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Agricultural landscape change (1937–2002) in three townships in Iowa, USA

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ABSTRACT

While agricultural landscape change over the course of 20th century has generally resulted in substantial gains in productivity, there is growing concern that the spatially uniform, functionally homogenized agricultural landscapes lack both environmental resilience and socioeconomic sustainability. The State of Iowa, USA provides a specific example where agriculture is highly developed and functions in a highly modified, human-dominated landscape; yet, few spatially explicit, comprehensive, and consistent data are available from which to assess change. To begin filling this gap, we digitized land cover information from aerial photographs for three Iowa townships (Orient Township in Adair County, Bloomfield Township in Clinton County, and Denmark Township in Emmet County) at five time steps between 1937 and 2002 and analyzed landscape change using a case study approach, landscape metrics, and graphical analysis. Results showed several consistent patterns across townships, including increased area devoted to row crops; decreased area devoted to small grains, hay, and grass; decreased numbers of farm fields concomitant with an increase in average field size; and a loss of rural infrastructure, such as farmsteads and rail lines. This generalized pattern describes an overall loss in agricultural landscape diversity over time, which is clearest in Denmark Township, while more detailed analysis reveals fine-scale diversification in Orient and Bloomfield Townships due to the adoption of conservation practices. A comparison of the three case study landscapes suggested that technology, economics, and federal farm policies, as meditated by variability in natural resource constraints, were drivers of the changes we observed.

1. Introduction

Croplands and pastures are now among the dominant ecosystems on the planet, occupying more than 35% of the world's ice-free land surface (Ellis and Ramankutty, 2008; Foley et al., 2007). While agriculture today garners phenomenal productivity for human benefit, hunger, malnourishment, and poverty continue to be persistent problems in many regions of the world (FAO, 2009; MEA, 2003; Thurow and Kilman, 2009). Gains in agricultural productivity have furthermore been concomitant with declines in the delivery of ecosystem services, and agriculture is now a major contributor to greenhouse-gas emissions, the growth of oceanic hypoxic zones, and declines in biodiversity on a global scale (Cassman, 1999; Diaz and Rosenberg, 2008; Foley et al., 2007; Kiers et al., 2008). Such compromised social-ecological functioning is causing some to call for a new, more balanced model for agriculture in the 21st century (Glover et al., 2010; Jordan et al., 2007; Scherr and McNeely, 2008).

The U.S. State of Iowa is a specific example of where agriculture is highly developed and functions in a highly modified, human-dominated ecosystem, both in terms of vegetation and hydrology. Iowa ranks 50th out of 50 states in the amount of natural vegetation remaining (Klopatek et al., 1979) – only 0.1% of the original tallgrass prairie ecosystems that once blanketed the state remain and approximately 99% of the original wetlands, marshes, and small streams have been drained and plowed (IDNR, 2000). The hydrology has been furthermore altered through the near ubiquitous deployment of subsurface drainage systems, ditch drainage, and stream channelization (IDNR, 2000). While this region has charted sizeable gains in agricultural productivity in each decade since the 1920s (Heady et al., 1965; Paarlberg and Paarlberg, 2000; Tweeten, 1970), there is growing concern that the spatially uniform, functionally homogenized landscapes that are typical in Iowa lack both resilience and sustainability (Beeman and Pritchard, 2001; Flora et al., 2004; Jordan et al., 2007; Kirschenmann et al., 2008). Recent, widespread, and severe flooding across the state has amplified these concerns and instigated statewide discussions about potential causes and solutions associated with land use (Mutel, 2010).

In an effort to provide a quantitative baseline for such discussions, we assessed the direction, magnitude, and rate of land cover change in three Iowa townships from 1937 to 2002 – a period of rapid change in agriculture (Heady et al., 1965; Paarlberg and

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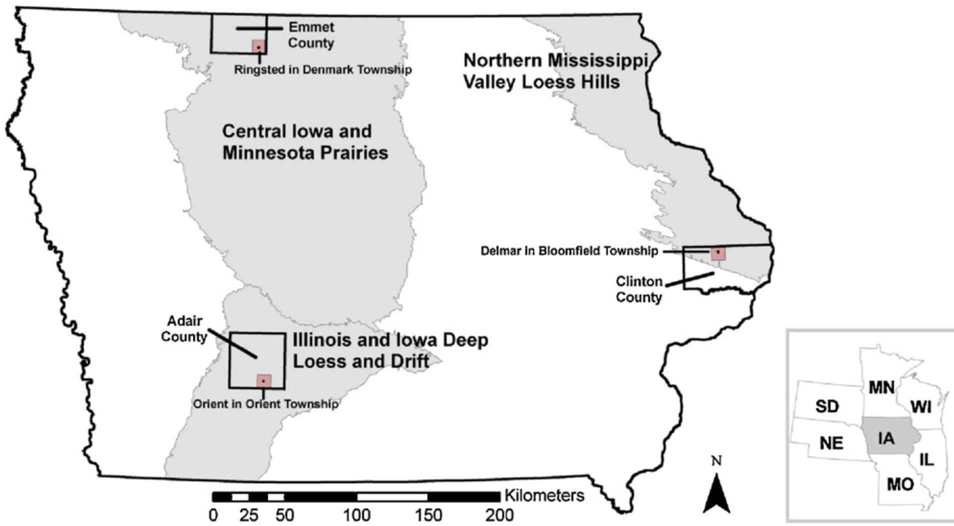

Fig. 1. Location of study townships within counties in Iowa, USA and major land resource areas; small town falling within each township also shown. Inset: Location of Iowa within the Midwestern U.S.

Paarlberg, 2000; Tweeten, 1970). While homogenized landscapes are widely acknowledged in Iowa and depicted by coarse-scale analysis (IDNR, 2000; Klopatek et al., 1979; Turner and Rabalais, 2003), few spatially explicit, temporally consistent, and comprehensive data exist from which to draw objective conclusions on agricultural landscape change. Detailed information sources are available and provide a wealth of data at often a county-level (e.g., USDA's Census of Agriculture, Iowa's "Year Book in Agriculture" series); yet, existing published reports and databases do not provide a comprehensive inventory of the agricultural landscape (e.g., wetlands, drainageways, home sites, towns are often excluded) and recording categories within these sources frequently change among years, preventing consistent analyses over time.

