the township and section divisions charted in the original Public Land Survey of Iowa, reinforced by the network of roads and highways within the watershed. The map of changes in mean housing density from 1940-2002 (Fig. 1.10) illustrates that, while substantial increases in housing density occurred in and around urban areas, changes in housing density could be observed throughout the watershed. As an example, quarter-sections in which housing density decreased from 1940-2002 occurred throughout the watershed (Fig. 1.10).
DISCUSSION

The strengths of our approach include its repeatability in other watersheds and our integration of multiple metrics of landscape change that have both ecological and social origins and implications. Such blending of ecological and social perspectives is particularly relevant in intensively managed landscapes, because it reflects the relationship between the people and the land on which they live and work (Miller and Hobbs 2002). For example, rural and exurban sprawl tend to spread outwards from urban cores along existing road networks, resulting in landscape change (shift from rural, agricultural landscapes to housing developments) that in turn may have dramatic effects on the movement of water and nutrients across the landscape, the quality of habitat, and the interactions between the people and the developing landscape (Theobald 2001).

Landscape change observed in this research occurred in a region that was already heavily transformed by anthropogenic land uses. As such, landscape change in the watershed from 1940-2002 represents a ‘second wave’ of anthropogenically-induced change. Sweeping changes associated with Euro-American settlement in the mid-1800s in the region largely eliminated the mosaic of native habitats (e.g., prairies, forests, savannas, and wetlands) as they were converted to agriculture (Thompson 1992, Nuzzo 1986). Landscape changes relative to land cover, stream sinuosity, and housing density from 1940-2002 were driven by anthropogenic forces, yet have both ecological and social implications for both the people and the land. For example, declines in stream sinuosity due to channelization have most likely exacerbated water-quality issues such as nutrient and sediment pollution from soil runoff and streambank erosion, which in turn have negative effects on aquatic habitat.
Our results echo the findings of Anderson et al. (1996) in that landscape changes were uneven through time, as periods of greatest change varied between the three metrics of landscape change. Land cover change was characterized by a rather continuous decline in agricultural cover coupled with concomitant increases in urban and forest cover; system thresholds were not apparent.

Substantial changes in land cover from 1940-2002 were seen in crop, forest, and urban cover classes mirroring results from other studies of Midwestern landscapes. For example, Brown (2003) observed decreases in crop cover and increases in forest cover in the Upper U.S. Midwest from 1970-1990, Anderson et al. (1996) observed increases in urban cover in the St. Croix River valley (MN) from 1940 to present, and Simpson et al. (1994) observed declines in crop cover coupled with increases in forest and urban cover in central Ohio from 1940-1988. We did not observe the expected decline in the diversity of land cover types, yet this result is likely due to the coarseness of our land cover classification scheme that did not allow for finer-scale classification of crop cover (i.e., row-crop vs. corn, soybeans or small grains).

In this study, the gradual decline in crop cover by over 2700 ha may have resulted from agricultural intensification and consolidation, as small farms may have been abandoned or sold due to financial hardship, potential profit from housing development, or a lack of children following in the footsteps of their farming parents (Cochrane 1993, Keeny and Kemp 2004). It is more likely, however, that the encroachment of both rural and urban sprawl into formerly agricultural land was primarily responsible for the observed decline in crop cover from 1940-2002, given the increases in total and mean housing density observed during the same time period. The absence of meaningful variation in mean perimeter-to-area
ratio of crop patches (Table 1.1) implies that, rather than changing in shape or becoming more fragmented, crop patches were disappearing from the landscape altogether. This conclusion is further supported by the observed decline in the number of crop patches during the study period (Table 1.1). This pattern of change in crop cover is in contrast to the pattern of change often observed in forest cover, where forests may become increasingly or decreasingly fragmented due to conversion to other land uses (Radeloff et al. 2005).

The increase in forest cover and decline in forest fragmentation from 1940-2002 was likely driven by the establishment and growth of woody vegetation in land formerly used for livestock forage, as well as a combination of tree-planting and retention induced by increasingly popular conservation programs (e.g., the Conservation Reserve Program) in more recent decades. Livestock have become increasingly concentrated in the Midwest over recent decades, and pastures have been abandoned or converted to other land uses as a result (IBC 2006). The increase in forest cover was most pronounced from 1980-2002, implying the rate of increase in forests may be accelerating. It is uncertain, however, if forests will continue to increase (or even persist), given the increasing urbanization of rural areas where forests typically occurred. For example, forests are an important component of the aesthetic quality of rural landscapes that is attractive to homebuyers, leading to the construction of new homes and associated development. Paradoxically, this construction and development often degrades the aesthetic quality of the rural landscape that was so desirable in the first place (Kaplan and Austin 2004).

An increase in forest cover has important conservation implications in a watershed that is almost completely transformed by intensive anthropogenic land use. Forested areas in the U.S. Midwest are most often located in the same locations as they were during the pre-
Euro-American period, despite considerable changes in species composition and forest structure (Radeloff et al. 2005). Within the watershed, forest patches that retain characteristics similar to those found in native forests (i.e., presence, species, soils) could potentially serve as anchors for future habitat expansion, as well as critical habitat for forest-dependent species (Lindenmayer and Franklin 2002). The persistence and expansion of riparian forests may be of added significance, given the potential for such habitat to influence water quality in Midwestern streams (Schultz et al. 2004).

We observed a decline in the sinuosity of the main stream channel of the watershed from 1940-2002, but this decline occurred exclusively from 1940-1963. Subsequent to 1963, no major changes in sinuosity were observed although declines in stream sinuosity persisted in many main channel stream segments (Fig. 5). This result points to a stream sinuosity ‘threshold’ between 1963 and 1980 (Fig. 4), after which latent, cumulative effects may continue to occur (e.g., increased flow rates, stream incision, loss of species). Our results mirror trends in stream sinuosity at the state level, since the majority of streams and rivers in Iowa were straightened prior to the 1930s and the bulk of channelization was conducted prior to 1970 (Bulkley 1975). Other hydrological modifications, such as the construction of tile drainage networks and the drainage of wetlands had also been ongoing in Iowa for decades prior to 1940 (Meek 1892, Pavelis 1987, Thompson 1992).

The observed decline in main channel sinuosity within the Clear Creek watershed has important implications, given the relationship between stream sinuosity and various factors associated with water quality. In identifying specific segments of the main stream channel that have decreased in sinuosity since 1940, our research may help to lay the groundwork for stream restoration efforts (such as the restoration of formerly sinuous stream segments, see
Fig. 1.5) within the watershed in the future. While the restoration of stream sinuosity at the watershed-scale is unrealistic (and perhaps undesirable from a conservation perspective in some instances), the targeted restoration of key stream reaches has the potential to reduce downstream transport of sediment and nutrients, to improve aquatic and riparian habitat, and to provide recreational opportunities and aesthetic experiences for people living in the watershed (Bulkley 1975, FISRWG 1998, Barbour et al. 1999).

