Zoning and Fragmentation of Agricultural and Forest Land Use on Residential Parcels in Monroe County, Indiana

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Urban growth and development in smaller cities or peri-urban communities is an increasingly important component of land-use change in the United States. One concern is that urban or residential growth will lead to increased fragmentation of other land uses such as forest or agriculture. Landscape fragmentation is important from both ecological and socioeconomic perspectives. In countries such as the United States the primary means of controlling landscape fragmentation are land use planning and zoning ordinances. Zoning is a way for local government officials to manage land use and attempt to guide the future land use into a configuration that is seen as desirable. The effectiveness of most planning and zoning in achieving the desired goals and landscape configurations remains unclear. This research addresses the following question: how effective is zoning within Monroe County, Indiana, in regulating fragmentation when considered at a meaningful socioeconomic landscape unit (i.e. the parcel)? Using Geographic Information Systems (GIS) to integrate spatially explicit socioeconomic data and a land use/land cover map created from a classified remotely sensed image of Monroe County, Indiana, we examine the impact of zoning-related policy on fragmentation of forest and agricultural land use/land covers on primarily residential parcels. We find that the degree of slope and parcel size affect fragmentation of agricultural, forest, and developed land use/land cover as expected, but that zoning is more significant.

Keywords: Urban sprawl, landscape fragmentation, land use/land cover, GIS and remote sensing, zoning.

A leading environmental issue for the next century in the United States is limiting the environmental impacts of urban sprawl (Karasov, 1997). Urbanization tends to alter major biogeochemical cycles, add or remove species, and alter habitat. These changes in turn trigger further alterations in ecosystem functions, most notably by driving global climatic change and causing irreversible losses of biological diversity, ecosystem resilience, and genetic vitality (Vitousek et al., 1997).

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Urban growth or sprawl is increasingly occurring in peri-urban or rural areas, particularly as agricultural and natural or forested areas are converted to residential development. This trend is often called counterurbanization, or the tendency for people to move out from cities and suburbs into rural areas which tend to have greater natural resources, leisure opportunities and ecosystem services (Midmore and Whittaker, 2000; Deller et al., 2001). Given that residential land use is an increasingly important component of total land use, how will it impact other land uses in a peri-urban community? More importantly, how well do traditional planning tools, such as zoning, perform in regulating this growth spatially? Using Geographic Information Systems (GIS) and remote sensing techniques, we examine landscape patterns at and around the (residential) parcel level in Monroe County, Indiana, to determine a) the relationship between parcel characteristics and land use/land cover; and b) how zoning relates to fragmentation of forest and agriculture within and near parcels.

RESIDENTIAL GROWTH AND LANDSCAPE FRAGMENTATION

Urban sprawl results in a loss of natural vegetation and a general decline in the spatial extent and connectivity of wetlands, wildlife habitat, and agricultural lands (Buchanan and Acevedo, 1997). Although much of the research analyzing spatial patterns in the landscape, particularly of forest cover, has emphasized the importance of biophysical factors, socioeconomic factors are also important and may be more important in some areas (Entwisle et al., 1998). Many current land use practices have resulted in fragmentation of both habitat and service areas. In terms of residential land use, increasing landscape diversity has more potentially conflicting edges and opportunities for externalities to positively or negatively affect neighbors (Geoghegan et al., 1997). Landscape fragmentation is also highly related to land use/land cover on individual parcels. Land use/ land cover at the parcel level results from a number of complex and interacting factors such as the degree slope, individual land management preferences and characteristics, and economic market incentives. Thus, spatial patterns in the landscape relate to both ecological and economic functions (Civco et al., 2000).

The primary tool for land managers to lessen or prevent landscape fragmentation is the zoning ordinance, which is based upon a comprehensive land use plan. Typically, a group of elected representatives take the recommendations of the planners and community members into account and draft a zoning ordinance or law. The rationale for creating a zoning ordinance is that it has the potential to channel growth in ways that are in the collective interest of the locality. However, some argue that the real motivation behind zoning policy is to sustain urban growth and development even at the expense of other social or environmental goals (Pfeffer and Lapping, 1994).

Many different types of land-use plans have been implemented in efforts to reduce the impact of urban sprawl and associated loss of open space and environmental degradation. However, little literature is available on how to generate empirical evidence of the success or failure of plans to guide the future physical development of cities (Weitz and Moore, 1998). In this article we argue that a combination of theory and methodology from landscape ecology and geography provides a means of empirically documenting the link between land use planning and zoning, and landscape fragmentation (see Hersperger, 1994 for an overview of landscape ecology in relation to planning).

