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Forty-eight years of landscape change on two contiguous Ohio landscapes

John W. Simpson[1], Ralph E.J. Boerner[2], Michael N. DeMers[3,*], Leslie A. Berns[1], Francisco J. Artigas[4] and Alejandra Silva[3]
*[1]Departments of Landscape Architecture, [2]Plant Biology and [3]Geography, and [4]Environmental Science Program, The Ohio State University, Columbus, Ohio 43210 U.S.A.***

Abstract

This study analyzes the current and historic structure of two contiguous, rural landscapes covering approximately 242 km^2 in central Ohio, USA: a till plain landscape with relatively homogeneous topography and soils, and a moraine landscape with greater geomorphological diversity and heterogeneity. These landscapes were chosen because they were both heavily dominated by agriculture during 1900–1940 and were both initially surveyed by the metes-and-bounds system. They differed, however, in the temporal pattern of settlement and development and in the inherent agricultural capability of their soils. We combined analysis of aerial photographs from 1940, 1957, 1971, and 1988 with historical archives and other available mapped data in a GIS data base to facilitate analysis of both spatial and temporal patterns of change. On the moraine, the agricultural matrix decreased over time as forest, urban/suburban areas, and industry increased. In contrast, on the till plain agricultural landcover increased through 1988, with concommitant decreases in upland forest and oak savanna. The moraine landscape exhibited greater diversity and equitability than the till plain on each date. The till plain had its greatest diversity and equitability in 1940, whereas the moraine increased in diversity and equitability during each time period. The undulating topography of the moraine encouraged landcover dynamism rather than stability, whereas the more homogeneous till plain exhibited considerable inertia. Patch and matrix shape remained constant and predominantly angular over the 48 year study period. Differences in the physical environment, especially topography and soil capability, and the socioeconomic environment, especially agricultural policies and patterns of urbanization, resulted in these two contiguous landscapes having different trajectories of change. It is clear from this study that socioeconomic factors must be combined with the physical setting to fully understand patterns of change in human-dominated landscapes.

Introduction

In recent years, landscape researchers have begun to examine the nature and patterns of rural landscape dynamism, with the goal of developing effective models of rural landcover change (*e.g.* Iverson 1988; Turner and Ruscher 1988; Hoover and Parker 1991). Analytical approaches employed in such studies have included spatial indices designed to quantify the size and shape of landscape patches, the arrangement of landscape elements (O'Neill *et al.* 1988), and the rate and direction of landscape

* Current address: Michael DeMers, Geography, New Mexico State University, Las Cruces, New Mexico, **USA.**
** Correspondence should be addressed **to J.W.** Simpson.