We sought to develop a detailed, comprehensive, and consistent understanding of agricultural landscape change within our study townships. Our specific objectives were to (1) quantify and describe how these agricultural landscapes changed over the study period, (2) determine whether and to what extent these changes were affected by constraints in the underlying natural resource base, and (3) assess potential drivers of these changes; in particular, the contributions of technological, economic, or policy drivers. To fulfill these objectives, we employed a comparative case study approach (Shrader-Frachette and McCoy, 1993) and historical-comparative research design principles (Neuman, 2006). This approach provides a powerful method for addressing questions on macro-level change or understanding processes that operate across time (Neuman, 2006). While it is beyond the scope of this study to determine the causes of change, we expect that developing an understanding of the landscape changes that occurred historically can provide important insights for researchers, policy makers, and land managers in our study region, as has been the case for similar studies in other locations (Hassett et al., 2005; Schulte et al., 2007; Sklar et al., 2005).

2. Methods

2.1. Study landscapes

We selected and sampled three townships, each containing a small town, located in three different physiographic regions in Iowa, USA. Such purposive sampling is a form of nonrandom sampling used in exploratory research, in which the researcher selects especially informative cases and with a specific purpose in mind (Neuman, 2006). We selected townships from three different major land resource areas (MLRAs) – physiographic regions representing broad, multi-state differences in soil resources and land utilization (USDA, 2006a). We expected different farming systems to have evolved within the MLRAs over the course of the study period and, thus, selecting study landscapes from different MLRAs would provide contrasting situations for investigation. The three MLRAs of focus included the Illinois and Iowa Deep Loess and Drift, Northern Mississippi Valley Loess Hills, and Central Iowa and Minnesota Till Prairies (Fig. 1).

Criteria for township selection within each MLRA were based on the results of a survey conducted by the Iowa State Planning Board in 1934–1935 (ISPB, 1935). These results clearly identified small towns and villages as the market centers of rural farming communities and classified them according to the population of the market center (ISPB, 1935). Towns and villages with populations ranging between 300 and 499 were shown to have an average market center trade area of 108 km^2, just over the 93-km^2 area of a township according to the rectangular survey system. Concomitant with the Planning Board's results, we interpreted the market center trade area as roughly the area of land required to support the farming community and, using the 1930 U.S. Census, we selected townships containing a town with a population of between 300 and 499 people. The number of towns meeting the population range criteria was then narrowed to 69 by selecting those (1) having an elementary to high school education program in 1930 (Iowa Department of Public Instruction, 1930), (2) having at least one through highway in 1930 (Rand McNally, 1930), and (3) being located at least 16 km from other population centers in 2002, due to urban growth that may have occurred since 1930. Among the 69 small towns that met our selection criteria, we chose the township–town combination where the town was located closest to the center of the township: Orient–Orient in Adair County, Bloomfield–Delmar in Clinton County, and Denmark–Ringsted in Emmet County (Fig. 1).

The uplands of Orient Township are rolling and dissected with steep-sided ravines that contain small streams, many of them intermittent. Elevation ranges from 364 to 419 m. Bloomfield Township consists of hilly uplands dissected by several small streams, most of which are intermittent, but two have more sustained flows. Elevation ranges from 213 to 274 m. Denmark Township is a nearly level to gently rolling plain, with elevation ranging from 375 to 390 m. This study landscape is located in the part of Iowa that was last covered by glacial ice 12,000–14,000 years ago (Prior, 1991). The

Table 1
Dates of aerial photographs used in characterizing landscape patterns within each study landscape.

Study landscape	County	Town	Aerial photograph dates				
Orient Township	Adair	Orient	1938	1954	1970	1983	2002
Bloomfield Township	Clinton	Delmar	1937	1951	1969	1984	2002
Denmark Township	Emmet	Ringsted	1939	1953	1972	1985	2002

relatively recent glacial advance and subsequent withdrawal and disintegration of ice created a prairie–wetland ecosystem with a unique hydrology (Prior, 1991). During the past century, many of the region's native wetlands were artificially drained for agricultural purposes (Prior, 1991).

2.2. Assessing landscape change

Data used in our analysis of landscape change were derived from historical aerial photographs obtained from the University of Iowa Map Collection, the U.S. National Archives and Records Administration, and the USDA Farm Service Agency Aerial Photo Field Office. Purposive sampling was used to select aerial photographs at five specific dates and intervals consistent with historical agricultural change associated with technological, economic, or federal policy developments (Benedict and Stine, 1956; Cain and Lovejoy, 2004; Green, 1990; Heady et al., 1965; Hurt, 2002; Paarlberg and Paarlberg, 2000; Tweeten, 1970; U.S. Congress, 1998) (Table 1). We used standard GIS protocols to georectify, digitize, and enumerate patches of relatively homogenous land cover at a resolution of 0.01 ha or greater from the aerial images; our minimum mapping unit was 10 m by 10 m. Because each set of photographs was unique (e.g., season of capture, type of film, image scale), we created coding guides containing examples of various cover types from aerial photographs, historical photographs of the same cover types at ground level, and explanations to aid in the interpretation of textures, colors, and shapes on the aerial photographs. Student coders were trained to use the guides to enhance their visual understanding of the landscape, delineate patch boundaries, classify land cover types, and identify rural home sites. Overall, patches were classified into one of 13 land-cover classes based on functional differences (e.g., row crops are annual plants planted in the spring harvested in the fall whereas small grains are often planted in the fall or early spring and harvested in the summer) and our ability to be reliably distinguish their features on the aerial images. These land-cover classes included row crop, hay, small grains, grass, woodland, wetland, drainageway, grass waterway, farm pond, home site, road, railroad, and town (Table 2). All patches were error checked by the first author to ensure consistency and accuracy. An obvious limitation of classifying landscape patterns from historical aerial photography is the inability to 'ground truth' these elements over time. We did, however, compare the proportional area in different crop types (i.e., row crops, hay, small grains) and pasture to *county-wide* USDA Census of Agriculture data from corresponding years and found our estimates to be similar (within 10%).

We used landscape metrics, including total area, proportional area, number of patches, average patch size, Shannon Diversity Index, Berger–Parker Index, and shape index, to summarize land cover composition and configuration at each time step and calculate changes in between. As is common practice in studies of landscape pattern (Turner et al., 2003), we chose a few landscape metrics that characterize different elements of pattern and that we expected to reveal differences either between study townships or within study townships across time. Shannon Diversity Index (hereafter, Shannon's diversity) is a measure of heterogeneity that takes the number of land cover classes and their area into account (Magurran, 1988). A landscape with only one cover type would have a Shannon's diversity value of zero. Higher relative values of Shannon's diversity are representative of a more heterogeneous landscape or a landscape where cover types are evenly distributed. All land-cover classes were used in calculating Shannon's diversity.