Geography and urban studies are increasingly incorporating aspects of landscape ecological research (and vice versa) in order to better integrate the human dimension into studies of landscape composition, configuration, and function. One indicator commonly used to quantify the quality of ecosystem function is the degree of land use/land cover or habitat fragmentation. The degree of fragmentation is based on the number and distribution of patches or distinct (non-adjacent) areas of the same land cover type (O'Neill et al., 1997). Patterns evident in spatial metrics can be used to infer ecological and socioeconomic functions. For example, habitat fragmentation may lead to a decline in biological diversity and the ability of ecosystems to recover from disturbance. Spatially fragmented urban growth may lead to declines in property values at the urban center, increased transportation costs, and less efficient use of land.

In order to quantify the degree of fragmentation in a landscape, metrics of the composition and configuration of the components of the landscape are often calculated. Frequently, the data used as inputs for such calculations come from remotely sensed imagery (O'Neill et al., 1997; Frohn, 1998; and Southworth et al., in press). Metrics correlate with specific aspects of both ecosystem function and socioeconomic characteristics. Differences in landscape metrics derived from remote sensing have been linked to differences in socioeconomic conditions (Medley et al. 1995; Turner et al., 1996; Wear et al., 1996; and Wickham et al., 2000).

STUDY AREA: MONROE COUNTY, INDIANA

Monroe County, Indiana offers an interesting case study of the impact of different land use and zoning policies on landscape fragmentation. Although urbanization is occurring within the county, a wide range of land uses and land covers coexist. Unlike in other areas, forest (mostly secondary succession) is still a dominant land cover. The city of Bloomington (Monroe County seat, regional economic and cultural center, and home to Indiana University) is located approximately in the middle of Monroe County. Bloomington is somewhat unique in the region of southern Indiana in that it is experiencing relatively rapid urban growth. Between 1950 and 1996, Bloomington grew at an annual rate of 1.97 percent from 28,163 to 66,479 residents. This is the largest percentage increase in total growth of the fifteen largest cities in Indiana. Over the last fifty years, Bloomington has grown at one of the fastest rates in Indiana and moved from the 19th largest city in the state to the eighth (City of Bloomington Environmental Commission, 1997).

Forests are an important component of the landscape of southern Indiana. In contrast to the glacially impacted northern portion of the state, southern Indiana is composed of hilly terrain with relatively thin, poor soils. The hills and steep topography have made areas unattractive for modern agricultural use and secondary forests have been allowed to re-grow in some areas.

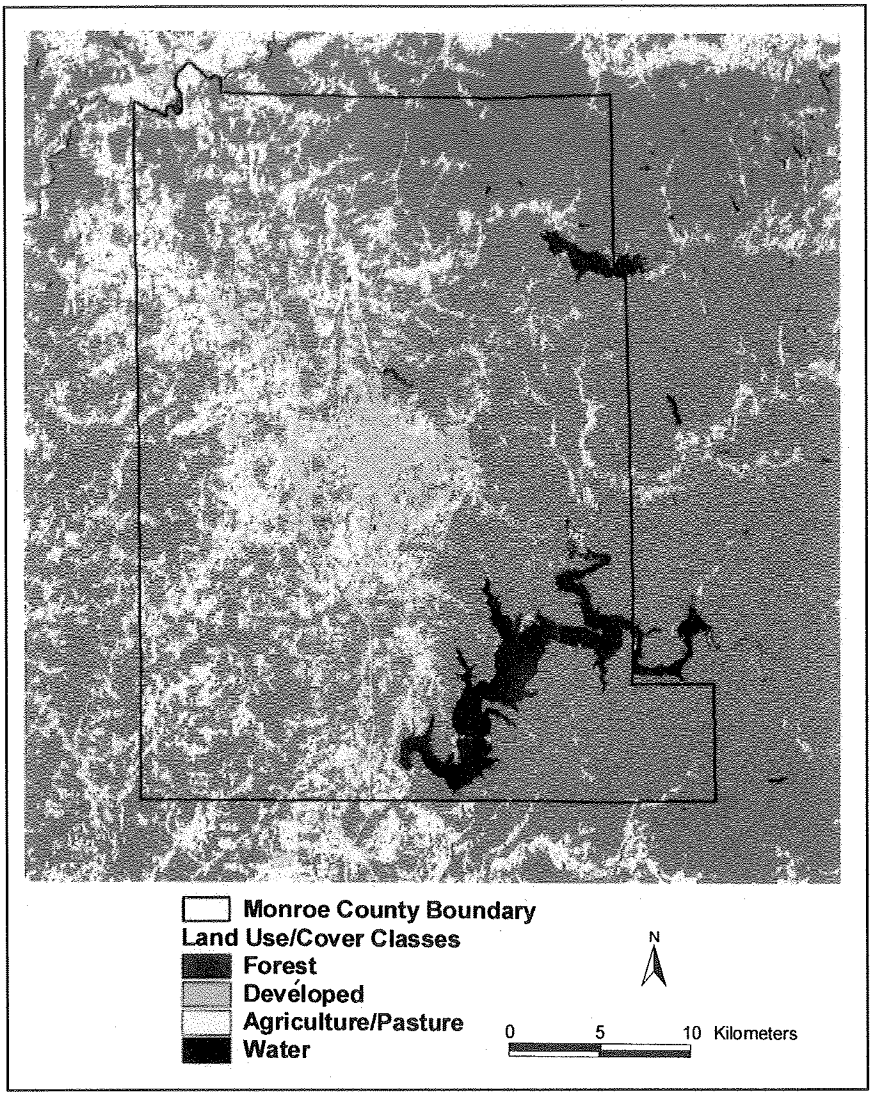
Management of open space is often a complex issue involving multiple owners and land use decision makers. Public purchase of land is expensive, especially in rural/urban fringe areas where there are often sharp increases in land values (Pfeffer and Lapping, 1994). Thus, effective policies must consider private land management. This is especially applicable for the management of forest and agricultural open space in Indiana. Approximately 87 percent of Indiana's forest cover is on private land (Petersen, 1998). Fragmentation of forest habitat and ownership comprise one of the largest threats for sustainable use of the forest resources (Petersen, 1998). Indiana's state foresters have indicated that the two biggest threats to the forests are residential development and the lack of coordinated management of non-industrial private forestlands (Fisher et al., 1993).