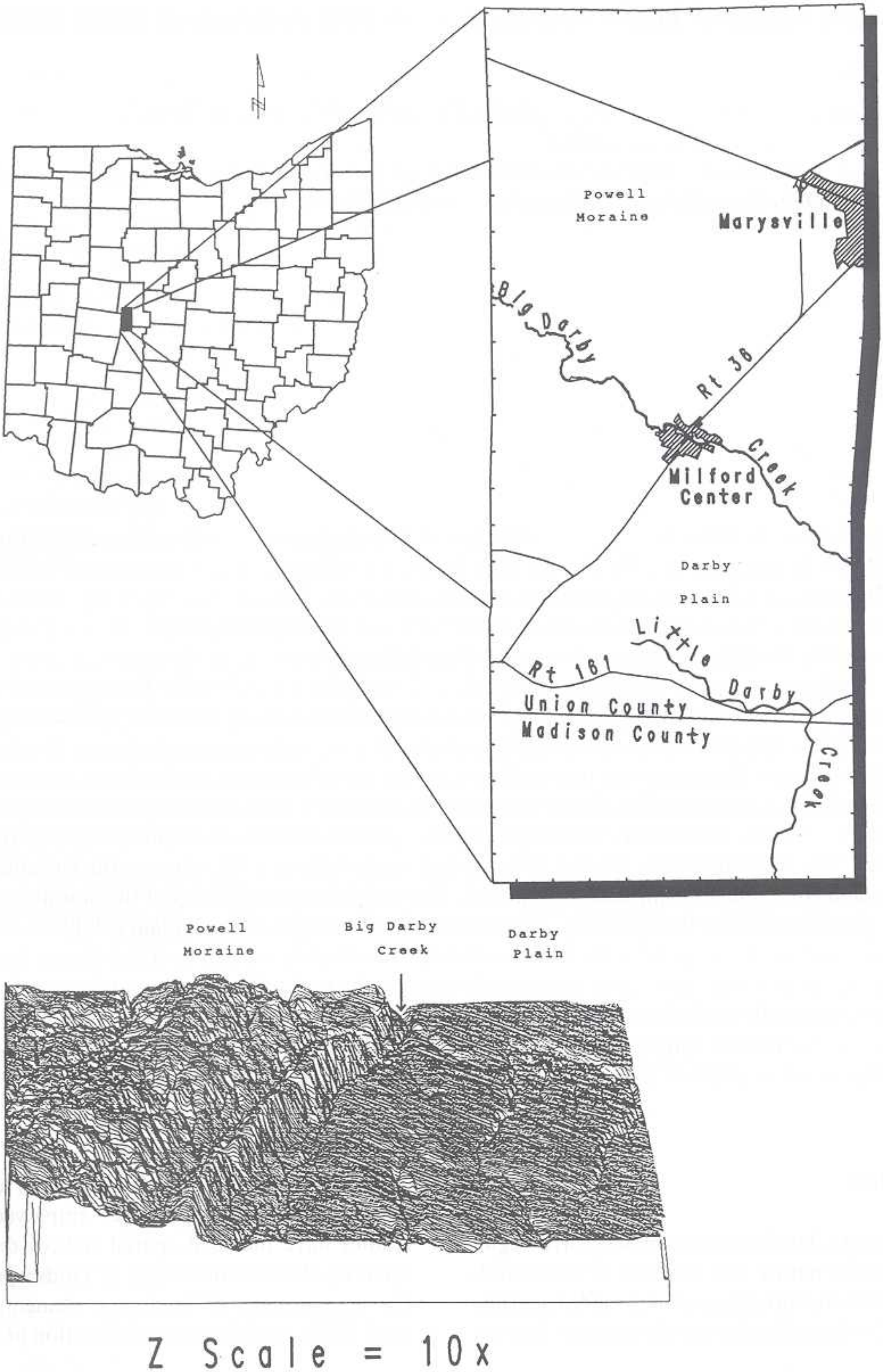

Fig. 1. Location and topography of the 242 km[2] study area in central Ohio.

change (Turner 1987). In some cases, several indices have been combined to generate models designed to predict future landscape change (Turner 1990).

Although landscape structure and dynamics have now been quantified in a number of specific settings, most have examined either a single landscape over time (*e.g.* Foster 1992, 1993) or multiple landscapes at a single point in time (*e.g.* Hoover and Parker 1991). As a result, the collective body of knowledge is still inadequate for a general model of rural landcover change. Before such a synthesis is possible, we must compare patterns of landscape structure and change across a wider array of physiographic and socioeconomic settings and over a range of time scales. When sufficient landscape settings have been examined in this manner, more robust generalizations about the behavior of landscape elements may be possible. In addition, an understanding of the nature and causes of these emerging patterns across a range of specific landscape settings may offer significant opportunities for planners to enhance biodiversity and environmental quality within current land management policies and programs.

This paper describes landcover change in two contiguous landscapes covering a 242 km^2, mostly rural, central Ohio study area. We chose to compare these two contiguous landscapes because they (1) were both dominated by agriculture at the beginning of our 48 year study period and had been so for at least four decades prior; (2) they were initially surveyed by the metes-and-bounds system, and thus patch shapes and boundaries reflected the underlying landforms, not arbitrary borders as in landscapes surveyed by the township-and-range system; (3) they differed in initial settlement pattern and timing, and (4) they differed in physiography, soils, and inherent agricultural capability. Within this context, the specific objectives of this study were to quantify the structure of these two contiguous physiographic and socioeconomic settings at four points in time over the period 1940–1988, and to attempt to relate the structures of these landscapes to both physiographic and socioeconomic processes.

