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Uses and Landscape Patterns

A Study of Relationships between Human Activities and Spatial Patterns of Land Use and Land Cover on Private Parcels in Monroe County, Indiana

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USES AND LANDSCAPE PATTERNS: A STUDY OF RELATIONSHIPS BETWEEN HUMAN ACTIVITIES AND SPATIAL PATTERNS OF LAND USE AND LAND COVER ON PRIVATE PARCELS IN MONROE COUNTY, INDIANA

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ABSTRACT

There is a need for landscape ecological analyses that focus on relationships between land and forest use decisions and forest ecosystem functions at the parcel level in order to better manage resources. This research addresses this need thorough a case study of Monroe County, Indiana. It explores whether landowners who make decisions based on discrete partitions in the landscape affect spatial patterns of land use and land cover on parcels and whether socioeconomic partitions in the landscape result in discrete land-cover edges. Specific socioeconomic data, including the types of land and forest uses that occur on privately owned parcels, are identified based on landowner responses to interview questions. Techniques from geographical information science and remote sensing are used to create a map of land use and land cover from which metrics of the spatial patterns on the parcels are calculated. The metrics indicate the degree of forest fragmentation on each parcel and the likely resilience of forest ecosystems. Relationships between differences in land and forest uses, factors affecting land-use decisions, and several landscape metrics are explored by using statistical tests. The results indicate that processes related to parcel-level land and forest use decisions significantly affect the spatial patterns of the landscape. Differences in human land and forest uses, including uses that have occurred in the past, correspond to differences in the spatial patterns on private parcels. The largest differences in patterns are between parcels that are used for agricultural land uses and parcels on which forests are used for aesthetics, buffering, and hiking. Models that include variables related to land and forest use decisions perform better than models that include only measures of population density, slope, and accessibility. The results imply that ecosystem management programs that aim to control land and forest use decisions through policies such as zoning may impact the health and resilience of forest ecosystems. However, participatory programs that offer benefits that are targeted to specific types of landowners and operate at local levels may encourage individuals to cooperate in forest management and be more effective than zoning regulations.

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CHAPTER 1

INTRODUCTION: OVERVIEW OF HUMAN-ENVIRONMENT RESEARCH THAT HAS EVOLVED FROM GEOGRAPHY, LANDSCAPE ECOLOGY, AND RESOURCE MANAGEMENT AND IDENTIFICATION OF RESEARCH NEEDS

1.0. Introduction

Analysis of human-environment interactions has undergone rapid changes in recent years. The development and proliferation of remote sensing and geographic information systems along with an increasing focus on interdisciplinary and explicitly spatial research has spurred new theories and methodology for integrating human actions and environmental functions (Cohen and Goward 2004). A number of disciplines have a tradition of landscape and human-environment research. This chapter focuses exclusively on theory and methodology related to human-environment interactions from the fields of geography, ecology, and resource management. It discusses an emerging, interdisciplinary approach to ecosystem management, identifies research needs, and describes how subsequent chapters in this thesis address these research needs.

1.1. Theories and Methodology from Geography

The field of geography has a long tradition of research on spatially explicit, human-environment interactions. This tradition includes studies of the impacts of the environment on humans (Semple 1903, Barrows 1923) as well as the impact of humans on the environment (Marsh 1965 [1864], Sauer 1925). Scale and space became well-established focuses in geographic literature by the early twentieth century (Giordano 2003). Sauer (1925) established the use of the term landscape to refer to both human and biophysical aspects of a location. He defined a landscape as a set of interrelated phenomena whose qualities as a whole (form, structure, and function) encompass characteristics not captured by its constituent parts separately. He also proposed that the landscape is a material record of both the cultural and natural environment.

The field of geography underwent a shift toward systems theory in the 1960s. Researchers who facilitated this shift include Chorley and Stoddart. Chorley (1962) called for a systems approach in geographic research that rejects balanced states equilibrium. Stoddart (1965) expressly linked ecosystems and geography and noted the utility of the idea of ecosystems in land-use research.

Geographers have stressed the dynamic rather than static state of ecosystems. For example, Tuan (1971) recognized that humans and their actions have dynamic impacts on the environment. He suggested that human actions, such as those associated with urbanization, disturb ecosystems, cause species extinctions, and introduce new species into a landscape over time. J. B. Jackson (described in Zube 1970) also focused on the dynamic relationships between natural landforms or physiographic regions and human cultural groups. He found that landscapes provide insights into both history and society and suggest the relationship between people and the environment. Similar to Sauer (1925), he proposed that landscapes are resistant cultural artifacts. Unlike Sauer, he advocated the study of all landscapes, not just the most pristine. He specifically identified the need to include aerial photography in studies of landscapes (Forman and Godron 1986).

Geographers have also developed theories that relate spatial location, economics, and land use. Much of this research builds upon the bid-rent models of von Thünen (1966 [1826])). In these models, land use is a function of land rent, land quality, and location. Later models expanded the basic model to include other factors such as utility maximization (Alonso 1964). Traditional spatial models have been developed by geographers to explain things such as the location of settlements or cities, roads, and markets (von Thünen 1966 [1826], Christaller 1966 [1933], Von Böventer 1969). Some researchers have explicitly identified the theories of von Thünen (1966 [1826]) and Christaller (1966 [1933]) as a basis of their more contemporary land-use research (Pond and Yeates 1993, Walker and Solecki 1999, Ishikawa and Toda 2000).

1.2. Theory and Methodology from Landscape Ecology

The concept of ecosystem as used and defined by Tansley (1935) and Odum (1959), among others, provides theory and methodology for analysis of holistic units. Ecosystems may be defined as dynamic groupings of plant or animal species that occur together in a landscape and are linked by similar ecological processes and underlying environmental features that form a cohesive and identifiable unit (Poiani et al. 2000). Many (such as Butzer 1990) have recognized benefits of an ecological emphasis in research. Such an emphasis allows a structured organization of unlike variables and emphasizes the function of systems such as the interchange between parts of the whole.

The theory of successional dynamics (Clements 1916) dominated ecological research until relatively recently. The focus of this theory is that a stable end-point or climax vegetation is determined by macroclimate over a broad region, and interdependencies among climate, biota and soil lead to long-term stability in the absence of climate changes (Turner 1989). Within the context of successional dynamics, ecosystems are viewed as static and predictable (Poiani et al. 2000). Before the 1960s, spatial heterogeneity was ignored by theoretical ecologists, for the most part, on the grounds that it compromised the assumptions of equilibrium (Perry 2002). However, Watt (1947) proposed that the distribution of the entire temporal progression of successional stages could be described as a pattern of patches across the landscape. This was an early linking of space and time at the scale of what we now call a landscape. Although Watt's theories were not widely incorporated into ecologic research immediately, they significantly contributed to the development of contemporary landscape ecological research.

The theory of island biogeography (MacArthur and Wilson 1967) illustrates dynamic hypothesis that are based on assumptions of equilibrium. In this theory, a larger number of species (based on species diversity or richness) is associated with islands that have larger spatial areas and islands that are less isolated. It is based on the premise that the resource base of an island dictates richness in a predictable fashion.

In the 1970s, the effect of spatial heterogeneity on ecological processes at multiple scales became more dominant, and a theoretical shift away from the equilibrium framework was occurring (Perry 2002). Troll (1971), a German geographer, is often credited with defining the term landscape ecology (Forman and Godron 1986). He defined it as the study of the physicobiological relationships that govern the different spatial units of a region with relationships both within the spatial unit and between spatial units. Most ecologists have focused on the relationships within spatial units (Forman and Godron 1986).

In landscape ecology, a landscape is a system, which consists of many interactive elements with a hierarchical structure, and is made of complex patterns of spatial heterogeneity consisting of patches of particular classes. Patches are areas of land composed of the same type of land use or land cover, which are defined according to a particular scale and classification system (O'Neill and Hunsaker 1997). Although land use and land cover are often related, there are differences between the terms (Brown et al. 2000). Land cover refers to classes evident on the surface of an area of land. Land use takes into account the intent and the reality of how a given land surface is altered or used by humans (Grimm et al. 2000).

Isolation of patches and loss of species diversity cause the system or ecosystem to have difficulty recovering from disturbance. The ability of a system to recover from disturbance defines its resilience. Resilience in ecological systems is the amount of disturbance that a system can absorb without changing stability domains (Holling 1973).

Based on the theory of island biogeography (MacArthur and Wilson 1967), landscape resilience can be related to the size of patches (or islands of habitat) and the distances between them or the degree to which a patch of habitat is isolated from like patches. The composition and configuration of the landscape affects the functioning of the ecosystems. Changes in the spatial pattern of the landscape in the form of habitat fragmentation have been associated with the decline of biological diversity and in the ability of the ecosystem to recover from disturbance. Links between the spatial patterns or the composition and configuration of patches and the functions of ecosystems are central to landscape ecology (Perry 2002) and, it is what differentiates landscape ecology from other ecological disciplines (Turner 1989). Methods for quantifying spatial patterns in a landscape have been developed (Gustafson and Parker 1994, McGarigal and Marks 1994, O'Neill et al. 1997, Frohn 1998). The measures are often based on the composition and configuration of patches of land use and land cover occurring within the landscape mosaic.

1.3. Theory and Methodology from Resource Management

Institutions, such as property rights (the structure of rights to resources and the rules under which those rights are exercised) are mechanisms people employ to control their use of the environment and their behavior toward each other. Institutions govern not only the level and intensity, but also the timing and specific form of resource use (Folke et al. 1998). They are an important component of sustainable use of forest resources because they are the means through which stewards set out to accomplish their goals related to resource use and management and, to a large extent, condition the decisions individuals make. Individual's land and forest use decisions impact natural resources. The aggregate pattern of forest cover is a collective result of gains and loss of forest due to land-use decisions that happen on each individual parcel of land.

Theories from institutional analysis have been used as a basis for studying relationships between land and forest uses and natural resources. Individually owned private parcels of land fall into a broad system of private property rights where landowners are assigned almost all rights to manage their lands (York et al. 2005). Property rights establish a set or bundle of economic and social associations that define the position of each individual with respect to the utilization of scarce resources (Giordano 2003). Often, analyses of why people make certain land and forest use decisions are based upon rational choice theory or game theory (Ostrom et al. 1994).

Landscape research that is conducted from the perspective of institutional analysis often considers certain factors that affect individuals' land and forest use decisions. Landowners make land-use decisions based on socioeconomic factors including profitability and personal preferences relating to aesthetics. The decision-making process is influenced by the individual's culturally affected knowledge, information, and time horizons, among other things (Moran et al. 2002, Munroe and York 2003). Landowners' views of landscapes are affected by personal histories, attitudes, values, beliefs, and individual perceptions (Lambin et al. 2003).

The public good and individual land-use decisions, which are based on private property rights, have been at odds with each other in many locations, especially those near urbanizing cities. In efforts to resolve such conflict, governmental agencies are offering incentives to landowners who make land and forest use decisions that improve the function and resilience of forests and are restricting land and forest uses that are thought to be harmful through land-use planning and zoning policies (York et al. 2005).

Theories and methodology from ecology have been used to draft and implement conservation policies particularly in land-use planning and zoning (Soule 1991, Harrison and Bruna 1999). Several laws that are considered the bedrock of environmental management in the United States are based on the theory of successional dynamics (Clements 1916). Such regulations include: the Endangered Species Act, the Wilderness Act, the National Environmental Policy Act of 1969 (NEPA), Section 404 of the Clean Water Act, and the broader non-degradation provisions of the Clean Air and Clean Water Acts. These laws were enacted based on the theory that if humans left areas alone, nature would achieve a permanence of form and structure that would persist indefinitely (Guruswamy 2001).

Ecological methodology has been integrated into the compliance and monitoring that is associated with these laws. In the 1970s and 1980s, biodiversity was viewed largely in terms of species richness and the protection of individual endangered species (Poiani et al. 2000). Ecological theories and models have tended to focus on the dispersal and geometric configuration of habitats and have been used as the basis for the creation of reserves and corridors in order to protect endangered species (Harrison and Bruna 1999) as required by the U.S. Endangered Species Act (Schweik and Thomas 2002).

Although, some policies continue to focus on the protection of single species of plants and animals, there has been a relatively recent shift in policies toward ecosystem management and protecting the entire ecosystem that contains species of interest. The change in policies has been accompanied by an emphasis on sustaining the functioning of systems rather than the harvesting of resources.

2.0. Interdisciplinary Integration of Characteristics of Human and Natural Systems

2.1. Ecosystems Management

The 1990s began a paradigm shift, in a number of academic disciplines, from isolated studies of parts or particular aspects (or species) of an ecosystem, to consideration of the system or landscape as a whole. In such a view, landscapes are considered functional conservation areas (Poiani et al. 2000). The paradigm has changed from focusing on equilibrium and stability to focusing on the dynamic nature of the systems in the landscape (Guruswamy 2001). The change in focus has encouraged cross-disciplinary analysis of landscapes (Palang et al. 2000).

Human impacts on the natural environment have been documented. Human actions transform the land surface through processes such as urbanization. Such activities alter the major biogeochemical cycles and add or remove species and genetically distinct populations in most of the Earth's ecosystems. These changes in turn led to further alterations to the functioning of ecosystems, most notably by driving global climatic change and causing irreversible losses of biological diversity. A loss of biodiversity is of global concern because it lowers the resilience of species and ecosystems and reduces the number and variety of natural products and genetic material that are potentially of vital importance to humans (Vitousek et al. 1997).

Human systems are dependent on the structure and functioning of ecosystems. For example, the economies of many local areas are dependent on forest resources, and ecosystems generate essential natural resources and ecological services (Folke et al. 1998). Many researchers now recognize that social, political, biological, and geographic variables should be included in what has been called an ecosystem, sustainability based, or holistic approach to resource management (Wear et al. 1996, Machlis and Force 1997, Sexton et al. 1998, Grimm et al. 2000). Such approaches focus on protecting the function and resilience of the entire system of ecosystems, or landscape, rather than protecting certain aspects or species within the systems.

In recent years many resource managers have adopted the concept of ecosystem management as a basis for forest management. Almost every manager has his or her own definition of ecosystem management. Even among U.S. governmental agencies there is no one definition. Most definitions of ecosystem management incorporate the sustainability of system functions such as the delivery of desired goods and services as a central goal or value and focus policies on the sustainability of uses and resilience of ecosystems (Yaffee 1999). Christensen et al. (1996) suggested that ecosystem management might be simply defined as managing ecosystems so as to assure their sustainability. Ecosystem management seeks to fulfill explicit goals that are executed by policies, protocols, and practices. It is not a fixed set of regulations, but, rather, is adaptable.

Ecosystem management recognizes that institutions and managers must consider and respond to dynamics in the human and biogeophysical systems. Such an approach can buffer the social-ecological system against various pressures and driving forces that may affect how a resource, such as forest, is used. It also recognizes that managers interpret, relate, and respond to ecosystem dynamics in a fashion that secures the flow of resources and ecosystem services for users (Folke et al. 1998). Ideally, management may change based on monitoring and research that has been done on the ecological interactions and processes necessary to sustain ecosystem structure and function (Christensen et al. 1996).

An example of a governmental agency that has officially adopted the ecosystem management approach is the U.S. Forest Service. Rigg (2001) presents a case study that examines the U.S. Forest Service's management of a giant sequoia forest in Sequoia National Forest, California that may be considered an example of how ecosystem management may be implemented. The managers of this forest have attempted to practice ecosystem management by associating on-the-ground management activities with ecosystem management themes, characteristics, and mechanisms identified in academic, industry, and agency literature. They have used collaborative stewardship and, a number of individuals with a wide variety of interests participated in drafting the management plan.

2.2. Integration of Landscape Ecology, Resource Management, and Geography

A primary concern of ecosystem management is land-cover conversions or the complete replacement of one cover type. Such conversion is measured by a shift from one land-cover category to another, such as in agricultural expansion, deforestation, or urbanization. Land-cover modifications are also of concern. This includes more subtle changes that affect the character of the land cover without changing its overall classification (Lambin et al. 2003). Land-cover modification in an area may indicate the initial stages of conversion and may therefore identify locations that would most benefit from conservation programs. Analysis of the composition and configuration of patches in the landscape, using the theories and methodology developed in landscape ecology, allows for the identification of patches that are in various states of modification. Many have described ecosystem management as ambiguous in how to implement principles (Theobald and Hobbs 2002). Landscape ecology offers theory and methodology that can be used to operationalize ecosystem management and inform resource managers.

As noted in the previous sections, theories and methodologies have been exchanged between ecology, resource management, and geography. Zimmerer (1994) proposes that the main themes of landscape ecology, structure, function, and change evolved from geography. He explicitly notes that geography, landscape ecology, and resource management share a focus on history, spatial scale, and what may be considered resilience.

The field of geography and its methods for spatially explicit analysis has experienced increasing interest due, in large part, to the development and proliferation of remote sensing imagery and GIS (geographic information systems). Some researchers have incorporated remote sensing imagery in an effort to link regional land-use and land-cover patterns to socioeconomic driving forces and draw social meaning from imagery (Geoghegan et al. 1998, Lambin et al. 2003). Biophysical and socioeconomic characteristics have been associated with spatial patterns of forest cover, which indicate forest fragmentation and, therefore, forest resilience (Gunderson 2000).

The focus of landscape ecology is to tie the spatial configuration of landscape elements to both ecological and human characteristics (Geoghegan et al. 1998). In landscape ecology, a landscape is often made up of a mosaic of land uses and land covers. The pattern of land uses interacts with ecological patterns and processes (Grove and Burch 1997). More recent research has found that these metrics correlate with specific aspects of both ecosystem function and socioeconomic characteristics (Medley et al. 1995, Turner et al. 1996, Wear et al. 1996, and Wickham et al. 2000, Croissant and Munroe 2002). The spatial patterns of land use and land cover relate to the suitability of the forest as habitat for particular species of plants and animals and the function and resilience of ecosystems (Medley et al. 2003).

Specific socioeconomic factors have been shown to impact the spatial patterns of land use and land cover on a landscape. Differences in historical land uses have been associated with variations in forest characteristics that persist in a landscape (Elliott et al. 1998, Black et al. 1998). This implies that the present composition, structure, and function of an ecological system are, in part, a reflection of historical events or conditions. Stanfield et al. (2002) suggest that land ownership patterns are strongly correlated with forest cover patterns, and understanding landscape structure requires consideration of land ownership institutions.

Remote sensing has been used to monitor changes in forest cover and to indicate relationships between human actions and forest conditions, especially in Central and South America (Skole and Tucker 1993, Sader 1995, Wood and Skole 1998, Moran and Brondízio 1994 and 1998, Moran et al. 1994, Sader et al. 2001). Researchers have noted the utility of remote sensing and GIS, particularly when used in conjunction with household surveys, as a means of providing insight into the behavior of households and the outcome of their decisions on the landscape (Moran et al. 1996, McCracken et al. 1999, Mertens et al. 2000). Remote sensing images and GIS are particularly useful for studying human impacts on the environment at different scales (Walsh et al. 1999). Researchers have also shown that analysis of spatial patterns of land use and land cover as evident in a remotely sensed image can be used to make policy prescriptions related to issues such as the protection of endangered species (Schweik and Thomas 2002).

Scale is inherently involved in landscape studies. It is commonly assumed, especially in landscape ecology, that the landscape is organized in a hierarchy of levels of organization that are based on interaction-minimizing boundaries (Allen and Starr 1982). In hierarchy theory, the environment can be partitioned into naturally occurring levels, which share similar temporal and spatial scales. The levels interact with higher and lower levels in systematic ways. Each level in the hierarchy experiences the next more aggregate level as a constraint and the finer levels as noise. Fine scale noise that occurs at a lower level can turn into significant perturbations on the higher level. These perturbations can transform the higher level when a critical threshold is reached (Costanza et al. 1993).

3.0. Research Needs

Although the emerging holistic or ecosystem management approach to resource management calls for integrating human and biogeophysical dynamics, a lack of theoretical linkages, straightforward methodology, and useable data has restricted its applicability (Folke et al. 1998). It is unclear how to effectively implement ecosystem management. The complex nature of human-environment interactions has limited the number of clear research findings that are useful for drafting and implementing resource management policies and further research on specific relationships is needed.

Aspects of the relationships between human actions and spatial patterns of land use and land cover have been studied from a wide variety of perspectives (Wickham et al. 1999, Irwin and Geoghegan 2001). However, much research related to ecosystem management has not incorporated data from real landscapes (Kline and Alig 1999). This is particularly true of studies of the impact of individual decisions on the patterns and functions at fine spatial scales. It is often difficult and expensive to collect data related to individual decisions.

Most landscape ecological studies explore relationships at relatively broad spatial scales (for example, LaGro and DeGloria 1992, Wear et al.1996, Wickham et al. 1999, Riitters et al. 2000). Frequently, landscape studies use biophysical boundaries such as those of a watershed (Wear and Bolstad 1998). However, a watershed boundary often lacks socioeconomic or political meaning (Bockstael 1996). In addition, the objectives for managing a watershed tend to be different from the objectives for management a parcel. Ecosystem management policies that may be effective at the scale of a watershed are likely to be different from policies that would be effective at the scale of an individual parcel. Therefore, there is a need for research that explicitly considers landscapes that correspond to socioeconomically or politically meaningful landscape units.. It is also necessary to conduct landscape research at the scale of individual parcels of land.

Different patterns and processes emerge at different levels according to hierarchy. Particular processes operate at each particular level, but the effects of a change in the processes or functions that occur at one level may become evident in other levels. Similar variables may affect processes that occur at multiple levels, but a shift in the relative importance of variables often occurs (Turner, Dale, and Gardner 1989). This means that parameters and processes that are important at one scale of analysis often do not have the same relationship or predictive power at another scale (Turner, O'Neil, Gardner, and Milne 1989). Variables found to be significantly connected to landscape patterns at broad scales may not be important at fine scales or at the parcel level. Therefore, it is necessary to analyze relationships between human processes and the functions of natural systems at a variety of scales (Moran et al. 2002). This includes analysis of forest fragmentation at the scale of the watershed as well as the scale of individual parcels.

Institutions exist at a number of scales and levels of complexity. Aspects of the relationships between institutions and forest resources have been examined (Schweik and Thomas 2002), but relationships, particularly at the scale of individual parcels, remain poorly understood. Parcel-level research facilitates understanding of relationships between human decisions and the pattern and function of ecosystems in a landscape.

Few studies of landscape pattern integrate both human and biophysical aspects of the landscape. There is a need for research on the relationship between differences in spatial patterns of land use and land cover and socioeconomic or political factors particularly for areas that are privately owned (Wear et al. 1996, National Research Council 1998, Wickham et al. 2000).