Although urbanization is occurring and will likely continue to occur within Monroe County, policies have the potential to direct the growth in such a way that impacts the natural ecosystem function and culturally important landscapes are limited. The following sections demonstrate how GIS and remote sensing can be used to improve such an analysis and produce information to better inform land use policy-makers on the effectiveness of land use planning and zoning.

DATA AND METHODS

A map of land use/land cover was produced from a supervised classification of a remotely sensed Landsat Thematic Mapper image from September 1997 (see Figure 1). Analysis of land use and land cover patterns offers a means of linking socio-economic processes associated with land development, agricultural activities, and natural resource management strategies and the ways that these changes affect the structure and function of ecosystems (Turner and Meyer 1991, Brown et al. 2000). Land use incorporates the influence of economic, cultural, institutional, and historical factors. Land cover is related to land use, however, it represents the directly observable biophysical component of the landscape (Brown et al. 2000). Our classification technique has allowed us to discern some human intervention on the landscape. For example, we have separate classifications of agriculture/pasture land use and forest. However, our classification technique is limited in that, for example, we cannot distinguish primary forest from secondary succession (for a more complete discussion of the classification process see Croissant 2001).

Figure 1: Land use/land cover classes for Monroe County, Indiana, 1997.



The classification used in this analysis consists of: (1) all forest including immature secondary succession; (2) developed areas including areas of residential and commercial land use, rocks, and concrete; (3) agricultural areas including row crops and pasture; and (4) water. In an effort to decrease the 'salt and pepper' appearance of the classification and reduce the number of very small patches, a fuzzy convolution algorithm was included in the maximum likelihood classification. There are very few natural rock outcroppings in the study area. The few areas of exposed rock in the study area are typically quarries or lake or stream shore. The rock areas associated with quarries are classified as developed lands in our classification due to their industrial land use. Areas of rock on the shores of streams and lakes were identified and added to the water class.

