LINKING LANDSCAPE PATTERN TO SOCIAL PROCESS: A MULTI-SCALE ANALYSIS OF FARM WOODLOTS IN NORTHERN INDIANA

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Introduction

It is estimated that, globally land-cover change has contributed as much carbon dioxide to the atmosphere as has the combustion of fossil fuels over the past 150 years (Turner et al. 1995). The effect of land-cover change on global biochemical cycles has potentially drastic implications for the global environment (Turner et al. 1995). Since 39% of all carbon stored in terrestrial ecosystems is held in forests, the degradation and removal of this land cover is responsible for about 20% of current emissions (World Resource Institute et al. 2000). As the concern over global environmental change has increased, so has the recognition of land-cover change as a driving force rather than just an outcome of this process (Reibsame et al. 1994). In addition to the effect on the global environment, the ecological consequences of the fragmentation of remaining forestland on plant and animal habitats is severe. Habitat fragmentation has been shown to adversely affect numerous animals ranging from avian (Hobson and Bayne 2000) to primate (Onderdonk and Chapman 2000) to insect (Schiegg 2000) species. The changing pattern of the landscape is as ecologically important as its composition. Linking global-scale environmental change to local-scale management issues is one of the most important and difficult challenges in research on the human dimensions of global environmental change (Moran et al. 1998).

Landscape ecology has shown the importance of the link between landscape pattern and ecological process (Barnes et al. 1998). Following this logic in human-dominated landscapes, the variation in landscape structure implies differences in the social and biophysical processes that drive the land-use decisions being made. To date, however, landscape ecology approaches have rarely attempted to link landscape patter to social processes (Turner et al. 2001). With the combination of remotely sensed data and geographic information systems (GIS), the means now exist to step outside of the landscape and measure this pattern. As the influences on land-use decisions cross spatial and temporal scales, GIS and remote sensing provide access to the landscape at the variety of scales necessary to see the patterns that have resulted from man's interactions with the land.

While radical land-cover changes have be seen in most parts of the world, the European settlement of the predominantly forested eastern half of the United States is an important case. The frontier period in American history saw the clearing and fragmentation of substantial amounts of forest stretching from the East Coast to the Mississippi River. Abandonment has led to a process of reforestation of the Midwest states that continues today. Prior to European settlement, nearly 90% of Indiana was forested (Lindsey et al. 1965). Presently, forest covers only about 20% of the state (LeMasters and Rans n.d.). At the beginning of the twentieth century the amount of forest in Indiana had reached a minimum, dipping well below 10% of total land cover (Koontz and Jones 1998).

The composition and pattern of forest regeneration, however, varies greatly across the state. The south-central portion of the Indiana has a much higher proportion of land in forest, and this forest is less fragmented than in the northern part of the state. In the more recently glaciated, flatter areas of the state, forest generally occurs in highly fragmented, privately owned patches or woodlots. These woodlots exist on land that was originally forested but has either been stripped of its old growth or completely cleared since settlement.

In the northeastern section of Indiana, DeKalb County typifies this pattern of discrete woodlots occurring in a predominantly agricultural area. DeKalb County provides an excellent study site for examining the processes underlying this land-cover pattern because of the lack of major urban centers or major physiographic features. The woodlots that comprise the forested landscape of the regions encompassing northern Indiana must be understood in terms of the interactions between biophysical and social forces over the last two centuries. Glaciation shaped the gently rolling topography of the land and deposited the rich but poorly drained soils. As the land was settled and increasingly put into agriculture production, the poor drainage of the soils necessitated massive ditching and tiling of the land (Wise 1987). As the forests were being felled for agriculture, the retention of some timber resources was necessary for uses such as building material, fuel wood, and game habitat.

In this region, the woodlots represent the only remaining forest habitat. The continued removal and fragmentation of the woodlots has greatly altered this ecosystem that was once almost entirely forested. Research in spatially explicit ecological modeling (see Levin 1999) have shown that in addition to the overall amount of habitat, the pattern of woodlots also has an important effect on ecosystem dynamics. The abrupt edges of the discrete woodlots also stand in stark contrast to the more gradual gradients of successional forest regrowth in other parts of the state and region.

Understanding Land-Use and Land-Cover Change

Social and biophysical processes integral to the understanding of land use occur across a broad range of spatial and temporal scales (Clark 1985) and the driving forces of land-use change vary at these differing scales (Turner and Meyer 1991). Even when the variables remain the same across scales, their interrelationships can potentially change at different levels of scale (Fresco et al. 1996). Since numerous scales may be important in land-use and land-cover change research, it is first necessary to determine the appropriate scale or scales of analysis for the particular research question. Once the salient scales and land managers have been identified, driving forces, institutions, biophysical constraints, and proximate causes of land-use and land-cover change may be identified.