While increases in housing density were observed most often in locations bordering urban areas and along road corridors, dramatic declines in housing density occurred in quarter-sections throughout the Clear Creek watershed. These findings suggest that the evaluation of housing density dynamics at a watershed-scale may occlude fluctuations in housing density at finer scales. Our results suggest that farms and/or other forms of rural housing in certain regions of the watershed were either abandoned or consolidated in larger aggregate units, which would be consistent with the rise of industrial agriculture after World War II and the subsequent increase in farm size (Duffy 2004). Finer-scale analysis of housing trends (e.g., at the scale of individual homesites) could potentially determine the fate of specific farmsteads or houses, which in turn could be linked to broader urbanization trends observed in this research.

Dramatic increases in both housing density and urban cover in the watershed, especially from 1980-2002, have important implications related to the conversion of farmlands, fields, and forests, water quality, and the aesthetic quality of the rural landscape. Urbanization results in the transformation of both managed and native landscapes, and rural sprawl has the potential to alter land use patterns in regions of the watershed that have historically been dominated by agriculture. Such shifts in land use may represent relatively unidirectional
changes in system states, given the unlikelihood of the conversion of developed, residential areas to fields or forests. Although no thresholds in housing density dynamics were observed, the rate of increase in housing density gradually increased throughout the study period. This result suggests that the effects of urbanization in the watershed may become more pronounced in decades to come, which in turn would make effective conservation within the watershed more difficult to achieve.

CONCLUSION

Our research details the dynamics of landscape change in a heavily transformed Midwestern watershed from 1940-2002. Crop cover has declined within the watershed over the last 60 years, while forest and urban cover has increased at a growing rate in recent decades. Declines in main channel stream sinuosity observed from 1940-1963 have persisted in the present-day landscape, although our results hint that sinuosity may be increasing slightly in recent decades. Urbanization will most likely continue to be an important driving force of landscape change, particularly increases in rural housing density that have the potential to further fragment and transform rural regions within the watershed.

Overall, the results of our research demonstrate that considerable landscape change occurred within the Clear Creek watershed between 1940 and 2002. These results are consistent with other studies of changes in Midwestern landscapes during the 20th century (e.g., Anderson et al. 1996, Brown 2003, Radeloff et al. 2005) and provide an example of a Midwestern agricultural landscape that is dynamic in both space and time.

Our results may be used in conjunction with other data to parameterize hydrological models or in the development of alternative future land use scenarios for Midwestern
landscapes (e.g., Nassauer et al. 2002, Santelmann et al. 2004). Our results are already forming the basis for restoration planning by a local watershed coalition group, illustrating the potential for similar research to inform conservation planning in managed landscapes. Such efforts are timely, given the current shift between agriculture and urban lands in regions of the Midwestern U.S. These shifts represent opportunities, but require a landscape perspective to be most effective and a historical baseline to document improvements, both of which we provide through this research.

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Natural Areas Journal 6:6-36.


## TABLES AND FIGURES

Table 1.1. Landscape statistics for crop, grass, closed forest, open forest, and urban land cover types within the Clear Creek watershed (IA), 1940-2002.

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Figure 1.1 Location of the Clear Creek watershed in eastern Iowa.
Figure 1.2. Percent area of crop, grass, closed forest, open forest, and urban land cover in the Clear Creek watershed (IA), 1940-2002.
Figure 1.3. Digitized stream network within the Clear Creek watershed (IA), 1940-2002.
Figure 1.4. Mean main channel stream sinuosity in the Clear Creek watershed (IA), 1940-2002. Error bars represent standard errors.
Figure 1.5. Number of sinuous ($s \geq 1.4$), semi-sinuous ($1.4 > s > 1.2$) and non-sinuous ($s \geq 1.2$) main channel stream segments within Clear Creek watershed (IA), 1940-2002.
Figure 1.6. Example of changes in stream sinuosity between 1940 and 2002 in three stream segments from the main stream channel of Clear Creek. Black lines represent stream segments in 1940, while gray lines represent the same stream segment in 2002.
Figure 1.7. Changes in a) urban and rural homes, b) urban and rural housing density, and c) mean housing density in the Clear Creek watershed (IA), 1940-2002. Error bars in c) represent standard errors.
Figure 1.8. Distribution of home sites within Clear Creek watershed (IA), 1940-2002. Each dot represents a single home site.
Figure 1.9. Housing density at the quarter-section resolution (0.65 km$^2$) within the Clear Creek watershed (IA) in a) 1940, b) 1963, c) 1980, and d) 2002.
Figure 1.10. Changes in housing density at the quarter-section resolution (0.65 km$^2$) in Clear Creek watershed (IA), 1940-2002.
CHAPTER 3. INTEGRATING HISTORIC DATA SOURCES TO DELINEATE

REMNANT NATURAL AREAS WITHIN MANAGED AGRICULTURAL LANDSCAPES

A paper to be submitted to the Natural Areas Journal

Andrew P. Rayburn and Lisa A. Schulte

ABSTRACT

The identification and protection of native prairie and wetland remnants has received significant attention in the Midwestern U.S., however forests are also important components of historical and modern Midwestern landscapes. Here we use a combination of data sources, including Public Land Survey records, state atlases, aerial photography, and forest inventory and analysis reports to examine forest change from 1840-2002 within the Clear Creek watershed in eastern Iowa. We then identify and characterize remnant forest patches that have persisted since settlement of the region by Euro-Americans, and discuss their conservation value. Significant changes in forest cover have taken place within the watershed since 1840, and increases in both total forest cover and mean patch area challenge the conception of agriculturally dominated landscapes as being static in both space and time. Forest composition has also changed, as oak forests have shifted to dominance by later-successional, mesic species. The delineation of remnant forest patches sets the stage for future field research, and informs ongoing conservation efforts by local stakeholder groups in the watershed. Traditional conservation efforts have focused on the establishment and protection of reserves, yet this approach is poorly suited for heavily transformed, agricultural landscapes characteristic of the Midwestern states. Our research complements newer
approaches to forest conservation that focus on ecological conditions within these intensively managed landscapes.