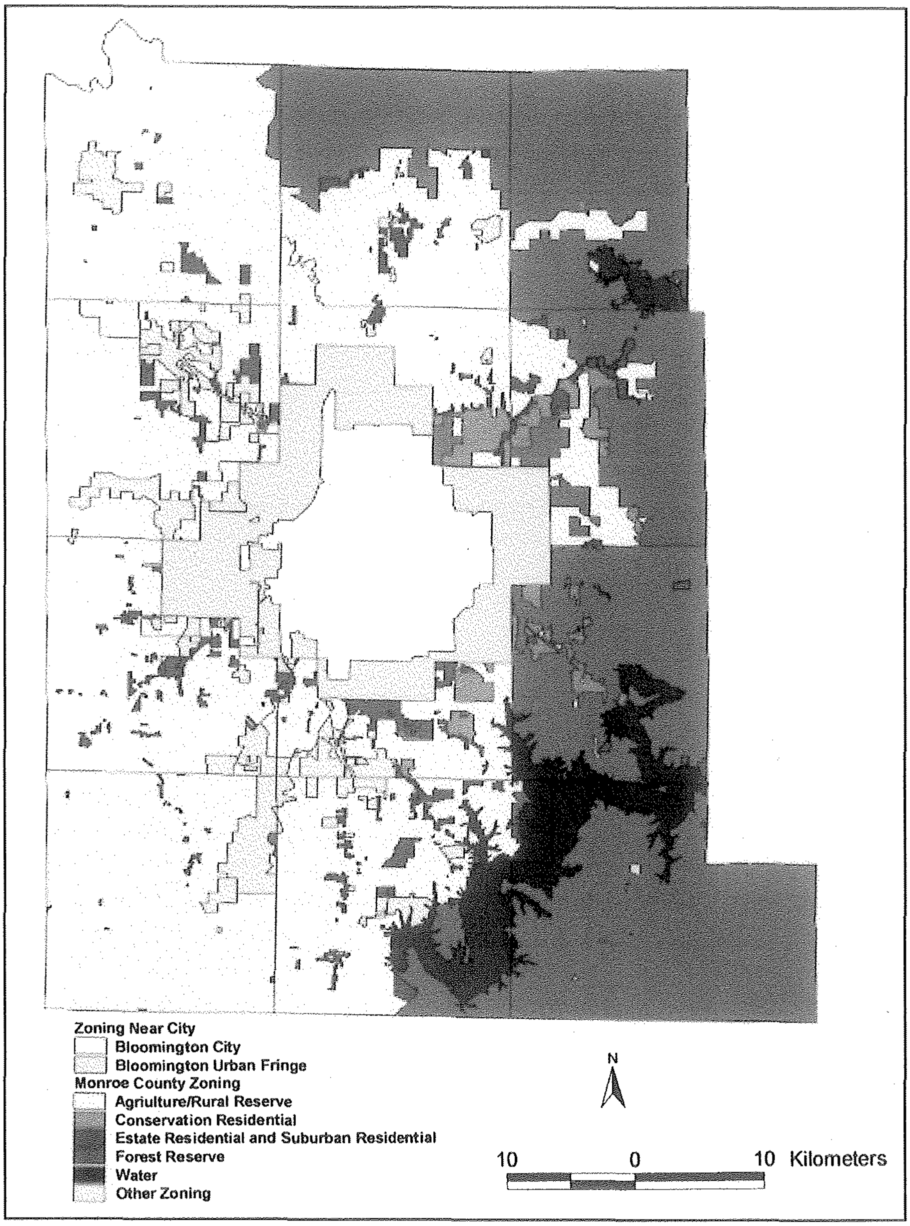
The resulting classification had an overall accuracy of 95 percent with a Kappa Statistic of 0.92. The Kappa Statistic measures the observed agreement between the classification and the reference data and the agreement that might be attained solely by chance matching (Campbell, 1996). A limitation of this analysis is the spatial resolution of the remotely sensed imagery data used to create the map of land use/ land cover. Because the minimum cell size of the data was 30 meters by 30 meters (or 900 m^2), it was not possible to distinguish variation in land use/land cover occurring over an area smaller than 900 m^2. Since we are interested in general trends, this limitation is acceptable for this analysis. The size of the parcels in the sample range from roughly 5 to 150 acres (or 2.02 to 60.7 hectares).

Because steep slopes can limit development in areas not served by municipal sewer systems, limit the potential for agricultural productivity, and encourage reforestation in an effort to reduce erosion, we include topographic data in our analysis. We also include parcel size in our analysis. Parcel size is also related to zoning in that certain types of zones require larger lots or parcels and development tends to follow parcel subdivision (Levia, 1998; Walker, 2001). Individuals who own a large parcel may react differently to a policy than those with smaller parcels due to wealth effects (Irwin and Geoghegan, 2001). Data on zoning, slope, and parcel size were entered into Arc/Info GIS. Slope data were obtained from a 1:24,000 scale digital elevation model, which was updated in June 2001 by the United States Geological Survey. Zoning within the county jurisdiction (see Figure 2) and parcel boundaries from approximately 1998 were obtained from maps produced by the Monroe County Planning Office (Camiron, 1991; Monroe County Planning Commission, 1996). We also calculated distance from the centroid of each parcel to downtown Bloomington as a measure of access to cultural and economic amenities, which is another important parcel characteristic.

In analyzing land use/land cover fragmentation from a socioeconomic perspective, the individual parcel is the unit of observation rather than a landscape pixel. The use of landscapes corresponding to individual parcel boundaries is preferred over the use of more biophysically based boundaries (Irwin and Geoghegan, 2001). Given this preference, a sample of 251 privately owned parcels which have non-industrial uses was chosen for this analysis based on a stratified random sample of parcels over five acres (about two ha.) in size within Monroe County.