Physical data about the parcel can be obtained from remote sensing images and linked to factors affecting land and forest use decisions, which can be obtained through interviews with the landowners (McCracken et al. 1999, Mertens et al. 2000). Much of the research that has linked interview or survey data with remote sensing data has focused on changes in the amount of forest cover in tropical areas (McCracken et al. 1999, Mertens et al. 2000). Since it is common for relationships between human uses and spatial patterns of forest cover to differ in post-industrial, temperate forests versus subsistence-based, tropical forests there is need for further research on relationships between factors affecting land-use decisions and temperate forests occurring in post-industrial areas (Brown et al. 2000).

Forest fragmentation is becoming a primary concern in efforts to protect forest ecosystem function in the United States and other areas (Riitters et al. 2000, Eriksson et al. 2002). However, few have documented relationships between socioeconomic factors and differences in spatial landscape characteristics in terms of landscape ecology metrics, especially in reference to temperate forests (Wear et al. 1996, Walker and Solecki 1999, Wickham et al. 2000). Few studies have treated the human and biophysical aspects of the landscape equally, and there is a lack of research that links specific forest uses to spatially explicit geographic areas (Folke et al. 1998).

Landscape managers frequently seek to achieve goals such as increasing the function and resilience of forest ecosystems by limiting the types of land uses that may be conducted on particular parcels. Such regulations assume connections among land use, land cover, and forest ecosystem function. However, little research is available to support these assumptions and, particularly for post-industrial areas such as the Upper Midwest, USA, a lack of connections between land use and land cover has been found (Brown et al. 2000). Often research that links land use and differences in forest cover consider only connections between single uses of the land and do not account for the majority of cases in which several types of land uses occur on the same parcel of land. Therefore, there is also a need for research that considers relationships between combinations of land uses and spatial patterns of land use and land cover that occur in temperate areas.

Factors that limit the types of land and forest use decisions that individuals may make have been associated with differences in the spatial patterns of land uses and land covers. For example, differences in historical land uses have been associated with variations in forest characteristics that persist in a landscape (Elliott et al. 1998). Parcel size and the length of time a parcel has been owned by an individual and his or her family may be related to differences in land-use decisions and differences in the spatial characteristics of the forest cover (Erickson et al. 2002). Links between landowner characteristics and the amount of forest cover on parcels have been proposed. Prior research has found that parcels with low landowner turnover or ones that have been used for farming for the longest periods of time, had the greatest percentage of land in forest and larger mean forest-patch sizes. This research was conducted n a predominantly agricultural area of the United States (Medley et al. 2003). Other research indicates that short-term landowners, who tend to use less of their parcel for agricultural production, tend to make land-use decisions that allow for more forest growth than longer-term landowners (Erickson et al. 2002). Further research is needed to understand better how factors that potentially affect land-use decisions also relate to spatial patterns in a landscape and forest ecosystem functions.

Much of the research on human-environment interactions refers to publicly owned land (Frentz et al. 2004). However, in many parts of the United States and the world, individuals own much of the forested land. In the future, most changes in forest lands in the United States will occur over these privately owned areas (Erickson et al. 2002). Researchers have noted the particular importance of conservation and management programs for privately owned lands (Theobald and Hobbs 2002). There is a need for research on relationships between land use and forest fragmentation that occur on private parcels (Wear et al. 1996, Geoghegan et al. 1997, Brown et al. 2000, Hilty and Merenlender 2003).

Management over relatively broad geographic areas such as watersheds is necessary, but limiting management authority to only those that regulate large areas of land is inefficient (Ostrom et al. 1993, Guruswamy 2001). Regional scale analyses are more suitable for observing processes the occur over large spatial extents, but they are limited in their ability to link land management decisions and specific land-use practices to landscape outcomes at more local scales. Successful ecosystem management should include policies and programs that are directed at fine spatial scales or specifically at the parcel level.

Conservation programs that encourage the participation of private landowners are essential for reducing forest fragmentation and maintaining biodiversity (Wear et al. 1996, Theobald and Hobbs 2002). However, as with efforts to manage the Sequoia National Forest (Rigg 2001), programs that attempt to incorporate individual and small group participation in management are often unsuccessful (Wear et al. 1996, Gunderson and Holling 2002). More successful methods of incorporating individual landowners into ecosystem management efforts need to be developed.

4.0. Research That Fills These Needs

The methods used in this dissertation present an example of how to quantify indicators of forest fragmentation and determine relationships between these measures and socioeconomic differences in a relatively simple analysis. These metrics provide non-subjective measures of conditions and, if compared across time, may be used in monitoring landscape conditions. The methods may also be used to evaluate the success of various projects.

In general, this research uses theory and methodology from geography, resource management, and landscape ecology to analyze relationships between socioeconomic factors and spatial patterns of land use and land cover. A classification of a remote sensed image is used as a basis for calculating metrics of landscape composition and configuration with the use of a GIS. These metrics indicate the degree of forest fragmentation in the landscape. The metrics are calculated for a sample of individual, privately owned parcels. Relationships between socioeconomic factors and the metrics of spatial patterns are determined through statistical analyses. The study area and general methodology are discussed in Chapter 2.

Chapter 3 explores whether spatial patterns of land use and land cover are affected by parcel boundaries created by the grid-based land survey system that initially divided much of the United States. A number of spatial metrics are calculated for areas of developed, agricultural, and forest land within and near the boundaries of each parcel. The variances of the metric values at increasing distances from the parcel boundaries are compared. It is hypothesized that the highest variance occurs for landscapes of areas near the parcel boundaries, which distinct changes in variance occur between these landscapes and landscapes that include areas a short distance from the boundaries, and that variance is comparatively low and changes little for landscapes encompassing areas at larger distances from the boundaries. The results of this analysis illustrate the potential impact socioeconomic and socioeconomic and political systems may have on spatial patterns in a landscape.

Chapter 4 explores links among spatial patterns of forest cover and socioeconomic factors that affect individuals' land-use decisions. The specific factors included in this analysis are: differences in the size of the parcel, whether or not the current owner shares similar land uses and management beliefs as the former owner, whether the parcel was acquired from a family member, length of time the parcel has been owned, the importance of the parcel for income generation, whether or not the parcel will be inherited by an heir, age of the landowner, highest level of education of the landowner, distances from the parcels to the city and major roads, landowners' income, parcels' mean slope, and past land uses that have affected the parcel. The chapter analyzes relationships between these socioeconomic variables (and slope) and measures of the spatial patterns in the landscapes. It is hypothesized that variables that indicate limits to the types of land and forest uses that may be conducted on a parcel and that indicate an individual's background, knowledge, and preferences are highly associated with measures of spatial patterns on in the landscapes. It is also hypothesized that models that include these variables will explain much of the variability in the spatial patterns of land uses and land covers on parcels in the study area.

Chapter 5 tests whether there are significant differences in the means of metrics that indicate forest fragmentation on private parcels that are used for different combinations of uses. It is hypothesized that different combinations of land uses are associated with significant differences in metrics of forest fragmentation. It is also hypothesized that including a variables that reflects landowners' land-use decisions in models of the spatial patterns of land uses and land covers will improve the performances of the models.

Chapter 6 focuses on relationships between forest fragmentation and how landowners use the forest on their parcels. It specifically identifies the most commonly important types of forest uses and correlates the importance landowners assign to various uses with metrics of forest fragmentation. It is hypothesized that different forest uses are associated with significant differences in metrics of forest fragmentation and that including a variable that reflects landowners' forest uses will improve the performance of models of spatial patterns of land uses and land covers. The final chapter, Chapter 7, provides an overview of the findings and conclusions from all the chapters and notes how the research has addressed the stated research needs.

CHAPTER 2
STUDY AREA AND GENERAL METHODOLOGY

1.0. Study Area: Monroe County, Indiana, USA

The subsequent chapters of this dissertation address these research needs through a case study of Monroe County, Indiana (IN). As evident in Figure 2.1, Monroe County is in the Midwest region of the United States and is in the south-central portion of the state of Indiana. It is approximately 50 miles south of the state capital, Indianapolis. The city of Bloomington occupies much of the center of the county, and the Bloomington urban area continues to expand into rural areas of the county. However, as evident in Figure 2.2, a wide range of land uses and land covers occupy the landscape. The town of Ellettsville, which has become almost a suburb of Bloomington, is the only other population center, besides Bloomington, in the County. There is officially a third town that is located in the northwest corner of the county, but it is quite small. Bloomington and surrounding areas have strong ties with the largest city in the state or Indianapolis.

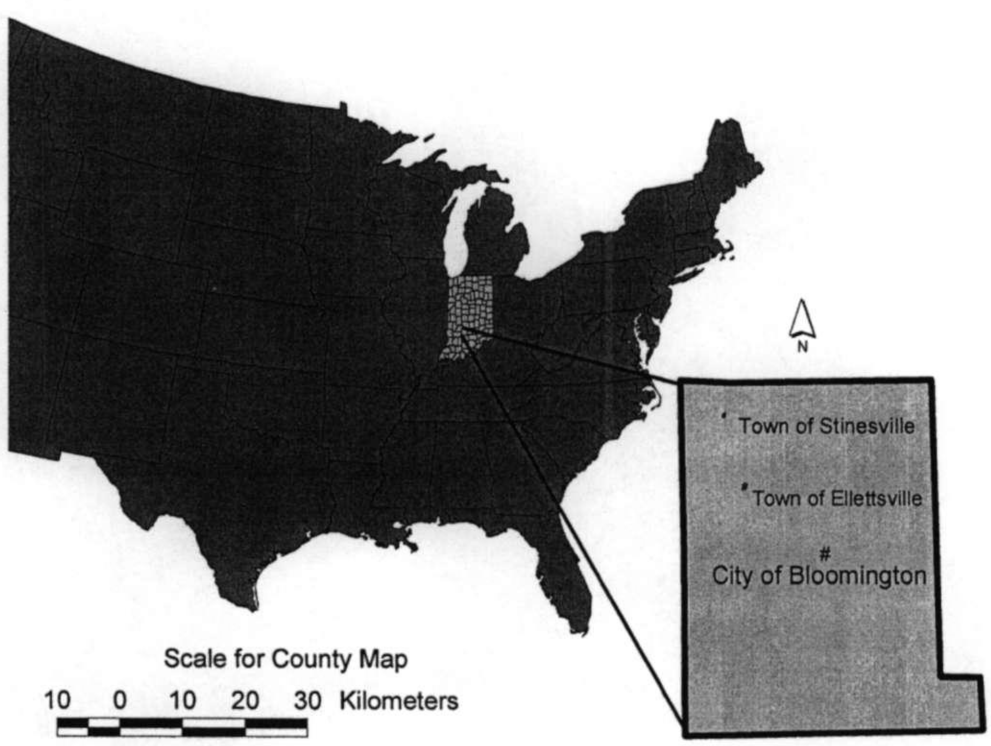

Figure 2.1. The Location of the Study Area, Monroe County, within the Eastern United States and Cities and Towns within the County

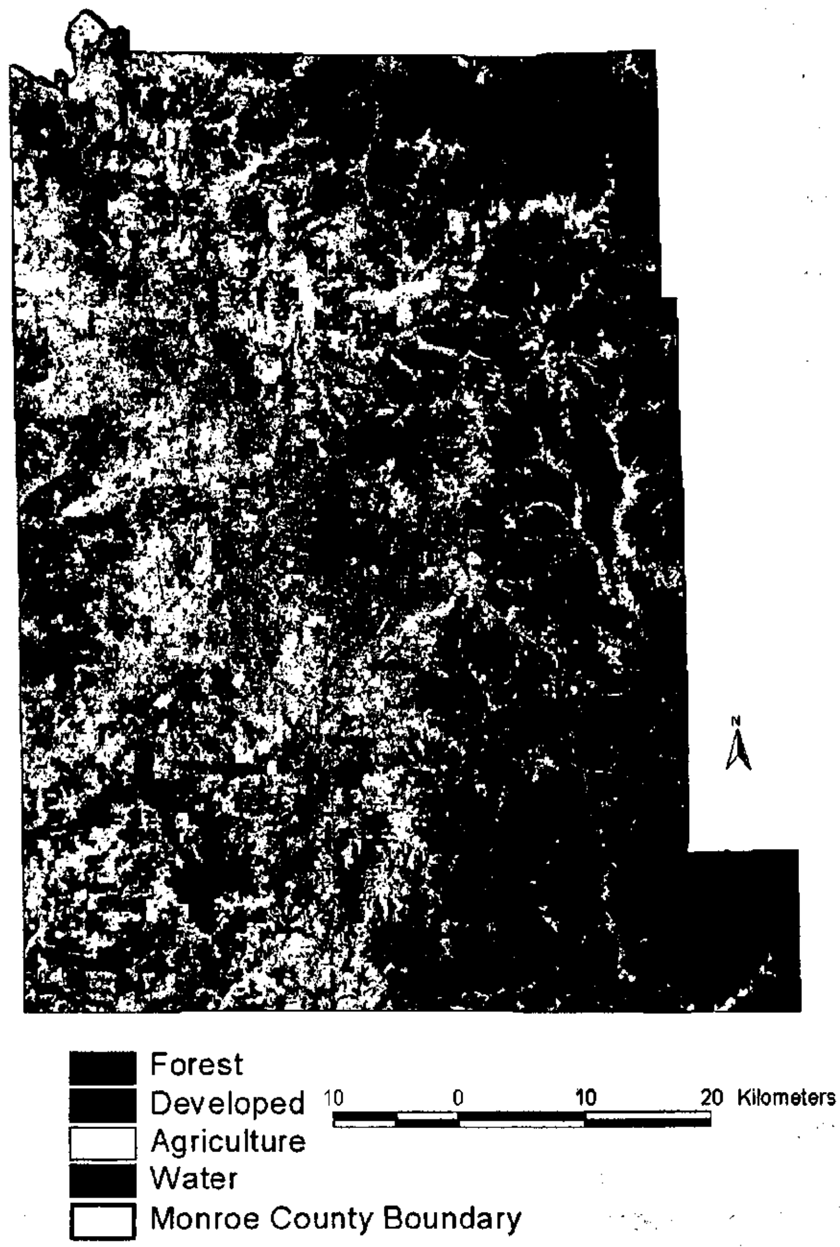

Figure 2.2. Land Uses and Land Covers in Monroe County, Indiana

Fragmentation of forest habitats is one of largest threats to forest resources in Indiana (Peterson 1998, Heilman et al. 2002). Since much of the forested land in the county occurs on a number of privately owned parcels, management of forest ecosystems is tied to land and forest use decisions made by a number of landowners. Fragmentation of ownership is also one of the largest threats for sustainable use of the forest resources in Monroe County (Petersen 1998).

Similar to the situation in many areas, policymakers are striving for balance in protecting private-property or land-use rights and protecting the public good that comes from the functions of forest ecosystems. Policymakers use county-level planning and zoning to regulate land uses on private property in order to protect the public good. Other policies protect the private property rights of the landowners and are intended to encourage reforestation and good forestry management by appealing to voluntary cooperation and participation. These policies, each of which offers a unique incentive, include: tax incentives, cost-sharing, certification, and easement programs (York et al. 2005).

There are a variety of grant programs available that share part of the cost of implementing forest management practices with landowners. Some of the most popular grants available focus on tree planting, timber stand improvement, and forest wildlife habitat improvement. A variety of programs exist that are based on tax incentives. The Indiana Classified Forest Program is one of the oldest forest conservation programs in the U. S. This program offers a lowered property tax and periodic woodland inspections by a professional forester in return for landowner commitment to practice forest conservation. The state has become involved in the federally funded Forest Legacy Program that offers financial incentives to private landowners to conserve forests that are under threat of conversion to another use (Fischer et al. 1993).

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 a 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 8th (City of Bloomington Environmental Commission 1997).

Further expansion of the urban area may have potentially detrimental social and environmental consequences. Bloomington has natural and institutional barriers beyond which urban development becomes either difficult or inappropriate. To the southeast, the Lake Monroe watershed restricts development; to the east, steep slopes limit the land available for development; to the west development is limited by karst and caves; to the west, agreements regarding utilities and annexation with the town of Ellettsville further limit urban growth, and to the north steep slopes of the Lake Griffy watershed limit development. Although urbanization has been occurring within the county, a wide range of land uses and land covers coexist. Land-use policies have the potential to direct urban growth in such a way that impacts to natural ecosystem function and culturally important landscapes are or will be limited.

In contrast to the glacially impacted northern portion of the state, southern Indiana, including much of Monroe County, is composed of hilly terrain with relatively thin, poor-quality soils. Agricultural areas within Monroe County tend to be small farms that have been in families for generations and farms cultivated as a hobby. Because of the hills and steep topography, many areas of the county are not suited for modern agricultural use. Many of these areas have been purchased by state or federal forest agencies after the owners declared bankruptcy. Secondary forests have regrown on much of both the private and publicly owned lands, and forest (mostly secondary succession) is a dominant land cover (Evans et al. 2001).

As the population of the county has grown and fewer residents pursue farming occupations, there has been less of a need for large landholdings. Many areas that were formerly in agriculture have been subdivided and have been developed for urban or suburban uses. This has resulted in a number of relatively small parcels. These parcels are particularly located near the city of Bloomington and the town of Ellettsville, which is seven miles west of Bloomington and is the only other sizeable town in the County.

2.0. Sample of Parcels

Although portions of Monroe County are publicly owned, most of the land consists of privately owned parcels. A sample of privately owned, non-industrial parcels within Monroe County was randomly selected as a basis for this research. A number of very small parcels near Bloomington and Ellettsville were considered too small for this analysis and were excluded from the pool of samples from which parcels were selected. The pool from which the parcels were selected consists of the more than 7,200 privately owned parcels of 5 acres or greater in sizes that were identified based on county tax assessment records. Most of these parcels were not used for industrial or commercial purposes.

As evident in Table 2.1, seven classes were created based on natural breaks in the sizes of the parcel included in the pool of non-industrial, private parcels that were over 5 acres in size (Koontz 2001). The total number of parcels within each size class in the county was calculated and divided by the total number of parcels within the pool. This provided the proportion of all parcels within the county that fell within each size class. Based on this stratified grouping, a sample of parcels was randomly selected.

The research team reached owners of 484 randomly selected parcels to request in-person meetings, 251 of whom agreed to participate, for a response rate of 52% (Koontz 2001). The number of parcels sampled for each size class was chosen so that the proportion of cases within the sample approximately matched the proportion of parcels of that size within the county. These proportions are shown in Table 2.1. The sizes of the parcels in the sample range from roughly five to 150 acres (or 2.02 to 60.7 hectares). The largest number of parcels (106) is in the smallest size class. This is called "size code 1" and consists of parcels from 5 to less than 15 acres in size. There are 38 parcels in the next smallest size class, which is called "size code 2" and consists of parcel between 15 and less than 25 acres in size. The proportions of parcels in the other middle-sized classes (25 to less than 35, 35 to less than 45, 45 to less than 65, and 65 to less than 85 acres) are all about 10 percent. The smallest number of cases, 14, or about 6 percent of the sample, is in the largest size class called "size code 7" (85 acres and larger).

Table 2.1. Size Classifications for a Sample of Non-Industrial Parcels Larger Than 5 Acres within Monroe County, Indiana

Size in Acres	Class Code	Number of Cases Sampled	Percent of Sample
5 – < 15	1	**106**	42
15 – < 25	2	**38**	15
25– < 35	3	**20**	8
35 – < 45	4	**26**	10
45 – < 65	5	**25**	10
65 – <85	6	**22**	9
85 +	7	14	6

The sizes of the parcels in the sample range from roughly five to 150 acres (or 2.02 to 60.7 hectares). All of the parcels included in the sample are in rural or semirural areas of Monroe County. During interviews, almost all of the landowners stated that they had at least some forest on their parcel. All of the parcels are subject to zoning regulations, which allow only certain residential, agricultural, and forest uses (Croissant and Munroe 2002). None of the sampled parcels are located within the limits of any city or town. Some of the parcels are located relatively near the major towns and highways, while others are somewhat inaccessible. The parcels have a variety of slopes, from steep to flat.

3.0. Historical Processes That Have Transformed Land Use and Land Cover in the Study Area

This study first examines the study area and the uses and relative value of forests to the local economy through historical processes that have transformed land use and land cover. Particular attention is given to the types of land and forest use decisions that have occurred over time. The historical discussion provides a context for subsequent analysis.

3.1. Pre-Settlement and the Biophysical Environment

Settlement and land use in Indiana have been greatly influenced by biophysical characteristics, particularly differences in underlying bedrock and geomorphic effects of glacial advances and retreats during the Wisconsin Ice Age. The advancing glaciers flattened the northern portion of the state and covered it with rich soil. In the south-central portion of Indiana, the glacial melt carved out stream and riverbeds, including tributaries of the Ohio River in the hilly terrain.

South-central Indiana is characteristically hilly with rugged upland ridges separated by narrow valleys. The Norman Upland, which can be found in Monroe and neighboring counties, consists of narrow ridges, steep slopes, few flat areas, and narrow, v-shaped stream valleys. The ridge tops provide some areas suitable for buildings and agriculture. The western portion of Monroe County occurs on the Crawford Upland, which includes flat areas, springs, and caves. A physiographic zone called the Mitchell Karst Plain separates the Norman and Crawford Uplands. The land in this plain is flatter and more rolling than the land in the Uplands, and it has accessible limestone bedrock that has been quarried. Limestone quarrying was an extremely important economic activity in the late 1800s and is still viable today (Sieber and Munson 1994).

Before European colonization, 85% of the land cover in the region was what we now consider "old growth" forest. The forest that occurred on both the Crawford and Norman Uplands was primarily oak-hickory with patches of beech-maple in riparian zones (Abrams 2003).

The area that is now Monroe County has been continuously inhabited for over 12,000 years. The earliest Native American inhabitants were hunter/gathers who established trails and nomadic camps. Later, Native Americans established settlements and began cultivating crops in south-central Indiana. The Native Americans' land-use activities, particularly burning, affected the distribution of tree species and contributed to the prevalence of oak trees in the pre-settlement landscape of Indiana (Abrams 2003).

3.2. Settlement

European explorers first entered south-central Indiana in the late 1600s. Few settled in south-central Indiana during the 1700s. Before the early 1800s, settlers came primarily from Europe

(Sieber and Munson 1994). The Ordinance of 1785, which is also know as the Northwest Ordinance, provided for a survey of the land of the Northwest Territory (land northwest of the Ohio River), including Indiana. This survey divided land into six-miles-square townships, which were subdivided into 36 sections that were each 640 acres in size. This subdivision allowed for the use of the Cadastral Survey Plat, a system for recording land patents and related case records that are essential to the chain of title in the public domain states. The rectangular survey system and, in 1800, the tract book system for permanent title recordation, became the legal method for the transfer of public lands into private ownership. The land subdivisions created by this system remain important (Croissant 2004). Roads often follow the north-south and east-west section lines and the survey divisions are the basis for legal descriptions of land ownership and administrative boundaries of townships and counties (Sieber and Munson 1994).