The notion that humans are the cause of environmental change in general and land-cover change in particular is important but too general to be of much use. The attempt to specify macro-level driving forces that underlie humans' effect on land cover has been a long-standing and controversial task. From Malthus (1798) to Boserup (1965), the most frequently cited potential driver of land use is some measure of population. The basic argument that more people consume more resources was expanded such that the impact of humans can be understood as a function of population, affluence, and technology (IPAT) (Ehrlich and Holdren 1971; Ehrlich and Ehrlich 1991). This formulation posits that wealth and technology provide the means for increases in per capita impact.

Pebbley (1998) cautions that the IPAT formulation was initially given as a means of calculating environmental impact rather than a framework for studying the relationships of its components. Conclusions about the effect of population on impact range from a direct relationship (Ehrlich and Holdren 1971) to an inverse relationship (Tiffen et al. 1994) to no relationship at all (Wolman 1993). Similar arguments about the direction of the relationships between affluence, technology, and environmental impact have been raised (see Turner 1995). Clearly the factors as well as the relationships between them must be examined rather than assumed in any analysis of environmental impact.

Turner and Meyer (1991) extend the IPAT model to include population, economic development, technology, socioeconomic organization, and attitudes and beliefs. Socioeconomic organization can be broadly understood as institutions ranging from international organizations to national governments to local collectives. The recognition of attitudes and beliefs highlights the issue of micro-level complexity and highlights the potential contributions of social sciences such as anthropology, sociology, and geography.

Harkening back to Malthus (1798), the inclusion of the biophysical characteristics of the land is clearly necessary for an understanding of land use. Where Malthus thought that these biophysical characteristics were the determinants of production, Pichon (1997) posits that the natural resources available to a land manager act as a straitjacket to the possible land uses at that location.

Rather than a single chain of influence, the constituents affect one another and are often engaged in non-linear and feedback relationships (Moran et al. 1998; Dale 1997). That is, in addition to interactions among the possible driving forces of land-use and land-cover change as described above, interactions among the major constituents are also present. This complexity is deepened by the multi-scale nature of the processes and necessitates an awareness and sensitivity to the spatial and temporal scales inherent in the process.

Contemporary Forest Managers

In the United States, more than half of the forest land is owned by private (non-governmental) landholders (Cubbage et al. 1993). Non-industrial private forest (NIPF) owners, however, are much more heterogenous in their views toward forest management and, therefore have not been well understood. A 1994 survey in the United States revealed that there are an estimated 9.9 million NIPF owners, with 90% owning less than 100 acres of forest land and an average holding of 24 forested acres (Birch 1995). The overall number of NIPF owners increased by 20% between the years of 1978 and 1995 (Agrow 1996). NIPF owners also exhibit a very high turnover rate with more than 40% having acquired their land during this period (Agrow 1996). Furthermore, owners of more than 90 million acres of forest are age 65 or older, and new owners are increasingly coming from urban backgrounds (Sampson and DeCoster 2000). These numbers clearly show that privately owned forests are a major constituent of the total forest area of the United States but are owned by an increasingly diverse group of people.

Research concerned with motivations conducted on non-industrial private landowners in southern Indiana show that non-monetary benefits dominate the list of reasons for performing land-use activities (Koontz 1999). Research in a similar landscape in southern Michigan also shows that non-economic motivations are driving land-use decisions. In a survey of woodlot owners, Erickson et al. (2001) report that aesthetic reasons and environmental protection rank higher than economic benefits. Characterized by hands-off management, this region is experiencing substantial reforestation both in areas with discrete woodlots and more sinuous riparian forests (Erickson et al. 2001). Although these areas exhibit different forest pattern outcomes, the motivations of the NIPF owners appear to be quite similar and stand in contrast to the economically driven theories often applied in forestry research.

Research Objectives

Working from the link between landscape pattern and underlying social processes, GIS and remote sensing provide the means for the recognition of unique human-environment interactions. This research will examine the pattern of woodlots found in northern Indiana as a function of biophysical and social processes occurring across spatial and temporal scales. To achieve this goal, a spatial database will be used to integrate the results from a household social survey with land-cover data derived from satellite remote sensing. Because the land managers make decisions within a broader spatial and temporal context, the household-level research is enhanced with a county-level study of forest cover for the rural counties of Indiana. Focused on the historical dynamics of agricultural land use in the state, a regression model will be presented that examines the change in forest cover over the past century. Remote sensing will again provides the land-cover information for this analysis, which takes an expanded view of the environmental impact as a function of IPAT approach. The following research questions will be addressed:

- What are the social and biophysical processes responsible for the amount of forest cover in the predominantly rural counties in Indiana?
- What is the current pattern of forest in DeKalb County, Indiaan and how has it changed over the past generation of land managers?
- What factors are important to a private landowner in the decision to retain a woodlot in DeKalb County, Indiana?