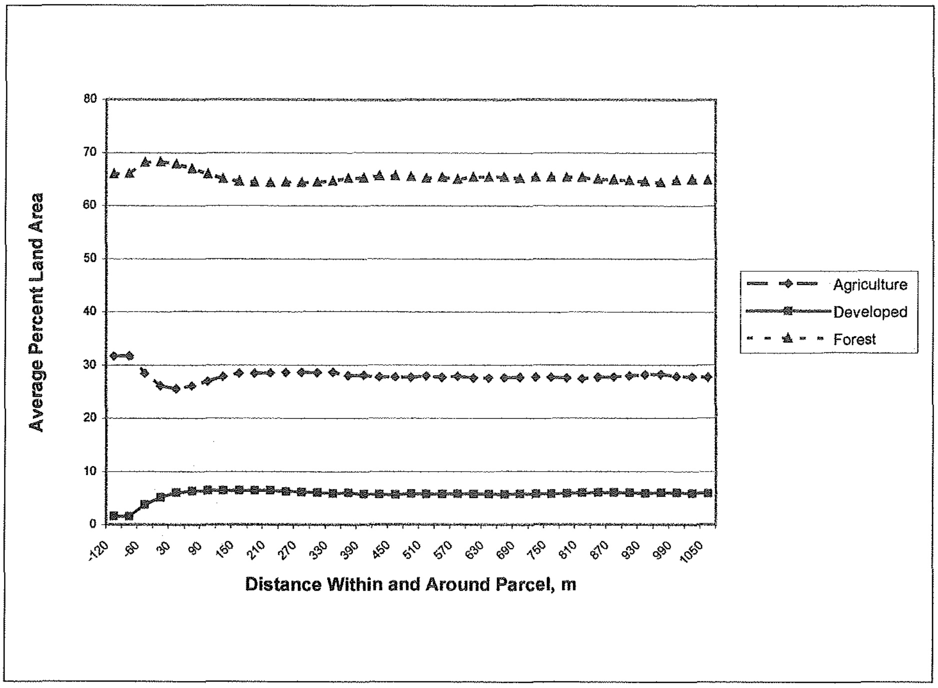
Because the metrics of fragmentation depend on the unit and boundaries used for analysis, it is important that the boundary be meaningful. We began with the assumption that parcel boundaries are meaningful units of analysis. It was expected that the parcel boundaries would correspond with a distinct change in land use/land cover from other nearby areas. A few articles in the literature have empirically investigated neighborhood effects in and around the parcel; that is to say, at what distance is there a drop-off in spatial autocorrelation or clustered patterns around the parcel? Following the work of Fleming (1999), we created series of buffers from the parcel

Figure 2: Monroe County zones.



boundaries to about a distance of one kilometer (Fleming, 1999) at 30-meter intervals. We found the average percentage of each interval covered by agriculture/pasture, developed, and forest over the 251 parcels (see Figure 3). The standard deviation of these mean values were 1.10, 1.06 and 0.97 for agriculture, developed, and forest cover, respectively. These percentages were plotted against distance.

Figure 3: Composition of land area by distance (meters).



As evident in Figure 3, there tends to be a sharp decline in the variation of land use/land cover near the parcel boundaries. The negative numbers on the graph correspond to distances extending into the parcel from the borders. These values give us some indication of the distribution of each class within and immediately around parcels. Developed and agricultural land use/land cover (or LULC) tends to be found in the center of parcels (though the developed LULC decreases and the agricultural LULC increases towards the parcel boundaries), and forest class tends to be located toward the edges. All three LULC types appear to level off at similar distances, and the average percentages tend to fit within the range of values for all the cases within that LULC class. Because the land use/land cover data were derived from a raster data set, which uses cells, and the parcel boundaries were derived from a vector data set, which uses lines, there is some mismatch between the two data sets. Therefore, it is not surprising that the leveling-out does not exactly match the parcel boundaries. The graphs indicate that the variation in percent cover begins to level off at approximately a distance of 90 meters. Based on these observations, we created raster GIS data sets of land use/land cover within 90 meters of each parcel and calculated metrics of fragmentation on these data sets.

A number of metrics of landscape composition and configuration were calculated using the Patch Analyst (Grid) extension in ArcView GIS. Table 1 presents an over-

Table 1: Metrics calculated.