There were relatively few settlers until Indiana became a state in 1816. After statehood, most settlers came from the former colonies rather than from Europe (Sieber and Munson 1994). The initial settlers in the region saw the forests as an obstacle and a resource for timber and fuel. During the mid- to late 1800s, the use of sawmills and gristmills allowed settlers to view forests as an economic resource, and both timbering and agriculture were key economic activities (Medley et al. 2003).

In the seventeenth and eighteenth centuries, the Anglo plantation owners of the southern American colonies obtained laborers from the poorer areas of England. These laborers were typically street orphans, debtors, and criminals. They were brought to America to work the fields of tobacco, indigo, and other cash crops. These workers included not only indentured servants, but also children stolen from the streets of London and other cities of the British Isles. These children did not have the opportunity to internalize the social institutions of the British culture. Many of these workers escaped the forced labor on plantations and fled to the Appalachian Mountains. There they learned how to survive on the land and experienced freedom from many of the institutions common in other areas of the colonies and the young United States. In this landscape, the formerly kidnapped children and their descendents developed their own culture and social institutions. The Appalachian culture spread as settlers moved into the hills of Kentucky and, eventually, southern Indiana. This culture was distinct from that common to the flatter, more northern areas (Caudill 1963).

In the mid and late 1800s, many settlers came to southern Indiana from Kentucky, North Carolina, Virginia, and Tennessee. A smaller number of settlers came from Pennsylvania and Ohio, and still fewer settlers came from New York, Maryland and New England. The middle-class settlers mostly cultivated corn and raised hogs for subsistence and market export along the rivers. By 1850, German-speakers comprised the largest group of immigrants to the region. Not all of these settlers came to the region directly from Germany. Many immigrated to other areas of the United States, such as Pennsylvania, before coming to Indiana. Many German immigrants clustered together (Sieber and Munson 1994).

Most of the settlers cut trees on their land for use as building material and fuel wood and to provide land suitable for cultivation. Extensive commercial forest clearing began in the 1860s with the introduction of sawmills. With the advent of sawmills, trees were cut for timber rather than primarily as clearing for agriculture (Sieber and Munson 1994).

By 1870, increased competition for land forced some settlers to farm on the steep hills and valleys of the region. Farmers also supplemented their income with industrial jobs such as limestone quarrying factory working. By the 1880s, Monroe County became more accessible to the larger region via the Louisville-Chicago rail line. The railroad provided a market for railroad timbers and encouraged settlement and industry in the area (Sieber and Munson 1994).

As technology improved and sawing became more mechanized, the amount of wood that could be cut increased greatly (Buckley 1998). Most of the forests were completely cleared by the mid-1900s, and timbering was no longer economically viable. Poor conservation practices resulted in major soil erosion and loss of agricultural productivity (Medley et al. 2003).

3.3. From Farm Abandonment through the 1990s

The removal of most of the trees affected the land in several ways. Extensive areas were left vulnerable to forest fires that eliminated any standing timber that may have remained and made surviving trees more susceptible to pest infestation. It also left topsoil exposed and vulnerable to erosion. Flooding and erosion swept sediment into the region's streams (Buckley 1998).

Beginning in the 1920s and continuing through the Great Depression of the 1930s, many small farmers were unsuccessful at cultivating land on the marginally agricultural land of south-central Indiana. Large areas of land were simply abandoned after failed attempts to produce sufficient harvests. In addition, many sawmill owners went out of business during this time due to a lack of available trees.

The small farmers in Monroe County had difficulty competing with larger farms using more mechanized practices. Modern farming technology was very slowly incorporated into the agricultural techniques used in the region mainly because these techniques require large areas of relatively flat lands. Long after mechanized, or modern, agriculture became the norm in other areas of Indiana, farmers in much of the region continued to use traditional methods of cultivation. The transition to mechanized farming did not take place until the 1940s and 1950s (Sieber and Munson 1994).

Knowledge of past land uses is important for understanding contemporary land uses because impacts of past uses linger in the landscape and constrain later uses. Forests with similar histories of pre-abandonment use tend to follow consistent patterns. Differences in use and agricultural abandonment lead to different early forest successional species and differences in successive forest cover (Grau et al. 2003). Succession refers to natural patterns of ecosystem change that takes place over time. The rate of forest recovery following agriculture depends largely on the previous land-use practices, such as the number of years under agricultural production and the types of fertilizers and herbicide applied (Elliott et al.1998). For example, woody species richness and cover is slower for abandoned agriculture than for clear cuts.

At the present time, there are few large monoculture farms in Monroe County. The farms produce a variety of crops and livestock. Agricultural production typically occurs on the flatter areas while the steeper areas have been allowed to revert to forest. Although some areas of the county are farmed, forest (mostly secondary succession) is the dominant rural land cover in much of the county (Evans et al. 2001).

4.0. Mapping Land Use and Land Cover

Measures of the spatial pattern of forest and other land uses and land covers in a landscape are based on the composition and configuration of patches. Patches are areas of land composed of the same type of land use or land cover, which are defined according to a particular scale and classification system (O'Neill and Hunsaker 1997). Although land use and land cover are often considered together and are closely related, there are distinctions between the two terms. Land cover is the more general term. Land cover refers to the surface cover on the ground, such as forest, urban infrastructure, or water. Land use describes how people use the surface cover (Brown et al. 2000). Land use and land cover are not redundant terms because a given land-cover type may be used in more than one way. The classes associated with image classification usually relate to land cover. Land use may be inferred from ancillary information or data derived from field work. The classification used in this analysis consists of classes that were created primarily based on remote sensing techniques. The classification also incorporates general references to land use such as agriculture that incorporate information obtained from interviews and field work.

In order to generate a map of the spatial patterns of land use and land cover in Monroe County, a supervised classification of a remotely sensed Landsat Thematic Mapper image from September 1997 was produced (for more information see Croissant 2001). The supervised classification was created using the ERDAS Imagine image processing software. A more discussion of the classification procedure is more completely described elsewhere (Croissant 2001). Because of the relatively coarse grain of the imagery data (about 900 m^2), it was not possible to distinguish variation in land use and land cover occurring at extremely fine scales. This limitation required analysis of only general trends occurring over broad categories of land use and land cover. The classification used in this analysis consists of: (1) all forest, including secondary succession, (2) developed areas, including areas of residential and commercial land use, quarries, and concrete, (3) agricultural areas, including row crops and pasture, and (4) water.

The "salt and pepper" appearance of the classification was reduced by using a neighborhood algorithm that reassigns small patches to the same class as a surrounding patch if there is a high probability that the small patch belongs to the class of the larger patch. The resulting classification has an overall accuracy of 95% and overall Kappa Statistic of 0.92. The Kappa Statistic measures the observed agreement between the classification and the reference data as opposed to the agreement that might be attained solely by chance matching (Campbell 1996).

5.0. Landscape Pattern Analysis

Although the term "landscape" has a number of meanings, within the context of landscape ecology, the term refers to a spatial unit or area of analysis consisting of a number of classes. A landscape is made of complex patterns of spatial heterogeneity consisting of patches of particular classes. Patches are areas of land composed of the same type of land use or land cover, which are defined according to a particular scale and classification system (O'Neill and Hunsaker 1997).

Several methods for calculating and interpreting measures of the composition and spatial configuration of a landscape have become popular in landscape ecological research based on remote sensing imagery (Cohen and Goward 2004). The foundations of such measures are the size, number, and distribution of patches in the landscape. As described previously, a patch is a spatial entity composed of the same type of land use or land cover (O'Neill and Hunsaker 1997). Methods for quantifying spatial patterns in a landscape have been developed within landscape ecology (Gustafson and Parker 1994, McGarigal and Marks 1994, O'Neill et al. 1997, Frohn 1998). The measures are based on the composition and configuration of patches of land use and land cover occurring within the landscape mosaic. These metrics correlate with specific aspects of both ecosystem function and socioeconomic characteristics (Medley et al. 1995, Turner et al. 1996, Wear et al. 1996, and Wickham et al. 2000, Croissant and Munroe 2002).

Measures of composition and configuration can be used as a proxy for habitat suitability for plant and animal species and as an indication of how well an ecosystem will recover from natural or human disturbances (Barnes et al. 1998). The spatial patterns in the landscape affect the flows of species, nutrients, energy and other materials among habitat patches and therefore indicate ecosystem functions (MacArthur and Wilson 1967). Spatial patterns of land use and cover also affect the efficiency of public services, the quality of life, and the sense of community in an area. This includes provision of infrastructure and utilities, movement of goods and communications, protection of rural lands and sensitive natural environments, and the support of agriculture and rural activities (Geoghegan et al. 1997, Neuman 2000, Pretty et al. 2001).

A patch is a spatial entity composed of the same type of land use or land cover (O'Neill and Hunsaker 1997). Analysis of the spatial characteristics of patches is complicated because patches at a particular scale are often themselves composed of smaller patches and can be aggregated into larger patches. A significant limitation of analysis of landscape patterns is that measures of composition and configuration may change if alternative methods of defining a study area are used. A particular pitfall to avoid in landscape analysis is truncating patches of interest when defining study area boundaries (Gustafson 1998). One method of lessening this problem is to calculate the statistical variances of data at different levels of geographic units. Studies have considered multiple scales in order to model the configuration of land-use and land-cover systems (Grove and Burch 1997, Walsh et al. 1999).

Other difficulties in landscape analysis include choosing the best measure and interpreting the measure correctly. Single measures of landscape composition and configuration are most useful when the same measure is compared across landscapes. It is sometimes difficult to determine the absolute meaning of landscape measures. However, relative changes such as an increase or decrease in the same measure for different areas are more easily understood (Gustafson 1998).

This research quantifies the spatial patterns in the landscape of the study area by calculating metrics of classes of land use and land covers by using a GIS. Methods of calculating the composition of a landscape are relatively straightforward. Calculating the percentage of area covered by relatively broad classes of land use and land cover is commonly used in a wide variety of landscape related research. Several metrics for quantifying the configuration of the patches in the landscape are used in this research including the mean patch fractal dimension, area-weighted mean patch fractal dimension, largest patch index, number of patches, mean nearest-neighbor index, mean patch interspersion index, interspersion and juxtaposition index, and Simpson's evenness index. More information on these metrics is presented in Table A.1 in the Appendix.

6.0. Forest Fragmentation, Spatial Patterns, and Ecosystem Function

This research focuses on forest fragmentation as an indicator of ecosystem function and resilience. Forest fragmentation results when a habitat is subdivided by a natural disturbance or human activities into several smaller chunks or patches. Fragmentation relates to resilience and the ability of an ecosystem to recover from stress. The spatial arrangement or configuration of forest patches in a landscape can indicate the habitat suitability for plant and animal species (Barnes et al. 1998, Cumming 2002). The spatial configuration of the forest affects the flows of species, nutrients, energy, and other materials (MacArthur and Wilson 1967, Du-ning and Xiu-zhen 1999). Smaller areas of forest and those that are widely scattered and subdivided tend to have more fragile ecosystems that are less resilient to further disturbances (Dale and Pearson 1997).

Metrics of landscape patterns have been found to correlate with specific aspects of both ecosystem function and socioeconomic characteristics (Medley et al. 1995, Turner et al. 1996, Wear et al. 1996,Wickham et al. 2000, Croissant and Munroe 2002). Particular metrics have been used to indicate forest function. For example, the percentage of area covered by the largest patch of forest and the mean nearest-neighbor distance between patches have been shown to be important indicators of forest fragmentation (Wear et al. 1996, Bianco Jorge and Garcia 1997, Wickham et al. 1999). Measures that indicate evenness, or the degree to which land-use and land-cover classes are concentrated in a few categories, or are distributed among many categories have also been used to indicate the degree of fragmentation (Dale and Pearson 1997, Geoghegan et al. 1997).

CHAPTER 3

LANDSCAPE PATTERNS AND PARCEL BOUNDARIES: ANALYSIS OF SPATIAL PATTERNS OF LAND USE AND LAND COVER IN SOUTH-CENTRAL INDIANA

1.0. Introduction

As noted in Chapter 2, most of the land in the Midwest and Western regions of the United States has been divided into individual spatial units, or parcels. The system of dividing the land was implemented according to the land-survey system developed originally in the Ordinances of 1784 and 1785 and the Land Act of 1796. Under this system, all lands in the public domain were to be measured and divided according to a grid-based system of straight survey lines whose coordinates would run north-south and east-west without regard for biophysical differences in the terrain. This system produced roughly square- or rectangular-shaped units or parcels of land that were sold to individuals in most cases (Meine 1997). Most spatially explicit political or socioeconomic units of land are defined based upon boundaries created by this system.

This research explores whether the process of land parcelization is evident in patterns of land use and land cover in the landscape of south-central Indiana. It investigates whether landowners, who make decisions based on discrete partitions in the landscape, affect spatial patterns and whether these partitions result, in some cases, in discrete land-use and land-cover edges. This research uses theory and methodology from geography, resource management, and landscape ecology to analyze patterns of land use and land cover in rural to semirural Monroe County. A classification of a remotely sensed image is used as a basis for calculating metrics of landscape composition and configuration with the use of a geographic information system (GIS). The metrics are calculated for areas of developed, agricultural, and forest land associated with a sample of individual parcels that were chosen to represent all the parcels within Monroe County. The variances in the metric values for areas near the parcel boundaries are compared with the values for areas at relatively short distances from the parcel boundaries. It is hypothesized that the highest variance occurs for landscapes of areas near the parcel boundaries, where distinct changes in variance occur between these landscapes and landscapes that include areas a short distance from the boundaries, and that variance is comparatively low and changes little for landscapes encompassing areas at larger distances from the boundaries. The results of this analysis illustrate the potential impact socioeconomic and political systems may have on spatial patterns in a landscape.

2.0. Methods

According to the terminology commonly used in landscape ecology, a spatial unit of analysis is called a "landscape". Measures can be calculated for the entire landscape or at the finer class level. Because forest, developed, and agricultural lands are considered separately in this research, the analysis is conducted at the class level (McGarigal and Marks 1994). Landscapes that correspond to the parcel boundaries were created by "clipping" the raster data set based on the vector data set containing the parcel boundaries. This was done using a combination of ESRI's ArcView and ArcInfo geographic information systems. The measures for landscapes that best correspond to parcel boundaries are labeled "0" in Figure 3.1 and in subsequent graphs. These landscapes were used as input to calculate the percentage of land covered by forest, developed, and agricultural land and the mean patch fractal dimension (MPFD) by class.

In this research, the spatial patterns of land use and land cover are quantified by using three metrics for agricultural, developed, and forest lands. The percentage of the landscape covered by each class is calculated because it is the basic indicator of the composition of land use and land cover on the landscapes. This research quantifies the configuration of the landscapes by calculating the fractal dimensions (MPFD) and area-weighted fractal dimensions (AWMPFD) of the component patches by class type (Turner, O'Neill, Gardner, and Milne 1989).

Among research that seeks to analyze the spatial configuration of patches in the landscape, the most commonly used method is to calculate and compare the fractal dimension of the patches (Hung 1999, Antrop and Van Eetvelde 2000). The fractal dimension measure indicates the degree of irregularity, general shape, or level of complexity within a landscape. Disturbed land and land comprised of smaller patches tend to have lower fractal dimension values (Iverson 1988). Research (Turner, Dale, and Gardner 1989) suggests that a plot of fractal dimension versus scale can identify scale-dependent changes in pattern, which may reflect the underlying processes creating those patterns and that an increase in variance can indicate a threshold as proposed by hierarchy theory.

The MPFD is a unitless measure that ranges between 1 and 2. As evident in Equation 1, it equals the sum of 2 times the logarithm of patch perimeter (m) divided by the logarithm of patch area (m^2) for each patch of the corresponding patch type, divided by the number of patches of the same type and adjusted to correct for the bias in perimeter that occurs with raster cells (McGarigal and Marks 1994).

$$\mathrm{MPFD} = \frac{\sum_{j=1}^{n}\left[\frac{2\ln(0.25p_{ij})}{\ln a_{ij}}\right]}{n_i} \quad (1)$$

The MPFD for each land-use or land-cover class was calculated using the Patch Analyst (Grid) extension for ArcView geographic information system (Elkie et al. 1999). Because the fractal measures may be skewed due to a large number of small patches, AWMPFDs were also calculated. As evident in Equation 2, the AWMPFD equals the average fractal dimension of patches of a particular class, weighted by patch area so that larger patches weigh more than smaller patches.

$$\mathrm{AWMPFD} = \sum_{j=1}^{n}\left[\left(\frac{2\ln(0.25p_{ij})}{\ln a_{ij}}\right)\left(\frac{a_{ij}}{\sum_{j=1}^{n} a_{ij}}\right)\right] \quad (2)$$

The measures of fractal dimension are unitless measures that are smaller for shapes with very simple perimeters, such as squares, and larger for shapes with highly convoluted, plane-filling perimeters (McGarigal and Marks 1994).

In order to properly use metrics of the fractal dimension in analysis, several issues need to be addressed. The scale of the landscape affects the values of the fractal dimension. Another limitation is that fractal measures assume that there is a power law relationship between perimeter and area. This assumption may be violated in remote sensing–based representations of actual landscapes (Frohn 1998, Gustafson 1998). In complex landscapes with a wide range of patch sizes and shapes, averages of the fractal dimension may not accurately represent the configuration. The greatest limitation in using the fractal dimension may perhaps be that it is not intuitive to understand and is difficult to conceptualize (McGarigal and Marks 1994).

This research uses measures of the fractal dimension in the analysis of landscape configuration, but lessens difficulties associated with such analyses by employing several techniques. One technique used is to calculate the fractal dimension with a formula that does not necessitate a regression analysis. Another technique is to group the data into size classes so that differences in the measures are less likely to be attributable to variability in the size of the landscapes. Other steps taken to reduce difficulties include: analyzing values for a series of landscapes that incorporate different geographic units, interpreting the same measures relative to each other rather than in absolute terms, and considering area-weighted measures.

A second set of landscapes were produced for each parcel by, in effect, "moving" the boundary lines the equivalent of one raster data set cell toward the center of the parcel. Buffering the parcel boundaries with a 30-meter interval (the equivalent of moving the distance of one raster cell) and clipping the raster data set to these buffers delineated the new boundaries. Landscapes in this second set are called "-30" in subsequent analysis and in Figure 3.1. For each landscape in this second set, a corresponding set of measures of the percentage of the area covered, MPFD, and AWMPFD for forest, developed, and agricultural land were calculated. A third set of landscapes the equivalent of two raster data set cells or 60 m toward the center of the parcel from the boundary lines was created, and a third set of the same measures were calculated for these landscapes. These landscapes are called "-60" in subsequent analysis. A buffering and clipping process similar to that described previously created a fourth set of landscapes. This produced a forth set of landscapes with boundary lines a distance of one raster data set cell or 30 m outside the parcel boundaries, and from these landscapes a forth set of the same measures were calculated. These landscapes and measures are identified as "30" in subsequent analysis and in Figure 3.1. A fifth set of landscapes and subsequent measures called "60" were similarly created. This set encompass an area 30 m out from the boundaries of the landscapes called "30".

Figure 3.1 illustrates the basic idea of the process that created the sets of landscapes. The landscapes increase in area as 30-meter increments are added. Each landscape is composed of a number of cells that are 30 by 30 m. Landscapes at increasing distances from the boundary encompass the landscapes at smaller distances. Measures generated for landscapes of areas within the parcels are identified with names beginning with a negative sign. Measures calculated for landscapes of areas outside the boundaries are identified with positive numbers.

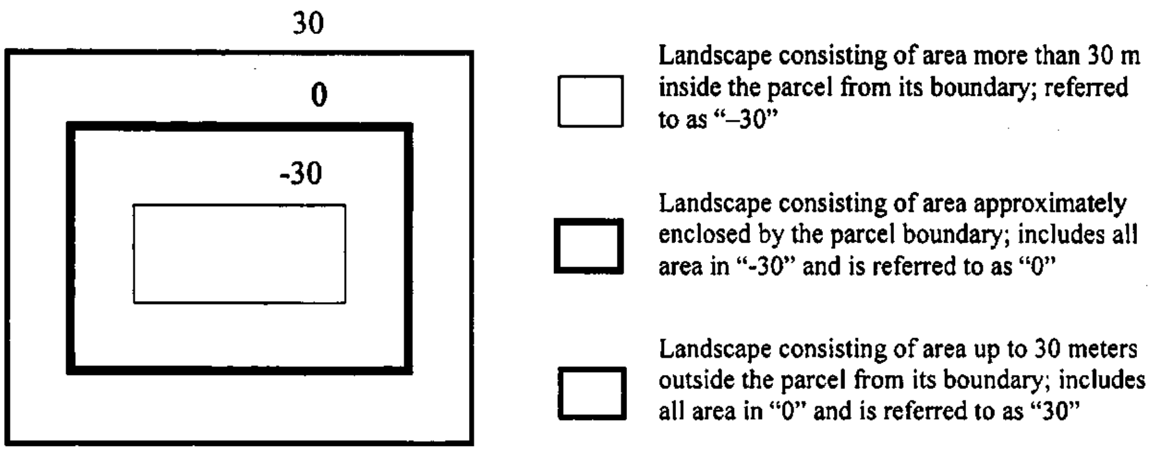

Figure 3.1. Hypothetical Example Depicting the Method Employed to Create a Series of Landscapes Associated with Each of the 251 Parcels Used in Subsequent Analysis. The darkest line (labeled 0) represents the parcel boundary, and the lighter lines represent the locations of boundaries the distance of one raster cell (30 m) inside (labeled -30) and outside (labeled 30) the parcel.

In addition to these landscapes that approximately correspond to the parcel boundaries, landscapes containing areas at a distance from the parcel boundaries were also generated. The process of creating new landscapes by buffering boundaries and increasing the area included in the landscapes in 30-meter intervals then clipping the landscapes from the raster data set was continued until a distance of 480 m outside the parcel boundaries was reached.

In summary, sets of landscapes were created as a basis for calculating measures of spatial pattern near and at a distance from the parcel boundaries. A total of 19 sets of landscapes associated with each of the 251 parcels were produced. For each of these landscapes, measures of the percentage of area covered, MPFD, and AWMPFD for the classes called forest, developed, and agriculture were calculated using the Patch Analyst software.

Descriptive statistics were calculated for each column in the various tables, and the variance in the measures of area covered, MPFD, and AWMPFD were graphed. These graphs illustrate trends in the variability as distance from the parcel boundaries increases and allow for visual comparison of values near the boundaries with those at a distance.