INTRODUCTION

The Corn Belt region of the central U.S. has a heavily transformed landscape, few reserves and little remaining native vegetation (Nuzzo 1986, Burkart et al. 1994, Rosenblatt et al. 1999). Conservation scientists and planners have increasingly recognized the importance of maintaining and improving ecological conditions within such intensively managed landscapes to achieve conservation goals, as opposed to focusing exclusively on reserves (areas specifically set aside or protected for the purposes of conservation) (Ricketts 2001, Lindenmayer and Franklin 2002, Schultz et al. 2004). A primary reason for this is that reserves within such fragmented landscapes are often small, isolated, and surrounded by a relatively inhospitable matrix of managed lands that may effectively isolate interior habitat and produce significant edge effects along the perimeter of the reserve (Ricketts 2001, Lindenmayer and Franklin 2002, Rothey et al. 2004). Conservation efforts in this region have focused on mitigating the impacts of intensive management for row-crop agriculture on soil and water resources. Example conservation measures include the establishment of grass waterways and filter strips (Heard et al. 2000), riparian buffers (Schultz et al. 2004), windbreaks and shelterbelts (Bird and Prinsley 1998), and wetland reconstructions (Galatowitsch and van der Valk 1998, Heard et al. 2000). Conservation of native biodiversity and ecological processes has received less attention, but are of growing interest (Heard et al. 2000, Jackson 2002).
Identification and protection of remnant habitat patches within the matrix of managed land is an essential component of biodiversity conservation in heavily transformed and fragmented landscapes (Lindenmayer and Franklin 2002), such as those in the U.S. Corn Belt. Once identified and protected, these remnant habitat patches may serve individually as midspatial-scale reserves (as opposed to more traditional large reserves) that contribute to the conservation of biodiversity, provision of habitat, and maintenance of key ecological processes (Lindenmayer and Franklin 2002).

While identification of remnant prairie, wetland, and savanna patches in the Midwest has received considerable attention (e.g. Nuzzo 1986, Smith 1998, Rosburg 2003), comparatively little research has attempted to identify patches of remnant forests. Although not as critically imperiled, forests are an important component of both the historic and present-day Midwestern landscape and provide ecological and socioeconomic benefits for the region. In some cases, such as the creation of riparian buffer strips between agricultural edges and streams, forests play a critical role in reducing non-point source sediment and nutrient loads moving from the terrestrial into the aquatic system (Schultz et al. 2004). Forest patches may also serve as important reservoirs of biodiversity (Lindenmayer and Franklin 2002). Finally, forests are also important sources of timber in the Midwest (Thompson 1992), and provide additional social benefits such as recreational opportunities and aesthetic appeal (Cordell et al. 2004).

Our goal was to examine the distribution and extent of forests from pre-Euro-American settlement to present (1840-2002) in a Midwestern watershed now dominated by intensively managed row-crops, and to inform conservation and restoration efforts within the watershed. In so doing, we identified remnant forest patches that have persisted in the
watershed since the pre-Euro-American settlement era (early 1800s). We achieved this by integrating and analyzing multiple forms of historic data in a GIS environment, including original Public Land Survey (PLS) records, state atlases, Forest Inventory and Analysis (FIA) records, and aerial photography. Through this analysis we are able to quantify forest change in the watershed since 1840 and identify those areas that appeared to have been continuously forested since the presettlement era. We conduct additional analysis to characterize the landscape position of these patches, and consult both PLS and FIA records in order to compare regional tree species composition in presettlement and modern eras. We discuss the conservation value of these forest patches in a landscape characterized by intensive row-crop agriculture.

METHODS AND MATERIALS

Study area

The Clear Creek watershed (27,520 ha) within Iowa and Johnson counties of eastern Iowa comprises the study area (Fig. 2.1). The watershed is currently dominated by anthropogenic land uses, with 60% of land cover in row crops, 19% in pasture/hay, and approximately 15-20% in urban and suburban settlement (Vogelmann et al. 2001). The watershed lies on the Southern Iowa Drift Plain, a pre-Illinoian glacial landscape characterized by steeply rolling hills and well-developed drainage (Prior 1991). Soils are moderately to highly erodible, and include silty clay loams, silt loams, or clay loams formed in loess and till (Schilling and Wolter 2000). The mean annual temperature within the eastern Iowa region is approximately 10° C, and mean annual precipitation is approximately
59 cm (NOAA 2005). The municipalities of Coralville, Iowa City and North Liberty are partially contained within the eastern half of the watershed.

**Data sources and collection**

The first spatially-explicit data on landscape conditions within the watershed come from the U.S. General Land Office’s original Public Land Survey (PLS) of Iowa (1832-1859), in which field surveyors recorded existing vegetation along section lines in the course of surveying the state (Stewart 1935). The PLS survey of Johnson and Iowa counties took place between 1837-1840 and 1840-1844, respectively. Although the purpose of the PLS was not ecological, surveyors recorded key information on the locations of ecosystem types and other vegetation attributes as they surveyed along section lines (Schulte and Mladenoff 2001). At survey points, located at half-mile intervals along section lines, surveyors recorded information on bearing tree species, diameter, and distances (Stewart 1935). Notes and township maps from the PLS have been digitized and georectified into GIS vegetation layers for each county within Iowa, and are available for research purposes (Anderson 1996). Although there are issues of resolution, accuracy, and interpretation associated with PLS-derived data (Bourdo 1956, Schulte and Mladenoff 2001, Mladenoff et al. 2002), the resulting GIS layers are spatially explicit and PLS data are commonly used in studies of landscape change (Almendinger 1997, Radeloff et al. 1999, Schulte and Mladenoff 2001). GIS layers of PLS township maps for Iowa and Johnson counties (Anderson 1996) were downloaded from the Iowa Geological Survey GIS Library. Thirty-eight vegetation types were originally identified in the original survey notes for Iowa, many of which referred to some form of forest, either dense or scattered (Anderson 1996). Nine out of 38 total GLO
vegetation types were present in the watershed in 1840, including prairie, timber, grove, thicket, field, marsh, pond, oak barrens, and slough. In order to delineate forest patches, vegetation types were reclassified based on descriptions of each type in Anderson (1996) (Appendix A). Timber and grove were reclassified as closed forest, while thicket and oak barrens were reclassified as open forest. All other vegetation types were reclassified as ‘other.’ We included only closed forest patches in subsequent analysis in order to remain consistent with other data sources.

Early maps and atlases provide the first spatially-explicit, post-settlement view of the watershed. The Illustrated Historical Atlas of the State of Iowa (Andreas 1875) and the Huebinger Atlas of the State of Iowa (Huebinger 1904) were published in 1875 and 1904, respectively, and county maps contained therein are similar in appearance and resolution. Neither atlas distinguished between open and closed forest types, but instead referred to all forested land as ‘timber,’ consistent with other published works (Kupfer and Malanson 1993, Poole and Downing 2004). We assumed that this term was a reference to denser stands of trees suitable for timber harvesting and used it as a surrogate for closed forest cover. A single forest cover class was used in digitizing forest cover from Iowa and Johnson county maps from both atlases.