Study Area

Indiana

Although relatively little is known about the pre-European inhabitants of the land that became Indiana, McCracken et al. (1997) suggest that the forests of Indiana prior to settlement were only slightly modified relative to the extensive clearing that the Europeans subsequently undertook. Following the War of 1812, European immigrants began to settle the state from south to north in much larger numbers (Madison 1986). Because they were easier to clear and had superior soils, agricultural development initially followed streams and flatter areas (Koontz et al. 1999). By 1860, nearly all of the population was engaged in subsistence farming (McCracken et al.1997). Very few people, less than 10%, lived in the few existing towns. According to figures kept by the National Agricultural Statistics Service (USDA 2001), this agricultural expansion peaked at the turn of the twentieth century. At this time, more than 92% of the land in Indiana was held in farms (McCracken et al. 1997). As electricity and natural gas became widely available, industrial employment opportunities increased the draw to urban centers. Since 1900, the population has grown from around 2.5 million to over 6 million while the percentage of the population living in rural areas has gone from 66% to 23% (USCB 2000).

The pattern of inhabitants on the landscape has been largely shaped by the Land Ordinance of 1785 which laid out a survey system that divided the western public lands, of which Indiana was a part, into a rectangular grid (White 1983). The aggregation of these rectangular cadastral units provided the basis for organization into counties and states. Originally sold as whole townships or sections, these areas were often subdivided into 40-acre (quarter-quarter sections) or 80-acre parcels and sold or distributed to settlers.

For a similar landscape in Ohio that sits on the boundary between the rectangular survey system and the meets and bounds system, Thrower (1966) shows that the initial method of dividing the land had a substantial effect on the subsequent patterns of parcelization and land cover. With other social and biophysical factors controlled for, the land divided into regular rectangles is more easily accessed and subdivided than the irregularly shaped parcels of the meets and bounds system. This results in parcel and land-cover patch sizes being smaller in the areas divided according to the rectangular system (Thrower 1966).

McCracken et al. (1997) recognize that prior to the turn of the century, land that had not been converted to agricultural purposes could generally be categorized as old-growth forest or some other natural vegetation. Subsequent to 1900, however, these non-agricultural lands were composed of urban uses and forest regrowth (McCracken et al. 1997). Just one hundred years after gaining statehood, Indiana had gone from nearly 90% to less than 10% forested with the existing forest having been cleared and allowed to regrow (Koontz and Jones 1998).

Of the 1.7 million ha of forest in the state, 85% is on privately owned land (Tormoehlen et al. 2000). Since 1978, the number of private timberland owners in the state has tripled with only a slight increase in overall forest area (Tormoehlen et al. 2000). The majority of the increase in timber-producing forests seen over the past two decades has occurred in the highly fragmented Northern Unit which covers the northern 60% of Indiana and of which DeKalb County is part (Schmidt et al. 2000).

DeKalb County

Located in the northeastern corner of Indiana (Figure 1), DeKalb County has an area of 940 km^2 with a population slightly greater than 35,000 people (USCB 1990). A predominantly agricultural county, seven hundred and eighty-five farms cover 75% of the county's total area (USDA 2001) but employ only 7% of the population (USCB 1990). The median household income is about $31,000 (USCB 1990). The number of households is split almost exactly in half in terms of rural and urban dwellings with 81% of households owning the land on which they live (USCB 1990). The largest town in the county is Auburn with approximately 9,000 inhabitants. Immediately to the south of DeKalb county, however, lies Allen County, which holds Indiana's second largest city, Ft. Wayne. This large and quickly growing metropolitan area undoubtedly will exert great influence on the much more rural DeKalb County in the near future. From the beginning of the twentieth century, the amount of land in farms in DeKalb County has steadily decreased while the average farm size has increased (USDA 2001). This reflects the statewide historical trends of mechanization and corporatization of agriculture.

The retreat of the Wisconsin age glaciers around 10,000 years ago left numerous "kettle" lakes dotting the landscape (Wise 1987), but no major rivers traverse the county. The lack of natural drainage meant that most of the county was very wet or flooded for much of the year (Wise 1987) prior to the construction of artificial drainage.