3.0. Results

3.1. Percentage of Landscape: Forest

The measures of variance in the percentage of the landscapes covered by forest at increasing distances from the parcel boundaries are shown graphically in Figure 3.2. The measures are separated into the seven size classes. For all size classes, the highest variance is found approximately at or slightly inside the parcel boundaries. The variance decreases relatively sharply between landscapes consisting of areas extending approximately 60 to 150 m from the boundaries. The measures for landscapes of areas between 180 and 480 m from the boundaries tend to be very similar within each size class. The differences in variance between the size classes tend to decrease for landscapes of areas at larger distances from the parcel boundaries. The variance in the percent forest cover for the landscapes of areas around parcels in the larger class sizes tends to be less than that of measures for landscapes in the smaller class sizes. However, the highest variance across all landscapes is for parcels in class size 4, which are mid-sized parcels. Because the measures for all parcels including the largest-sized parcels (those with the class size code 7 or those 85 acres or larger) have the same general patterns, the differences in variance are not attributable purely to differences in the size of the parcels. These results indicate that once a certain threshold in landscape size is reached, measures of the amount of forest in the landscape are similar regardless of changes in the definition of the study area boundaries. The results also indicate that changes in the amount of forest cover tend to occur around parcel boundaries.

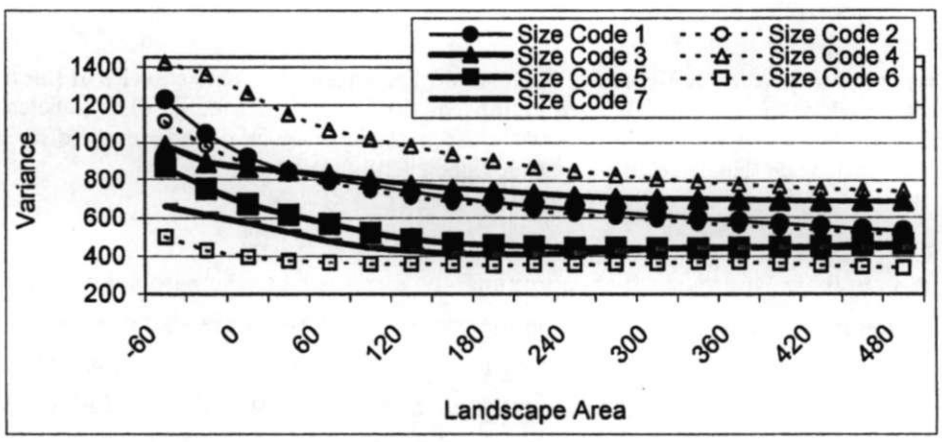

Figure 3.2. Graphic Comparison of Measures of Variance in Percentage of Area Covered by Forest. The horizontal axis represents the set of landscapes of areas at increasing distances from the center of the parcels. Measures for landscapes that best correspond to the parcel boundaries are labeled "0." Measures for landscapes consisting of areas the distance of one raster cell (30 m) inside the parcel from the boundaries are labeled –30, and those for the distance of two cells are labeled –60. Positive label numbers (30, 60, 90, . . . 480) correspond to sets of landscapes created at 30-meter intervals out from the parcel boundaries. The variance values are grouped into the parcel size classes (size code 1, size code 2, . . . size code 7) that are described in Table 2.1.

3.2. Percentage of Landscape: Developed Land

The processing technique used to reduce the number of small, isolated patches may have affected some measures of composition and configuration. This may have particularly affected the measures for developed areas (shown in Figure 3.3) because they tend to be smaller and more isolated from one another than patches of forest or agricultural land. Therefore, the measures of the percentage of landscapes covered by developed land may be slightly low. Because the parcels in the sample were from rural or semirural areas, it is not surprising that there are both relatively small portions of the landscapes covered by developed land and little differences in the values between parcels. The graph of the measures of variance in the percentage of the landscapes covered by developed land (Figure 3.3) shows little change across all the landscapes. The measures of variance are similar for all the size classes and change little as area is added to landscapes at increasing distances from the parcel boundaries. The variance in the percentage of area covered by developed land is much lower for all landscapes than the variance in the percent of the landscapes covered by forest and agriculture. For the smallest size class, size code 1, the variation is highest near the parcel boundaries. For the landscapes of areas in the other size classes, the variation is highest for the areas further from the parcel boundaries. Because the values are so similar, and the differences in values are so small, it is difficult to determine if particular changes in the amount of developed land tend to occur near the parcel boundaries.

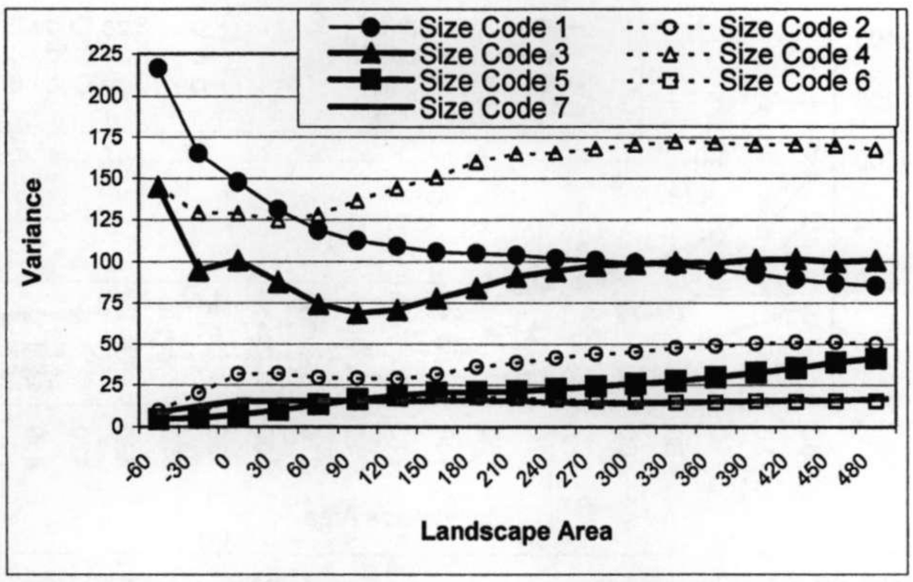

Figure 3.3. Graphic Comparison of Measures of the Variance in Percentage of Area Covered by Developed Land. The horizontal axis represents the set of landscapes of areas at increasing distances from the center of the parcels. Measures for landscapes that best correspond to the parcel boundaries are labeled "0." Measures for landscapes consisting of areas the distance of one raster cell (30 m) inside the parcel from the boundaries are labeled –30, and those for the distance of 2 cells are labeled –60. Positive label numbers (30, 60, 90, . . . 480) correspond to sets of landscapes created at 30-meter intervals out from the parcel boundaries. The variance values are grouped into the parcel size classes (size code 1, size code 2, . . . size code 7) described in Table 2.1.

3.3. Percentage of Landscape: Agricultural Land

Figure 3.4 graphically illustrates the measures of variance in the percentage of area covered by agriculture for landscapes at increasing distances from the parcel boundaries. The general patterns are similar to those in the graph of variance in the percentage of area covered by forest. For all size classes, the highest variance occurs near or slightly inside the parcel boundaries. The variance decreases steadily until it levels off for landscapes including areas approximately 240 m from the boundaries. Similar to the results for forest, the largest parcels (those with size code 7, or those 85 acres or larger) have the same general patterns of variance for landscapes encompassing areas at increasing distances from the parcel boundaries as the smaller parcels. Therefore, the differences in value are not purely attributable to differences in the size of the parcels. These results also indicate that once a certain threshold in landscape size is reached, measures of the amount of agricultural land in the landscape are similar regardless of changes in the definition of the study area boundaries. The slope of the line representing variation in the percentage of land covered by agriculture for landscapes of areas at increasing distances from the parcel boundaries is relatively steep for areas a short distance (about 90 m) from the boundaries. These results support the hypothesis that a relatively abrupt change in the composition of the landscape occurs near the parcel boundaries.

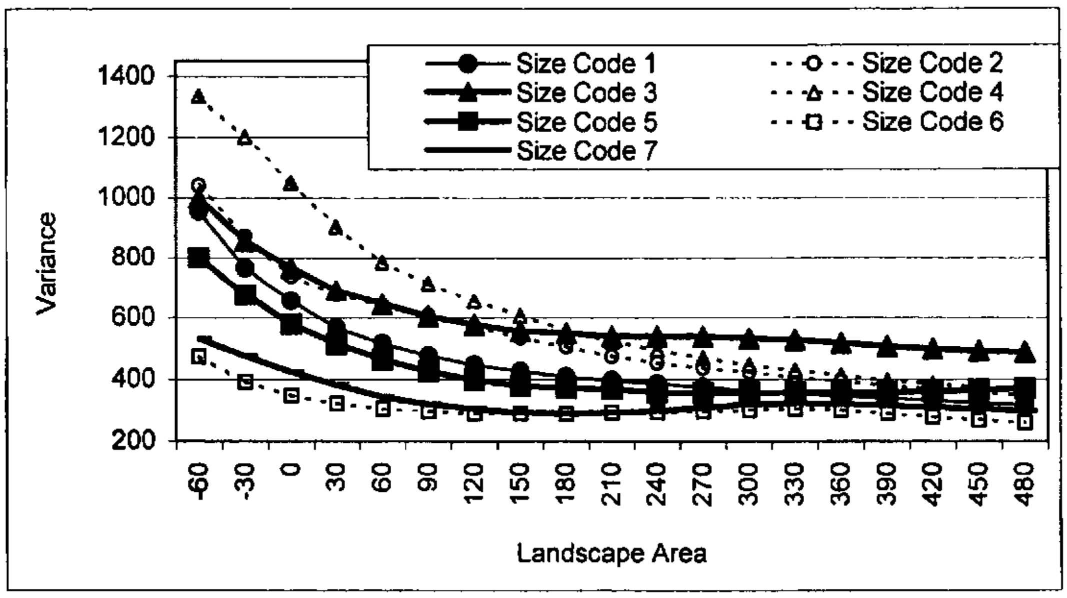

Figure 3.4. Graphic Comparison of Measures of the Variance in Percentage of Area Covered by Agricultural Land. The horizontal axis represents the set of landscapes of areas at increasing distances from the center of the parcels. Measures for landscapes that best correspond to the parcel boundaries are labeled "0." Measures for landscapes consisting of areas the distance of one raster cell (30 m) inside the parcel from the boundaries are labeled –30, and those for the distance of 2 cells are labeled –60. Positive label numbers (30, 60, 90, . . . 480) correspond to sets of landscapes created at 30-meter intervals out from the parcel boundaries. The variance values are grouped into the parcel size classes (size code 1, size code 2, . . . size code 7) described in Table 2.1.

3.4. Fractal Dimension: Forest

As illustrated graphically in Figure 3.5, there is little variability in the measures of variance in MPFD and AWMPFD for forest on landscapes consisting of areas at increasing distances from the parcel boundaries. The only major change in variance measures occurs between approximately 30 m inside and 30 m outside the boundaries of parcels in size classes 1 and 2. The other measures are all similar across size classes and for landscapes encompassing areas at increasingly larger distances from the parcel boundaries. This indicates that there is little change in the configuration or shape of forest patches regardless of the size of the parcel or the area included in the landscapes used for analysis. The area-weighted measures of variance are slightly higher than those not weighted for landscapes encompassing areas further from the boundaries. This indicates that the little variability evident is most likely due to differences in small patches.

Generally, the results indicate that areas of forest within one parcel tend to have similar shape or configuration as forest a short distance from the boundaries and that little change in forest configuration is evident around the parcel boundaries.

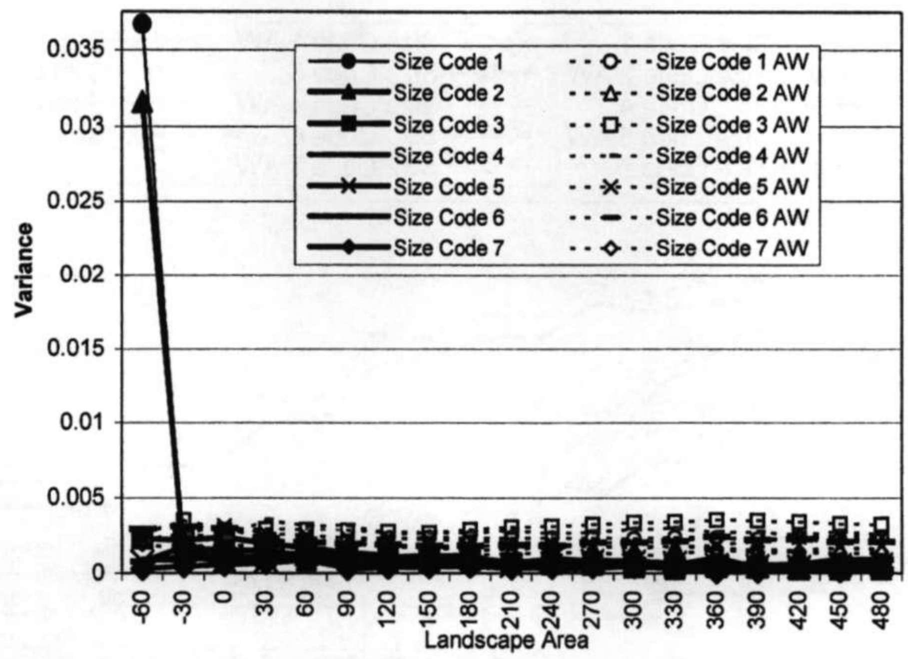

Figure 3.5. Graphic Comparison of Measures of the Variance in MPFD and AWMPFD (noted as AW) for Forest. The horizontal axis represents the set of landscapes of areas at increasing distances from the center of the parcels. Measures for landscapes that best correspond to the parcel boundaries are labeled "0." Measures for landscapes consisting of areas the distance of one raster cell (30 m) inside the parcel from the boundaries are labeled –30, and those for the distance of 2 cells are labeled –60. Positive label numbers (30, 60, 90, . . . 480) correspond to sets of landscapes created at 30-meter intervals out from the parcel boundaries. The variance values are grouped into the parcel size classes (size code 1, size code 2, . . . size code 7) described in Table 2.1.

3.5. Fractal Dimension: Developed Land

Variance in MPFD and AWMPFD measures for developed land are presented graphically in Figure 3.6. The measures tend to be higher for developed land than forest. For most of the size classes, the variance is highest for landscapes that correspond approximately with the parcel boundaries. The variance measures for parcels in the largest size class (that is with size code 7) follow a general pattern of peaking for landscapes that approximately correspond to the parcel boundaries and then gradually decreasing for landscapes of areas further from the boundaries.

The area-weighted measures tend to be only slightly higher than those that were not weighted, which implies that the larger patches tend to have slightly more complex shapes than smaller patches. For all size classes, the largest changes in variance occur between landscapes that correspond approximately to the parcel boundaries and those that include areas just outside the boundaries. These results indicate a relatively abrupt change in the shape or configuration of developed areas occurs near the parcel boundaries.

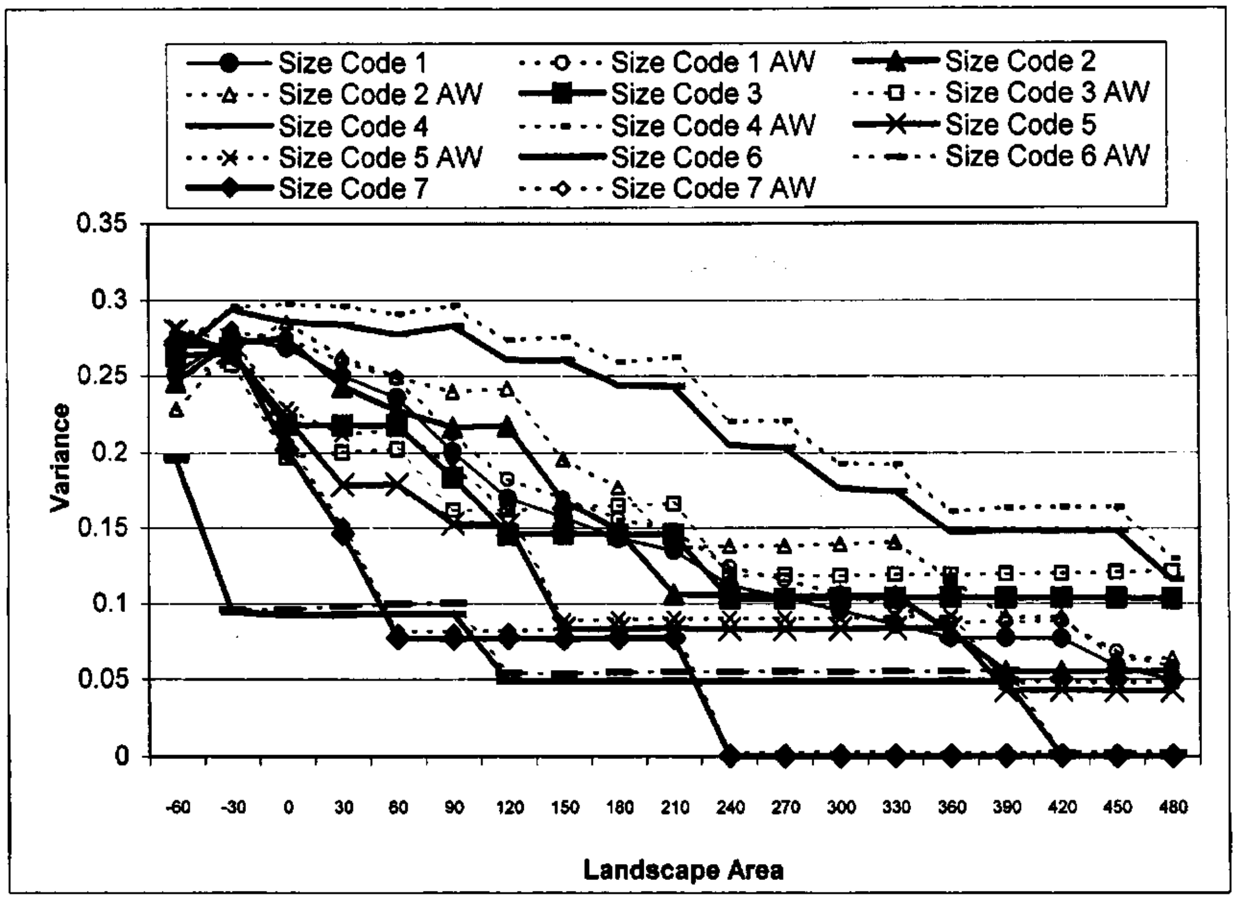

Figure 3.6. Graphic Comparison of Measures of the Variance in MPFD and AWMPFD (noted as AW) for Developed Land. The horizontal axis represents the set of landscapes of areas at increasing distances from the center of the parcels. Measures for landscapes that best correspond to the parcel boundaries are labeled "0." Measures for landscapes consisting of areas the distance of one raster cell (30 m) inside the parcel from the boundaries are labeled –3, and those for the distance of 2 cells are labeled –60. Positive label numbers (30, 60, 90, . . . 480) correspond to sets of landscapes created at 30-meter intervals out from the parcel boundaries. The variance values are grouped into the parcel size classes (size code 1, size code 2, . . . size code 7) described in Table 2.1.

3.6. Fractal Dimension: Agricultural Land

Figure 3.7 is a graph of variance in MPFD and AWMPFD of agricultural land at increasing distances from the parcel boundaries. The highest variance in the percent of area covered by agriculture occurs near the boundaries. The values for the landscapes with size codes 2, 3, and 5 indicate that there are changes in the shape or configuration of agricultural areas that tend to occur near the boundaries of parcels. Relatively sharp decreases in measures of variance occur for landscapes of areas at increasing distances from the boundaries until a threshold value is reached (for landscapes encompassing areas approximately 90 m from the boundaries). After this point, the addition of more area to the landscape does not change the values greatly until another threshold value is reached.

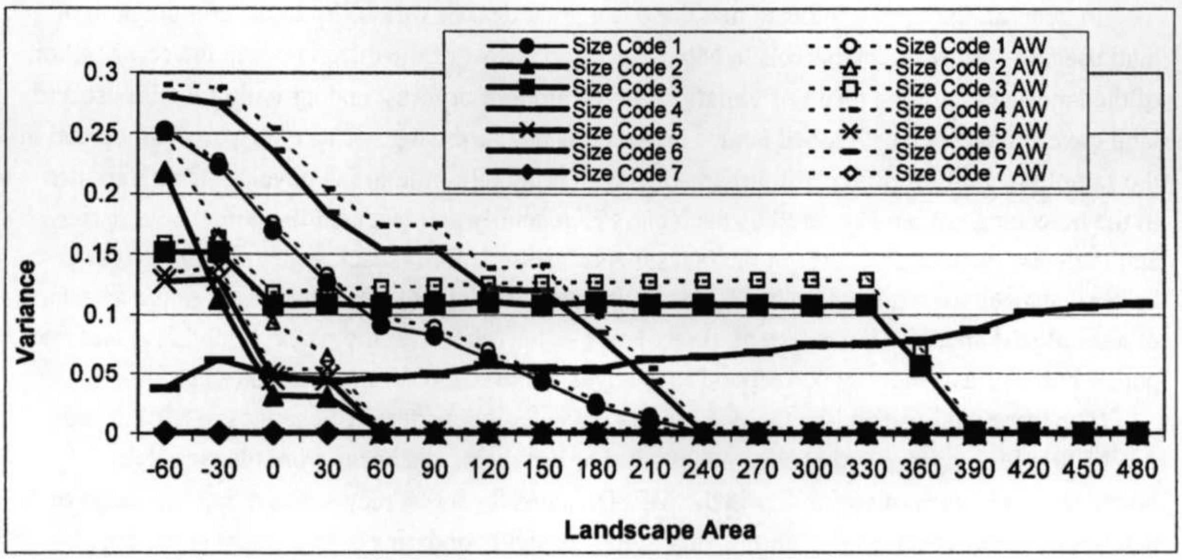

Figure 3.7. Graphic Comparison of Measures of the Variance in MPFD and AWMPFD (noted as AW) for Agricultural Land. The horizontal axis represents the set of landscapes of areas at increasing distances from the center of the parcels. Measures for landscapes that best correspond to the parcel boundaries are labeled "0." Measures for landscapes consisting of areas the distance of one raster cell (30 m) inside the parcel from the boundaries are labeled –30, and those for the distance of 2 cells are labeled –60. Positive label numbers (30, 60, 90, . . . 480) correspond to sets of landscapes created at 30-meter intervals out from the parcel boundaries. The variance values are grouped into the parcel size classes (size code 1, size code 2, . . . size code 7) described in Table 2.1.