Beginning in the 1930s, changes in historic forest cover within the watershed can be derived from aerial photography. Forest cover was digitized in ArcGIS (version 9.1; ESRI 2004) from aerial photography from four timesteps: 1940, 1963, 1980, and 2002 (Iowa County: 1940 [1:20000, black and white], 1963 [1:20000, black and white], 1979 [1:40000, black and white], 2002 [1:20000, false color IR]; Johnson County 1937 [1:20000, black and white], 1963 [1:20000, black and white], 1983 [1:40000, false color IR], 2002 [1:20000, false
color IR]). Due to issues such as missing or damaged photos, certain time periods required use of photos from two different years. In these cases, we made an effort to locate photos that were separated by the least amount of time possible. Photos were scanned at 600 dpi and georeferenced in ArcGIS. The 2002 color aerial photographs were acquired in a digital format, and did not require scanning or georectification. Two forest cover classes were used, with open forest comprising areas with 10-25% canopy cover and closed forest comprising areas with >25% canopy cover (Fig. 2.2). Patches with <10% canopy cover were excluded from the analysis. The minimum dimensions of digitized forest patches were 10 m x 10 m. Data were captured at the highest possible resolution, given the limits of the photographs as well as the digitizing process.

Forest patch distribution was mapped and traditional patch metrics (number of patches, mean patch area, mean patch perimeter, mean patch perimeter-to-area ratio) were calculated for each timestep (1840, 1875, 1904, 1940, 1963, 1980, and 2002) (Forman and Godron 1986). Total forest area, the proportion of the landscape occupied by forest cover, and total forest perimeter were also calculated for each time step at the watershed-scale. Intersection analysis was then performed in ArcGIS on distribution maps for all seven time-steps to approximate locations within the watershed that were continually forested over three time periods (1840-1904, 1940-2002, 1840-2002). The 1840-2002 time period represents the changes between Euro-American settlement and today, while the 1840-1904 and 1940-2002 time periods divide this broader timeframe into ‘settlement’ and ‘modern’ periods, respectively. The former range is represented by lower resolution data from two historical sources, while the latter is based on higher-quality data derived from aerial photographs. Patches from each layer smaller than 100 m² in area were excluded from further analysis,
since the minimum dimensions of digitized landscape elements were 10 m x 10 m and because such small patches were most likely slivers created by the intersection analysis rather than remnant forest patches.

We used GIS analysis to examine the landscape position of remnant forest patches in relation to hydric soils and the distance from streams within the watershed. The rationale for these additional calculations was the recognition of the important role of riparian forests, especially remnant riparian forests, in affecting water quality and providing habitat corridors in heavily transformed, Midwestern landscapes. A state-wide soils data layer (IGS 2003) was clipped to the extent of the watershed in ArcView (version 3.3; ESRI 2002). Soil categories were reclassified based on the hydric soils code, and a hydric soil layer was created and intersected with each layer of continually forested patches (1840-1904, 1840-2002, and 1940-2002) to determine the percentage of remnant forest patches occurring on hydric soils. The distance between remnant forest patches from each time period and the nearest present-day stream (see chapter 1) was then calculated, taking patch shape into account. Centroids of each patch were calculated in ArcGIS, and the distance between the centroids and the nearest edge of the patch in which they occurred was calculated and subtracted from the distance between the centroids and the nearest stream. Patches less than 25 m from the nearest stream were considered to be adjacent, in the sense that they had important ecological connections with the streams to which they were near.

We consulted both PLS survey notes and 1990 Forest Inventory and Analysis records to compare forest composition from presettlement and modern eras (Miles 2006). Witness tree species were compiled from PLS records of ten townships comprising the Clear Creek
watershed, and their relative abundances were compared to relative abundances of tree species derived from 1990 FIA records from Iowa and Johnson counties.

RESULTS

Settlement era

Maps from the Euro-American settlement era (1840-1904) show the estimated distribution of historic forests within the watershed (Fig. 2.3). Forests occurred in relatively large patches in the eastern two-thirds of the watershed, often near streams. The map of continuously forested patches from the settlement era (1840-1904) illustrates how most patches occurred along the main stream channel (Fig. 2.4). 6.2% of remnant forest cover from the settlement era occurred on present-day hydric soils. Results from landscape metric calculations (Table 2.1) indicate that total forest area in the watershed declined by 907.5 ha (47.6%) from 1840-1904.

Modern era

Distribution maps of forest patches from the modern settlement era (1940-2002) show that certain areas of the watershed remained forested, while other regions of the landscape were more dynamic (Fig. 2.3). The number of forest patches declined from 337 in 1940 to 266 in 2002, a decrease of 71 patches. Total forest area increased from 1723.7 ha in 1940 to 2342.6 ha in 2002, an increase of 618.9 ha (Table 2.1). Increases in forest area, as well the decline in patch number, are visually apparent from the distribution maps (Fig. 2.3). Mean patch area increased from 5.1 ha in 1940 to 8.8 ha in 2002, an increase of 3.7 ha. Total forest edge increased from 508.6 km in 1940 to 577.0 km in 2002, an increase of 68.4 km. Mean
patch edge increased from 1.5 km in 1940 to 2.2 km in 2002, an increase of 0.7 km. Mean perimeter-to-area ratio of forest patches declined slightly from 0.06 in 1940 to 0.05 in 2002.

**Identification of remnant natural areas**

Three distribution maps show the estimated locations of remnant forest patches from the three time spans of interest (1940-2002, 1840-2002, and 1840-1904) (Fig. 2.4). We report results from 1940-2002 and 1840-2002, since patches from these time periods represent remnant forest patches that persist in the present-day landscape. We estimate that 87.9 ha (32 patches, 0.3% of the watershed) were continuously forested from 1840-2002, and that 697.0 ha (213 patches, 2.6% of the watershed) were continuously forested from 1840-2002. At both temporal scales, remnant forest patches were largely concentrated along the riparian corridor associated with the main stream channel in the watershed. For the modern period (1940-2002), many remnant patches also occur within the broader landscape of the watershed. A small portion of remnant forest cover (5.9%) from 1940-2002 occurred on present-day hydric soils and 82 patches (38.5%) were adjacent (within 25 m) of a stream; the number of patches steadily declines with distance from the nearest stream (Fig. 2.5).

Between presettlement and today (1840 and 2002), 1.2% of remnant forest cover occurred on present-day hydric soils and the number of patches declined steadily with increasing distance from the nearest present-day stream (Fig. 2.5).

**Changes in forest composition**

PLS surveyor notes from townships encompassing the Clear Creek watershed reveal that presettlement forests were dominated by a variety of oak species, including white oak
(Quercus alba L.), bur oak (Quercus macrocarpa Michx), and red oak (Quercus rubra L.) (Table 2.2). White ash (Fraxinus americana L.), American elm (Ulmus americana L.), and American basswood (Tilia americana L.) were also common in presettlement forests within the watershed (Table 2.2). FIA (1990) records from Iowa and Johnson counties reveal significant shifts in forest composition, including a dramatic decline in the relative abundance of oaks and the increase in the relative abundance of later-successional, mesic species such as American elm, hackberry (Celtis occidentalis L.), and Eastern hop hornbeam (Ostrya virginiana Mill.).