Methods

Using a combination of raster and vector-based geographic information systems (GIS) we developed a spatial data base depicting landcover for 1940, 1957, 1971 and 1988 for an area of 242 km^2 in the northern Virginia Military District of central Ohio (Fig. 1). The study area was located west of Marysville (1990 population 9,656) and covered the southern 1/3 of the Peoria 7.5' U.S.G.S. topographic quadrangle map, all of the Milford Center quadrangle, and the northern 1/3 of the Plumwood quadrangle. The entire study area is located in the Till Plains physiographic province of central and western Ohio, an area comprised of mosaics of ground moraine till plains and undulating end moraines. We divided the study area into two distinct landscapes of virtually equal area: an undulating northern half defined by the Powell Moraine, and a flat, somewhat featureless southern half defined by the Darby Till Plain.

We first examined historical archives and reconstructions to determine the general nature of the landscape prior to Euro-American settlement, the nature and timing of settlement patterns, and the local history of agricultural practices since the early 1990's as they had been affected by regional and national agricultural policies and programs. We also interviewed local agricultural extension agents and district conservationists to obtain insights into the socioeconomic factors that operated at the local level.

We interpreted landcover patterns for 1940, 1957, 1971, and 1988 from a combination of 1:20,000 and 1:40,000 black and white aerial photographs. We used a classification system to represent the predominant landcovers: upland forest (closed canopy), young woodland (open canopy), oak savanna/parkland, riparian forest, agriculture (including row crop, pasture and farmsteads), urban/suburban, borrow pits from gravel mining activity and industry. Following manual photo interpretation of unrectified aerial photo mosaics and ground-truthing of the 1988 landcover patterns, we transferred the interpretated classes to mylar overlays for digital input and co-registration into an ARC/INFO GIS data base.

Each landcover data layer was subdivided into virtually equal north and south portions to represent the moraine and till plain physiographic types (landscapes), respectively. We then produced landcover maps for each date, and used the capabilities of the GIS software to generate descriptive statistics for the entire study area and separately for each landscape. Rates of change over time were analyzed by linear regression (Proc GLM of SAS 1985).

History and Socioeconomic Development: 1800–1940

At the time of Euro-American settlement in the early 1800's, the moraine landscape was covered by relatively unbroken deciduous forest, ranging from beech-maple ***(Fagus-Acer)*** on mesic slopes to oak-hickory ***(Quercus-Carya)*** forest on morainal ridges (Dobbins 1937; Howe 1857; King 1981; Sears 1925). Openings in the canopy ranged in size from treefall gaps in more mesic sites to large openings caused by fire and catastrophic windthrows on drier and/or more exposed sites. The riparian forests along the major drainages were dominated by combinations of elm, ash, and maple ***(Ulmus, Fraxinus*****, and** ***Acer).*** In contrast, the till plain was a mosaic of tallgrass (*Andropogon-Sorghastrum*) prairie, bur oak ***(Quercus macrocarpa)*** savanna, and oak-hickory forest (Dobbins 1937; Howe 1857; King 1981; Sears 1925).

Euro-American settlement and subsequent development through the 1800's removed the Native American population from these landscapes, cleared much of the primary forest, and created a low density agricultural landscape composed of small farms and communities scattered across a matrix of secondary forest (Durant 1883; Howe 1857). By the 1850's, the population density was approximately 7.7 people/km^2 (Howe 1857).

Land parcelization in the study area followed the random pattern which resulted from the use of metes and bounds typical of this portion of the Virginia Military District (Dobbins 1937; Durant 1883). This contrasted with the orderly layout of adjacent land areas surveyed on the basis of the Land Ordinance of 1785 or other systematic survey practices (Thrower 1966). However, the pattern was not totally random, as the settlers usually selected property in response to the perceived quality of the soil, vegetation, and topography for the intended landcover (Durant 1883; Thrower 1966). In particular, agriculture initially began earlier on the moraine and the areas of the till plain that had originally been the forests and oak savannas than on the poorly drained flats and prairies of the till plain. This patchwork landscape of farms, prairies, towns, and secondary forest changed little through the 19th Century.

The second period of significant landscape change began in the early 1900's as the result of the widespread installation of agricultural drain tiles. This enabled more of the poorly-drained till soils on the till plain to be cultivated, thus increasing the amount of agricultural land and decreasing the area of moist forest and wet prairie (J. Rush, U.S.D.A. District Conservationist for Union County, Ohio, personal communication). Thus, even though the soils of the till plain had agricultural capabilities 14–59% greater than those of the moraine (depending on crop), portions of the better drained moraine were converted to agriculture earlier than was the till plain (Waters and Matanzo 1975).