The Berger–Parker Index (hereafter, B–P dominance) is a dominance measure expressed by the proportional importance of the most abundant cover type (Magurran, 1988). An increase in the value of the index accompanies an increase in dominance and a reduction in diversity. This index provides another dimension of

Table 2
Definitions of land cover classes distinguishable from aerial photographs.

Land-cover class	Definition
Drainageways	Either natural (i.e., streams) or human-constructed (i.e., ditches) water courses and their riparian margins; no attempt was made to separate streams from ditches because all water courses showed some evidence of human modification over time
Farm ponds	Patches of water that showed evidence of human construction (e.g., regular margins, dikes)
Grass	Mixed herbaceous plant cover heterogeneous in color and texture and often showing evidence of grazing (e.g., trails along fence lines or to gates or water), especially in the early time periods of study (before 1970), and no evidence of frequent inundation; trees and shrubs may or may not have been present at low densities (<25% cover)
Grass waterways	Small (<0.5 ha), near-linear areas of herbaceous plant cover located within row crop fields
Hay	Grass, alfalfa, clover, or a grass-legume mix harvested as a crop as evidence by color, texture, and uniform plant cover and/or harvest at certain times of year
Home sites	Rural areas with concentrated evidence of human habitation (i.e., the presence of buildings, including a house, shed, and/or barn, driveway(s), and sometimes gardens, an orchard, and small paddocks)
Railroads	Linear features with rails and ties and their grass margins
Roads	Paved or gravel linear features of clear human construction and their grass margins
Row crops	Corn or soybeans as evidenced by color, texture, and uniform plant cover and/or harvested or tilled at certain times of year
Small grains	Oats, wheat, barley, flax, or rye as evidenced by color, texture, and uniform plant cover and/or harvested at certain times of year
Towns	Areas with concentrated buildings and roadways
Wetlands	Mixed herbaceous plant cover heterogeneous in color and texture and showing evidence of frequent inundation (e.g., vegetation zonation around water); trees and shrubs may or may not have been present at low densities (<25% cover)
Woodlands	Woody plant cover (≥25%) heterogeneous in color and texture and often showing evidence of grazing (e.g., trails along fence lines or to gates or water), especially in the early time periods (before 1970)

Table 3
Land capability classes and the percentage of land in each class per study area; e = a primary limitation of erosion; w = primary limitation of wetness (USDA, 1961, 2006b,c, 2007).

Landcapability class	Description	Orient township	Bloomfield township	Denmark township
Land suitable for cultivation				
Class I	Soils that have no serious limitations for cultivation of the usual crops of the area	4%	5%	24%
Class II	Soils that have moderate limitations that permit cultivation of the usual crops of the area with suitable conservation practices such as erosion control or soil drainage	24% (e) 21% (w)	29% (e) 14% (w)	14% (e) 45% (w)
Class III	Soils that have strong limitations that restrict the cultivation of some crops of the area, require intensive conservation practices, or both	35% (e) 2% (w)	33% (e) 1% (w)	5% (e) 11% (w)
Land suitable for limited cultivation				
Class IV	Soils that have severe limitations that permit only occasional cultivation of the usual crops of the area, require very intensive conservation practices, or both	10% (e) 4% (w)	5% (e)	
Land not suitable for cultivation				
Class V	Soils that can be used for pasture, range, forest, wildlife, or recreation without being likely to deteriorate but have limitations such as wetness, stoniness, or climate that prevent them from being cultivated		1% (w)	
Class VI	Soils that can be used for pasture, range, forest, wildlife, or recreation with suitable erosion control practices but that have strong limitations such as erodibility, wetness, shallow depth, stoniness, or climate that make them generally unsuited to cultivation		5% (e)	
Class VII	Soils that can be used for pasture, range, forest, wildlife, or recreation, but have very severe limitations that require intensive management and make them unsuitable for cultivation		7% (e)	

diversity by identifying the most dominant cover type and its relative percentage of overall landscape cover. All land cover classes were considered in calculating B–P dominance.

Shape index, calculated according to Baker and Cai (1992), was computed for each two-dimensional patch shape as a measure of shape complexity. The index varies from a value of 0.0 for a circle, to a value of 1.1 for a square, and to infinity for an infinitely complex shape. We focused on dominant agricultural land cover types in our calculation of shape index, excluding railroad, road, and town cover types.

2.3. Natural resource constraints

The land capability class system was used to indicate constraints posed by the underlying natural resource base of each township; specifically, the suitability of soils for cultivation according to USDA Natural Resources and Conservation Service soil survey reports (Table 3). Land capability assessments are a widely used interpretive classification designed to classify land according to physical limitations for agricultural use (USDA, 1961). Classes are based on limitations or hazards when land is used for field crops, the risk of damage when used, and how they respond to treatment.

3. Results

Patterns of landscape change consistent across townships included increasing area devoted to row crops; decreasing area devoted to small grains, hay, and grass; decreasing numbers of farm fields concomitant with increases in the average field size; and a loss of rural infrastructure, such as farmsteads and rail lines (Figs. 2 and 3). This generalized pattern describes an overall loss in agricultural landscape diversity over time, which is clearest in Denmark Township; however, more detailed analysis reveals fine-scale diversification in Orient and Bloomfield Townships due to the adoption of conservation practices (Fig. 2). We focused our detailed analysis on three salient patterns of change: the loss of crop diversity, patterns imposed by responses to natural resource constraints, and loss of rural infrastructure.

3.1. Loss of crop diversity

All three case study landscapes show a marked increase in the extent and dominance of row crops across time periods (Fig. 2). This pattern becomes clearly visible in 1950s in Denmark Township, but is not obvious until the 1980s in Orient and Bloomfield Townships. Yet, at the beginning of the study period, we found a high degree of heterogeneity, in terms of the proportional extent and spatial distribution of cover types, in all townships (Fig. 2). High relative values of Shannon's diversity and low values of B–P dominance supported our visual assessment of a diverse landscape (Fig. 3A and B).