The MPFD values for parcels with size code 6 have a unique pattern. The variance for this class increases for landscapes encompassing areas at larger distances from the boundaries. The values of the AWMPFD for the landscapes of areas around parcels with size code 6 are similar to the values for those with size code 7. The values of MPFD are only slightly lower than those of AWMPFD for most of the landscapes, except those with size code 6. The MPFD values for landscapes with size code 6 may be skewed because of a large number of smaller patches. Generally, the results indicate that the values are not greatly affected by a large number of small patches. The pattern of variance for landscapes classified with size code 7 differs from the others in that the values for the landscapes change little. This indicates that there is little variability in the shape or configuration of areas of agriculture near the boundaries of very large parcels, but there is variability around the boundaries of smaller parcels.

4.0. Discussion

The results generally indicate that the remotely sensed data (Landsat Thematic Mapper imagery) provided enough detail for analysis of landscapes associated with at least moderately large parcels. However, research focused explicitly on patterns of variability in the land-use class associated with developed land may require finer-scale data than Landsat Thematic Mapper imagery or analysis of larger units such as neighborhoods or subdivisions. The results also suggest that spatial patterns that are observed for landscapes encompassing areas broader than about half a kilometer from the parcel boundaries may provide slightly different measures of spatial patterns than landscapes that correspond to the parcel boundaries.

In general, the results indicate that there is a great deal of variability in the composition of land use and land cover on parcels in Monroe County. Most of the differences in the composition of the landscapes are the result of variations in the amount of forest and agricultural land use and land cover rather than developed land. This result is not surprising because the parcels included in the sample were from rural or suburban areas with relatively little urban development. Variance in the percentage of land covered by each class is generally greatest near the parcel boundaries, and there are distinct decreases in the measures of variance for landscapes that include areas at larger distances from the boundaries. This indicates that relatively abrupt changes in the amount of agricultural and, to a lesser extent, forest lands occur roughly at the parcel boundaries and that parcel boundaries generally correspond to changes in the composition of a landscape.

The three land-use and land-cover classes have distinct patterns of changes in MPFD and AWMPFD for landscapes that encompass areas at increasing distances from the parcel boundaries. The lack of variability in the MPFD values for forest may suggest that the shape of patches of forest cover do not tend to vary across parcel boundaries or that forest cover may be spread among parcels without respect to boundary lines. It may also suggest that variability in the shape of forest cover is more strongly connected to processes and characteristics that vary at scales broader than individual parcels, such as differences in slope, than to the grid-based system of land division. In general, the slope of lines connecting values of variance in MPFD for developed land occurring on landscapes of areas at increasing distances from the parcel boundaries are less steep than the slope of a line connecting variance for agricultural lands. This could mean that changes in the shape or configuration of areas of developed land occur gradually and over larger areas than changes in agricultural lands. The results imply that changes in the configuration of agricultural and, to a lesser extent, developed lands occur near parcel boundaries.

Landowners consider parcel boundaries when choosing the location of types of land uses and land covers on their property. For example, landowners may plant trees along the boundaries of their property and along roads as a buffer, and a concentration of forest cover may occur along the perimeter of parcels and along roads. The results of this research indicate that individual land-use decisions significantly impact the spatial patterns of land uses and land covers in Monroe County.

An externality is any action that affects the welfare of or opportunities available to an individual or group without direct payment or compensation, and may be positive or negative (Pretty et al. 2001). Landowners can increase the benefits of the positive externalities by clustering similar land uses and land covers together, often across parcel boundaries. Forest may be concentrated in particular areas because of the positive externalities that larger areas of forest offer to landowners such as aesthetics, buffering, and wildlife watching. Thus, forest may not change much near the boundaries of adjacent parcels. Developed areas may be concentrated in particular areas because of the availability of utilities such as sewer lines or roads.

Some residential landowners may view aspects of agricultural production negatively. Such a view may result in agricultural land uses being confined to particular parcels that have forest and residential uses surrounding them. This may aid in explaining the relatively sharp changes in the amount of agricultural land use and its spatial configuration between adjacent parcels.

The continuing process of land subdivision and the associated increase in the number of landowners is related to the process of urbanization that is occurring in the county. This process tends to increase the economic value of the land, increase the taxes that must be paid on the land, and increase the pressure on farmers to sell the land to developers. A landowner may subdivide or sell his or her land for development while a neighboring landowner continues to use his or her land for agriculture. This may also partly explain the rather abrupt change in the spatial patterns of land use and land cover, particularly for agricultural land use, occurring at the parcel boundaries.

5.0. Conclusion

This research illustrates a connection between the political and socioeconomic process of land parcelization and the spatial patterns in a landscape. The results of this analysis support the hypothesis that the grid-based system of land parcelization in general and parcel boundary delineation in particular have had an impact on patterns of land use and land cover in Monroe County, Indiana. More specifically, the results suggest that parcel boundaries are generally associated with distinct changes in the composition of agricultural and, to a lesser degree, forest lands. They also suggest that parcel boundaries correspond to changes in the configuration of agricultural and, to a lesser degree, developed lands. Parcel boundaries, in general, correspond to interaction-minimizing boundaries and are associated with changes in the composition and configuration of the landscape.

The initial divisions of land continue to impact the spatial patterns in the landscape. The results indicate that the initial parcelization of land and the subsequent subdivision and privatization of land ownership have affected the spatial patterns of land uses and land covers in the landscape of Monroe County, Indiana. After the land had been divided and privatized, individual land rights become the dominant form of land and forest management. Landowners make decisions about land and forest uses for an area enclosed by parcel boundaries. Thus, parcel boundaries correspond to borders between areas managed by different individuals. The results of this research indicate that different land and forest management decisions are related to differences in the spatial patterns of land use and land cover in a landscape.

Factors other than parcelization affect the spatial patterns in the landscape. For example, biophysical characteristics that occur across a landscape may also affect the distribution of land uses and land covers. Areas of steep slope or particular soil types tend to extend across parcel boundaries, and forest cover is likely to cross parcel boundaries and follow the steep slopes. Forest cover may also cross ownership boundaries as it follows stream banks. This may explain why the configuration of forest lands tends to be similar across parcel boundaries.

Future research will investigate relationships between other biophysical and socioeconomic factors and spatial patterns in the landscape. It is interesting to note that some exceptions to general patterns of changes in variance exist for some size classes. Differences in measures between size classes will be explored in future research. Other statistical tests may also be employed to determine changes in the spatial patterns among various landscapes.

CHAPTER 4
LAND-USE DECISIONS AND SPATIAL PATTERNS ON PRIVATE PARCELS IN MONROE COUNTY, INDIANA

1.0. Introduction

As discussed in Chapter 2, biophysical and socioeconomic characteristics have been associated with spatial patterns of forest cover, which indicate forest fragmentation and, therefore, forest resilience (Gunderson 2000, Marzluff and Ewing 2001, Medley et al. 2003). In Monroe County, Indiana, as in many parts of the United States and the world, individuals own much of the forested land. In the future, most changes in forest lands in the United States will occur over these privately owned areas (Erickson et al. 2002). Fragmentation of forest habitat and ownership comprise one of the largest threats for sustainable use of the forest resources in Monroe County (Petersen 1998, Marzluff and Ewing 2001, Frentz et al. 2004). Fragmentation of forest cover through processes such as urbanization is increasingly impacting forest function and resilience.

Research on land-use and land-cover change in initially forested ecosystems has found that biophysical variables such as soil fertility and topography most effectively explain broader scale land-use change but differences in human knowledge and management techniques are the strongest explanatory variables at a finer scale (Moran 1993, Moran and Brondízio 1998). Therefore, there is a need to include variables that represent landowners' knowledge and land management techniques in analysis of spatial patterns of land use and land cover on parcels.

The aggregate pattern of forest cover is a collective result of gains and loss of forest due to land-use decisions that happen on each individual parcel of land. A number of factors including economic, political, and biophysical constraints, as well as knowledge, past land uses, attitudes, values, and beliefs affect an owner's land-use decision (Moran et al. 2002, Munroe and York 2003, Lambin et al. 2003).

There are a number of studies that have found significant relationships between socioeconomic variables and spatial patterns in a landscape. For example, Levia (1998) concluded that the distance to the nearest city center, distance to nearby highways, and parcel size are related to the probability of conversion of farmland to residential use in Massachusetts. Turner et al. (1996) determined socioeconomic variables including distance to roads, city centers, and population density to be key landscape variables. LaGro and DeGloria (1992) also identified population density and proximity to highways as being related to urban development probabilities in a land-use study in New York State.

Recent research has begun to connect spatial measures of forest pattern, which is indicative of ecosystem function, with socioeconomic differences (Wickham et al. 2000). For example, Medley et al. (1995) found connections between population density, land use, and transportation and metrics of spatial patterns including the distribution, sizes, and shapes of forest patches. They found that forest patches in the more urban area were small with typically simple geometric shapes. In the suburban zone, they found high variability in forest-patch sizes and greater complexity in forest shapes. In rural areas they found a low number of large forest patches.

Factors that limit the types of land use a landowner may choose to conduct on a parcel may impact the spatial patterns in a landscape. For example, if a landowner is very dependent on the parcel for income generation, that limits the types of land uses that can be conducted. In the study area, an owner who is very dependent on income generated by the parcel is more likely to use the parcel for agriculture than for residence. The highest education achieved by an owner also limits his or her land-use decisions. A higher degree of education or higher income may allow the owner to have a job in which he or she can live in the rural area, or use the parcel for residence and forest, and commute into the city to work.

Differences in historical land uses have been associated with variations in forest characteristics that persist in a landscape (Elliott et al. 1998). Past land uses often restrict later land-use decisions and indirectly impact land-use decisions by other variables that have been affected. Variables that are related to past land uses include the size of the parcel because if there is a change in land use toward more urban uses, the parcel is often subdivided.

The size of the parcel can be an important variable to include in an analysis of spatial patterns of land use and land cover. A smaller parcel size generally indicates that more urban land uses have taken place on the parcel. Parcel size and the length of time a parcel has been owned by an individual and his or her family reflect land-use attitudes and management practices that may be related to differences in the spatial characteristics of the forest cover (Erickson et al. 2002). The size of the parcel is also related to zoning restrictions that are based on minimum lot sizes. Research has shown that zoning restrictions and the degree of slope on a parcel are significantly related to spatial patterns of land use and land cover on parcels in Monroe County (Croissant and Munroe 2002, Munroe et al. 2005).

Factors that are related to landowners characteristics, preferences, and knowledge may also affect land and forest use decisions. A higher rate of landowner turnover often indicates more urban land uses have occurred on the parcel. A longer length of ownership is often associated with more of an emphasis on agricultural production. The longer a parcel has been owned by an individual or his or her family, the more knowledgeable the owner is likely to be in terms of agricultural production and the more ingrained the tradition of agricultural use is likely to be. It is more likely that a landowner will continue the land-use tradition implemented by the previous owner, which in the study area is most likely to be agricultural or forest uses, if the owner acquired the parcel from a relative. If a landowner shares similar management beliefs and uses as previous owners, as often occurs when a parcel is inherited or obtained from a family member, then there is likely to be consistency in land uses and the results of past land-use decisions will persist in the landscape (Medley et al. 2003). An owner who anticipates passing the parcel to an heir is more likely to be concerned with sustainable use of the resources than someone who plans to sell the land. The age of the landowner is also tied to landowner turnover. Younger owners are likely to have owned the land for a shorter period of time and to choose more urban types of land uses.

Research by Erickson et al. (2002) indicates that short-term landowners, who tend to use less of their parcel for agricultural production, tend to make land-use decisions that allow for more forest growth than longer-term landowners. However, Medley et al. (2003) report results that are contrary to these conclusions. They found that parcels with the lowest landowner turnover or ones that had been used for farming for the longest periods of time, had the greatest percentage of land in forest and largest mean forest-patch sizes for parcels of land included in a study conducted in a predominantly agricultural area of the United States.

Although research has linked factors that affect land-use decisions and differences in aspects of the spatial patterns of land use and land cover on parcels, more research is needed to explore relationships between other factors related to land-use decisions and forest fragmentation. This study specifically explores relationships between metrics that indicate forest fragmentation and differences in the size of the parcel, landowner characteristics, slope, accessibility, neighborhood population density, and past land uses that have affected the parcel. It is hypothesized that variables that indicate limits to the types of land and forest uses that may be conducted on a parcel and that indicate an individual's background, knowledge, and preferences are highly correlated with measures of forest fragmentation. In addition, it is hypothesized that there are significant differences in the metrics between parcels with different landowner characteristics and parcels with different land-use histories. It is also hypothesized that models which include variables that are related to landowners characteristics, knowledge, and preferences will perform better than models that include only measures of slope and accessibility and that models that include all these variables will explain much of the variability in the spatial patterns of land uses and land covers on parcels in the study area.

It is expected that larger amounts of less fragmented forest occur on parcels with shorter periods of ownership by an individual and his or her family and on parcels that are less important for generating income for the landowner. It is also expected that there are significant differences in the spatial characteristics of forest on parcels that have and have not had similar land uses and management beliefs over subsequent owners, have and have not been inherited or obtained from a family member, have and do not have owners who anticipate transferring the parcel to an heir, and have or have not been affected by tilling, quarrying, and drilling. Significant correlations are expected between education, income, accessibility, parcel size, length of time parcel owned, age of owner, mean slope, and the metrics that indicate forest fragmentation. This research explores these issues in a case study of private parcel that are located in Monroe County, Indiana. Details about the study area are presented in Chapter 2.

2.0. Data and Methods

Data for this analysis come primarily from in-person interviews with landowners, remotely sensed imagery, and digital spatial data. The sample of 251 parcels that is described in Chapter 2 is the basis of this analysis. The digital spatial data are processed in a geographic information system (GIS) with the use of theory and methodology from geography, landscape ecology, and resource management. The spatial patterns of land use and land cover on the parcels come from a classification of a remote sensing image. The theory and methods are further described in Chapter 2.

In order to quantify spatial patterns that indicate forest fragmentation on each parcel, landscapes that correspond to each of the 251 sampled parcels were produced. The area within the boundaries of each parcel plus an area that extends 90 m from the boundaries was used to crate a landscape that corresponds to each parcel. The process used to create the landscapes associated with each parcel is described in Chapter 3. The results of Chapter 3 indicate that landscapes that incorporate an area about 90 m outside the parcel boundaries tend to contain the largest variance in the composition and configuration of the land use and land cover on the landscapes and correspond to distinct landscape units (see also Croissant 2004).

2.1. Quantifying Forest Cover and Forest Fragmentation on the Parcels

In this research, the Patch Analyst (Grid) extension for the ArcView GIS (Elkie et al. 1999) is used to calculate measures of the spatial patterns, particularly those related to forest cover, in the landscape on each parcel. Although properly incorporating quantitative measures of spatial patterns of land use and land cover in an analysis is often complicated, the use of landscape metrics is now widespread (Riitters et al. 1995, Cohen and Goward 2004). There are a number of metrics for calculating the composition and configuration of patches in a landscape (O'Neill and Hunsaker 1997). Several metrics have been used to indicate forest functions (Cohen and Goward 2004).

Seven metrics are used in this research in order to provide a robust indicator of the degree of forest fragmentation on the parcels. The metrics where chosen from all the available metrics because they emphasize the dispersion, spatial association, interspersion, isolation, and connectivity of forest patches. The first metric calculated in this research is the percentage of the landscape that is covered by forest (PER_FOR). This measure is one of the primary metrics that indicate the composition of the landscape. Calculation of the percentage of the landscape that is covered by forest has been a primary component in research linking human and biophysical systems (see for example Medley et al. 2003).

The second metric calculated in this research is the percentage of landscape area covered by the largest patch of forest (LPI). This metric indicates the degree to which forest cover is concentrated in the landscape, and it has been shown to be an important indicator of forest fragmentation (Wear et al. 1996, Wickham et al. 1999). The mean nearest-neighbor distance between patches of forest (MNN) is the third metric used in this analysis. Research has shown that measures of MNN are useful for determining the degree of forest fragmentation on a landscape (Bianco Jorge and Garcia 1997). Measures that indicate evenness or whether land-use and land-cover classes are concentrated in a few categories or are distributed among many categories have also been used to indicate the degree of forest fragmentation (Dale and Pearson 1997, Geoghegan et al. 1997). In this research, the degree of evenness in the types of land uses and land covers in the landscapes is quantified with the SIEI (Simpson's Evenness Index) metric.

In order to properly interpret most of the metrics that are used in this analysis, it is necessary to take the number of forest patches into account. The final metric calculated in this research, the number of forest patches (NUMP), provides key information on the degree of forest fragmentation. The PER_FOR, LPI, and NUMP metrics are similar to the metrics Medley et al. (2003), and others have used in their analyses.

The mean patch interspersion index (MPI) and the interspersion and juxtaposition index (IJI) focus on the degree of interspersion of forest patches and spatial associations between forest patches and other types of land uses and land covers. They have not been commonly used in studies of forest fragmentation and this research explores their utility in analysis of human-environment interactions. Table A.1, in the Appendix, provides more detail on how the metrics are calculated and interpreted. Most of the metrics are intuitive to use, but the IJI metric is more difficult to understand. The IJI is a measure of patch adjacency. In general, the higher the value of the IJI, the more all patch types are equally adjacent. In other words, the higher the IJI value, the more often forest patches are adjacent to a wide variety of other types of land use and land covers. The MPI index is also less intuitive to understand than most of the metrics. The MPI index is a measure of the degree of isolation of patches but, unlike MNN, it takes the size of the patches into account. The higher the MPI value, the more highly interspersed the forest patches are.

All the metrics used in this analysis measure similar, but not redundant, aspects of the composition and configuration of the landscapes. For example, PER_FOR and LPI both refer to the percentage of area covered by forest. However, PER_FOR indicates the percentage of the landscape covered by forest and LPI presents the percentage of the landscape covered by the largest patch of forest. The LPI value indicates how concentrated the forest cover is in a way that the PER_FOR value cannot. The SIEI and IJI values both refer to the degree of variability in land-use and land-cover types in the landscape. However, SIEI quantifies how even the distribution of land-use and land-cover types are on the landscape compared with the maximum possible evenness, and IJI refers to the degree of variability in the types of land uses and land covers that are adjacent to patches of forest. Both MNN and MPI indicate the degree of interspersion of forest cover in a landscape and how far apart the forest patches are from each other, but MPI also takes the size of the patches into account. When considered together, the metrics indicate the degree of forest fragmentation and, therefore, the functions and likely resilience of the forest.

One of the reasons a relatively large number of metrics is included in this research is that an analyst should consider the values for a number of values when interpreting the results in terms of forest fragmentation. Some of the metrics will produce similar values for landscapes with very different characteristics (Riitters et al. 1995). For example, if a parcel is entirely covered by forest, it will have one patch of forest, which will cause the patch interspersion or MPI value to be low. The MPI value will also be low if a landscape is made of small patches of forest that are far apart from each other. Many of the parcels included in this analysis are almost completely covered by forest and have a few large patches of forest. Specifically, almost 34% of the cases have only one forest patch, over fifty percent of the sample has fewer than three patches of forest, and ninety percent have less than ten patches of forest. The small number of forest patches should be interpreting the metrics.

2.2. Variable Collection

Several variables that are included in this analysis were calculated with the use of ARC/INFO GIS. The size of the parcel (variable called "HECT") was taken from the boundaries of the parcel. The population density of the area in which the parcel is located was calculated from the 1990 block group-level U.S. census data (variable called "POPDEN"). The mean slope value for each parcel was obtained from a 1:24,000 scale digital elevation (variable called "SLOPE"). Several measures were calculated to indicate the accessibility of each parcel. The distances between each parcel and the nearest part of the central business district of the city of Bloomington (variable called "CBD"), the main north-south highway or highway 37 (variable called "HWY37"), and the main east-west highway or highway 46 (variable called "HWY46") were calculated.

Other variables used in this analysis were obtained from in-person interviews with the owners of the parcels included in the sample. The year of most recent transfer of ownership is taken directly from the respondents' answers (YRTR). The age (variable called "AGE") of the respondents is also taken from the interview data.

The length of time a parcel has been owned by the respondent's family (variable called "TIMEFAM") is also from the interviews. An ordinal type of classification scheme is used for this variable because many of the respondents were unsure of the exact year the parcel became owned by their family. The following four classes are used for the variable "TIMEFAM": 1, which indicates that the parcel was not obtained from a family member, 2, which indicates that the parcel has been owned by the family since the 1960s, 3, which indicates that the parcel has been owned by the family since the 1930s, and 4, which indicates that the parcel has been owned by the family since the late 1800s.

The respondent's ratings of the importance of the parcel for generating income (variable called "IMPINC") are also analyzed as ordinal rankings with the following classes: 1, or not important, 2, or of minor importance, 3, or not primary, but substantial, and 4, or a primary source of income. Other ordinal variables included in the analysis are the landowners' highest level of education (variable called "EDU") and income (variable called "DINC"). Differences in these variables reflect differences in resources that may be available to landowners in order to implement land and forest use decisions. They also reflect possible differences in the knowledge and preferences of landowners.

A number of interview responses are categorized into yes-or-no type groups for analysis. Each parcel is assigned a 1 or 2 based on whether or not: it was inherited, it was obtained from a family member (for example, purchased rather than inherited and called " FROMFAM" in the analysis), it was intended to be passed to an heir ("HEIR"), the current owner has similar land management beliefs as the previous owner ("SIMBEL"), and the current land uses are similar to the land uses of the previous owner ("SIMUSE"). Most respondents knew whether or not the parcel was inherited, obtained from a family member, and used for the same purposes as under the previous owner, but a number of respondents did not know whether or not the current land management beliefs were similar to those of the previous owner.

Other variables that are related to past land use are also included in the analysis. The parcels are assigned a 1 or 2 based on whether or not the parcel has been affected by each of the following: tilling (TILLING), quarrying (QUARRYING), drilling for oil or gas (DRILLING), dredging (DREDGING), filling (FILLING), or damming (DAMMING). Each of the uses is considered as an independent variable. All cases in which the respondent did not know the requested information are excluded from subsequent analysis.

2.3. Statistical Tests of Relationships

Mann-Whitney U tests are preformed to determine if there are significant differences in the PER_FOR, NUMP, IJI, MNN, MPI, LPI, and SIEI metrics for the parcels assigned to the yes and no groups for the following variables: obtained from a family member, INHERITED, HEIR, SIMBEL, SIMUSE, TILLING, QUARRYING, oil/gas DRILLING, DREDGING, FILLING, and DAMMING.

Peterson's correlation coefficients and their significances (2-tailed) are calculated in order to determine relationships between the size of the parcels (HECT) and the seven metrics that indicate forest fragmentation (PER_FOR, IJI, MNN, MPI, LPI, SIEI, and NUMP). Peterson's correlations are also calculated for the year of the most recent transfer of land ownership

("YRTR"), age ("AGE"), slope ("SLOPE"), population density ("POPDEN"), the measures of accessibility (CBD, HWY37, and HWY46), and each of the seven metrics.