The typical farm of the period produced both row crops and livestock. These integrated farms were generally small, family run, and scattered throughout both the moraine and till plain through the 1930's. A closely-knit German-Lutheran community developed along the southern edge of the moraine in the eastern portion of the study area during this period. This community remains intact today and greatly influences current agricultural practices (Rush, personal communication).

Results

Number, cover, and size of landscape patches

Agriculture remained the matrix and predominant landcover for both landscapes throughout the 1940–1988 study period (Figs. 2 and 3). During that time, the agricultural coverage on the moraine decreased from 80% to 75%, whereas on the till

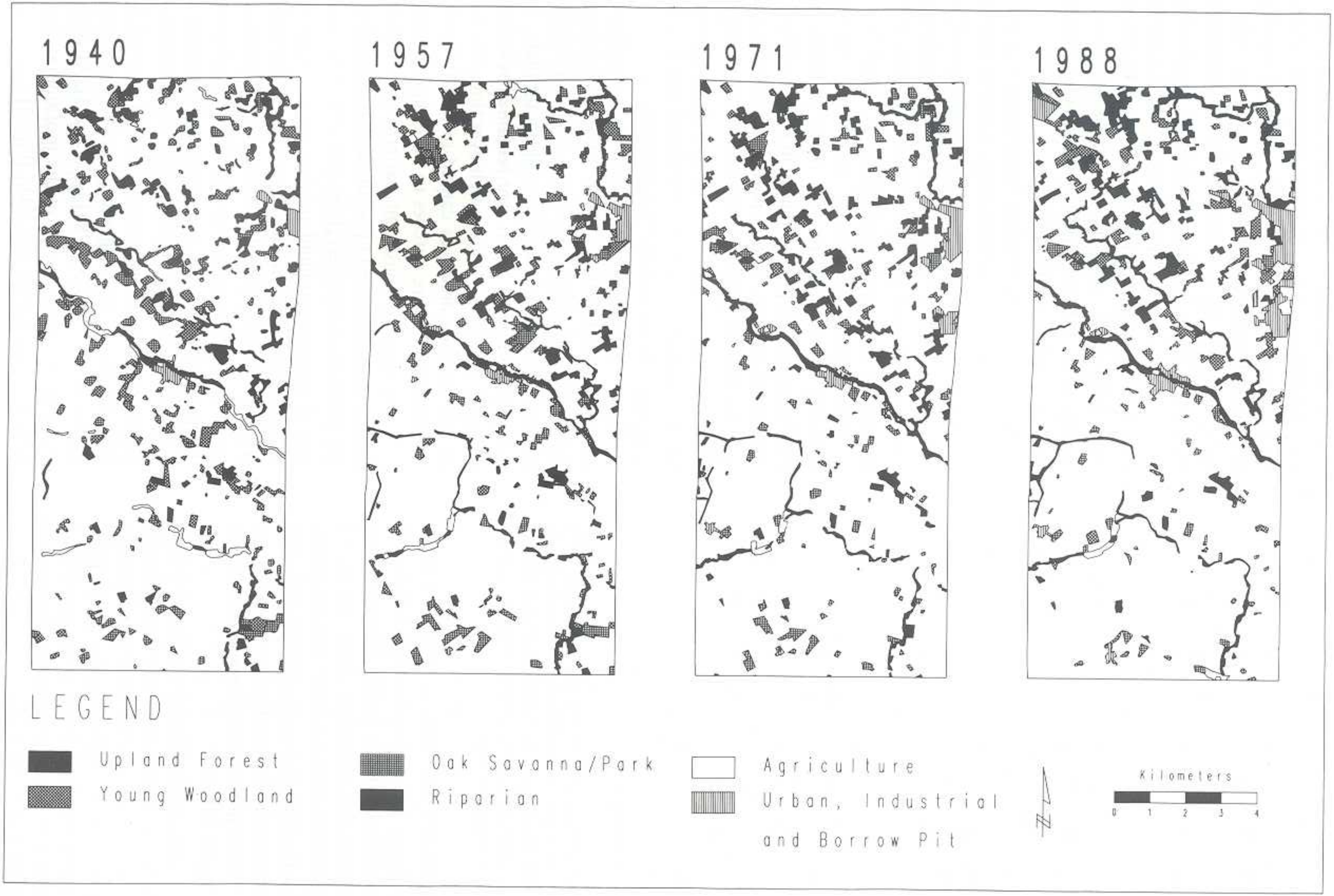

Fig. 2. Landcover maps for the moraine and till plain landscapes at four points in time during the period 1940–1988.