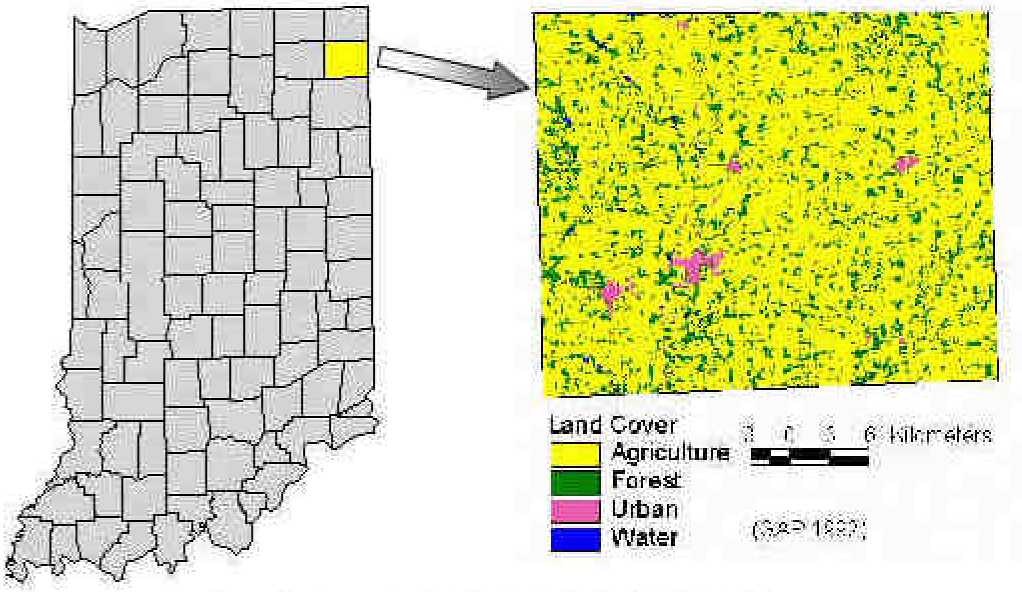

Figure 2. Location of DeKalb County, Indiana, USA
(land cover derived from GAP 1993)

Methodology and Data

The multi-scale nature of both the social and biophysical processes that drive land-use and land-cover change necessitates a multi-scale analysis. In the privately owned landscape of DeKalb County, Indiana, the primary level of decision making is the household. To understand the context of household-level land-use and land-cover decisions, a county-level analysis also will be undertaken

County-Level Analysis

This research will focus on the period from 1900 to 1997. The beginning of the period defined by the apex of land in agricultural use and the latter date being dictated by the most recent agricultural census (USDA). Because of different management goals and practices in urban areas, counties that are classified as greater than 10% urban according to the Gap Analysis Project (GAP) land-cover classification (GAP 1993) have been excluded from this research. Of the 92 counties in Indiana, five are excluded for this reason, leaving 87 observations. The processing of all spatial datasets was done using Arc/Info 7.2 (ESRI 1999) and ArcView 3.2 (ESRI 1992) GIS software packages.

The county-level model tested here is an ordinary least squares regression of the form:

$$Forest = f(PopDens, ManagedLand, AgLoss, Machinery, Slope, Drainage)$$

where *Forest* is the percent of the county that has regenerated to forest, *PopDens* is the change in total population, *ManagedLand* is the percent of the county in publicly held lands, *AgLoss* is the amount of land that has gone out of agricultural use, *Machinery* is the average value of agricultural equipment per farm, *Slope* is the average slope of the county, and *Drainage* is the percent of the county classified as poorly drained.

The dataset employed to quantify this regrowth was produced jointly by groups at Indiana State University and Indiana University. The dataset is derived from a set of classified Landsat Thematic Mapper (TM) satellite images that were acquired from 1989 to 1993. The dataset was aggregated from 16 classes to four (agriculture, forest, urban, and water), thereby increasing the overall accuracy of the classification from 70.98% to 84.13%. The final classification was filtered raising the minimum mapping unit to approximately 1 ha while retaining the original 30 m x 30 m cell size.

The operationalization of population measures as either population change or population density has been debated. In Indiana, however, the population density at the beginning of the study period was very homogeneous, making the two measures effectively equivalent. Population density is used here. The population of Indiana counties is taken from the 2000 United States Census (USCB 2000).

While institutions are difficult to quantify, an important dimension of the socioeconomic structure of the state comes from the dichotomy of privately versus publicly managed lands. The percent of the county managed for public use was obtained from a spatial dataset maintained by the Indiana Department of Natural Resources (IDNR).

As the move from subsistence farming to mechanized agribusiness provided the space for much of what would become Indiana's forestland, the difference of land in farms from the beginning to end of the study period is used to quantify the change in economic structure. These values were obtained through the NASS's Agricultural Census (USDA 2001).

On the assumption that all subsistence farms used approximately the same level of technology at the beginning of the study period, the dollar amount of farm machinery in use at the end of the study period is used here to measure technological change. This variable has been operationalized as estimated mean value (in dollars) of all machinery and equipment per farm from the NASS Agricultural Census (USDA 2001).

The dominant biophysical constraints present in the state vary spatially according to glacial history with slope generally more important in the south and drainage more important in the north. An average slope value for the county is included as a biophysical constraint to land use and land cover from United States Geological Survey (USGS) 1:250,000 Digital Elevation Models (DEM) which have a spatial resolution of 80m x 80m. The STATSGO soil dataset contains a measure of drainage calculated from hydraulic conductivity, water-holding capacity, and depth to water table. The percent of the county categorized as having poor drainage was used to quantify this biophysical constraint.