Kendall's Tau correlations are calculated to determine relationships between the ordinal type data and the seven metrics. Specifically, correlations are calculated for the following variables: the time the parcel has been owned by the respondent's family ("TIMEFAM"), the importance of the parcel as a source of income for the respondent ("IMPINC"), the highest level of education of the landowner ("EDU"), landowner's income (DINC), PER_FOR, IJI, MNN, MPI, LPI, SIEI, and NUMP.

The variables that were determined to be significant in the correlation analyses are included as independent variables in regression models with the metrics as the dependent variables. Seven models are constructed, one for each metric included in this analysis. Because the metrics are not normally distributed, they are recoded into ordinal rankings based on natural breaks in the data. The categories and the number of cases in each category are shown in Table A.2 in the Appendix.

The seven ordinal regression models were run using SPSS© for Windows version 11.5.0. In this procedure, an ordered logit model, also known as the cumulative logit model, estimates the effects of independent variables on the log odds of having lower rather than higher scores on the dependent variable. It models the dependence of a polytomous ordinal response on a set of predictors, which can be factors or covariates. The design of ordinal regression is based on the methodology of McCullagh (1980). Factor variables are assumed to be categorical while covariate variables must be numeric. For more information on ordinal regression see, for example, Bender and Benner (2000).

The ordinal regression model can be specified as:

$$\ln\left(\frac{p(Y \le j)}{p(Y > j)}\right) = \alpha_j - \sum_{k=1}^{K} \beta_k X_k \quad for\ j = 1\ to\ J-1$$

In the equation, α_j are intercepts indicating the logodds of lower rather than higher scores when all independent variables equal zero. The effects of the independent variables $\beta_k X_k$ are subtracted from rather than added to the intercepts. They are subtracted so that positive coefficients indicate increased likelihood of higher scores on the dependent variable. The intercepts for J - 1 categories convey the categorical nature of the dependent variable. A parallel odds restriction that lets independent variables have the same effects on all cumulative logits results in a parsimonious model for ordinal data.

3.0. Results

3.1. Tests of Significant Differences between Groups

Table 4.1 presents the numbers of cases and the percentages of the sample that fall into the yes and no categories for the following variables: FROMFAM, INHERITED, HEIR, SIMBEL, SIMUSE, TILLING, QUARRYING, DRILLING, DREDGING, FILLING, and DAMMING. Most of the variables have much larger numbers of cases in one group than the other. It is interesting to note that only about 7% of the owners inherited their parcels, but more than 21% obtained their parcel from a family member. Most respondents do anticipate transferring the parcel to an heir. The responses are more evenly divided in regard to whether or not the current land uses and management beliefs are similar to those of the previous owner. Relatively few of the parcels have been affected by most of the land uses specifically listed in the table. It is likely that most of the parcels included in this research have been farmed at one time, and the results most accurately reflect relatively recent historical decisions to till or not.

Table 4.1. Percentages of Cases in Yes and No Groups

Variable	No	Yes
FROMFAM	78.86	21.14
INHERITED	93.23	6.77
HEIR	23.29	48.19
SIMBEL	28.00	38.40
SIMUSE	51.00	48.59
TILLING	92.98	7.02
QUARRYING	97.11	2.89
DRILLING	97.52	2.48
DREDGING	94.21	5.79
FILLING	96.69	3.31
DAMMING	95.04	4.96

Percentages may not equal 100 because missing or unknown responses are excluded.

Mann-Whitney test results, shown in Table 4.2, indicate the significance of the differences in the metrics of forest fragmentation for the yes and no groups for the variables listed in Table 4.1. Differences between the groups associated with whether or not tilling has affected a parcel are significant at the 99% confidence level for MNN and SIEI. The groups are significantly different at the 95% confidence level for the measures of PER_FOR, LPI, IJI, and MPI.

Table 4.2. Significance of Mann-Whitney U Tests of Differences between Yes and No Groups

Variable	N No group	N Yes group	PER_FOR	IJI	MNN	MPI	LPI	SIEI	NUMP
FROMFAM	194	52	0.11	0.69	0.15	0.48	0.08	0.30	0.08
INHERITED	234	17	0.53	0.56	0.71	0.97	0.67	0.37	0.97
HEIR	58	120	0.53	0.16	0.98	0.16	0.63	0.67	0.26
SIMBEL	70	96	0.14	0.79	0.11	0.47	0.13	0.20	0.09
SIMUSE	127	121	0.57	0.72	0.58	0.68	0.47	0.70	0.35
TILLING	225	17	**0.03**	**0.02**	**0.00**	**0.01**	**0.02**	0.15	**0.01**
QUARRYING	235	7	0.35	**0.03**	0.79	0.23	0.42	0.44	0.73
DRILLING	236	6	**0.02**	0.56	0.92	0.59	**0.02**	**0.01**	0.20
DREDGING	228	14	0.21	0.77	0.55	0.68	0.16	0.37	0.20
FILLING	234	8	0.09	0.95	0.73	0.41	0.09	0.09	0.06
DAMMING	230	12	0.76	0.33	0.92	0.86	0.83	0.59	0.97

Note: Correlations significant at the 0.05 level are in bold.

The other variables do not have groups that are different at the 99% confidence level. Groups associated with whether or not a parcel has been quarried have significantly different measures of IJI at the 95% confidence level. Parcels that have and have not been drilled for oil or gas have significantly different measures of PER_FOR, LPI, and SIEI, at the 95% confidence level. It is interesting to note that whether or not a parcel was inherited is not associated with significant differences in any of the metrics. The groups that are associated with whether or not the respondent obtained the parcel from a family member or anticipates transferring the parcel to an heir are also not significantly different.

Table 4.3 compares the mean metric values for the no (1) and yes (2) groups. The group that has not been affected by tilling has a larger percentage of area covered by forest, larger area in the largest patch of forest, smaller numbers of forest patches, smaller distances between the forest patches, and less even distributions in the types of land uses and land covers on the landscape than the group that has been affected by tilling. The cases that have not been affected by tilling also have a lower MPI value than those that have been affected, but the low value results from the low number of forest patches rather than a lack of interspersion of the forest patches.

Table 4.3. Mean Metric Values for Yes and No Groups (1 = No; 2 = Yes)

Variable	N	PER_FOR	IJI	MNN	MPI	LPI	SIEI	NUMP
FROMFAM								
1	194	68.04	44.12	26.15	90.11	64.51	0.51	4.29
2	52	59.41	44.09	28.52	64.54	54.63	0.56	6.02
INHERITED								
1	234	66.25	44.33	26.77	85.75	62.52	0.52	4.54
2	17	66.61	41.05	24.77	72.56	62.15	0.47	6.13
SIMBEL								
1	70	68.93	44.3	23.37	75.79	65.07	0.49	4.18
2	96	62	42.59	28.67	85.57	57.82	0.55	5.58
SIMUSE								
1	127	67.75	44.86	26.38	81.09	64.35	0.53	4.33
2	121	64.53	42.81	26.88	87.56	60.3	0.51	5
HEIR								
1	58	66.29	51.15	25.25	52.17	62.14	0.52	4.28
2	120	64.48	43.89	27.27	107.24	60.84	0.53	5.08
TILLING								
1	225	67.34	45.56	25.51	79.67	63.71	0.51	4.41
2	17	52.1	24.78	41.67	154.67	46.27	0.64	7.75
QUARRYING								
1	235	66.58	43.26	26.77	86.92	62.78	0.52	4.66
2	7	56.45	71.43	22.49	20.13	53.3	0.6	4
DRILLING								
1	236	65.86	44.48	26.78	85.46	62.02	0.53	4.69
2	6	89.61	23.35	18.75	52.16	88.92	0.19	2

It is interesting to note that even though the parcels that have not been affected by tilling have a lower mean SIEI value than those that have been affected by it, they have higher forest IJI values than those that have been affected by tilling. This indicates that parcels that have not been affected by tilling have a larger variety of land-use and land-cover types adjacent to the forest patches than those that have been affected by tilling but less even distributions in the types of land uses and land covers that occur over the parcel. Most of the means for the metrics indicate that the parcels that have not been affected by tilling have more forest that is less fragmented than the parcels that have been affected by tilling.

Significant differences also exist between the parcels that have and have not been affected by drilling for oil and gas. As shown in Table 4.3, parcels that have been affected by drilling have a higher mean percentage of area covered by forest, more area covered by the largest patch of forest, fewer patches of forest, less distance between the forest patches, less even distributions of types of land uses and land covers, and less diversity in the types of land uses and land covers adjacent to the forest patches. The cases that have been affected by drilling also have a lower mean MPI value than those that have not been affected by drilling, but that is due to the low number of forest patches rather than a lack of interspersion of the forest patches. The results indicate that there are larger areas of forest that is less fragmented on parcels that have been affected by drilling than those that have not been affected. This may be because areas that had been drilled have not been used for agricultural purposes and the forests have been allowed to regrow on them.

The only other significant difference between the groups is in the IJI values of parcels that have and have not been affected by quarrying. The parcels that have been affected by quarrying have a higher mean IJI value than those that have not been affected by it. In the classification of land use and land cover that is used as a basis for calculating the metrics, areas being quarried are classified as developed. Given that there is a lot more land in the developed class on parcels used for quarries than on other parcels, it is not surprising that there is a larger variety of land use and land cover occurring on these parcels as compared with other parcels that may not have any developed land.

3.2. Correlations

The results of the Peterson's correlation analysis (shown in Table 4.4) indicate that there are significant relationships between the size of the parcel, length of time a parcel has been owned, and some of the metrics that indicate forest fragmentation. The size of the parcel (HECT) and the number of forest patches are positively correlated with a p-value significance of 0.00. The size of the parcel (HECT) and MPI are also positively correlated with a p-value significance of 0.00. These results imply that as parcel size increases there tends to be larger numbers of patches of forest, but the patches are well interspersed with each other. Lower MPI values occur on landscapes that have a small number of patches. The IJI metric is negatively correlated with the size of the parcel with a p-value significance of 0.05. This indicates that larger parcels have less diverse types of land uses and land covers adjacent to forest patches than smaller parcels.

Table 4.4 presents the results of the Pearson's correlation analysis of relationships between the following variables: HECT, AGE, YRTR, CBD, HWY37, HWY46, SLOPE, POPDEN, and the seven metrics of forest fragmentation (PER_FOR, IJI, MNN, MPI, LPI, SIEI, and NUMP).

Several metrics are significantly correlated with the year of the latest transfer of ownership of the parcel (YRTR). The year of most recent transfer is negatively correlated with the size of the parcel with a p-value significance of 0.01. This indicates that the shorter the length of time a parcel has been owned, the more likely it is to be relatively small. The percentage of the parcel covered by forest is positively correlated with the year of most recent transfer with a p-value significance of 0.03. A similar relationship occurs between the length of ownership and LPI, which is also positive with a p-value significance of 0.03. A larger percentage of parcel area tends to be covered by forest on parcels that have newer owners.

The year of the most recent transfer of ownership and number of forest patches are negatively correlated with a p-value significance of 0.02. The parcels with newer owners tend to have fewer patches of forest. It is important to note that low MPI values result from landscapes with few forest patches. Because the parcels with newer owners tend to have fewer forest patches, the MPI values for these parcels tend to be low. The year of most recent transfer is negatively correlated with MPI with a p-value significance of 0.03. Because parcels with newer owners tend to have fewer patches of forest, these results do not indicate that the parcels with newer owners tend to have more fragmented forests.

The correlation between the most recent year of ownership transfer and SIEI is negative with a p-value significance of 0.04. This indicates that as the length of time a parcel has been owned decreases, the types of land uses and land covers occurring on the parcel tend to become less evenly distributed. It can be inferred, given the other results, that these parcels tend to be more dominated by forest. The year of most recent transfer of ownership and size of the parcel are strongly and negatively correlated, with a p-value significance of 0.01, and there is a correlation between the size of the parcel and IJI. Given these relationships, it is surprising that the correlation between the year of most recent transfer and IJI is not significant.

AGE is significantly and positively correlated with MPI and NUMP. This indicates that parcels with older landowners have a larger number of forest patches but they are well interspersed. SLOPE and POPDEN have highly significant relationships with all the metrics except MPI. The relationships indicate that larger amounts of less fragmented forest occur on steeper slopes and in less populated areas. HWY46 is not significantly correlated with any metrics and CBD is only significantly and negatively correlated with IJI. The correlations between HWY37 and most of the metrics are highly significant. Larger areas of less fragmented forests tend to occur at larger distances from Highway 37.

The percentages of the sample associated with each of the ordinal rankings for the variables "TIMEFAM" and "IMPINC" are shown in Table 4.5. The largest number of cases is associated with a rank of 1 for "TIMEFAM". In these cases, the respondent's family has owned the parcels for a relatively short time. Smaller numbers of cases are associated with rankings of 2 and 3, and the smallest number of cases is assigned a rank of 4, which indicates the parcel has been owned by the family since the late 1800s. It should be noted that the mean metric values for the parcels in the group of parcels that have been owned by the respondent's family since the late 1800s tend not to follow the general trends in forest fragmentation that are evident in the other three groups based on the length of time a parcels has been owned by the respondent's family. These variations may occur because of the relatively small number of cases in the group.

Table 4.4. Pearson's Correlations for HECT, AGE, YRTR, CBD, HWY37, HWY46, SLOPE, POPDEN, and Metrics (Coef = Correlation Coefficient; Sig. = Significance for 2-tailed)

Metric		HECT	AGE	YRTR	CBD	HWY37	HWY46	SLOPE	POPDEN
	Coef	0.01	-0.108	0.13	0.103	0.275	0.071	0.639	-0.370
PER_FOR	Sig.	0.88	0.103	**0.03**	0.104	**0.000**	0.263	**0.000**	**0.000**
	N	251	227	251	251	251	251	251	251
	Coef	-0.12	0.009	-0.04	-0.251	-0.268	-0.079	-0.249	0.226
IJI	Sig.	0.05	0.889	0.49	**0.000**	**0.000**	0.213	**0.000**	**0.000**
	N	251	227	251	251	251	251	251	251
	Coef	0.10	0.079	-0.07	0.035	-0.150	0.035	-0.451	0.159
MNN	Sig.	0.12	0.235	0.29	0.584	**0.017**	0.580	**0.000**	**0.012**
	N	251	227	251	251	251	251	251	251
	Coef	0.52	0.229	-0.14	0.113	0.089	0.114	0.065	-0.085
MPI	Sig.	**0.00**	**0.001**	**0.03**	0.075	0.161	0.070	0.305	0.179
	N	251	227	251	251	251	251	251	251
	Coef	.001	-0.106	-.135	0.090	0.262	0.064	0.628	-0.363
LPI	Sig.	.990	0.111	**.033**	0.157	**0.000**	0.312	**0.000**	**0.000**
	N	251	227	249	251	251	251	251	251
	Coef	0.06	0.123	-0.13	-0.016	-0.224	0.025	-0.565	0.235
SIEI	Sig.	0.37	0.064	**0.04**	0.801	**0.000**	0.698	**0.000**	**0.000**
	N	251	227	251	251	251	251	251	251
	Coef	0.31	0.134	-0.14	-0.094	-0.219	-0.038	-0.428	0.340
NUMP	Sig.	**0.00**	**0.044**	**0.02**	0.139	**0.000**	0.546	**0.000**	**0.000**
	N	251	227	251	251	251	251	251	251
	Coef	1.000	.153	.158	.080	.114	.014	.060	-.083
HECT	Sig.	.	**.000**	**.000**	.058	**.007**	.749	.158	.055
	N	251	249	227	251	251	251	251	251
	Coef	.158	1	.468	-0.137	-0.117	-0.075	-0.050	0.066
AGE	Sig.	**.000**	.	**.000**	**0.039**	0.079	0.261	0.455	0.319
	N	227	227	225	227	227	227	227	227
	Coef	.080	-0.137	-.010	1	0.345	0.629	0.054	-0.449
CBD	Sig.	.058	**0.039**	.812	.	**0.000**	**0.000**	0.395	**0.000**
	N	251	227	249	251	251	251	251	251
	Coef	.114	-0.117	-.073	0.345	1	-0.101	0.286	-0.334
HWY37	Sig.	**.007**	0.079	.090	**0.000**	.	0.110	**0.000**	**0.000**
	N	251	227	249	251	251	251	251	251
	Coef	.014	-0.075	.022	0.629	-0.101	1	0.057	-0.274
HWY46	Sig.	.749	0.261	.604	**0.000**	0.110	.	0.371	**0.000**
	N	251	227	249	251	251	251	251	251
	Coef	.060	-0.050	-.057	0.054	0.286	0.057	1	-0.258
SLOPE	Sig.	.158	0.455	.189	0.395	**0.000**	0.371	.	**0.000**
	N	251	227	249	251	251	251	251	251
	Coef	-.083	0.066	.035	-0.449	-0.334	-0.274	-0.258	1
POP-DEN	Sig.	.055	0.319	.421	**0.000**	**0.000**	**0.000**	**0.000**	.
	N	251	227	249	251	251	251	251	251

Note: Correlations significant (2-tailed) at the 95% confidence level are in bold.

The percentages of the sample associated with the rankings respondents gave for the importance of the parcel for income generation (IMPINC) are also listed in Table 4.5. The percentages of the sampled cases that are associated with these rating are very similar to the percentages for the length of time the parcel has been owned by the family. Most of the owners rated the importance of the parcel for income generation as 1, or not important. Very few respondents rated the parcel as a primary source of income generation (a rating of 4).

Table 4.5. Total Number of Cases and Percent of Sample in Variables with Ordinal Ratings

Rating	TIMEFAM	IMPINC
1	62.9	63.3
2	27.1	24.2
3	5.6	10.9
4	4.4	1.6
Total Number of Cases	251	248

As shown in Table 4.6, both the length of time a parcel has been owned by the respondent's family and the importance of the parcel as a source of income generation for the owner are significantly correlated with most of the metrics that indicate forest fragmentation. The length of time that a parcel has been owned by the respondent's family and the importance of the parcel for income are positively correlated with each other with a p-value significance of 0.00. This indicates that the longer the parcel has been held in a family, the more important it tends to be as a source of income. All of the metrics except IJI are correlated with the importance of the parcel for income generation with p-value significances of 0.00. PER_FOR and LPI are negatively correlated with the importance of the parcel for income while MNN, MPI, NUMP, and SIEI are positively correlated with the importance of the parcel for income. This indicates that the more important a parcel is for income generation, the less forest is likely to occur on the parcel and the smaller the largest patch of forest is likely to be. The more important the parcel is for income generation, the more forest is likely to occur in a larger number of patches that are farther apart from each other but are relatively well interspersed. Parcels that are more important for income generation tend to have more even distributions of land-use and land-cover types. DINC is not significantly correlated with any of the metrics of forest fragmentation.

The correlations between the length of time a parcel has been owned by a respondent's family (variable called TIMEFAM) and the metrics of forest fragmentation tend to be extremely similar but slightly less significant than the correlations between the metrics and the importance of the parcel for income generation. All of the metrics except IJI are also correlated with TIMEFAM with p-value significances of less than 0.05. PER_FOR and LPI are negatively correlated with TIMEFAM while MNN, MPI, NUMP, and SIEI are positively correlated with TIMEFAM. This indicates that the longer a parcel has been owned by a family, the less forest is likely to occur on the parcel and the smaller the largest patch of forest is likely to be. The longer the parcel has been owned by a family, the more forest is likely to occur in a larger number of patches that are farther apart from each other but are relatively well interspersed, and the more evenly land-use and land-cover types are likely to be distributed.

Table 4.6. Kendall's Tau Correlations for Ordinal Variables and Metrics (Sig. for 2-tailed)

Metric	Statistic	EDU	TIMEFAM	IMPINC	DINC
	Coefficient	0.197	-0.12	-0.22	0.051
PER_FOR	Sig.	**0.00**	**0.02**	**0.00**	0.339
	N	234	251	248	181
	Coefficient	-0.027	0.05	-0.01	-0.011
IJI	Sig.	0.58	0.29	0.82	0.836
	N	234	251	248	181
	Coefficient	-0.217	0.12	0.21	-0.069
MNN	Sig.	**0.00**	**0.03**	**0.00**	0.218
	N	234	251	248	181
	Coefficient	-0.102	0.11	0.23	-0.054
MPI	Sig.	**0.04**	**0.03**	**0.00**	0.332
	N	234	251	248	181
	Coefficient	0.196	-0.12	-0.23	0.054
LPI	Sig.	**0.00**	**0.01**	**0.00**	0.308
	N	234	251	248	181
	Coefficient	-0.187	0.10	0.20	-0.081
SIEI	Sig.	**0.00**	*0.04*	**0.00**	0.128
	N	234	251	248	181
	Coefficient	-0.179	0.16	0.29	-0.082
NUMP	Sig.	**0.00**	**0.00**	**0.00**	0.150
	N	234	251	248	181
	Coefficient	-.158	1.00	0.19	-.113
TIMEFAM	Sig.	**.01**	.	**0.00**	.068
	N	234	251	248	181
	Coefficient	1.000	-.158	-.144	.306
EDU	Sig.	.	**.006**	**.012**	**.000**
	N	234	234	231	180
	Coefficient	-.144	.195	1.000	-.171
IMPINC	Sig.	**.012**	**.001**	.	**.006**
	N	231	248	248	179

Note: Correlations significant (SIG.) at the 0.05 level (2-tailed) are in bold.

All the metrics except IJI and MPI are correlated with the highest degree of education achieved by the landowners (EDU). Relationships between EDU and PER_FOR and EDU and LPI are positive while the rest are negative. This indicates that larger areas of forest that are less fragmented tend to occur on parcels with better-educated owners.

3.3. Ordinal Regressions

The variables included in the ordinal regression models are presented in Table 4.7. The variables with significant correlations with the metrics are included in the models for each metric. Whether or not the parcel has ever been tilled (variable called TILLING) is included in some models because there are significant differences between parcels that have and have not been tilled and, experimentation showed that it improved the explanatory power of the model. Although SLOPE, POPDEN, and HWY37 are included in most of the models, there are variations in the other independent variables that are included in the models for each metric.

Table 4.7. Dependent and Independent Variables Used in the Ordinal Regression Models

Dependent Variable	Independent Variables
PER_FOR	SLOPE, POPDEN, HWY37, EDU, INPINC
IJI	SLOPE, POPDEN, HWY37, CBD
MNN	SLOPE, POPDEN, HWY37, EDU, IMPINC, TILLING
MPI	SLOPE, CBD, EDU, IMPINC, AGE, HECT
LPI	SLOPE, POPDEN, HWY37, EDU, IMPINC
SIEI	SLOPE, POPDEN, HWY37, IMPINC, TILLING
NUMP	SLOPE, POPDEN, HWY37, IMPINC, AGE, TIMEFAM, EDU, HECT

Table 4.8 presents an overview of the results of the models. The table allows the results of the models that include all the independent variables listed for each model in Table 4.7 to be compared with models for the same dependent variables that include only SLOPE, POPDEN, and HWY37 as independent variables.