Metric abbreviation	*Metric name*	*Interpretation*
MPI	Mean proximity index	Based on average size and distance measures by patch type. MPI=0 if all patches of a particular land use/land cover have no neighbors of the same type within 90m. MPI increases as patches of the corresponding patch type become less isolated and the patch type becomes less fragmented in distribution.
IJI	Interspersion and juxtaposition index (percent)	Approaches 0 when the corresponding patch type is adjacent to only 1 other patch type and the number of patch types increases. IJI=100 when the corresponding patch type is equally adjacent to all other patch types. It indicates the degree to which landscape is divided into many small patches vs. a few large patches.
LPI	Largest patch index (percent)	Approaches 0 when the largest patch of the corresponding patch type is small relative to the landscape. LPI=100 when the entire landscape consists of a single patch of the corresponding patch type.
NumP	Number of patches in landscape or class	NumP=1 when the landscape contains only 1 patch of the corresponding patch type.
% LAND	% landscape covered by the class of interest	Ranges between 0 and 100.

Source: McGarigal and Marks, 1994.

view of the metrics calculated in this analysis and how they are interpreted (see McGarigal and Marks, 1994 for more details). The basic metric calculated is the number of patches (NumP). The largest patch index (LPI) indicates how much of the area is covered by the one largest patch of a particular class. The metric MPI or mean patch interspersion is used as one indication of the degree of land use/land cover fragmentation. MPI equals the average proximity index for patches in a class (see Gustafson and Parker, 1994 for more details). A second measure of fragmentation is the interspersion and juxtaposition index (IJI), which indicates how many different types of patches are adjacent to each other.

We classified the parcels according to the zone into which they fell. As evident in Table 2, the zoning categories used were (1) agriculture/rural reserve; (2)

Table 2: Monroe County zoning categories.

Name	*Primary intended purpose*
Agriculture/Rural Reserve (AG/RR)	Single family residential associated with agriculture uses.
Conservation Residential (CR)	To provide a residential option at environmentally sound locations while protecting the environmentally sensitive areas.
Forest Reserve (FR)	Preservation of forests, recreational areas, parks and greenways, limited agricultural uses and low-density single-family residential uses.
Estate Residential and Suburban Residential (ER/SR)	Low density, single family residential development on relatively flat land in areas that have some, but not full, public services.
Bloomington Fringe Residential (Fringe)	Transition zone: this zone is similar to the estate residential and suburban residential except it was created under the jurisdiction of the city of Bloomington.

Source: Camiron, 1991, and Monroe County Planning Commission, 2000.

conservation residential; (3) forest reserve; (4) estate and suburban residential; and (5) Bloomington fringe residential. The conservation residential differs from the other residential mainly in that it requires very large lots and is typically associated with environmentally sensitive areas. The Bloomington fringe residential differs from the estate or suburban residential in that it falls within an area defined as the two-mile fringe of the city of Bloomington. This area was under the management of the City of Bloomington planning and zoning until recently and its management remains slightly different than that of the other residential areas within the jurisdiction of the county.

In order to determine whether the level of fragmentation for land use/land cover class varied significantly by zone, we used a non-parametric test of means (Kruskal-Wallis test for k-independent samples in SPSS© for Windows version 10.0.7) to find whether the means of the metrics varied significantly (95 percent confidence level). We also divided the parcels based on categories for slope (percent of land area by parcel with greater than twelve percent slope), parcel size, and distance to Bloomington city center. We created four categories or quartiles for each parcel characteristic, calculated mean values for each quartile, and tested if the means were significantly different.

RESULTS AND DISCUSSION

As evident in Table 3, most of the area within 90 meters of the parcel boundaries (90 percent) was in forest land cover. Little of the area (4 percent) was in developed land use/land cover. Over 70 percent of the area in the conservation residential zone was in forest. This matches the intent of the planners to keep forest on the steep slopes associated with the conservation reserve zone. As expected, most of the land in the forest reserve zone was covered by forest (90 percent). The forest reserve zone had the least evenly distributed land use/land cover of all the zones. The estate and suburban residential zone (ER/SR) offers the most unexpected results. The highest proportion (58 percent) was in the agriculture/pasture land use/land cover class. This result may have been affected by several factors. It may be the result of a relatively small sample of parcels in the ER/SR zone, or because of hobby farming occurring. It may also be affected by difficulty in determining if some overgrown agricultural fields should be classified as agricultural or forest lands in the remote sensing classification. This resulted in a small degree of confusion between these two classes. The overall classification accuracy was 94 percent, with a kappa statistic of 0.92 (Campbell 1996). Only eight out of 74 agriculture/pasture test points were confused with forest. These were most likely areas in early forest succession and had landscape characteristics between those of forest and agriculture. Two out of the 74 points were confused with developed land. These points were most likely lawns.

Table 4 presents the landscape metrics we calculated by zone type and land cover class. Almost every zone is significantly different for every land use/land cover class. The agriculture/pasture land use/land cover class has the highest MPI value in the land zoned for agriculture. This means agricultural LULC is well interspersed in areas zoned for agriculture. There was also a surprisingly high MPI value for forest LULC in the areas zoned for agriculture, which indicates relatively well-connected forest in areas zoned for agriculture. This may reflect that the parcels in the sample were non-industrial and much of Monroe County is marginally productive for agriculture and land is left in forest.