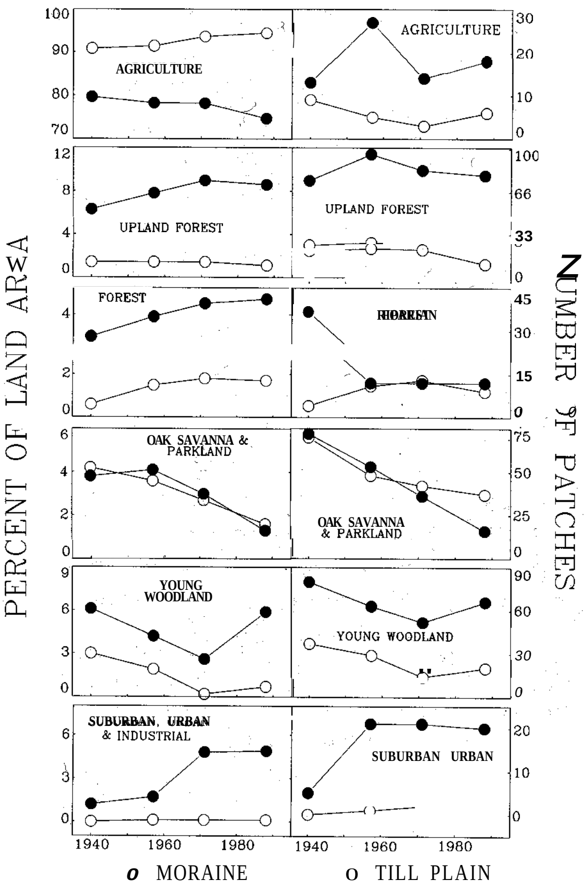

Fig. 3. **Percent of land area and number of patches occupied by each of six landuse types for two Ohio landscapes during the period 1940–1988. The moraine landscape is indicated by filled symbols and the till plain by open symbols. Note that vertical scales vary among landcover types.**

plain it increased slightly, from < 91% to > 94%. Mean agricultural patch size on the moraine decreased from **736** to 500 ha/patch. Over the same period, the mean agricultural patch size on the till plain increased from **1228** to almost **1910** ha/patch. It is important to note that mean agricultural patch size does not equate to mean field or farm size, as we made no attempt to locate property boundaries between adjacent farms.

On the moraine, upland forest was the next most abundant landcover type throughout the study period (Figs. **2** and **3**), increasing from **1940** through **1971,** then decreased slightly during **1971–1988.** The net increase in upland forest cover over 1940–**1988** was 37%, and mean patch size on the moraine increased from **10.1** to 13.1 ha.

Overall, there was < **25%** as much area in upland forest on the till plain as on the moraine (Figs. **2** and **3**). There was little change in the area and number of forested patches on the till plain from **1940–1971,** followed by a decrease of **20%** in forested area and **42%** in the number of forest patches between **1971** and **1988.** Mean forest patch size on the till plain remained steady at about 6.7 ha/patch from **1940–1971,** then increased to 8.9 ha/patch during **1971–1988** as smaller patches were cleared and returned to agriculture.

On the moraine, riparian forest area increased 55% between **1940** and **1988** (Figs. **2** and **3**). On the till plain, riparian forest increased by almost a factor of 2 between 1940 and 1971, though total riparian forest area on the till plain was still only 37% of that on the moraine in **1988** (Figs. **2** and **3**).

Mean riparian woodland patch size on the moraine increased from **11.7** ha to **47.0** ha, as patches coalesced and decreased in number (Fig. **2**, Fig. **3**). In contrast, mean riparian woodland patch size on the till plain varied little and averaged **23.5** ha/patch during **1940–1988,** with an increase in the number of riparian woodland patches accounting for the increase in total area.