Household-Level Analysis

Set in the above context, specific land-management decisions for privately owned parcels of land are made at the household level. To obtain information on factors affecting household-level decision making, a questionnaire was sent to a randomly selected sample of landholders. This social data was tied to land-cover outcomes, specifically the choice to maintain a woodlot or not, by means of land-cover data derived from remotely sensed data. The decision whether to maintain a woodlot or not was analyzed through the generation of a decision tree based on the spatial and questionnaire data.

The most recently produced, commercially available plat maps (Authentic 2000) were scanned and georegistered to a 1:24,000 vector dataset of roads produced by the USGS. The plat maps were digitized to produce a vector layer of parcel boundaries. Because this research is focused on decisions made by non-industrial private land owners, all commercial, industrial, and publicly held parcels were excluded from the study. Furthermore, since the focus of this research is on rural land management, residential parcels (parcels with an area of less than 5 acres or about 2 ha) were also excluded.

The survey instrument was mailed to the owners of a random sample consisting of 300 of the 3,359 eligible parcels in the study area. The respondents were directed to fill out a separate questionnaire for each land holding. Sixty-three usable surveys were returned, and the information was coded as attributes of the parcels in the GIS. The types of information collected in the questionnaire are listed in Table 1.

A Landsat Multi-Spectal Scanner (MSS) image from September 1976 was used as a baseline land-cover dataset. This image was georegistered to available digital orthophotos with a resulting root mean square (RMS) error of .43 pixels or 25.8 m. The image was classified into 25 classes using the ISODATA unsupervised clustering algorithm in ERDAS Imagine 8.2 (ERDAS 2001). The clusters were interpreted according to scanned and registered 1972 aerial photos. Based on 200 randomly generated test points, the overall accuracy for the forest/non-forest classification was 94.1%.

Table 1. Information Collected in Household survey

Household Demographics	Parcel Characteristics	Landowner Views on Value of Woodlot
Number of household members	Owned or rented by respondent	Most important reasons for keeping a woodlot
Members' ages	Changes in ownership or size	Most important benefits from the woodlot
Members' highest education levels	Improvements (ditching, tiling)	Most important sources of information in making decisions about management
Income	Importance as a source of income	Participation in government programs
	Agricultural activities	History of changes made to the woodlot
	Presence and size of a woodlot	Future management plans

The 2000 land-cover dataset was obtained through the National Agricultural Statistics Service (USDA 2001). This classification was derived from Landsat TM scenes acquired in June and August of 2000. A supervised maximum likelihood method used land-cover signatures generated for locations corresponding to information collected in the annual June Agricultural Survey. The number of signatures used in classification was not reported, but 231 signatures were used for accuracy assessment yielding a 95.56% overall classification accuracy. The aggregation of land cover from 11 to two classes (forest, non-forest) for use in this research will certainly have increased the overall accuracy from the already very acceptable numbers above.

In order to compare the two images, the 2000 classification was resampled from the original 30 m to 60 m in order to match the resolution of the 1976 MSS data. Both datasets were then filtered raising the minimum mapping unit to five cells (1.8 ha or almost 5 acres). This cutoff was chosen to remove smaller patches such as tree lines or residential areas that are not considered woodlots. These datasets were used to calculate land-cover change metrics at the patch level using the Patch Analyst extension of ArcView 3.2 (ESRI 1992).

Decision Tree Analysis

To locate patterns in the household survey data regarding the decision to retain or remove woodlots, the decision tree generation software See 5.0 was employed. In terms of this research, each landowner can be understood as a case. The outcome (or type) of each case that is to be explained is whether or not that landowner has made the decision to maintain a woodlot on his or her parcel. The four possible land-cover change scenarios of forest and non-forest were simplified according to their outcomes as either woodlot or no woodlot. Each attribute collected in the household survey is a candidate attribute for creating a branching node by which to distinguish and classify the landowners. Classifying the landowners by means of a decision tree provides an output that is intuitively interpretable as a hierarchical set of factors that are involved in a management decision. This means that the higher the attribute occurs in the tree, the higher its ability to discriminate among the possible outcomes. To test the predictive accuracy of the decision tree created, a set of test cases may be provided. For this research, the 63 cases were randomly divided into training (32 cases) and testing (31 cases) sets.

Results

County-Level Results

The results of the OLS regression model are presented are presented in Table 2.