Denmark Township provides the most dramatic case of landscape change, although just two primary cover types were dominant in this landscape in 1939. Of the four primary agricultural cover types, row crops, small grains, hay, and grass respectively comprised 45%, 34%, 15%, and 3% of the landscape (Fig. 3C–F); woodlands made up less than 0.5% of the land cover (Fig. 3G). The primary cover types were spatially distributed at this time across 1314 fields that averaged 6.5 ha in size (Fig. 3H and I). By 2002, the Denmark Township was clearly dominated by row crops while small grains, hay, and grass became remnants on the landscape; row crop B–P dominance increased to 93% and each of these latter cover types comprised less than 1% of the township area (Figs. 2 and 3). Shannon's diversity was at an all-time low given declines in the relative abundance of cover types of non-row crop cover types and uniform pattern in their distribution (Figs. 2 and 3A). The spatial grain of the landscape increased as the number of fields declined to 288 and the average field size increased 25% to 30 ha (Fig. 3H and I). While Orient and Bloomfield Townships also showed marked loss in landscape diversity over time, they retained larger proportions of hay

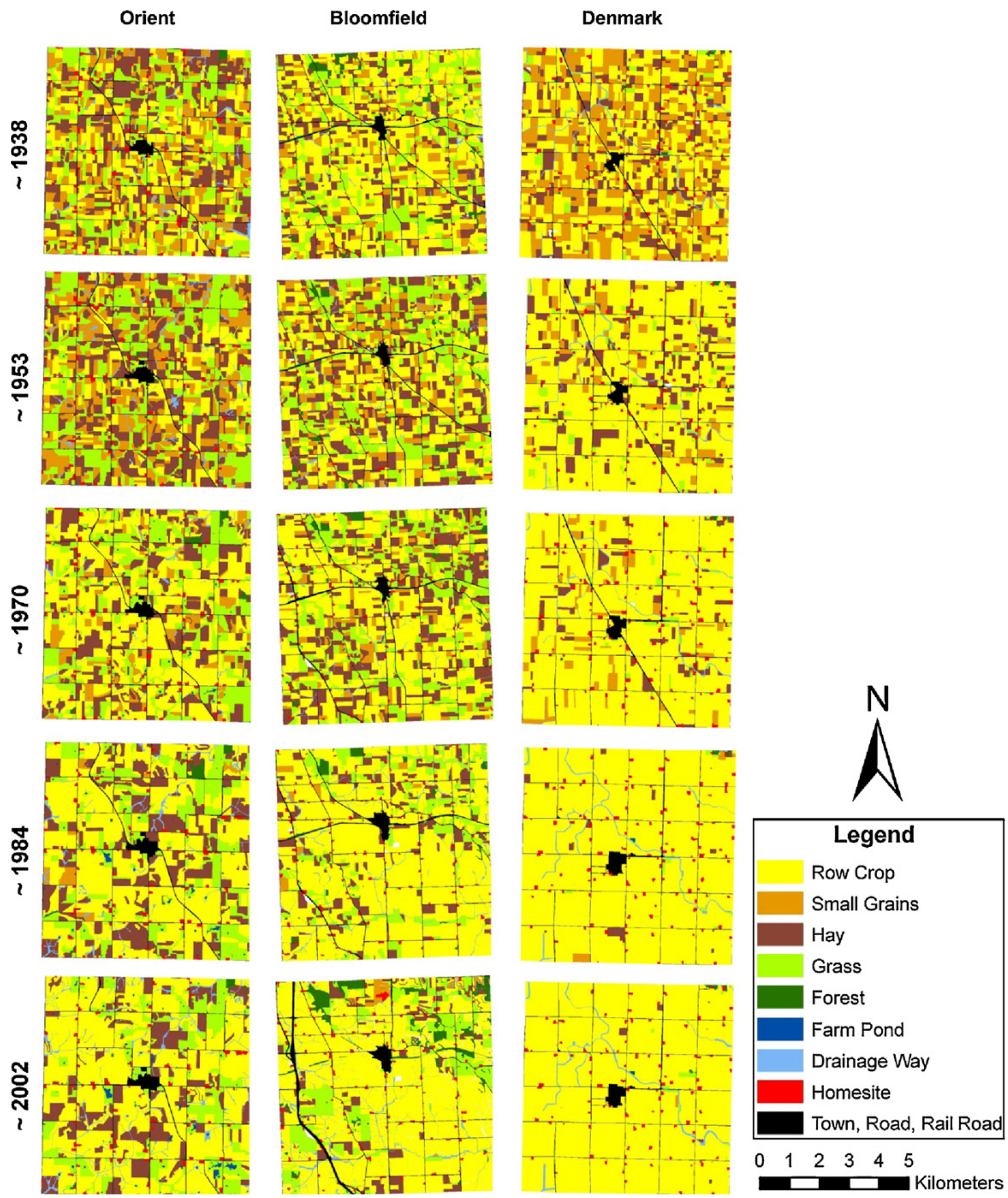

Fig. 2. Comparison of land cover change over time and among three agricultural landscapes in Iowa: Orient Township, Bloomfield Township, and Denmark Township.

(Fig. 3E) and grass (Fig. 3F) cover, and a greater number of smaller fields (Fig. 3H and I) in comparison to Denmark Township. Small grains largely disappeared from all three townships, however, after the 1970s (Fig. 3D).

3.2. Patterns imposed by responses to natural resource constraints

Constraints to agricultural expansion are most substantial in Bloomfield Township, with 5% of the land base suitable for only limited cultivation and 13% unsuitable for cultivation due to steep slopes. Land that is suitable for cultivation has moderate to strong limitations, and requires implementation of conservation practices to reduce erosion (Table 3). At the other end of the spectrum, 100% of Denmark Township is considered suitable for cultivation, with the majority of the land base having no to moderate limitations (Table 3); in locations where the land is less suitable, wetness is of primary concern. Orient Township lies between these two extremes (Table 3).