The area covered by oak savanna/parkland decreased steadily during **1940–1988** on both landscapes (Figs. 2 and 3). The net loss over **48** years was 67% on the moraine and 62% on the till plain. As mean oak savanna patch size remained relatively constant around 8–10 ha/patch over time, the loss in oak savanna area was caused primarily by the conversion of entire patches to other landcovers.

There were no consistent patterns of temporal change in area covered by young woodland (including old fields with trees) (Figs. **2** and **3**). The mean size of young woodland patches on the moraine changed little over time and averaged 8.4 ha/patch (Fig. **3**). On the till plain, mean young woodland patch size decreased from a **1940–1957** mean **of** 9.0 ha/patch to a 1971–**1988** mean of 3.3 ha/patch.

The area covered by urban and suburban landcover on the moraine increased by a factor of **3.5** over 48 years, with the great majority **of** it appearing between 1971 and 1988 (Figs. 2 and **3**). All of the industrial landcover was on the moraine and appeared between **1971** and **1988** (Fig. **2**).

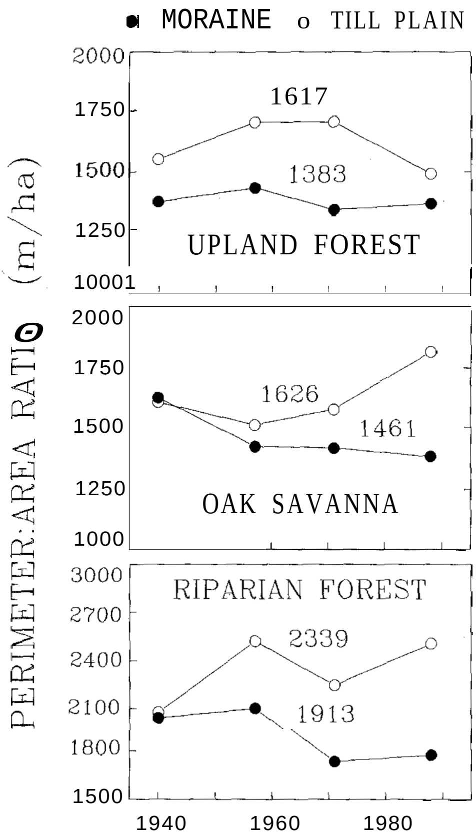

Fig. 4. Perimeter: area (P:A) ratios, in m/ha, for patches of six landcover types in two contiguous Ohio landscapes during the period 1940–1988. The moraine landscape is indicated by filled symbols and the till plain by open symbols. Note that vertical scales vary among landcover types. The numbers associated with each line is the mean **P:A** for all four dates pooled.

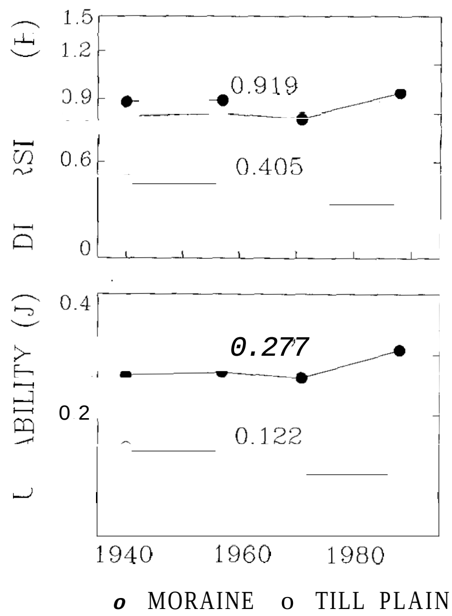

Fig. 5. Landscape diversity (Shannon-Wiener H') and equitability (J) of two contiguous Ohio landscapes during the period 1940–1988. The moraine landscape is indicated by filled symbols an the till plain by open symbols.

Patch shape

To evaluate spatial and temporal patterns of patch shape, we calculated the perimeter: area ratio (P:A) for each landcover type, except agriculture. As agriculture comprised the matrix of our landscapes, the perimeters of agricultural patches were often the arbitrary boundaries of our study area; thus the P:A we would calculate for agriculture would be an artifact of our methods rather than an accurate representation of what existed in these landscapes. Note: we also calculated the fractal dimension for all landcover types; however, as the trends of the two shape indices were essentially the same, we present only the results of the P:A analysis.