DISCUSSION

Historical data sources

There are various sources of historic data related to landscape change available in Iowa, including aerial photography, historic maps and atlases, forest inventory and health reports, census results, other records from the local, county and state levels, and first and second hand written accounts. Since our research focused on quantifiable changes in forest cover in the Clear Creek watershed since the time of first settlement by Euro-Americans, we utilized a combination of spatially explicit data sources that covered that time period (1840-2002). This method allows for a broader understanding of forest distribution and trends within the Clear Creek watershed than would have resulted from relying solely on aerial photography from 1938-2002 (Fig. 2.3). This method also allowed for the estimation of patches that had remained forested continuously from 1840 to 2002. As aerial photography, state atlas maps, and PLS-derived vegetation layers exist for most, if not all Iowa counties, these methods are employable in other regions of the state to assess changes in forests over
time. Similar methods may be employed in other Midwestern regions, depending on the availability of historic data. Care must be taken, however, to avoid overstepping the limits of data derived from state atlas maps and PLS-derived vegetation layers (Almendinger 1997, Schulte and Mladenoff 2001).

The accuracy of the PLS records has been widely discussed, and authors have generally agreed that, despite significant inconsistencies among surveyors related to survey technique, nomenclature, and species identification, the records provide an exceptionally useful source of information of historic vegetation and landscape characteristics (Schulte and Mladenoff 2001, Whitney and Decant 2001, Bolliger and Mladenoff 2005). Hewes (1950) notes that PLS maps of Iowa forest cover were likely quite accurate in light of the conspicuousness of forests in a landscape largely dominated by prairie. An important caveat is that the surveyor records are less accurate at finer scales, as a result of surveyor bias and sampling technique (survey points spaced ~0.5 mi apart). Almendinger (1997) notes that much of the inaccuracy of the PLS vegetation records can be overcome by examining the data at a landscape scale, and other authors have noted the effectiveness of examining the records at scales ranging from a square mile (Delcourt and Delcourt 1997, Manies and Mladenoff 2000) to broader landscapes (Almendinger 1997, Schulte and Mladenoff 2001, Schulte et. al 2002)

County maps from historic state atlases of Iowa have similar limitations. The exact method by which county maps in both atlases were produced is unclear, but notes included in 20th century reprints of the 1875 atlas imply that Andreas’ staff relied on extant county maps (Andreas 1970). Miller (1995) used canonical correspondence analysis to examine the degree of areal agreement for prairie and timber cover between digitized PLS vegetation and
county maps from Andreas (1875) in two counties in Iowa. The results showed that the two data sources were more than 50% in agreement, and Miller (1995) concluded that the people involved in producing the 1875 atlas may have relied on PLS maps as they prepared county maps. The 1904 atlas is almost identical in appearance, and most likely was produced using similar techniques. As such, county maps from both atlases are more accurate at broader spatial scales, and like the PLS records are not be suitable for analysis at finer scales (< 1 mi²).

**Delineation of forest patches**

PLS vegetation types reclassified as closed forest (timber, grove) were described as comprising dense stands of small to large trees (Anderson 1996). Other vegetation types present in the watershed were also described as containing some trees, but also a mixture of grasses (oak barrens) or grasses and shrubs (thickets) and were reclassified as open forest patches based on these descriptions. These divisions represent a reasonable attempt to derive closed and open forest classes from descriptions of PLS vegetation types; however, we did not compare open forest patches across time periods. Atlas maps did not distinguish between dense and scattered trees, and we assumed that the ‘timber’ that was recorded on both atlas maps referred to dense forest stands. Although similar assumptions have been made by other researchers, the discussion by Johnson (1994) implies that the assumption of historically delineated timber stands being dense forests may not be entirely warranted. We had the most confidence in regards to identifying closed and open forest from historic aerial photography, since both individual trees and forest patches were dark in color and contrasted with the surrounding agricultural landscape.
Settlement era results

The substantial decline in forest area from 1840-1904 in the Clear Creek watershed is a historical trend that is reflected at the state level, as forest area decreased dramatically across Iowa due to conversion to agriculture and other land use changes (Leatherberry et al. 1990). Substantial changes in forest distribution during this time were also driven by the harvesting of timber from old-growth stands and from local woodlots. Sources of timber were vital to early settlers in Iowa, especially in a landscape dominated by prairie in which forests could be scarce (Hewes 1950). In fact, the population of Iowa townships in 1860 was correlated with timber accessibility, such that nearness to timber may have been the most important variable affecting settlement decisions (Hewes 1950). Three Iowa townships that were essentially devoid of timber were the least populated in the state in the mid-late 1800s (Hewes 1950).

The timber industry in Iowa got its start in the 1830s, peaked in the late 1800s, and flourishes today in the eastern half of the state (Widner 1968, Piva and Michel 2000). Sawmills in Iowa historically relied on timber from local sources, so that the timber industry was mostly confined to the eastern half of the state where large stands of harvestable timber were easily accessible (Widner 1968).

The cutting of timber from local woodlots, in contrast, was ubiquitous across the state as early settlers relied on local woodlots for firewood, building material, and fence-posts (Hewes 1950). Even at a national scale, woodlots were an important source of raw materials. One estimate of woodlot timber volume was that, in the period from 1860-1920, woodlots may have contained up to 15% of the nation’s timber supply, and in 1910 up to 170 million
dollars worth of fuel wood (Williams 1989). From 1860-1910, the re-cutting of rural woodlots may have provided approximately half (~3 billion cords) of the nation’s total consumption of fuel wood (Williams 1989).

The cutting of old-growth timber in eastern Iowa would have resulted in declines of forest cover across areas subject to harvest, which would have substantially altered the landscape pattern in the region. What little forest cover remained would have been concentrated along riparian corridors, in areas inaccessible to agriculture. The use of woodlots for fuel wood and other materials would have affected the species composition and abundance, but most woodlots would have persisted though time in the same location since they were generally linked to a nearby farm (Hewes 1950). The planting of new woodlots and timber stands resulted in local additions of forest cover (Hewes 1950); in contrast to patches of old growth forest, these stands would have most likely been small in size and rectangular in shape (Russell 1997).

Modern era results

The increases in area of forest cover in the watershed through the 20th century ran counter to trends at the state level, at which forest cover declined until the mid-1970s (Thompson 1992). The increase in total forest area in the watershed from 1940-2002 was unexpected, given the dramatic increases in urban cover and housing density that occurred within the watershed during the same time period (see chapter 1). This result suggests that the two categories of landscape change (increasing forest cover and increasing urban cover) are not by definition mutually exclusive, even though urbanization is often identified as a
primary driver of habitat loss and urban cover is often assumed to be negatively correlated with forest cover (Radeloff et al. 2005). Urbanization continues to compete with forest and other cover types for available land, and it is uncertain whether increases in total forest area and average patch size will continue.

Increases in both total forest area and average patch area may benefit area-sensitive species, (such as forest-interior birds) that are especially sensitive to decreases in patch size (Helzer and Jelinski 1999). Furthermore, these expansions in area may have increased the ability of individual patches to serve as midspatial-scale “reserves” and for the network of forest patches to serve as a “meso-reserve” (Lindenmayer and Franklin 2002). Increases in total and mean patch edge were likely by-products of increases in total and mean patch area.