The pattern of row crop dominance evolved differently in Bloomfield and Orient Townships, concomitant with greater level of constraints to cultivation posed by the natural resource base in these landscapes. While field sizes increased in all townships over time, these changes have been of lower magnitude in Bloomfield and Orient Townships (Fig. 3I). Neither township achieved the near complete dominance of row-crop cover witnessed in Denmark Township; yet, Bloomfield supported a greater percentage of row crops in 2002 than Orient Township (Fig. 3C), despite the recorded presence of more severe limitations to cultivation (Table 3). Both Bloomfield and Orient Townships were covered by substantial

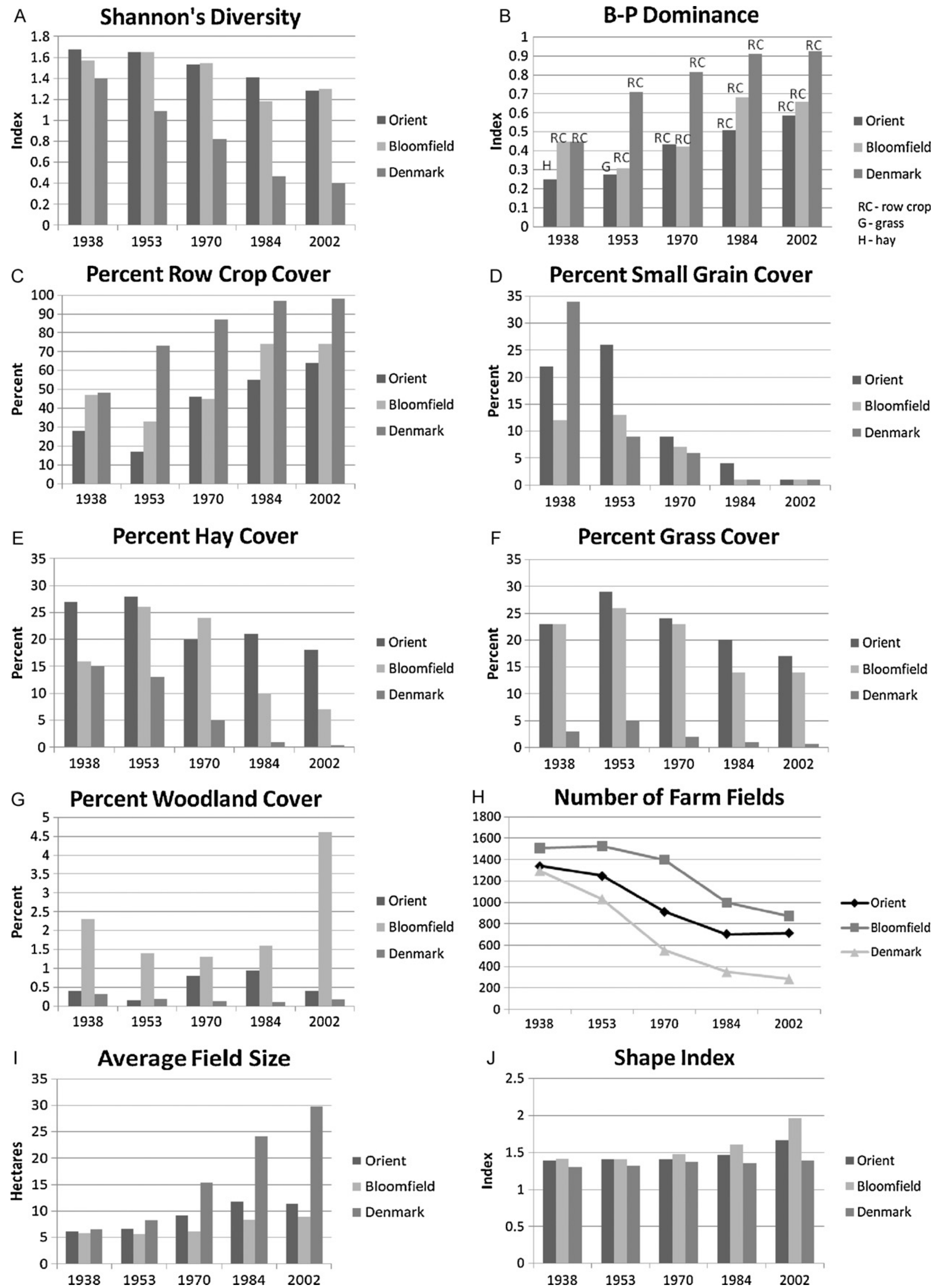

Fig. 3. Changes in (A) Shannon's diversity, (B) B–P dominance, (C) percent row crop cover, (D) percent small grain cover, (E) percent hay cover, (F) percent grass cover, (G) percent woodland cover, (H) number of farm fields, (I) average field size, (J) shape index, (K) number of farm ponds, L) percent drainageway of total area, and (M) number of rural homesites over time and among three agricultural landscapes in Iowa: Orient Township, Bloomfield Township, and Denmark Township. As row crop, small grain, hay, and grass consistently comprised over 90% of the total land area in each township, percentages are calculated and reported according to the area devoted to these four primary agricultural cover types, rather than total area, for ease of comparing among townships and across years.

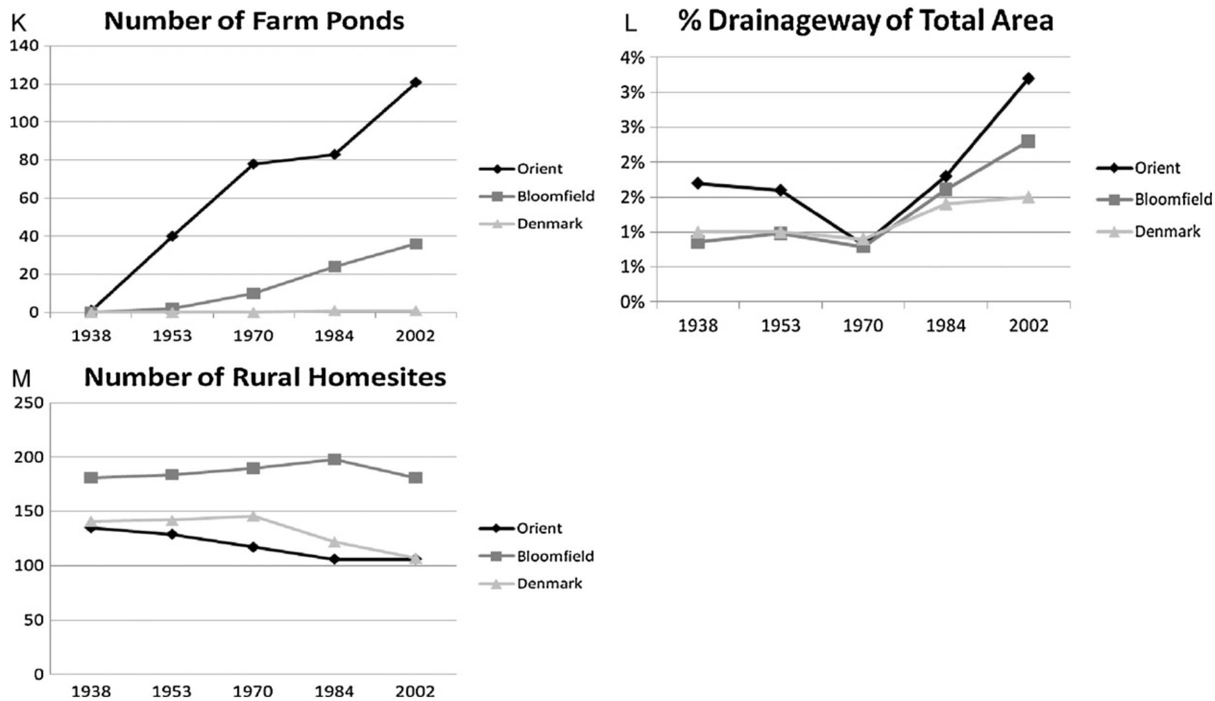

Fig. 3. (*Continued*).