Table 2. County-Level OLS Model Results

Variable	Unstandardized		Standardized		
	Coefficient	Std. Error	Coefficient	t	p-value
Constant	.168	.046		3.686	.000
AgLoss	.248	.077	.267	3.682	.000
ManagedLand	.357	.167	.132	2.247	.027
Machinery	-4.17E-07	.000	-.059	-1.000	.321
PopDens	-4.92E-02	.022	-.095	-2.257	.027
Drainage	-1.48E-03	.000	-.183	-3.300	.001
Slope	5.974E-02	.009	.452	6.747	.000
Model Fit: R = .943 R^2 = .889 Adjusted R^2 = .881					

The overall model is statistically significant and predicts nearly 90% of the variation in the proportion of the county in forest. All of the individual predictors are significant at the $p < 0.05$ level except the mean market value of machinery per farm. The amount of land taken out of agriculture, the amount of land managed for public use, and the mean slope are positively related to the amount of forest cover. The mean value of farm machinery per farm, population density, and the proportion of the county with poorly drained soils have a negative relationship with the amount of forest cover.

As operationalized in the model, mean market value of farm machinery is the only variable that is not a significant predictor of the amount of forest cover at the county level. The reason for this may stem from the fact that the vast majority of agriculture that currently exists is similar in its high level of mechanization and so insufficient variation exists to predict variation in forest cover. Further study is necessary to establish the details of these relationships and appropriate indicators.

Household-Level Results

The study sample included 1.8% of the population of eligible parcels (Table 3). While the proportion of parcels with a woodlot in the sample was very similar to that of the population, the mean area of sample parcels and the mean area of sample parcels with a woodlot were higher than the population means.

Table 3. Parcel Characteristics

Parcels	N	Mean Area (ha)	Parcels with Woodlot	Mean Area of Parcel with Woodlot (ha)
Sample	63	30.24	63.5%	39.90
Population	3359	22.96	64.7%	28.35

Change in Forest Cover

Land-cover change analysis was accomplished through forest/non-forest classification of Landsat images from 1976 and 2000 (Table 4).

Table 4. Change in Forest Cover from 1976 to 2000

	Woodlots	Mean Area (ha)	STD	Mean Shape Index	Total Area (ha)	Percent of Landscape (%)
1976	1097	10.38	16.52	1.816	11386	14.8
2000	1074	9.75	18.23	1.887	10473	13.6
Change	-2%	-6%			-8.0%	-1.2
196 woodlots removed with average area of 3.28 ha						
153 woodlots gained with average area of 2.81 ha						

The net change in the number of woodlots over the study period was a decrease of 23. The actual change was more dynamic with the removal of 196 woodlots and the addition of 153 woodlots. These more dynamic woodlots were much smaller than the mean woodlot size. The dynamics of these small woodlots were not reflected in the sample where no wholly new woodlots or wholly removed woodlots were reported. One important distinction is that the statistics reported for woodlots in Table 3 (and throughout) refer to patches of land cover. That is, the definition of woodlot does not take into account property boundaries, so one woodlot could (and often does) occur across multiple parcels. When the respondents referred to woodlots in the questionnaire responses, it was assumed that they were referring to the wooded area that occurs on their property regardless of whether it was adjacent to someone else's woodlot. The mean area per woodlot decreased by .63 ha or 6.0%. The mean shape index changed very little over the study period. Total forest area dropped by 8.0%, decreasing the percent of landscape in forest by 1.2%.

Decision Tree

A decision tree was created based on a randomly drawn sub-sample of the 63 total questionnaires received (Figure 2). Using 31 cases for the creation of the decision tree, the remaining 32 cases were used to test its predictive power. The tree shown below correctly predicts the presence or absence of a woodlot in 87% of the test cases. The variable that most powerfully descriminates between respondents with and without woodlots is parcel size. The largest parcels have woodlots, whereas the smallest do not. Of the midsize parcels, the use of artificial drainage is the next most powerful predictor of the presence of a woodlot. The use of artificial drainage is associated with having a woodlot while the absence of artificial drainage is associated with not having a woodlot. Of parcels that do not have artificial drainage, change in parcel size over the study period predicts the lack of a woodlot. Where the parcel did not change size, its importance as a source of income is the final branching in the tree. High importance as a source of income is associated with the presence of a woodlot whereas low importance is associated with the lack of a woodlot.