Forest reserves zones strive to protect forest areas and allow only very limited residential development. Correspondingly, the level of forest fragmentation is low (given by a relatively high measure of MPI and low IJI) and percentage of the landscape covered by the largest forest patch (LPI), is high. The least fragmented landscapes in general, and those for forest cover in particular, are found on parcels zoned for forest reserve.

Estate/suburban residential (ER/SR) zoning strives to allow low-density development in areas that do not yet have full services such as sanitary sewers. Generally, these areas have more fragmented, smaller forested areas, and less fragmented areas

Table 3: Composition of land cover by class and by zone, in hectares.

	Agriculture	*Forest*	*Developed*	*Total*	*Agriculture* %	*Forest* %	*Developed* %
Total area	871.35	2,081.13	130.94	3,094.02	28	67	4
By zone							
AG/RR	698.73	1,310.33	89.48	2,098.55	33	62	4
CR	24.56	70.11	5.68	100.35	24	70	6
FR	52.18	486.26	3.61	542.06	10	90	1
ER/SR	17.70	9.63	3.33	30.65	58	31	11
Fringe	78.20	204.80	28.84	311.83	25	66	9

Table 4: Landscape metrics by zone type and land cover class (mean values).

Mean Patch Interspersion (MPI)	*Land cover class*			
Zone type	Agriculture	Forest	Developed	All land cover
AG/RR	**34.98**	57.24	2.61	27.97
CR	17.81	38.08	3.77	20.03
FR	*9.83*	28.65	*0.68*	10.93
ER/SR	25.68	*8.31*	4.97	*10.63*
Fringe	25.21	50.23	5.57	19.94
All zones	28.81	49.02	2.91	23.06
Interspersion/Juxtaposition Index (IJI)				
Zone type	Agriculture	Forest	Developed	All land cover
AG/RR	52.55	44.49	71.80	51.83
CR	47.74	34.02	82.27	42.44
FR	21.75	26.69	73.50	23.94
ER/SR	57.55	43.13	49.85	51.83
Fringe	52.57	55.51	69.94	56.38
All zones	47.63	41.75*	71.70	46.52
Largest Patch Index (LPI)				
Zone type	Agriculture	Forest	Developed	All land cover
AG/RR	28.91	56.82	4.06	68.48
CR	15.93	75.20	5.86	75.76
FR	*9.66*	**89.79**	*1.34*	**90.91**
ER/SR	44.67	*38.95*	8.86	*75.48*
Fringe	21.03	56.86	9.80	67.84
All zones	24.64	63.72	4.72	73.22
Mean number of patches				
Zone type	Agriculture	Forest	Developed	All land cover
AG/RR	4.26	4.38	4.64	12.80
CR	3.25	2.38	*2.25*	7.00
FR	2.75	*1.48*	2.35	*4.56*
ER/SR	*2.20*	**6.40**	5.50	13.40
Fringe	5.39	3.93	5.04	**14.00**
All zones	4.06	3.71	4.39	11.07
Percent land area				
Zone type	Agriculture	Forest	Developed	
AG/RR	33.88	61.21	6.70	
CR	17.97	78.77	7.44	
FR	*11.55*	**90.53**	*1.92*	
ER/SR	**46.02**	*43.85*	12.43	
Fringe	26.81	59.97	15.55	
All zones	29.00	67.24	7.53	

*Denotes insignificance of Kruskal-Wallis test statistic of k independent samples across zones. Bold font indicates highest values; italics indicate lowest.

of agricultural cover. The size and composition of developed areas is also higher on these parcels than on the parcels zoned for conservation residential. IJI is highest for agricultural land use/land cover in this zone and the number of patches of forest and developed land is also highest in the ER/SR zone. This indicates that all of the land use/land covers are fragmented in the ER/SR zone, and even though there are relatively large patches of agricultural LULC, the patches are typically surrounded by a variety of other land use/land covers.

The Bloomington fringe represents an area that was caught between city and county jurisdiction, thus, we anticipated that this area might exhibit greater fragmentation. This area also contains much forest cover, relatively concentrated, though in smaller patches. The IJI statistic is the highest for this category for all land cover, indicating that these fringe areas have the most interspersed uses overall. The developed land use/land cover class has the highest MPI value in the Bloomington Fringe Residential zone and the percent of land area covered by developed is highest in the Bloomington fringe residential zone. This indicates that the developed LULC is most concentrated in this zone. IJI for forest is highest in the Bloomington fringe zone indicating that forest is frequently surrounded by a number of other land use/land covers. The zone with the largest average number of patches of land use/land cover in general is the Bloomington fringe residential.