amounts of hay and grass cover, with the proportion of each declining since the 1950s (Fig. 3E and F). Woodland cover was consistently greatest in Bloomfield Township, especially on steep slopes and since 1984, but woodlands still only comprise a small percentage of the overall agricultural landscape (Fig. 3G).

The shape complexity of patches increased in Bloomfield and Orient Townships concomitantly with increases in the area under row crops and decreases in hay and grass cover (Fig. 3J). In Bloomfield Township, the higher level of shape complexity is associated with the expansion of woodlands (Fig. 3G), the installations of farm ponds (Fig. 3K) and grass waterways (Fig. 2), and the adoption of strip cropping (Fig. 2). Between 1984 and 2002, 454 grass waterways were installed throughout Bloomfield Township, and strip cropping was instituted on several fields in its northern portion, both adding fine scale features to this agricultural landscape (Fig. 2). Grass buffers along drainageways were also widened (Fig. 3L). Between 1938 and 2002, farm ponds proliferated across the agricultural landscape of Orient Township, and grass buffers along drainageways were installed and widened (Fig. 3K and L). By comparison, the implementation of such conservation features was not obvious in Denmark Township. Small wetlands that were visible in the early aerial photographs were absent from all agricultural landscapes by the 1980s, and most dramatically in Denmark Township.

3.3. Loss of rural infrastructure

While some roads were widened or paved in subsequent periods, the loss of human infrastructure from these agricultural landscapes was more evident (Fig. 2). In all cases, the number of rural home sites (primarily farmsteads) was lower in 2002 than at some preceding time period. This loss was greatest in Denmark Township, which declined in rural housing density from 1.59 to 1.16 home sites/km^2 between 1972 and 2002 (Fig. 3M). The number of rural home sites was greatest in Bloomfield Township in 1984 (2.11 home sites/km^2); this peak represents an increase over 1937 and 2002 housing density, which was 1.93 home sites/km^2 in each of these two years both cases (Fig. 3M). The density of rural home sites consistently declined among time periods in Orient Township from 1.48 to 1.16 home sites/km^2 in 1938 and 2002, respectively (Fig. 3M). The average size of home sites also changed over time, with home sites in Orient (1.68 ha) and Denmark (1.59 ha) Townships smaller in 2002 than in the 1930s (1.79 ha in both cases). Qualitative changes we observed from aerial photographs that generally affected the size of home sites included the loss of small paddocks, orchards, and gardens. In contrast, the average size of home sites in Bloomfield Township was smaller by comparison but increased over time, from 0.83 ha in 1937 to 1.07 ha in 2002. In this township, few paddocks existed around home sites, explaining the smaller home site size in early time steps. Instead, farm buildings were neatly arranged to accommodate multiple livestock enterprises, likely poultry and hogs that do not require as much land area, and pastures were located away from home sites, linked to the home site by long lanes. Reduction in the number of home sites and home site area in Orient and Denmark Townships was not paralleled by substantial increases in the area of the small town contained within them: Orient and Ringsted were only about 1 ha larger in 2002 than their 1930s area. Delmar in Bloomfield Township, however, grew by 16 ha. Rail lines disappeared after 1953 in Bloomfield Township, after 1970 in Denmark Township, and after 1984 in Orient Township. The rail line was replaced by a major highway that bypassed the small town in the Bloomfield Township in the 1990s (Fig. 2).

4. Discussion

Given the lack of spatially explicit, comprehensive, and consistent data on agricultural landscape change for regions such as Iowa, our analyses provide baseline understanding on how many, seemingly insignificant human decisions scale up to impact their overall composition and structure. We found two patterns held in common across our study townships and one key difference: consistent loss of crop diversity, different responses to constraints in the natural resource base, and consistent erosion of human infrastructure. We focus our discussion on potential technological, economic, and policy drivers of these patterns in the sections that follow. While determination of the causes of change is beyond the scope of this

study, comparative analysis can pinpoint and provide strong support for its potential drivers (Shrader-Frachette and McCoy, 1993; Neuman, 2006).

4.1. The homogenization of agriculture

The homogenization of agriculture, in terms of loss of crop diversity and increases in field size, was a predominant trend affecting our study landscapes. The shift from small grains, hay, and grass and widespread adoption of row crops was evident in all cases (Figs. 2 and 3). In Orient, Bloomfield, and Denmark Townships the total land base in row crop production increased by 34%, 21%, and 48%, respectively, from around 1937 to 2002, with final percentages of 59%, 66%, and 93% (Fig. 3C). A companion study shows that losses in crop diversity are paralleled by losses in livestock diversity over the same period (Brown, 2008). Although the relative proportions of cover types differed among townships in the initial time period, all were dominated by agriculture and exhibited similar overall spatial patterns (Fig. 2). For example, average field size was comparable among the Orient, Bloomfield, and Denmark Townships at 6.2 ha, 5.8 ha, and 6.5 ha respectively around 1938 (Fig. 3I). This finding was somewhat unexpected given the similarities in landscape diversity shared by Orient and Bloomfield Townships in contrast with the extreme dominance of row crops and small grains in Denmark Township (Fig. 2). This small average field size during was likely a function of limitations associated with the prominent use of draft horsepower at this time. The loss of small grains from these landscapes was largely concomitant with the loss of horses, adoption of tractors (Brown, 2008), and widespread ownership of automobiles.