At the same time that total forest cover was increasing, there was a decline in the number of discrete forest patches coupled with a significant increase in average patch size. These trends were indicative of the expansion of forests and the merging of formerly isolated patches. The fact that there were not significant differences in mean patch area between any intermediate time periods from 1940-2002 is suggestive of a slow, continuous decline in forest fragmentation that may have important conservation implications in a landscape so highly dissected by roads, fencerows, driveways, and other forms of development. The presence of large, contiguous patches of forest in 2002 was especially significant in that forest patches larger than 20 ha are rare in the heavily transformed landscape of Iowa (IDNR 2001). The specific conservation value of such forest patches in the watershed is uncertain, however, since the ecological character of individual patches (e.g. overstory and understory species composition, soil quality, utilization of patches by wildlife) was not examined. In the light of research that shows that even unfragmented forest patches may experience declines
in understory plant diversity (Rooney et al. 2004), there is a need for patch-level field work to quantify the conservation potential of the existing forest patches within the watershed.

**Remnant natural areas**

As remnant forest patches identified through this research may represent the only remaining native vegetation in the watershed, they may serve as important conservation targets (especially in terms of rare, forest-dependent species) as well as anchors for expansion of forest habitat through restoration. Greater than 30% of remnant forest patches from each temporal scale (1840-2002, 1940-2002) were within 25 m of a stream, and these near-stream patches may be especially important as targets of conservation because of the potential for riparian forests to improve and maintain water quality (Schultz et al. 2004). In conjunction with other forest patches, remnant patches may also serve as ecological corridors that preserve and enhance connectivity across the managed landscape.

While some remnant forest patches identified through this research may represent historical woodlots, other patches may have persisted on steep slopes, hydric soils, or in other areas inaccessible to agriculture. Woodlots, or areas of forested land in a non-forest matrix (in this case, agriculture and pasture), were generally set aside for wood production. In addition to being sources of firewood, fenceposts, and building material, many woodlots were selectively logged and/or grazed by livestock (Hewes 1950, Thompson 1992, Russell 1997).

The existence of woodlots within the Clear Creek watershed was reinforced through communication with the Clear Creek Watershed Enhancement Project (CCWEP), as several members of the CCWEP board confirmed that woodlots were historically common within the
watershed (CCWEP 2005, personnel communication). Woodlots in Iowa were often found in poorly drained soils along streams or in other areas inaccessible to agriculture (Hewes 1950, Russell 1997), as are many of the remnant forest patches we identified (Fig. 4). In non-riparian areas, woodlot location was related more to the distance from the nearest farms and were often planted to afford easy access to wood products and to serve as windbreaks (Russell 1997). This leaves open the possibility that some remnant forest patches we identified that were not near streams might still be woodlots, planted as resources for nearby farms (Fig. 4).

While it is often difficult to determine the specific history of forest patches (i.e., whether they are remnant forests or second growth on formerly agricultural land), patches isolated in an agricultural matrix tend to have tree species with wind dispersed seeds (such as birch and maple) versus tree species with animal dispersed seeds that are no longer transported from woodlot to woodlot (Russell 1997). Furthermore, selective logging of species such as oak, walnut, or maple may have further altered forest stand composition. Our comparison of forest composition within the watershed between presettlement and modern eras revealed changes in tree species composition, such a dramatic decline in the relative abundance of oak species in addition to the increased abundance of more mesic hardwoods. Some species (e.g. quaking aspen, *Populus tremuloides* Michx.) were present in the PLS notes but absent in the FIA records, while others (e.g. Eastern red cedar, *Juniperus virginiana* L.) were present in the FIA records but absent in the PLS notes. Shifts in tree species composition within the watershed are mostly likely a result of changing land use dynamics, including selective logging, clearing of land for agriculture, fire suppression, grazing
regimes, and the escape of cultivars accompanying increases in housing density and exurban
development.

Identification of remnant forest patches within the watershed sets the stage for future
field work that may help to elucidate more detailed information regarding patch
characteristics, such as soil characteristics and the abundance and distribution of overstory
and understory species, as well as patch utilization by birds or small mammals.

CONCLUSION

Overall, the results of our research demonstrate the dynamic nature of forests within
the Clear Creek watershed and inform future conservation and restoration efforts in the
region. While many landscape elements in heavily transformed, agricultural landscapes may
remain relatively static over time (e.g., prime farmland, farmsteads, roads, urban areas),
forests within the watershed have been increasingly in total area since 1904 and in mean
patch area since 1940. These increases in forest area may have important conservation
implications related to water quality, habitat protection and expansion, and
recreation/aesthetic value. Remnant forest patches were also identified, which are unique in
themselves as relics (post-settlement changes notwithstanding) of the presettlement
landscape within the watershed. Furthermore, these patches may serve as anchors for habitat
expansion, in addition to providing a host of conservation opportunities.

Depending on the availability of historic data, the methods presented here may be
employed in other Midwestern regions in order to investigate changes in forested landscapes
since settlement by Euro-Americans and to identify remnant forest patches. The need for
such work is exacerbated by the degree to which many Midwestern landscapes have been
transformed, and by the paucity of native habitat that remains in such regions.

ACKNOWLEDGEMENTS

We gratefully acknowledge financial support for this research by Iowa State
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Anderson (Iowa State University), James Martin (Iowa NRCS), Mary McInroy (University
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e especially thank our team of undergraduate research technicians, including Kellie Barrie,
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Table 2.1. Patch statistics for closed forest patches with the Clear Creek watershed (IA), 1840-2002.

<table>
<thead>
<tr>
<th>Year</th>
<th>Total forest area (ha)</th>
<th>Number of forest patches</th>
<th>Mean patch area (ha)</th>
<th>Mean patch perimeter (km)</th>
<th>Mean P/A ratio (km/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1840</td>
<td>2075.4</td>
<td>19&lt;sup&gt;a&lt;/sup&gt;</td>
<td>109.2&lt;sup&gt;a&lt;/sup&gt;</td>
<td>7.3&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.07</td>
</tr>
<tr>
<td>1875</td>
<td>2265.8</td>
<td>14&lt;sup&gt;a&lt;/sup&gt;</td>
<td>161.8&lt;sup&gt;a&lt;/sup&gt;</td>
<td>5.4&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.03</td>
</tr>
<tr>
<td>1904</td>
<td>1167.8</td>
<td>13&lt;sup&gt;a&lt;/sup&gt;</td>
<td>83.8&lt;sup&gt;a&lt;/sup&gt;</td>
<td>4.8&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.06</td>
</tr>
<tr>
<td>1940</td>
<td>1723.7</td>
<td>337</td>
<td>5.1</td>
<td>1.5</td>
<td>0.06</td>
</tr>
<tr>
<td>1963</td>
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<td>348</td>
<td>5.6</td>
<td>1.6</td>
<td>0.06</td>
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<tr>
<td>1980</td>
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</tr>
<tr>
<td>2002</td>
<td>2342.6</td>
<td>266</td>
<td>8.8</td>
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<td>0.05</td>
</tr>
</tbody>
</table>

<sup>a</sup>Data from 1840-1904 were derived from historical data sources that were of a lower resolution than aerial photography from 1940-2002.
Table 2.2. Tree species composition within the ten townships comprising the Clear Creek watershed, Iowa (1840) and within Iowa and Johnson counties (1990), as derived from PLS surveyor notes and FIA records, respectively. Taxonomy follows citation.