We conclude that landscape fragmentation does significantly vary with zone type. The developed land use/land cover class is much more fragmented than the other classes especially forest. Forest LULC in areas zoned for forest reserve tends to have much less fragmentation. The Bloomington fringe residential zone tends to have the most fragmented LULC of all zones. The forest reserve zone has the least fragmented landscape and agriculturally zoned areas seem to be performing better in preventing fragmentation of open space, agriculture, and forest lands than in the residential zones. The conservation residential zone seems to be preventing open space fragmentation better than other types of residential zoning.

In a final aspect of this analysis, we ask the question, is zone type more important than individual parcel characteristics? To test this hypothesis, we grouped the parcels by quartiles for three indicators: slope (percent of land area with slope greater than 12 percent), parcel size, and distance to Bloomington city center. According to the Kruskal-Wallis comparison of means test, few of these metrics varied by parcel characteristics. Table 5 reports the significant differences by parcel characteristics. Generally, the fragmentation of both agricultural and developed land use and cover increased with slope. Fewer but larger patches of forest were found on steeper slopes. Therefore, flatter areas are more suitable to both agricultural and developed uses, while steeper areas are more likely to be forested. The concentration of agriculture and forest both increased with parcel size, but developed LULC tends to decrease with parcel size. Distance to city center was not significant in any case, except for the MPI for agriculture. To summarize, we find that Agriculture/pasture LULC tends to be more fragmented on smaller parcels and on parcels with steeper slope. Forest

Table 5: Significant* differences in mean metric values by parcel characteristics and land cover class.

	Change in mean value relative to changes in parcel characteristics (arrows indicate positive/negative relationship):		
	Increasing slope	*Increasing parcel size*	*Increasing distance to city center*
Agriculture	IJI, LPI, and percent land area ↓	MPI and number of patches ↑	MPI ↓
Forest	MPI highest at mid-range, IJI and number of patches ↓, and LPI and percent land area↑	MPI and number of patches ↑	-
Developed	MPI, LPI, number of patches and percent land area ↓	LPI and percent land area↓, number of patches ↑	-

*Rascal-Wallis statistic indicated significantly different mean values across quartiles.

LULC tends to be more fragmented on flatter and smaller parcels, and developed LULC tends to be more fragmented on parcels with steeper slope and larger size.

CONCLUSIONS

Zoning is currently an important determinant of landscape configuration as well as composition in Monroe County. In particular, zoning restrictions on rural residential land use, such as the conservation and forest reserves, seem to be preventing fragmentation of agricultural and forest cover, especially compared to the estate/suburban residential zoning class. In addition, biophysical and socioeconomic factors have combined to allow for a relatively large area of the county to become or remain forest-covered. However, there are differences in the forest cover associated with different zoning classifications. The conservation and forest reserve zone is associated with larger areas of less fragmented forest. This differs from the parcels zoned for agriculture, which are associated with relatively large areas of less fragmented agriculture and forest LULC.

As pressure from urban sprawl increases, there is a danger that the current zoning policies may not protect forest and agricultural open lands. Land that is marginal for agriculture (e.g., land found on steep slopes) is more likely to remain in forest or experience forest regrowth (Evans et al. 2001). However, this land can also become prime residential land as Bloomington continues to grow. Steep slopes and forest cover can make for attractive, high-value residential use. This becomes increasingly important as the most easily converted areas of agriculture become scarce and the creeping residential market drives up the land values and crowds out the more consumptive land uses (Midmore and Whittaker, 2000). Therefore, we conclude that current zoning policies seem to be adequately protecting agricultural and forest open space and areas on steep slopes, but wonder if this will be adequate in the near future. This analysis may serve as a base line with which to compare future landscapes and evaluate the effectiveness of zoning in light of increased urban pressure. Remotely sensed data has great utility for analyzing land use/land cover change over time and we hope to pursue such an analysis in the future.

The use of GIS and remote sensing technologies in studying urban growth/sprawl is not new (for a recent study, see Ward et al., 2000). However, most studies deal with large, well-established urban complexes. Little research has focused on peri-urban areas in which zoning has the largest potential to shape future landscapes. This research centers on the issue of urban sprawl in a relatively rural setting; we have the opportunity in Monroe County to influence policy before urban growth is a fait accompli. By incorporating the GIS and remote sensing tools of landscape ecology spatial analysis to examine fragmentation of agriculture and forest lands in relation to developed lands, we also contribute to a more complete picture of the complexities of the relationships between land use/land cover and urbanization.

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