Upland forest and oak savanna/parkland had similar P:A, whereas the riparian forests had a mean P:A approximately 30% greater (Fig. 4). This difference reflected the dendritic nature of riparian forest patches in these landscapes and the relatively regular outline of forest and oak savanna remnants within the agricultural matrix (Fig. **2).**

Linear regression indicated that the P:A of riparian woodlands on the moraine decreased over the study period (Fig. 4) as a result of the coalescence of smaller patches into larger ones (Fig. **3).** Over the same period, the P:A of young woodland patches on the till plain increased, reflecting the change from larger to smaller young woodland patches on the till plain during this period. There were no other significant linear changes in P:A over the study period within any landcover type. However, within any landcover type the mean P:A of patches on the moraine was generally less than on the till plain (Fig. 4).

Diversity and equitability

Landscape diversity, as measured by Shannon-Wiener H', was consistently greater on the moraine than on the till plain (Fig. 5). There was no consistent trend over time on the moraine, though the greatest diversity we recorded was in 1988. In contrast, there was a decrease of 27% in H' on the till plain from 1940–1957 to 1971–1988. On the till plain, the greatest diversity occurred in 1940.

Equitability remained relatively constant on the moraine from 1940 to 1971, then increased during 1971–1988 (Fig. 3). This reflected the increase in urban, industrial, and forest landcover and the decrease in agricultural coverage during that period. There was a steady decrease in equitability over time on the till plain as more and more land was cleared for agriculture.

Discussion

Landscape structure and change

The overall patterns of change in landcover in these two landscapes during 1940–1988 differ quite markedly from those reported elsewhere in the Eastern Deciduous Forest region of North America. While the proportion of land area under agriculture changed slowly in our study area, agricultural land decreased greatly in areas of Massachusetts and other parts of New England (Foster 1992, 1993), all of the State of Georgia outside of the upper coastal plain (Turner and Ruscher 1988), and in the more rugged, unglaciated hill county of southeastern Ohio (Artigas and Boerner 1993). At the same time, the proportion of the landscape covered by forest increased in all of those areas while it remained constant or grew slowly in our study area. The differences are presumable due to differences in the inherent agricultural productivity of the soils, with farms on the shallow granitic soils of New England (Foster 1993), acidic, nutrient-poor soils of southeastern Ohio (Boerner and Kooser 1989) and the extensively and intensively cropped soils of the piedmont of Georgia (Turner and Ruscher 1988) being less economically viable than those on the deep, fertile till plains of Ohio (Waters and Matanzo 1975), Indiana, and Illinois (Iverson 1988).

On a finer spatial scale, the differences we observed between the moraine and till plain landscapes in both physiography and socioeconomics also affected the nature and rate of landscape change in our study area. During 1940–1988, the coverage of the agricultural matrix showed a small net increase in the till plain and a net decrease on the moraine. From the 1940's through the 1960's, the amount of row cropping on the till plain gradually increased because there were still areas of potentially productive soils that had yet to be tiled and drained. Federal cost-sharing programs in the post-World War II period encouraged farmers to begin crop rotations, and triggered the construction of fences to keep livestock from the fields. This period also saw the discontinuation of the strict tractor allotments imposed during World War 11. As tractors became more readily available, pastures and hay fields once necessary to feed draft horses were converted to row crop production. Thus, both the physical and socioeconomic environments of the till plain made it possible to increase farm acreage during 1940–1971 in a profitable manner.

In contrast, during this same period the amount of agricultural land on the moraine was stable, mostly due to the marginal inherent productivity of the soils and topography (Rush, personal communication). By the 1960's farm commodity surpluses had increased nationwide, and net farm income began to decline. At the'same time, many farms had become heavily dependant on fuel-intensive equipment, petroleum-based agrochemicals, and bank financing. The oil embargo of 1973 and the rise of interest rates through the 1970's further reduced profitability. Some of the farms on the moraine were sold to 'gentleman farmers' who typically converted these farms to 'country estates' with some land abandoned to succession. As landowners not as dependant on farm income tend to participate more in conservation reserve programs that set aside land from agricultural production, a greater proportion of land on the moraine reverted to natural vegetation. This same pattern of change in landcover and ownership was observed in Massachusetts during 1865–1935 as competition from Midwest agriculture made many New England farms unprofitable (Foster 1992, 1993).