The significance values for the models are all quite high at least in part because of the large numbers of independent variables included in the models. The pseudo R-square values provide more useful information than the significance values. The pseudo R-square results indicate that the models perform fairly will. All of the models, except the one for IJI, perform better with the addition of variables that are from the interviews with the landowners and that are highly correlated with the metrics. The performance of the model for NUMP is quite improved with the addition of the socioeconomic variables as independent variables.

Table 4.8. Results of Ordinal Regression Models with Metrics of Forest Fragmentation as Dependent Variables and Variables Listed in Table 4.7 as Independent Variables (also presented are models with metrics as dependent variables and only SLOPE, POPDEN, and HWY37 as independent variables)

Models with all variables listed in Table 4.7 as independent variables					
DV of Model	-2 Log Likelihood	Chi-Square	df	Sig. (2-tailed)	Nagelkerke Pseudo R-Square
PER_FOR	417.6748	154.9739	12	0.0000	0.5335
LPI	475.0748	135.8474	12	0.0000	0.4786
NUMP	448.0876	121.9519	17	0.0000	0.4578
MNN	419.4987	80.1318	13	0.0000	0.3378
MPI	511.8016	72.2953	13	0.0000	0.2995
IJI	648.2111	37.7908	4	0.0000	0.1495
SIEI	489.6162	106.8397	13	0.0000	0.4088

Models with only SLOPE, POPDEN, and HWY37 as independent variables					
DV of Model	-2 Log Likelihood	Chi-Square	df	Sig. (2-tailed)	Nagelkerke Pseudo R-Square
PER_FOR	484.8953	140.4937	3	0.0000	0.4673
LPI	542.1674	125.4424	3	0.0000	0.4229
NUMP	576.3968	72.2314	3	0.0000	0.2705
MNN	513.0781	60.7392	3	0.0000	0.2393
MPI	649.1910	11.6255	3	0.0088	0.0488
IJI	653.2548	32.7471	3	0.0000	0.1308
SIEI	589.4227	89.9261	3	0.0000	0.3227

4.0. Discussion

The results of this research illustrate connections between socioeconomic factors that affect landowners' land-use decisions and forest fragmentation. For example, the results of this research indicate that landowners who are less dependent on their land for income generation, have higher educations, and are younger tend have larger amounts of forest that is less fragmented. The results also suggest that characteristics related to agricultural production are significantly related to the spatial patterns of land use and land cover on a landscape. Even past agricultural land use is related to contemporary forest fragmentation. Whether or not a parcel has ever been affected by tilling is significantly correlated with differences in spatial patterns of the forest cover. The more important the parcel is for income generation and the larger it is the smaller and more fragmented the forest is likely to be. Whether or not a parcel was inherited or obtained from a family member tends not to be significantly correlated with the spatial patterns that indicate forest fragmentation.

Variables related to how urban a parcel and its owner are including the age of the landowner, the size of the parcel, the length of time the parcel has been owned by a landowners family, parcel accessibility, and neighborhood population density also significantly impact the spatial patterns of land use and land cover. The more urban a parcel is, the more likely it is to have relatively large areas of well-connected forest.

Larger areas of less fragmented forests tend to occur at larger distances from Highway 37. Highway 37 is a limited access highway and, it is the route connecting the county with the state capital, Indianapolis. Parcels that are closer to highway 37, even if they occur at a distance from the center of Bloomington, are likely to be more urban than those that occur at larger distances from the highway. This indicates that there is more forest that is less fragmented in more rural areas of the county.

The results of this analysis expand upon prior research. For example, research by Medley et al. (2003) suggests that it may be possible for governmental programs to encourage landowners to make decisions regarding land and forest uses that would improve environmental conditions at the broader scale and have a profound effect on the quantity and quality of forest resources in the region. They found that the longer a decision maker has owned a parcel of land, the more forest occurs on that parcel. They propose that policies that successfully preserve agricultural land use may encourage conservation and forest regrowth. The authors suggest that more forest may occur because these landowners anticipate transferring the land to their heirs and want to protect the sustainability of the land. They argue that conservation programs should be tailored to new landowners as well as longer-term owners.

The results of research presented in this chapter indicate that the longer a parcel has been owned by the landowner's family, the more important it is for income generation, and the larger the parcel (all indicators of greater dependence on agricultural production), the more fragmented the forest. Therefore, the results do not support the proposal of Medley et al. (2003) that preserving agricultural production will improve the quality of the forest ecosystem functions.

Similar to the work of Erickson et al. (2002), the results of this research indicate that short-term landowners tend to make land-use decisions that allowed for more forest growth than longer-term landowners. This is because short-term landowners are less likely to have large areas of their parcels in agricultural production. They tend to allow at least some areas that had been used for agriculture to revert to forest. These owners may encourage forest growth because they appreciate forests on their parcels for their visual quality, environmental functions, and recreational potential. The results support the suggestion by Erickson et al. (2002) that governmental programs that are based on the concept of ecosystem management may be able to recruit more landowners if they promote the aesthetic benefits, recreational potential, or positive externalities offered by the forests. Targeted conservation programs that emphasize benefits such as wildlife restoration, improvement of visual quality, and lowering of heating bills may encourage non-farm owners (particularly relatively new landowners) to join the programs. A further discussion of how to improve ecosystem management policies is presented in Chapter 7 of this dissertation.

The regression models indicate that the variables SLOPE, POPDEN, and HWY37 explain a relatively large portion of variability in most of the metrics that indicate forest fragmentation. However, the addition of socioeconomic variables that affect landowners' land and forest use decisions improves the performance of the models for all the metrics except IJI. This is not surprising because IJI is not significantly correlated with any of the variables that were obtained from the interviews with the landowners. The models for PER_FOR, LPI, NUMP and SIEI perform particularly with the addition of socioeconomic independent variables.

The regression analysis indicates that the performance of fine-scale models of spatial patterns of land use and land cover and forest fragmentation would improve if socioeconomic variables were included. The variables that appear to explain the most variation in the metrics are measures of slope, accessibility (to the main north-south highway not to the central business district of the city), neighborhood population density, age of the landowner, highest level of education achieved by the landowner, the importance of the parcel for income generation (not the landowner's income), the size of the parcel, how long the parcel has been owned by the current owner's family, and whether or not the parcel has ever been tilled. According to this research, these would be the ideal variables to incorporate into fine-scale landscape analysis.

5.0. Conclusion

This research indicates that several socioeconomic variables should be incorporated into analyses of spatial patterns of land uses and land covers and models of forest fragmentation. Land use and management policies can be inherited from the previous landowner and past land uses may be evident in contemporary landscapes. As evident in the results this research, differences in some past land uses, particularly tilling, correspond to differences in contemporary forest fragmentation. The results also suggest that the importance of agricultural uses on the parcel is highly related to the degree of forest fragmentation.

The results further indicate that urbanization and parcelization are not always associated with an increase in forest fragmentation. More urban parcels tend to be covered by larger percentages of forest that is the least fragmented. Variables that constrain landowner's land and forest use decisions such as age, education, prior land uses, size of the parcel, previous agricultural uses, and the need to rely on the parcel as a source of income are highly correlated with spatial patterns that indicate forest fragmentation. When these variables are included with measures of accessibility, slope, and population density as independent variables in models where the metrics are dependent variables, the models tend to perform well.

These results may be somewhat unique to the study area because the parcels included in this analysis occur in areas with relatively low densities in housing. This allows for large areas of lawn on which forest may occur. This research confirms the findings of previous analyses that neighborhood population density is an important variable in models of the spatial patterns of land use and land cover. Therefore, relationships between similar variables and metrics of spatial patterns of land use and land cover in other areas of the world or even the United States, particularly areas with significantly different population densities, may be different.

The differences in results between this and previous research illustrate the complex nature of human-environment interactions. Different relationships are evident between human and environmental factors in areas that are similar in may respects. The relationships differ because of slight variations in the socioeconomic and biophysical factors that affect the interactions or because relationships are analyzed at different scales. Future research will build upon this research and explore more deeply which processes affect forest fragmentation by including additional factors and exploring relationships at different scales.

CHAPTER 5
LINKING LAND USES AND FOREST FRAGMENTATION: A CASE STUDY OF PRIVATE PARCELS IN MONROE COUNTY, INDIANA

1.0. Introduction

Forest fragmentation is becoming a primary concern in efforts to protect forest ecosystem function in many areas of the world (Riitters et al. 2000, Eriksson et al. 2002). Better understanding of the relationships between human land uses and forest fragmentation is needed to improve landscape management policies, especially those that emphasize ecosystem management and forest resilience. Often landscape managers seek to achieve such goals as increasing the function and resilience of forest ecosystems by limiting the types of land uses that may be conducted on particular parcels. Such regulations assume connections among land use, land cover, and forest function. However, little research is available to support these assumptions and, particularly for post-industrial areas such as the Upper Midwest, USA, a lack of connection between land use and land cover has been found (Brown et al. 2000).

Aspects of the relationships between human actions and spatial patterns of land use and land cover have been studied from a wide variety of perspectives (Wickham et al. 1999, Irwin and Geoghegan 2001). Most of these studies explore relationships at relatively broad spatial scales (for example, LaGro and DeGloria 1992, Wear et al. 1996, Wickham et al. 1999, Riitters et al. 2000), refer to publicly owned land (Frentz et al. 2004), and consider only single categories of land use (Brown et al. 2000). Because much of the land in the United States consists of individually owned private parcels, there is a need for research on relationships between land use and forest fragmentation that occur on private parcels (Wear et al. 1996, Geoghegan et al. 1997, Brown et al. 2000, Hilty and Merenlender 2003). Although some relationships between socioeconomic factors and forest fragmentation have been explored, further research is needed in order to understand better the complex nature of the interactions.

This research tests the following hypotheses in a case study of Monroe County (Chapter 2 discusses the study area in more detail):

- There are significant differences in the means of metrics that indicate forest fragmentation on parcels with different land uses.
- Parcels with different combinations of land uses have significantly different mean indicators of forest fragmentation.
- Parcels used for forestry have larger amounts of forest that is less fragmented.
- Parcels used mostly for residential purposes have moderate amounts of forest that is moderately fragmented.
- Parcels used primarily for agricultural purposes have the least amount of forest that is the most fragmented.
- Models of spatial patterns of land use and land cover can be improved with the addition of the types of land uses that are conducted on the parcels.

2.0. Data and Methods

The results of Chapter 3 indicate that landscapes, which include the area within the parcel boundaries and two raster cells outside the boundaries, maximizes variability in the land-use and land-cover data associated with each parcel (see also Croissant 2004). In this research, landscapes corresponding to these areas were created for each of the 251 sampled parcels by using a combination of ESRI's ArcView and ArcInfo geographic information systems. These are the same landscapes that are used in Chapter 4. The analysis conducted in this chapter also uses the same seven metrics of spatial pattern that were used in Chapter 4. The metrics are PER_FOR, LPI, SIEI, MNN, MPI, IJI, and NUMP. Information on these metrics is presented in the Appendix in Table A.1.

Information on the types of land uses conducted on each of the parcels was obtained from interviews with the owners of the parcels that were randomly selected (see Chapter 2 for more information on the sampling). Each of the parcels was assigned to a group based on the types of land uses that occur on the parcel according to the responses given by the landowners. In order to limit the number of groups used in the analysis, the parcels are divided based on the following general categories of use: agriculture, forest, and residential. The agriculture group includes barns and gardens, while the residential group includes lawns, buildings, and driveways. Because many landowners use their parcels for more than one type of land use, the following groups, which include combinations of land uses, were added to the group classification scheme: agriculture/residential, forest/agriculture, forest/agriculture/residential, and forest/residential. A total of seven land-use groups (the four mixed use group, agriculture, residential, and forest) are used in the analysis.

A Kruskal-Wallis test is used to determine if the means of each of the following seven metrics, which indicate forest fragmentation, tend to be significantly different between the land-use groups: percent of landscape covered by forest (PER_FOR), percentage of landscape covered by the largest patch of forest (LPI), number of forest patches (NUMP), forest mean nearest-neighbor index (MNN), forest mean patch interspersion (MPI), forest interspersion and juxtaposition index (IJI), and the degree of evenness in the landscape (Simpson's Evenness Index, or SIEI). A non-parametric test is employed because the metrics do not tend to be normally distributed. The Kruskal-Wallis test is based on the Mann-Whitney U test and is the nonparametric analog of one-way analysis of variance.

Differences between groups that share similar uses—for example, all the groups that have forest as a land use (specifically the forest, forest/agriculture, forest/agriculture/residential, and forest/residential groups)—are calculated using Kruskal-Wallis tests. The significances of the differences between each of the groups are determined by non-parametric Mann-Whitney U tests.

The mean values of the seven metrics that indicate forest fragmentation are discussed for each of the seven land-use groups. Groups with relatively large and small amounts of forest and those with relatively high and low levels of fragmentation are identified.

In this chapter, the same methods used to create the ordinal regression models discussed in Chapter 4 are used to generate seven new models. In this analysis, ordinal regression models are calculated with the metrics as the dependent variables and the socioeconomic variables that are included in Table 4.7 as the independent variables just as in Chapter 4. The variable, LANDUSE, is added to the list of independent variables for each model and a new series of model results are created. LANDUSE is a categorical variable that corresponds to the land-use group for each parcel. The benefits of adding LANDUSE to the models are analyzed. Refer to Chapter 4 for more specific information on the ordinal regression models. The categories for ranking the metrics and the number of cases in each category are shown in Table A.2 in the Appendix.

3.0. Results

3.1. Test of Significant Differences between Groups

3.1.1. Differences among All Seven Land-Use Groups

As evident in Table 5.1, the results of the Kruskal-Wallis tests indicate that there is sufficient evidence to reject the null hypothesis that the means of the metrics are not different in favor of the alternative hypothesis that the mean measures of some of the metrics are significantly different when all seven of the land-use groups are considered.

Table 5.1. P-Value Significances (2-tailed) of Kruskal-Wallis Test of Differences in the Mean Measures of Metrics of Forest Fragmentation for All Land-Use Groups

Groups Included	df	PER_FOR	IJI	MNN	MPI	LPI	SIEI	NUMP
All Groups forest forest/agriculture forest/agriculture/residential forest/residential agricultural/residential agricultural residential	6	.000	.011	.000	.000	.000	.000	.000
Forest Groups forest forest/agriculture forest/agriculture/residential forest/residential)	3	.000	.078	.000	.000	.000	.000	.000
Residential Groups agricultural/residential forest/agricultural/resident forest/ residential residential	3	.000	.080	.000	.004	.000	.000	.000
Agricultural Groups agricultural/residential forest/agricultural/residential forest/agricultural agricultural	3	.000	.011	.001	.001	.000	.013	.001

df = Degrees of Freedom

The groups' mean PER_FOR, IJI, MNN, LPI, NUMP, and SIEI values are all significantly different with p-values of approximately 0.000. The mean MPI is also significantly different among the groups with a p-value of about 0.011. The amount of forest, largest patch of forest, the number of forest patches, the distances between forest patches, the interspersion of the patches, and the degree of evenness in the types of land use and land cover in the landscape varies significantly between parcels with different land uses. These results indicate that significantly different levels of forest fragmentation occur on parcels with different land uses.

3.1.2. Differences among Groups That Have a Use in Common

The significances of the differences in the metrics for the groups that share a common use are determined through Kruskal-Wallis tests and are presented in Table 5.1. Differences among all the groups that share forest as a land use are similar to the differences among the groups that share residential land uses. The results indicate that there is sufficient evidence to reject the null hypothesis that the means of most of the metrics are not different in favor of the alternative hypothesis that the group means are significantly different. Specifically, the groups with forest and residential uses have mean PER_FOR, IJI, MNN, LPI, NUMP, and SIEI values that are all significantly different with p-values of approximately 0.00. The mean IJI is not significantly different. The results indicate that the amounts of forest, the size and number of forest patches and distances between them, and the degree of evenness in the types of land use and land cover in the landscape differ among parcels that share forest or residential land uses.

The results of the Kruskal-Wallis test of the differences in mean metric values for the groups with agricultural uses (agricultural/residential, forest/agricultural/residential, forest/agricultural, and agricultural) are also included in Table 5.1. The results indicate that there is sufficient evidence to reject the null hypothesis that the means of most of the metrics are not different in favor of the alternative hypothesis that most of the group means are significantly different when these four groups are considered. Differences among these groups are similar to those among groups that share forest or residential uses except for IJI and SIEI. The mean IJI is significantly different (a p-value of 0.011) among parcels that share agriculture as a land use. It is interesting to note the lack of significant differences in the SIEI measures for groups that share agricultural uses. These results indicate that the amount of forest cover, the types of land use and land cover adjacent to the forest patches, the number of patches of forest, how well interspersed they are, and the largest patch of forest tend to differ among parcels with various combinations of agricultural and other land uses. The degree of evenness in the types of land uses and land cover in the landscapes does not tend to differ among these parcels. In other words, similar degrees of domination by one type of land use or land cover tend to occur on all parcels with any combination of uses that include agriculture.

3.1.3. Differences between Combinations of Land Uses

In order to determine the significances of the differences between each of the land-use groups, Mann-Whitney U tests are conducted between pairs of groups. As shown in Table 5.2, most of the pairs of groups tend to have significant differences in several of the metrics that indicate forest fragmentation.

All pairs of groups except the forest/residential and forest (only) pair and the forest/agriculture and forest/agriculture/residential pair have at least one metric that is different with a p-value significance of 0.05 or less. In many cases, parcels that have different combinations of land uses have significant differences in the metrics of forest fragmentation. However, the results indicate that forest fragmentation on a parcel used only for forest tends not to be significantly different from the fragmentation on a parcel that is used for both residential and forest purposes. A similar lack of difference in forest fragmentation is likely between a parcel used for both forest and agriculture and a parcel used for forest, agriculture, and residential purposes. Therefore, it appears that the addition of residential land use does not significantly change the degree of forest fragmentation on parcels that also have forest or agricultural uses.

Table 5.2. P-Value Significances (2-tailed) of Mann-Whitney U Tests of Differences in Mean Metric Values between Pairs of Use Groups

Group 1	Group 2	PER_FOR	IJI	MNN	MPI	LPI	SIEI	NUMP
Agriculture, Residential	Agriculture	0.847	0.01	0.16	0.53	0.54	0.11	0.69
Agriculture, Residential	Forest	0.00	0.00	0.00	0.02	0.00	0.00	0.00
Forest	Agriculture	0.00	0.38	0.00	0.01	0.00	0.00	0.00
Forest, Agriculture	Agriculture	0.00	0.38	0.00	0.00	0.00	0.34	0.00
Forest/Agriculture	Agriculture/Residential	0.00	0.01	0.01	0.00	0.00	0.01	0.01
Forest/Agriculture	Forest	0.00	0.10	0.00	0.00	0.00	0.00	0.00
Forest/Agriculture	Forest/Agriculture/ Residential	0.54	0.11	0.64	0.15	0.58	0.54	0.61
Forest/Agriculture/ Residential	Agriculture	0.00	0.06	0.00	0.08	0.00	0.22	0.00
Forest/Agriculture/ Residential	Agriculture/Residential	0.00	0.10	0.02	0.03	0.00	0.00	0.00
Forest/Agriculture/ Residential	Forest	0.00	0.01	0.00	0.00	0.00	0.00	0.00
Forest/Residential	Agriculture	0.00	0.71	0.00	0.11	0.00	0.00	0.00
Forest/Residential	Forest	0.11	0.23	0.13	0.35	0.11	0.17	0.14
Forest/Residential	Forest/Agriculture	0.00	0.86	0.00	0.00	0.00	0.00	0.00
Forest/Residential	Forest/Agriculture/ Residential	0.00	0.21	0.00	0.00	0.00	0.00	0.00
Forest/Residential	Agriculture/Residential	0.00	0.02	0.00	0.25	0.00	0.00	0.00
Residential	Agriculture	0.20	0.12	0.07	0.10	0.08	0.85	0.00
Residential	Agriculture/Residential	0.27	0.80	0.17	0.26	0.06	0.40	0.00
Residential	Forest	0.00	0.05	0.01	0.26	0.00	0.00	0.01
Residential	Forest/Agriculture	0.16	0.10	0.75	0.00	0.24	0.32	0.14
Residential	Forest/Agriculture/ Residential	0.09	0.57	0.95	0.02	0.16	0.26	0.29

Unlike the other metrics, the IJI metric is not directly dependent on the size or number of patches in the landscape. It is often the only metric that is not significantly different between the groups. Therefore, it is interesting to note that between the agriculture/residential and agriculture (only) groups, IJI is the only metric that is significantly different. The difference may occur because a larger variety of land uses and land covers are likely to be adjacent to forest patches on parcels used for agriculture and residential purposes than on parcels that are just used for agriculture.

The NUMP is the only significantly different metric between the residential (only) and agriculture (only) groups. It is also the only metric that is significantly different between the residential (only) and agriculture/residential groups. Similar to the results for the differences between the forest and forest/residential groups, most of the metrics are not significantly different between the agriculture and residential groups. The differences in the number of forest patches may occur because forest is confined to isolated patches on parcels used for agriculture, and because residential use tends to cover very small areas of the parcels in the sample.

The only significantly different metric between the forest/agriculture and residential (only) groups is the number of forest patches. This implies that parcels used for residential purposes have a similar amount of forest as those used for both forest and agricultural purposes, and the forest tends to be similarly interspersed. It is interesting to note that the forest/agriculture and agriculture/residential groups are significantly different with p-values of less than 0.01 for each metric.

MPI is the only significantly different metric between the residential (only) and forest/agriculture groups and the residential and forest/agriculture/residential groups. These results again illustrate that adding residential uses to combinations of other uses tends not to have a significant impact on differences in measures of landscape patterns.

The groups that appear to be the most significantly different across all seven metrics are the forest/agriculture group and the agriculture/residential group. Although parcels in both groups are used for agriculture, the metrics that indicate forest fragmentation vary considerably between them. This pairing of groups is the only one that has p-value significances of 0.01 or less for all the metrics.

In contrast, differences between the metrics for the forest/agriculture and residential (only) groups and the forest/agriculture and forest/agriculture/residential groups tend not to be significantly different (except for their MPI values). These results indicate a significant change in the patterns of land use and land cover among parcels that have and do not have agricultural uses.