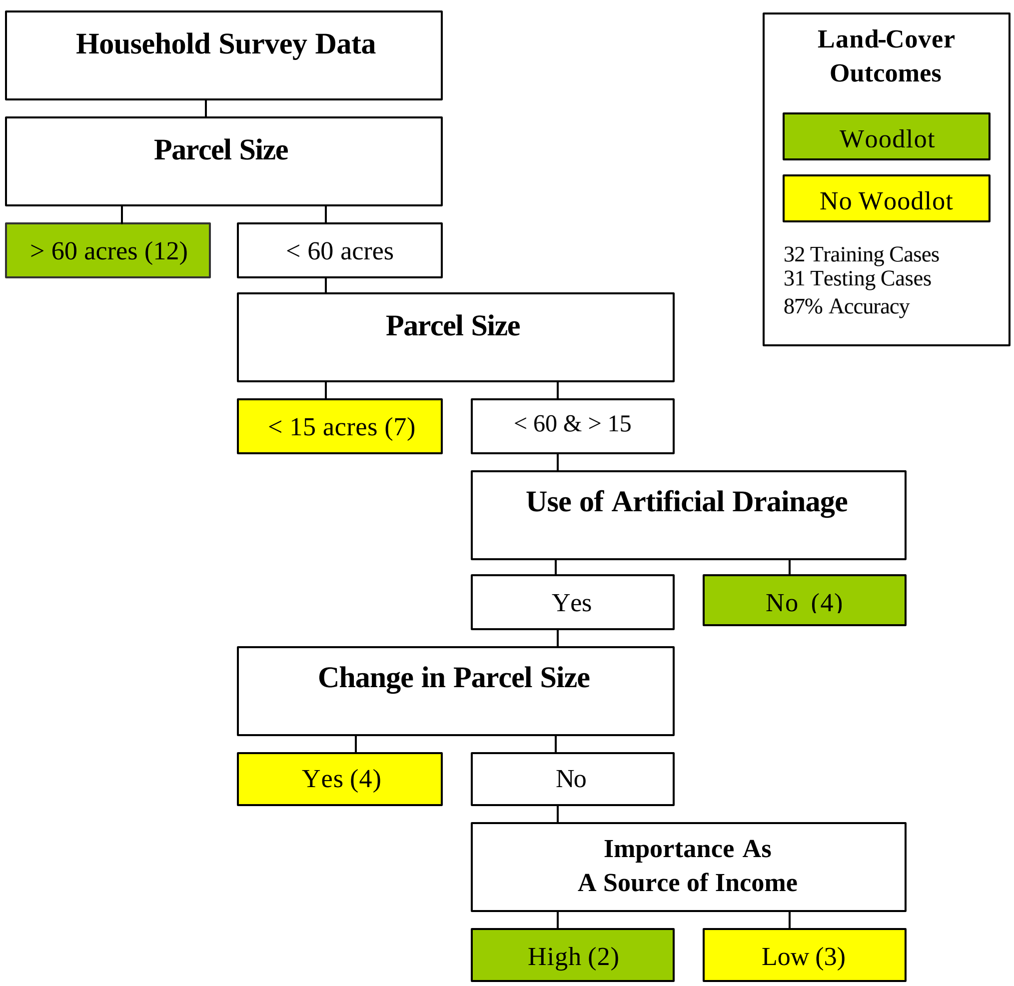

Figure 2. Land-Use decision tree

Discussion and Conclusions

The significance of the county-level model confirms the understanding of the regeneration of forests as a function of the retraction of agriculture. More specifically, the significance of the loss of agricultural land indicates that the more area taken out of agriculture, the higher proportion of forested land in the county. Although counties that are now predominantly urban are not included in this research, counties with high population densities show significantly less forest. The Malthusian notion of a negative relationship between population and environmental impact has been hotly contested but can be understood here in terms of agricultural retraction.

As the retraction of agriculture on overused lands did not go unnoticed by the state and federal governments, they also purchased some of this land with the aim of encouraging forest regeneration as a future resource. For this reason, the proportion of a county managed as a public-use nature reserve exhibits a positive relationship to the amount of forest cover. The steep slopes and thin soils of the unglaciated south-central portion of the state saw the greatest amount of agricultural retraction and purchase of public land for this reason.

While the model has high explanatory value, several assumptions limit its potential to explain all the variation in forest cover. The dependent variable of forest cover is implemented as the change from an entirely deforested forest landscape at the beginning of the study period. This is of course not true as there was some proportion of the landscape at the beginning of the study period that had (1) never been deforested, (2) been cut but allowed to regenerate to forest, and (3) never been forested at all. While it is important to note these assumptions, the model clearly captures important aspects of the underlying processes of forest change in Indiana.

The pattern of woodlots in DeKalb County is also a function of its agricultural past. The poor natural drainage of the study area necessitates artificial drainage in the form of ditches and tiles to make agricultural land uses possible (Wise 1987). According to the district forester, as the land was initially cleared and drained for farmland, some woodland had to be retained as a resource for building materials and fuel (Lichtsinn 2001). Land was drained and cleared first along the roads because these areas were easiest to access. Roads were generally constructed along section or quarter section lines (Thrower 1966). Because it was necessary to keep some wooded land, the areas furthest from the road and less accessible were not drained or cleared. As multiple landowners followed this same strategy, often times the woodlots that were left standing would be on the "inside" corners of subdivided sections (Lichtsinn 2001). When multiple parcels underwent this same pattern of clearing, woodlots would end up adjacent to one another in the center of sections, creating larger forest patches. As the overall demand for agricultural land diminished in the state, the conversion of these woodlots became less and less likely. This pattern persists in the current landscape to the extent that nearly 77% of the wooded land in the county occurs in the 50% of land that is furthest from the roads (Figure 3).