It is well established that advances in technology and economic developments after World War II extended the size or scope of the efficient agricultural production unit (Heady et al., 1965; Paarlberg and Paarlberg, 2000; Tweeten, 1970), and were periodically assisted by U.S. federal farm policies (Benedict and Stine, 1956; Hurt, 2002). While technology removed the drudgery of farm life and generated phenomenal increases in productivity, it was also a major driver of agricultural landscape change (Rhodes, 1995; Tweeten, 1970). U.S. agriculture was caught on a technology treadmill that involved cycles of introduction of new technology, adoption by farmers, increased output, depressed prices, and further search for new technology to maintain income as falling prices threatened farm returns (Rhodes, 1995; Tweeten, 1970). Some of the successive new technologies available to individual farmers over the course of our study period included the tractor, hybrid corn, soybeans, synthetic fertilizers, progressively larger equipment, pesticides, and transgenic crops (Anderson, 2008; Benedict and Stine, 1956; Hurt, 2002). Eventually, all farmers were forced to adopt current technologies and continually seek new technologies to achieve economies of scale where the average total cost per unit of output decreased as output increased (Kay and Edwards, 1994). In other words, the increased cost of investing in new technology was offset by increasing the size of the business (e.g., acres farmed and field size), so fixed costs were spread over more units of production.

Prior to 1942, U.S. farm policies largely emphasized the stabilization of crop prices often through production control (Benedict and Stine, 1956; Cain and Lovejoy, 2004; U.S. Congress, 1998), but upon entering World War II the federal government emphasized maximum production of farm commodities to ensure a supply of food to feed not only the American workforce and soldiers, but the allies as well (Hurt, 2002; U.S. Congress, 1998). Production controls and commodity price supports were again implemented in 1949, 1954, and 1955; however, they did little to control surpluses (Benedict and Stine, 1956; Green, 1990). As agriculture leapt into a new era of industrialization during the 1970s, the Agriculture and Consumer Protection Act of 1973 introduced the financial tool of target prices that established guaranteed price levels by the government and deficiency payments on commodity crops to qualifying farmers whenever market prices fell below target prices (Green, 1990; U.S. Congress, 1998). Deficiency payments allowed loan rates to be kept below world market prices, but farm income could be supported at levels sufficient to cover production costs (U.S. Congress, 1998). Loans often supported the investment in the new technology and, because they were tied to commodity crops – corn and soybeans in our study landscapes – they facilitated the homogenization of land cover. The Food and Agriculture Act of 1977 further introduced the farmer-owned reserve (U.S. Congress, 1998). Commodity loans paid farmers to store their grain when prices were depressed and then authorized release when supplies decreased and prices rose sufficiently (Green, 1990). In essence, this policy tool reduced economic risks associated with farming row crops, providing a further financial incentive for farmers to plant row crops and further assisting the homogenization of land cover.

The degree of change associated with such technological advances and the policies that promoted them was most evident in Denmark Township – landscape diversity decreased dramatically after the initial time step, when row crop-dominated matrix emerged with less dominant cover types disappearing or becoming isolated remnants throughout the remainder of the study period (Fig. 2). This pattern may be associated with high demand for agricultural grain crops during World War II and technological advancements associated with the post-war era. The emergence of a row crop matrix and the marginalization of other cover types occurred over a longer period and became discernable in Bloomfield and Orient Townships after 1970 and obvious in the 1980s (Fig. 2), and may be more tied to policy incentives to plant row crops.

4.2. Limits to expanded cultivation

The biophysical template in Corn Belt states such as Iowa poses fewer constraints to farming in comparison to other parts of the world, which allowed farmers to capture economies of scale as farm equipment improved and family traditions influenced the size of farms and related land management practices (Medley et al., 1995; Salamon, 1992). This has not been the case in other agricultural regions in the U.S., where natural resource constraints have led to the abandonment of croplands less suitable for cultivation and regrowth of woodlands starting in New England, followed by Mid-Atlantic and Lake States, and more recently the Southeast (Auclair, 1976; Brown et al., 2005; Ramankutty and Foley, 1999). The more productive soils and comparatively fewer topographic constraints offered by the Iowa landscape were important factors contributing to landscape homogenization (Medley et al., 1995).

Among our study landscapes, this phenomenon was especially clear in the case of Denmark Township, where 93% of the land base was under row crop cultivation and field size became constrained by the 259 ha grid of the rectangular survey system by the close of the study period (Figs. 2 and 3C). Although wet soils associated with its prairie pothole landform initially inhibited agricultural expansion, the widespread drainage of excess water through tiling and ditching largely occurred prior to our study period and removed most natural impediments; 100% of the land base is considered suitable for cultivation (Table 3). Given that the area devoted to other crops is trivial at present, further expansion of row crop cultivation within Denmark Township can only be achieved by taking out roads, farmsteads, or the town of Ringsted. It should also be noted that, although there are no strong limitations to cultivation in the township, soil erosion is of concern on 19% of the land base and USDA recommends the adoption conservation practices with cultivation of these areas (Table 3). While conservation tillage, which

is not visible from aerial photographs, may be practiced here, we found little evidence of the adoption of other conservation practices in this landscape. Grass buffers were established along some drainageways after 1970 (Fig. 3L).

While still subject to substantial levels of homogenization (Fig. 2), spatial variation in the edaphic and topographic environment appeared to exercise more constraint on the cultivation of row crops and field sizes in Orient and Bloomfield Townships (Fig. 3C and I). Over half the land area in each of these townships is composed of soils that either pose strong limitations to cultivation (Capability Class III), are suitable for only limited cultivation (Capability Class IV), or are not suitable for cultivation (Capability Classes V–VII). Yet, it appears that 10% and 17% of lands within Orient and Bloomfield Townships, respectively, were under row crops in 2002 despite substantial limitations to cultivation (Capability Class III and above). USDA recommends restricted to no cultivation of row crops, the adoption of intensive conservation practices, or both on such lands (Table 3).

Why were such sensitive lands placed under cultivation in Orient and Bloomfield Townships? We expect that technology, economic, and policy drivers at work since World War II, and especially federal farm policies enacted during the 1970s, were powerful enough to overcome both USDA recommendations and farmer hesitation. Trajectories established in the 1970s then continued into the 80s, as depressed commodity prices and farm incomes forced farmers to try to achieve economies of scale to remain viable (Green, 1990; U.S. Congress, 1998). The Federal Agriculture Improvement and Reform (FAIR) Act of 1996 likely further exacerbated the trend by eliminating historical acreage reduction obligations and eliminating almost all planting constraints on farmers participating in Title I of this law, popularly called “freedom to farm.”