On the till plain, these same socioeconomic forces resulted in the conversion of most small, integrated farms to larger, single crop operations (Rush, personal communication). Again, a similar consolidation of smaller farms into larger ones occurred in Massachusetts between 1865 and 1935 on areas of more productive soils (Foster 1992, 1993).

During the 1970's and 1980's, the moraine landscape became a patchwork of small, row crop farms scattered amidst successional forests and abandoned fields. Construction of a major automobile assembly plant outside Marysville triggered surburban-urban development, most of which is just outside the eastern boundary of the study area. Consequently, much of the moraine land now held by speculators remains as a mosaic of secondary forest, abandoned fields, and leased crop land.

The diversity of these two Ohio landscapes was considerably less than those calculated for four physiographic provinces in Georgia (Turner and Ruscher 1988), presumably the result of the strong dominance of our two Ohio landscapes by the agricultural matrix. Hoover and Parker (1991), in a separate analysis of landscape structure and diversity in Georgia, reported lesser community diversity and heterogeneity on the topographically-complex mountain and piedmont provinces than on the more homogeneous coastal plain. This result is counter to our observation of greater landscape diversity on the more topographically-complex moraine than on the till plain, a difference we feel is related to differences the underlying structure of the two regions. In both cases, the role of human activity in shaping landscape structure and the range of soil moisture regimes was greater in the areas of high landscape diversity (the coastal plain in Georgia and the moraine in our study) than in areas of lower diversity. This once again points out the difficulties of comparing structural indices of landscapes with very different geomorphological and socioeconomic histories (Turner and Rusher 1988).

Despite differences in the pattern and direction of change in these two Ohio landscapes, we observed little change in patch shape over our 48 year study period. This we believe is a lasting effect of the original metes and bounds land survey system: the landscape patchwork remained highly angular and consistent despite significant changes in land use and socioeconomic forces.

Use of the GIS data base in landscape analysis

The geographic information system we utilized for this study was essential for our analyses in many respects, not the least of which was to organize spatially-explicit data in a manner that allowed testing of hypotheses of patterns of change. We did, however, encounter difficulties and have some concerns about the use of GIS which others should be aware of before embarking on similar endeavors.

Many months were spent inputting various data layers, especially the landcover maps interpreted from aerial photography, because of problems with scale, unmatched dates, and unrecitified photos. We used 81 points of known location as registration points prior to using the GIS conflation routine to rectify the maps. Despite all the care taken in the production of the original data base, the potential errors inherent in the interpretation and rectification procedures should make one cautious about drawing strong inferences based on very small percentage increases in statistical indices derived from rectified map layers.

The landcover matrix itself caused some difficulties for data analysis, particularly when measurements of the patches were performed. Because so much of the matrix was in contact with the edge of the overall study area, as well as in contact with other patches, GIS measurement errors were more prevalent for matrix patches than for those isolated patches of other landcovers that were completely surrounded by agricultural matrix. Ideally, the study area would encompass the entire matrix. Similarly, patch size and shape indices are distorted where patches abut the study area boundary, and thus reflect the arbitrary cuts across the patches caused by the boundary. For shape and size analyses to be entirely representative of the actual landscape, they must be limited to patches wholly contained within the study area.

Recommendations

Unanswered questions concerning the area and characteristics of our study area remain, and suggest further research opportunities. Studies using areas of various sizes are necessary to determine the scale-dependence of landcover change phenomena. We also suggest selecting study areas to test results across landscape gradients and/or sharp edges between, for example, agriculture vs successional forest, urban vs rural, or differential land parcelization systems, in addition to the physiographic differences we examined. In such studies, multiple dates should be used and at least a cursory analysis of the socioeconomic dynamics should be performed to detect both overall trends and individual events.

Lastly, we believe that better understanding of rural landcover change offers significant opportunities for improved landscape planning and management within existing conservation practices and programs. This insight may be used in combination with land conservation programs such as the **USDA** Conservation Reserve Program, wetlands and riparian protection programs, or general conservation set-asides or land acquisition programs to target and/or configure conservation activities.

Acknowledgements

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