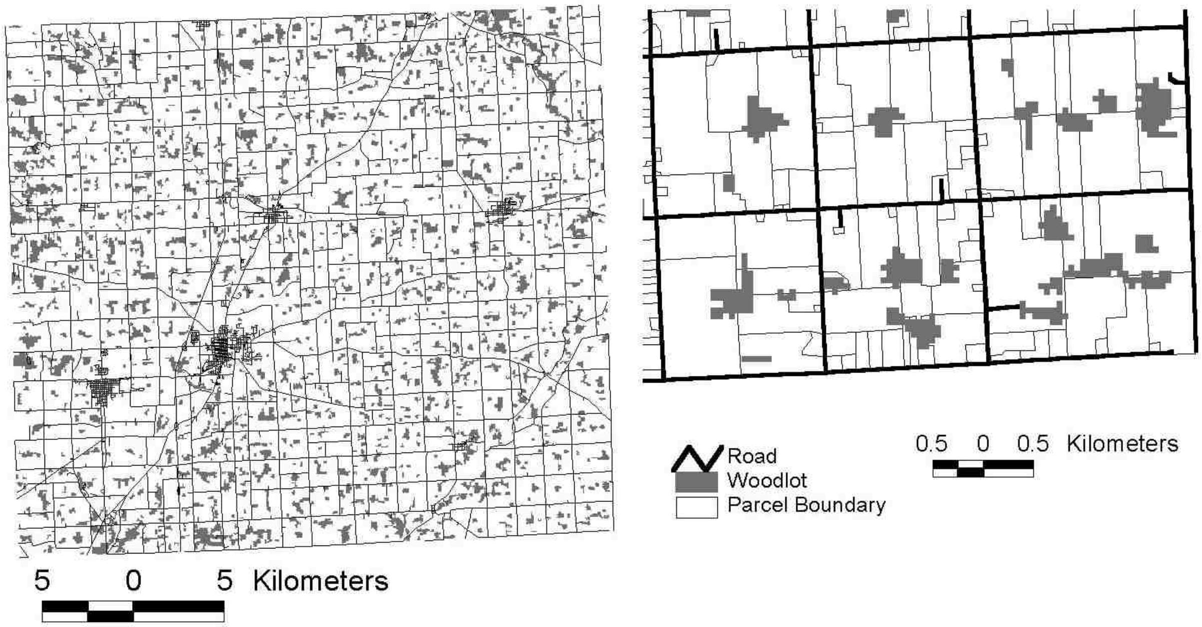

Figure 3. Pattern of Woodlots in DeKalb County

The decision tree analysis again points to the role of agriculture in the presence or absence of woodlots. Larger parcel size, artificial drainage, lack of subdivision, and importance of the parcel as a source of income all tend to be correlated with the presence of a woodlot. At each bifurcation in the tree, the branch that represents the stability of agricultural land use strongly predicts the presence of a woodlot. Clearly, the stability provided by agricultural land uses has allowed the perpetuation of woodlots that were once necessary resources.

Although collected from the questionnaire and included in the generation of the decision tree, demographic factors are conspicuously missing as important predictors of the presence of a woodlot. Characteristics such as household income and education level are often cited as important factors in land-use and land-cover decision making. For this region, however, parcel characteristics better convey the importance of current and historical agricultural processes that underlie the landscape pattern.

When trying to tie the results of these analyses together, however, they at first seem contradictory. At the county level, more dynamics in agricultural land use over the past century have resulted in a higher proportion of forest cover. On the other hand, dynamics in land use at the parcel or household level in the study area have resulted in a less forested landscape. The direction of forest change at these two scales is contrary while the general underlying process is the same.

At the aggregated level, the state is becoming more forested which bodes well both in terms of biogeochemical cycles such as carbon and in terms of habitat. The ecological effects of near total removal of the forest prior to the current regeneration have not yet been fully understood, but the regeneration of forests is proceeding. At the household and parcel level, the reduction of woodlots renders a more pessimistic outlook. Even if this landscape is on the brink of a transition to a more forested, non-agricultural organization as has occurred in some southern parts of the state, the interim period of decline may have negative consequences. The further diminution of this highly fragmented forest landscape could result in catastrophic shifts before the habitat is totally removed. While still dominated by agricultural land use, the landscape of DeKalb County and the surrounding region may well be moving toward such a threshold as the pattern of forest is further altered.

As the primary social processes shaping the landscape change from agriculture to residential, so shall the pattern and composition of the forest landscape. Residential landowners bring different motivations that may allow more land to regenerate to forest. As the number of landowners increases, however, ownership becomes more fragmented which will almost certainly lead to land-cover fragmentation. It seems clear that this landscape that has changed little since the turn of the century is approaching a time of rapid change.

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