<table>
<thead>
<tr>
<th>Species</th>
<th>PLS Relative % (1840)</th>
<th>FIA Relative % (1990)</th>
</tr>
</thead>
<tbody>
<tr>
<td>White oak</td>
<td>29.1</td>
<td>2.9</td>
</tr>
<tr>
<td>Red oak</td>
<td>15.8</td>
<td>5.7</td>
</tr>
<tr>
<td>Bur oak</td>
<td>14.3</td>
<td>0.1</td>
</tr>
<tr>
<td>Black oak</td>
<td>10.6</td>
<td>0.9</td>
</tr>
<tr>
<td>Elm</td>
<td>6.8</td>
<td>33.9</td>
</tr>
<tr>
<td>Hickory</td>
<td>6.0</td>
<td>5.6</td>
</tr>
<tr>
<td>White ash</td>
<td>4.5</td>
<td>4.6</td>
</tr>
<tr>
<td>American basswood</td>
<td>3.0</td>
<td>5.5</td>
</tr>
<tr>
<td>Willow</td>
<td>1.7</td>
<td>0.8</td>
</tr>
<tr>
<td>Birch</td>
<td>1.5</td>
<td>0.6</td>
</tr>
<tr>
<td>Aspen</td>
<td>1.3</td>
<td>0.0</td>
</tr>
<tr>
<td>Maple</td>
<td>1.3</td>
<td>6.2</td>
</tr>
<tr>
<td>Black walnut</td>
<td>1.3</td>
<td>1.1</td>
</tr>
<tr>
<td>Eastern hop hornbeam</td>
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<td>7.1</td>
</tr>
<tr>
<td>Eastern cottonwood</td>
<td>0.7</td>
<td>1.1</td>
</tr>
<tr>
<td>Honey locust</td>
<td>0.5</td>
<td>1.2</td>
</tr>
<tr>
<td>Blackjack oak</td>
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<td>0.0</td>
</tr>
<tr>
<td>Black cherry</td>
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<td>5.8</td>
</tr>
<tr>
<td>Box elder</td>
<td>0.2</td>
<td>0.5</td>
</tr>
<tr>
<td>Species</td>
<td>PLS Relative % (1840)</td>
<td>FIA Relative % (1990)</td>
</tr>
<tr>
<td>---------------------</td>
<td>-----------------------</td>
<td>-----------------------</td>
</tr>
<tr>
<td>Eastern red cedar</td>
<td>0.0</td>
<td>0.8</td>
</tr>
<tr>
<td>Hackberry</td>
<td>0.0</td>
<td>6.7</td>
</tr>
<tr>
<td>Hawthorn</td>
<td>0.0</td>
<td>5.2</td>
</tr>
<tr>
<td>Osage-orange</td>
<td>0.0</td>
<td>0.3</td>
</tr>
<tr>
<td>Red mulberry</td>
<td>0.0</td>
<td>2.5</td>
</tr>
<tr>
<td>Sycamore</td>
<td>0.0</td>
<td>0.1</td>
</tr>
<tr>
<td>Choke cherry</td>
<td>0.0</td>
<td>0.6</td>
</tr>
<tr>
<td>Northern pin oak</td>
<td>0.0</td>
<td>0.3</td>
</tr>
</tbody>
</table>
Figure 2.1. Location of the Clear Creek watershed in eastern Iowa.
Figure 2.2. Examples of a) closed forest (>25% canopy) and b) open forest (10-25% canopy) from Clear Creek watershed, (IA) as derived from aerial photographs.
Figure 2.3. Distribution maps of forest patches (shaded areas) in the Clear Creek watershed (IA) as derived from historic survey (1840), map (1875-1904), and aerial photography (1940-2002) data.
Figure 2.4. Estimated locations of forest remnants (shaded areas) in Clear Creek watershed (IA) for time periods: (a) 1940-2002, (b) 1840-2002, and (c) 1840-1904. Present-day stream networks are displayed in gray.
Figure 2.5. Distances from remnant forest patches (~1940-2002 and 1840-2002) in Clear Creek watershed (IA) to the nearest present-day stream for the ~1940-2002 and 1840-2002 time periods.
CONCLUSIONS

The landscape of Clear Creek watershed, like other Midwestern agricultural landscapes (e.g., Anderson et al. 1996), has changed dramatically as a result of anthropogenic land use since settlement of the region by Euro-Americans in the early to mid-1800s. While almost all native habitat within the watershed has been converted to agriculture (or developed for housing and commercial uses), we have used a combination of historical data sources to estimate locations that have remained continually forested since 1840 and 1940. Depending on the ecological characteristics of these remnant forest patches (such as the degree of degradation) they may play important conservation roles in the watershed in terms of habitat provision, water quality, and recreation.

The landscape outside of these remnant patches had already been extensively modified by 1940 (Nuzzo 1986), the first time period in my analysis of changes in land cover, stream sinuosity, and housing density. Since 1940, crop cover has declined, while forest and urban cover have increased. The present-day watershed is still dominated by agricultural land use, yet the observed increases in both urban and forest cover (especially since 1980) suggest that these cover types may become more common within the watershed in the future. Shifts in relative dominance of these cover types (crop, forest, and urban) may have important ecological and social implications.

As one component of the broader suite of hydrological modifications that have taken place within the watershed since the time of first settlement, stream sinuosity (within the main channel) was observed to decline dramatically from 1940-1963. This decline may have
affected water quality and riparian habitat within the main channel of Clear Creek, and these
effects may be enduring since the decline in main channel sinuosity persists in the present-
day watershed.

Housing density has increased dramatically from 1940-2002, and the rate of increase
has been especially rapid over the last 20 years. Urbanization of formerly rural landscapes
has been observed throughout the Midwest, and this trend has been linked to both ecological
and social changes (Theobald 2001, Radeloff et al. 2005) that have the potential to further
alter Midwestern agricultural landscapes.

My research revealed the dynamic nature of Clear Creek watershed over the past 150
years, using a combination of historic data sources in a GIS environment. Depending on the
availability of historic data, my methods are repeatable in other Midwestern watersheds, and
these results could be compared to the results of similar studies in order to gain a broader
understanding of post-settlement landscape change in the Midwestern United States.