Based on our qualitative observations of severe erosion and gully formation in aerial photographs, we further expect that the limitations to cultivation posed by the land base in Orient and Bloomfield Townships did not take long to reveal themselves. Indeed, farm ponds were adopted as a conservation measure in Orient Township subsequent to our first time step and in Bloomfield Township after 1953, with adoption continuing throughout our study period (Fig. 3K). More extensive conservation practices, including the establishment of woodlands, grass buffers, grass waterways, and strip cropping were not adopted until later, however, and were likely tied to conservation incentives associated with U.S. federal farm policies. The Food Security Act of 1985 was the first farm bill to have a specific title devoted to conservation (Cain and Lovejoy, 2004; Green, 1990; U.S. Congress, 1998), and included two new programs that were likely drawn upon by farmers within our townships: Conservation Compliance and Conservation Reserve. Conservation Compliance required farmers and landowners to develop a conservation plan for highly erodible land to remain eligible for federal farm aid (Cain and Lovejoy, 2004). The Conservation Reserve Program (CRP) was designed to pay farmers to retire highly erodible land from production for at least 10 years.

There is growing concern that the increased reliance on land with cultivation limitations to produce annual row crops will increase the global ecological footprint of agriculture (Foley et al., 2005; Kiers et al., 2008). This concern arises from trends indicating increased dependence on mechanization, fossil fuel energy, and other chemical inputs to meet present and future demands for food, fiber, and fuel, and because opportunities for agricultural land-use expansion are being exhausted (Foley et al., 2007; Robertson et al., 2008). Such expansion is likely to further compromise biodiversity and undermine the delivery of ecosystem services and the well-being of human communities (Foley et al., 2005; Kiers et al., 2008; MEA, 2003). We see evidence of these phenomena in our study townships, Iowa more generally (Atwell et al., 2009; Kirschenmann et al., 2008; Mutel, 2010; Rayburn and Schulte, 2009), and other regions of the globe (Cramer and Hobbs, 2002; Jardine et al., 2007; Klink and Machado, 2005).

4.3. Loss of strategic market center infrastructure

Our analysis of aerial photographs records the loss of strategic market center infrastructure as rail lines, initially intersecting each small town, disappeared from the landscape in the latter half of the 20th century (Fig. 2). While specific reasons for rail line disappearance are likely related to transportation economics rather than landscape change, their loss does have an effect on the market center function of rural trade areas. Prater and Babcock (1998) note that rail branchline abandonment has several potential negative impacts on rural areas. These include lower grain prices received by farmers, higher transportation costs, loss of market options, lost economic development opportunities, and higher road maintenance and reconstruction costs. For the future, loss of rail line infrastructure will impact the ability of rural areas to provide cost-effective means of transporting biomass for conversion into bioenergy and other bio-based products (Haddad and Anderson, 2008).

We also cataloged the disappearance of farmsteads from each of the study landscapes. This loss was more pronounced in Orient and Denmark Townships and associated with a reduction in home site size as farmsteads lost outbuildings, gardens, orchards, and paddocks (Figs. 2 and 3M). Although the number of home sites in Bloomfield Township slightly declined, the remaining sites showed increases in size, perhaps associated with the development of small-scale crop and livestock production systems. A companion study shows that Bloomfield Township maintained higher overall livestock numbers with the exception of hogs, which are much higher in Denmark Township today due the recent emergence of high-density, confined animal feeding facilities (Brown, 2008). Delmar, the small town located within Bloomfield Township, also showed a threefold increase in size over the study period, while the size of towns in the other two townships essentially remained unchanged. While we cannot definitively determine whether the higher landscape and livestock diversity of Bloomfield Township was linked to Delmar’s growth, the pattern is suggestive.

Also for the future: we question how the loss of rural home sites and the reduction in their size might affect a rural community’s ability to participate in the emergence of local food systems and to provide opportunities for younger agricultural entrepreneurs interested in producing high-value, low-volume commodities. A study of Midwest community supported agriculture (CSA) operations found these operations to be approximately 12 ha in size and to involve farmers who were younger, better educated, and of both genders (Tegtmeier and Duffy, 2005). Small-scale livestock operations have high labor demands, which provide opportunities for younger farmers and tend to keep farmers fully employed (Hogberg et al., 2005; Honeyman, 1996). Numerous studies have shown that small-to-medium scale family-operated farms result in more vibrant agricultural communities with higher average incomes and greater civic engagement (Goldschmidt, 1946; Kirschenmann et al., 2008; Stofferahn, 2006).

5. Conclusion

Our study townships represented three trajectories of agricultural landscape change. Comparison among them revealed that technological advances and federal farm policies likely drove the loss of agricultural landscape diversity, as revealed by increasing field sizes and dominance of row crops. The key driver and timing of change, however, varied among townships. Declines in diversity occurred earlier in Denmark Township and appeared to be more connected with technological and market changes associated with

the World War II era than explicit federal farm policies. The trajectory of change in Denmark Township was also highly influenced by the lack of constraints posed by its natural resource bases, which allowed farmers to capitalize on economies of scale and invest in new technology, in comparison to Orient and Bloomfield Townships. Smaller proportions of these latter townships are suitable to the cultivation of row crops. Adopting advanced technologies to support row-crop farming likely made less economic sense in these townships until financial tools associated with U.S. farm policies in the 1970s incentivized the conversion of hay and grass to row crops. Landscape analysis also revealed the adoption of conservation practices within Orient and Bloomfield Townships, especially in the last two decades of the 20th Century, resulting in fine-scale diversification of land cover within these townships. The adoption of these conservation practices was likely driven by the combination of negative impacts of row crop farming on each township's land base and the enactment of conservation programs associated with the 1985 and 1990 federal farm policies. Finally, the loss of railroads and rural home sites was evident in all three agricultural landscapes, but was most pronounced in Orient and Denmark Townships. The loss of such rural infrastructure may affect the ability of these agricultural communities to respond to new opportunities in the future. There are concerns that homogeneous agricultural landscapes are less resilient, increase the ecological footprint of agriculture, and diminish opportunities for the next generation of farmers (Beeman and Pritchard, 2001; Flora et al., 2004; Jordan et al., 2007; Kirschenmann et al., 2008; Mutel, 2010). While we do not expect farmers or agricultural communities to "turn back the clock" on time and technology, initiatives that the foster diversification within and among agricultural landscapes, rather than their further homogenization, may be more likely to achieve the common goal of enhancing agricultural sustainability.

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