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Geographical Review 91:544-564.
Appendix A. Dates and sources of aerial photography used as a basis for land cover, home site, and stream sinuosity digitization.

<table>
<thead>
<tr>
<th>Time period</th>
<th>County</th>
<th>Year</th>
<th>Month</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>1940</td>
<td>Iowa</td>
<td>1940</td>
<td>July</td>
<td>University of Iowa Library</td>
</tr>
<tr>
<td></td>
<td>Johnson</td>
<td>1937</td>
<td>October</td>
<td>University of Iowa Library</td>
</tr>
<tr>
<td>1963</td>
<td>Iowa</td>
<td>1963</td>
<td>August</td>
<td>University of Iowa Library</td>
</tr>
<tr>
<td></td>
<td>Johnson</td>
<td>1963</td>
<td>July</td>
<td>University of Iowa Library</td>
</tr>
<tr>
<td>1980</td>
<td>Iowa</td>
<td>1979</td>
<td>Summer</td>
<td>Iowa County Assessor</td>
</tr>
<tr>
<td></td>
<td>Johnson</td>
<td>1983</td>
<td>April</td>
<td>University of Iowa Library</td>
</tr>
<tr>
<td>2002</td>
<td>Iowa</td>
<td>2002</td>
<td>Summer</td>
<td>Iowa DNR</td>
</tr>
<tr>
<td></td>
<td>Johnson</td>
<td>2002</td>
<td>Summer</td>
<td>Iowa DNR</td>
</tr>
</tbody>
</table>
Appendix B. Description of land cover classes and key characteristics used to distinguish cover classes from aerial photography.

<table>
<thead>
<tr>
<th>Cover class</th>
<th>Description</th>
<th>Key characters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crop</td>
<td>Row-crop and other agriculture</td>
<td>Regular patch shape (often rectangular); linear rows; uniform landscape color, pattern and texture</td>
</tr>
<tr>
<td>Grass</td>
<td>Pastures, hay fields, fallow fields</td>
<td>Irregular to regular patch shape; patchy landscape color, pattern, and texture; in-field structures; cattle paths</td>
</tr>
<tr>
<td>Closed forest</td>
<td>Dense forest often associated with riparian areas</td>
<td>Patch shape ranging from regular to irregular, well-defined borders; often along streams or along patch borders; dark color, somewhat uniform in pattern and texture</td>
</tr>
<tr>
<td>Open forest</td>
<td>Scattered trees associated with abandoned or fallow fields, riparian areas, along edges of closed forest</td>
<td>Patch shape ranging from regular to irregular, poorly defined borders; often along streams or along patch borders; dark color, irregular in pattern and texture</td>
</tr>
<tr>
<td>Urban</td>
<td>Urban areas, cities, towns</td>
<td>Patch shape ranging from regular to irregular, well-defined borders; obvious buildings and other associated structures; relatively high road density</td>
</tr>
<tr>
<td>Homesite</td>
<td>Individual housing units and associated buildings (e.g., barns), including yards, landscaping, and occasionally driveways</td>
<td>Regular to irregular patch shape, well-defined borders; obvious driveways and buildings</td>
</tr>
<tr>
<td>Road</td>
<td>Roads of varying width, including grass medians</td>
<td>Linear shape, well-defined borders; contrasting appearance compared to surrounding landscape</td>
</tr>
<tr>
<td>Other</td>
<td>Land cover not classified according to above schemes</td>
<td>Unidentifiable landscape features, buildings of unknown category</td>
</tr>
<tr>
<td>Missing</td>
<td>Areas lacking coverage by aerial photography</td>
<td>N/A</td>
</tr>
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</table>
Appendix C. Sinuosity values for main channel (Clear Creek) stream segments, 1940-2002.

<table>
<thead>
<tr>
<th></th>
<th></th>
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<td>1</td>
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Appendix C. (continued)

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Appendix D. Results of stream sinuosity calculations at the watershed-scale and at the main channel-scale in Clear Creek watershed (IA), 1940-2002.

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<tr>
<th>Year</th>
<th>Mean watershed-scale sinuosity</th>
<th>Standard error</th>
<th>Mean main channel sinuosity</th>
<th>Standard error</th>
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<td>1940</td>
<td>1.07</td>
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<td>0.0034</td>
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<td>0.052</td>
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<td>2002</td>
<td>1.12</td>
<td>0.0046</td>
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Appendix E. Housing statistics by and among years in Clear Creek watershed (IA), 1940-2002.

<table>
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<tr>
<th>Year</th>
<th>Number of homes</th>
<th>Number of rural homes</th>
<th>Housing density (homes/km$^2$) at the watershed scale</th>
<th>Rural housing density (homes/km$^2$)</th>
<th>Mean housing density (homes/km$^2$) at the quarter-section scale</th>
<th>Standard error</th>
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<td>1940</td>
<td>695</td>
<td>385</td>
<td>2.60</td>
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<td>0.69</td>
<td>4.22</td>
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<tr>
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<td>1507</td>
<td>119</td>
<td>5.64</td>
<td>0.48</td>
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<td>3068</td>
<td>322</td>
<td>11.48</td>
<td>1.30</td>
<td>12.16</td>
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</table>
Appendix F. Digitized land cover maps of the Clear Creek watershed (IA), 1940-2002.
Appendix G. List and description of vegetation types present in the watershed at pre-Euro-American settlement (1840), as derived from the original Public Land Survey (Anderson 1996). Vegetation types reclassified as closed forest were included in the analysis.

<table>
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<tr>
<th>PLS vegetation type</th>
<th>Description</th>
<th>Cover class (reclassified)</th>
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<tbody>
<tr>
<td>Grove</td>
<td>Relatively small, dense stand of small trees</td>
<td>Closed forest</td>
</tr>
<tr>
<td>Timber</td>
<td>Relatively large areas of large trees</td>
<td>Closed forest</td>
</tr>
<tr>
<td>Oak barrens</td>
<td>Areas with a mixture of trees (predominantly oak) and grasses, often in transitional zones between forests and prairie</td>
<td>Open forest</td>
</tr>
<tr>
<td>Thicket</td>
<td>Small stands of trees, shrubs, and grasses</td>
<td>Open forest</td>
</tr>
<tr>
<td>Field</td>
<td>Small, flat areas used for agriculture by early settlers</td>
<td>Other</td>
</tr>
<tr>
<td>Marsh</td>
<td>Wetlands of variable size and hydroperiod</td>
<td>Other</td>
</tr>
<tr>
<td>Pond</td>
<td>Small, permanent bodies of water</td>
<td>Other</td>
</tr>
<tr>
<td>Prairie</td>
<td>Grassland vegetation with occasional scattered trees</td>
<td>Other</td>
</tr>
<tr>
<td>Slough</td>
<td>Long, narrow bodies of flowing or standing water, frequently associated with rivers</td>
<td>Other</td>
</tr>
</tbody>
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