3.1.4. Comparisons of Means for Land-Use Groups

The mean metric values for each of the land-use groups are listed in Table 5.3. It is not surprising that the parcels used only for forest purposes have the highest percentage of area covered by forest and highest percentage of area covered by the largest patch of forest. Parcels used for forest also have the lowest mean number of forest patches, smallest distances between forest patches, least even types of land use and land cover, and least variety of land uses and land covers adjacent to forest patches. All the metrics indicate that these parcels have the least fragmented forest. The mean values for most of the metrics are similar for the forest and forest/residential groups. The forest/residential group has relatively high values for PER_FOR and LPI. It also has low values for NUMP, MNN, and SIEI. Forest/agriculture and forest/agriculture/residential have mean values that are very similar to each other and that indicate moderately high amounts of forest that are moderately fragmented. Residential use is associated with a smaller amount of forest that is slightly more fragmented as compared with the groups that include forest uses, but it has a larger area of forest that is less fragmented when compared with groups that include agricultural land use. The agriculture and agriculture/residential groups have very similar mean metric values. These values indicate relatively small amounts of relatively highly fragmented forest are associated with agricultural land use. The groups that include residential use tend to have relatively high IJI values, and the agriculture/residential group has the highest IJI value.

Table 5.3. Comparison of Mean Metric Values by Land-Use Groups

Group	N	PER_FOR	IJI	MNN	MPI	LPI	SIEI	NUMP
All cases	251	66.81	44.39	26.76	83.01	63.10	0.51	4.54
Agriculture	19	31.75	36.21	49.67	34.18	24.56	0.68	9.71
Agriculture, Residential	19	31.15	63.82	41.91	24.90	22.64	0.78	8.74
Forest	46	87.54	33.43	12.97	87.11	86.69	0.30	1.83
Forest, Residential	67	81.56	42.34	17.06	61.56	79.62	0.37	2.60
Forest, Agriculture	41	60.73	42.74	32.16	147.99	55.63	0.65	5.66
Forest, Agriculture, Residential	50	62.65	51.04	31.84	107.65	58.08	0.61	5.54
Residential	11	47.63	57.60	38.77	18.22	44.06	0.66	3.73

3.2. Regression Models

Table 5.4 presents an overview of the ordinal regression models for each of the metrics. The seven metrics of forest fragmentation are the dependent variables. The independent variables that are part of the model for each metric are the same as those listed in Table 4.7. These variables, which are from the interviews with the landowners, are significantly correlated with the metrics of forest fragmentation. They differ across the models. The main difference between the ordinal regressions discussed in this chapter and the ordinal regressions discussed in Chapter 4, is that the categorical variable LANDUSE (the land-use class) is added to the independent variables that are used in each of the models that are calculated in this chapter.

Table 5.4. Ordinal Regression Model Results with Metrics as Dependent Variables and Socioeconomic Variables That Are Significantly (2-tailed) Correlated with the Metrics (variables listed in Table 4.7) and the Types of Land Use Conducted on the Parcel (LANDUSE) as Independent Variables

Model	-2 Log Likelihood	Chi-Square	df	Sig.	Nagelkerke Pseudo R-Square
PER_FOR	339.520	233.129	18	0.000	0.694
LPI	417.461	193.462	18	0.000	0.611
NUMP	407.585	162.454	23	0.000	0.562
MNN	401.625	98.006	19	0.000	0.398
MPI	495.371	88.726	19	0.000	0.355
IJI	636.786	49.216	10	0.000	0.190
SIEI	456.287	140.169	19	0.000	0.501

The significance values for the models are all quite high at least in part because of the large numbers of independent variables included in the models. The pseudo R-square values provide more useful information than the significance values. The pseudo R-square measures are quite high for most of the models especially for those with PER_FOR, LPI. NUMP, and SIEI as dependent variables. The pseudo R-squares for these models are over 0.50. The model for PER_FOR performs the best and, the model for IJI performs the worst.

Table 5.5 lists the pseudo R-square values for all the models that have been analyzed thus far as part of this dissertation. The table facilitates comparison of the models so that the benefits of adding the socioeconomic variables can be determined. The dependent variables for all the models are the metrics. The model labeled Model 1 in the table is the model that includes only SLOPE, POPDEN, and HWY37. The model labeled Model 2 in the table includes the socioeconomic data, especially data from the survey of landowners, that are significantly correlated with the metrics. The variables used in this model are listed in Table 4.7. The model labeled Model 3 in the table is the same as Model 2 except that LANDUSE is added as an independent variable.

Table 5.5. Comparison of Nagelkerke Pseudo R-Square Value for Models That Include Different Independent Variables

Dependent Variable	Model 1	Model 2	Model 3
PER_FOR	0.467	0.533	0.694
LPI	0.423	0.479	0.611
NUMP	0.270	0.458	0.562
MNN	0.239	0.338	0.398
MPI	0.049	0.300	0.355
IJI	0.131	0.149	0.190
SIEI	0.323	0.409	0.501

Table 5.5 indicates large improvements in the performances of the models when LANDUSE is included as an independent variable. Particularly large improvements in performance are evident for PER_FOR, LPI, NUMP, and SIEI. All of these models have pseudo R-square values that are over 0.05. Model 3 for LPI has a pseudo R-square value over 0.60 and Model 3 for PER_FOR has a pseudo R-square value that is almost 0.70.

4.0. Discussion

Comparisons of the mean values for the metrics of forest fragmentation confirm that parcels that are used for forests tend to have the largest amounts of forest that is the least fragmented, parcels that are used for residential purposes tend to have moderate amounts of forest with moderate forest fragmentation, and parcels that are used for agricultural purposes tend to have the least amount of forest that is relatively highly fragmented.

The results also suggest that different combinations of land uses that may occur on a parcel impact the degree of forest fragmentation. Of the seven metrics of forest fragmentation that are included in this analysis, only forest IJI tends not to differ significantly among parcels in the four groupings of parcels that include forest uses. These groups are: forest, forest/residential, forest/agriculture, and forest/agricultural/residential. Forest IJI is also the only metric that is not significantly different among parcels in the four groups that include residential uses. These groups are: residential, residential/forest/agricultural, residential/forest, and residential/agricultural. The results are similar for parcels that have agricultural land use in common, except that the differences in forest IJI are more significant and the differences in landscape SIEI are less significant than they were for parcels that have forest or residential uses in common. These results suggest that although parcels may have a land use in common, the amount of forest cover, its spatial arrangement, and its degree of fragmentation are likely to vary if the other types of land use that occur on the parcel differ.

Parcels that are used for both forest and residential uses tend not to have significant differences in metrics of forest fragmentation from parcels used only for forests. This indicates that residential uses tend to have similar impacts on the spatial patterns of land use and land cover as forest use in the study area. This may be because the impact of residential use on the spatial patterns is too small to detect in the landscapes created from the Landsat Thematic Mapper imagery. However, parcels used for both residential and forest uses tend to have significant differences in IJI from parcels used only for forest. In addition, parcels used for both residential and agricultural uses tend to have significant differences in IJI from those used only for agricultural purposes. Because significant differences in one metric are evident among parcels used for residential uses and those that are not used for residential purposes, it is likely that the grain of the data would have been sufficient to detect significant differences in the other metrics. The relatively small number of cases in the residential group may also have affected the statistical results.

Similar to many areas, the spatial patterns of land use and land cover in Monroe County have been affected by the process of urbanization or, more specifically, suburbanization. In the process of suburbanization, rural areas consist of increasingly smaller sized parcels, smaller areas of agriculture, and larger areas of developed land. The process of suburbanization affects the types of land uses and land covers that occur in a landscape, the proportions of the landscape occupied by each type and the spatial arrangement of the types of land use and land covers. For example, suburbanization may result in clustering of developed areas because of the availability of utilities such as sewer lines or roads.

Suburbanization tends to increase the economic value of the land, increase the taxes that must be paid on the land, and increase pressure on the landowners to sell the land to developers. One landowner may subdivide or sell his or her land for development while a neighboring landowner continues to use his or her land for agriculture. In this situation, agricultural land use may stop abruptly at the parcel boundary and a relatively large variety of land uses and land covers may be adjacent to each other. That may explain why there are significant differences in IJI among parcels that are and are not used for residential purposes.

One of the characteristics of urban sprawl, or the spread of developed land uses into rural areas, is the relatively high level of diversity of land uses that are adjacent to each other. It is likely that parcels used for residential purposes occur in more suburban areas where a relatively wide variety of land uses and land covers are adjacent to each other. Therefore, variation in forest IJI may be an early indication of urban pressure and land-cover modification in an area. These results support research by Dean and Smith (2003) that found that subparcel variability in land use and land cover becomes more significant in more developed areas.

The differences in fragmentation are most obvious with parcels that are or are not used for agricultural purposes. These results support research (Dean and Smith 2003) that found that a parcel-level analysis was especially suited for analysis of agricultural landscapes because they have an inherent parcel structure and that variability in land use and land cover becomes more significant in more developed areas.

The processes affecting the landscape in Monroe County differ somewhat from the processes that may occur in other areas. Much of the county has steeper slopes than other areas of Indiana. Therefore, the county is not like many Midwestern counties that are mostly flat and dominated by broad-scale agricultural production. The county has a variety of land and forest uses occurring relatively near each other. That may also help explain why the IJI measure differs significantly among some parcels in the study area and why there are few significant differences in forest fragmentation between parcels used for forest and those used for residential purposes. There are only small patches of developed land in many rural areas of the county.

The regression analysis indicates that fine-scale models of the spatial patterns of land use and land cover that indicate forest fragmentation should include the types of land uses that are conducted on the landscape. Including the types of land uses conducted on the parcel would improve the performance of the models.

5.0. Conclusion

In general, the results of this research support the hypothesis that different land uses on parcels are associated with significant differences in many of the metrics that indicate forest fragmentation. In particular, the percentage of area covered by forest, the largest patch of forest, the number of forest patches, distances between forest patches, interspersion of forest patches, and the degree of evenness in the types of land uses and land covers in the landscape tend to vary with different land uses. Measures of forest IJI or the degree of diversity in land-use and land-cover types that are adjacent to forest patches are less likely to be significantly different on parcels with dissimilar land uses. Parcels that have a land use in common are likely to have significantly different measures of forest fragmentation if the parcels differ in the other land uses that occur on the parcel. The results also show that landowners' land-use decisions can greatly impact the spatial patterns of land use and land cover on a landscape and, therefore, land-use decisions greatly impact forest fragmentation at fine scales.

Although Monroe County is affected by urban growth associated with a city, land prices remain relatively inexpensive and development consists mainly of relatively low-density single-family homes that have large lawns. The urbanizing or suburbanizing of rural areas is tied to landowners' desire for the benefits of a "country" setting such as the aesthetics, buffering, wildlife watching, and hiking that are associated with forests. The spatial patterns of land use and land cover reflect this trend. A number of parcels contain small, compact areas of developed land and relatively large, well-connected areas of forest.

There may be a threshold associated with the density of development and the amount forest and its fragmentation. Up to a certain point, suburbanization may be associated with an increase in the amount of forest and its connectivity. The results of this research indicate that differences in the metrics of forest fragmentation between parcels that are used for residential purposes and those that are used for forests are not significant. However, if urbanization continues and the study area is developed for high densities, then the amount of forest and its connectivity may decrease, and parcels with residential uses may differ significantly in the metrics of forest fragmentation from those used for forests.

Differences in land use are associated with differences in many aspects of the spatial patterns of forest cover and thus forest function and resilience on rural or semirural parcels in Monroe County, Indiana. The results generally support the assertion that regulating land uses on parcels is an effective means of managing forest fragmentation. Regulations that focus on forest and agricultural uses may have significant impacts on the spatial patterns in a landscape, which indicate forest fragmentation and ecosystem function. A number of both biophysical and socioeconomic processes have affected the spatial patterns in the landscape of Monroe County. Analysis that includes other variables and focuses on other scales will be conducted in the future.

CHAPTER 6

FOREST USES AND FRAGMENTATION: RELATIONSHIPS BETWEEN FOREST USES AND SPATIAL PATTERNS ON PRIVATE PARCELS IN MONROE COUNTY, INDIANA

1.0. Introduction

Fragmentation of privately owned forest land is of increasing concern in many areas of the world. Efforts to implement ecosystem management, without regard to private lands, are not likely to impact greatly the overall landscape structure and therefore ecosystem function. Private land is much more likely than public land to undergo changes in land use such as urbanization, which may lead to a loss of forest area and fragmentation of habitat (Heilman et al. 2002).

Although connections between human actions and forest fragmentation have been determined, the complexity of the interactions necessitates further research (Hobson et al. 2002, Theobald and Hobbs 2002, Stanfield et al. 2002). Results of research that was conducted at one spatial scale may not be applicable to another scale. Few studies have explored connections between particular forest uses and spatial patterns in the landscape, and no research has connected forest uses with patterns at the scale of individual parcels.

This research addresses these research needs and focuses on the following questions:

- What forest uses are considered to be the most important by the largest number of private landowners?
- Which uses are associated with high and low levels of forest fragmentation?
- Do measures that indicate forest fragmentation significantly differ among landscapes associated with different forest uses?
- Are they significantly correlated with the degree of importance landowners assign to the uses?
- What impact does adding a variable that represents differences in landowners' forest use decisions have on models of forest fragmentation?

It is expected that parcels with different types of forest uses have significantly different metrics of forest fragmentation, the degree of importance landowners assign to various forest uses is significantly correlated with measures of forest fragmentation, and models of forest fragmentation can be improved with the addition of parcel-level socioeconomic data that specifically include the types of land and forest uses that are conducted on the parcel. The questions are addressed in a case study of non-industrial, privately owned parcels of land in Monroe County, Indiana. Chapter 2 describes the study area in more detail.

2.0. Methods

Forest fragmentation in this research is estimated by using metrics that were developed in the field of landscape ecology and are further discussed in Chapter 2. Differences in the metrics indicate differences in the spatial patterns on the landscape. The different spatial patterns, particularly those related to forests, indicate relatively high or low levels of forest fragmentation. High levels of forest fragmentation are associated with poor ecosystem functions and a decrease in resilience.

2.1. Creating the Landscapes and Quantifying Forest Fragmentation

The general methods used in this research are similar to those used in Chapter 5: the use of a geographic information system (GIS) to quantify the spatial patterns of forest and other land uses and land covers that are identified from a classification of a remotely sensed image, identification of important forest uses based on information from interviews with owners of private parcels, determination of statistically significant relationships between forest uses and metrics of forest fragmentation, and comparison of models that include and do not include the dominant type of forest use as an independent variable. The seven metrics used in the previous chapters (PER_FOR, LPI, SIEI, MNN, MPI, IJI, and NUMP) are also used in this chapter. Refer to Table A.1 in the Appendix for more information on these metrics.

2.2. Quantifying the Importance of Forest Uses on Parcels

The owners of the sampled parcels rated the importance of a number of forest uses during interviews. Specifically, the landowners rated the importance of the following forest uses: hunting, hiking/walking, animal or off-road vehicle riding, animal (horses and cattle) grazing, wildlife watching, camping, timbering, collecting firewood, collecting non-tree products like mushrooms, erosion control, windbreak, buffer from road or neighbors, aesthetics, spiritual, and watershed protection. The importance ratings for each of the uses relate only to the individual parcel randomly selected to be included in the sample and do not include other properties that the respondent may own or uses conducted on publicly owned land.

Each case was assigned to a class or group based on the importance rating the respondents gave to the uses. Two slightly different methods of classifying the parcels into groups are used in this research. In one, the cases are classified according to the single use that landowners rated the most important. The second classification takes into account all of the uses that respondents rated as at least somewhat important and groups together landowners that are likely to share similar views on forest management. Two variations of grouping the parcels are analyzed in order to minimize error that may result from poorly classifying the parcels. In interpreting the results, particular emphasis is given to relationships evident in both classifications.

2.3. Groups Created Based on the Most Important Use

In the first system of grouping or classifying cases, each forest use, which was specifically rated by respondents, is included as a class. Cases are assigned to the group or class that the respondents rated as having the highest importance rating. Table 6.1 presents the number of cases in which landowners rated each of the uses (harvesting non-wood products like mushrooms, spiritual, camping, wind break, erosion control, horse or off-road vehicle riding, watershed protection, horse or cattle grazing, harvesting wood products, hunting, buffer, timbering, aesthetics, wildlife watching, and hiking or walking) as the most important. The fifteen cases in which the respondents did not rate one particular forest use as the most important are not included in subsequent analysis based on this classification system.

Table 6.1. Number of Cases for Which Each Forest Use Is Most Important

Forest Use	Number of Cases	Percent of Sample
Harvesting non-wood products	5	2.5
Spiritual	5	2.5
Camping	6	3.0
Wind Break	6	3.0
Erosion Control	8	4.0
Riding	9	4.5
Watershed Protection	9	4.5
Grazing	11	5.5
Harvesting Wood	11	5.5
Hunting	13	6.5
Buffer	16	8.0
Timbering	18	9.0
Aesthetics	23	11.4
Wildlife Watching	29	14.4
Hiking or Walking	32	15.9
Total	201	100.0
Missing	23	
No one use most important	15	
No forest or use of forest	12	

As evident in Table 6.1, some of the uses were rarely rated as the most important. For example, only five respondents (about 2 percent) noted that the harvesting of non-timber products was the most important use of the forest. Other uses such as hiking or walking were rated as the most important use by a relatively large number of respondents (about 16 percent). Combining similar groups eliminated groups associated with the smallest numbers of cases.

The final groups included in the classification that is based on the most important uses are presented in Table 6.2. In this classification, cases in which respondents rated the following uses as important are combined: spiritual with aesthetic, collecting tree products with collecting non-tree products, wind break with erosion control and watershed protection, and camping with hiking/walking. The other groups are the same as those listed in Table 6.1. The numbers of cases in the combined classes are more similar to each other than the numbers of cases for the groups listed in Table 6.1.

Table 6.2. Listing and Number of Cases for Groups Based on the Most Important Use

Group Name; Based on Combinations of Forest Use Identified as Most Important	Number of Cases in Group	Percent of All Classified into Groups
Hunting (ht)	13	6.5
Buffer (bf)	16	8.0
Collecting tree and non-tree products (nttf)	16	8.0
Timbering (tm)	18	9.0
Riding and agricultural grazing (arag)	20	10.0
Watershed protection, wind break, and erosion control (ew)	23	11.4
Aesthetics and spiritual (as)	28	13.9
Wildlife watching (ww)	29	14.4
Hiking/walking and camping (hk)	38	18.9
Total	201	100.0

2.4. Groups Created Based on Likely Similarities in Landowners' Views

It has been found that forest users who participate in similar types of uses often belong to similar groups, such as horse riding or hiking clubs, and share similar views of forest management on publicly owned lands (Welch et al. 2001). A second method of classifying cases takes these tendencies into account and groups the parcels according to likely similarities in how landowners view forest uses and management.

The first cases assigned to a class in the second system are those whose landowners rated animal (horse or cattle) grazing as an important—but not necessarily the most important—use of the forest. Cases in which landowners rated riding (horses or off-road vehicles) as important comprise a second group. Those with timber harvesting as at least somewhat important make up a third group. Another group consists of respondents who rated the following environmental services as important: erosion control, watershed protection, and wind block. Respondents who considered forests important as a buffer from neighbors or roads are grouped together. The sixth group is based on respondents who rated hunting as an important use of their forest. The rest of the cases are separated into hiking/walking, wildlife watching, and aesthetics groups based on which of the uses were noted as the most important. The nine groups or classes included in this second classification system and the numbers of cases included in each are listed in Table 6.3. The names of most of the classes or groups included in both classifications are very similar. The two classifications are most different regarding which cases are assigned to each class and in the number of cases in each class.

As with the first classification, both the cases in which respondents did not rate any forest uses as important and the cases with missing data are excluded from analysis. Because the second method of grouping cases does not require one use to be rated as the most important, a larger number of cases (216) is included. As shown in Table 6.3, the smallest group in this classification is environmental services (erosion control, watershed protection, and wind break). It contains 7.4 percent of the classified sample. The timbering class has the largest number of cases (18 percent of those classified). The other groups each contain between 9 and 13 percent of the cases assigned to groups.

Table 6.3. Listing and Number of Cases for Groups Based on Likely Similarities in Landowner Views of Forest Management

Group	Number of Cases in Group	Percent of All Classified into Groups
Environmental services including erosion control, watershed protection, and wind break (ew)	16	7.41
Riding (ar)	20	9.26
Hunting (ht)	20	9.26
Buffer (bf)	22	10.19
Hiking/walking (hk)	23	10.65
Wildlife watching (ww)	23	10.65
Aesthetics (as)	26	12.04
Grazing (ag)	27	12.50
Timbering (tm)	39	18.06
Total	216	100.00

2.5. Differences between Groups

A Kruskal-Wallis test is used to determine if the means of each of the following seven measures that indicate forest fragmentation tend to be significantly different between the groups: PER_FOR, NUMP, LPI, MNN, MPI, IJI, and SIEI. The non-parametric Kruskal-Wallis test is used because the metrics do not tend to be normally distributed. A total of 14 Kruskal-Wallis tests (one test for each of the seven landscape metrics in both classifications) are conducted.

In order to understand better specific differences in the metrics between groups, a discussion of similarities and differences in mean measures for the metrics is also presented. In particular, high and low values are identified and interpreted in relation to forest fragmentation.

2.6. Correlations

Relationships between different forest uses and the metrics that indicate forest fragmentation are further explored by analyses of correlations. The correlation analyses consider relationships between the seven measures of forest fragmentation (PER_FOR, NUMP, LPI, MNN, IJI, MPI, and SIEI) and the importance ratings respondents gave for the following 15 forest uses: harvesting non-wood products (such as mushrooms), spiritual, camping, wind break, erosion control, riding, watershed protection, grazing, harvesting wood products, hunting, buffer, timbering, aesthetics, wildlife watching, and hiking or walking. Because the importance rankings are ordinal type data, the non-parametric Kendall's tau statistic is calculated as the measure of correlation.

2.7. Regression Analysis

The same ordinal regression procedures that were used in Chapters 4 and 5 are used in this chapter. Refer to Chapter 4 for more specific information on the ordinal regression models. The categories for ranking the metrics as ordinal type data and the number of cases in each category are shown in Table A.2 in the Appendix. The same ordinal regression models, those called Model 1, Model 2, and Model 3, in Table 5.5, are further analyzed in this chapter. The models presented in Table 5.4 are expanded in this chapter to include the variable FORUSE. The groups created based on likely similarities between landowners' view of forest management are the basis for the categorical variable FORUSE.

3.0. Results

3.1. Differences between Groups

The results of the Kruskal-Wallis tests indicate that there is sufficient evidence to reject the null hypothesis that the means of some metrics are not different in favor of the alternative hypothesis that the group means of some of the metrics are significantly different. The results for the forest use group classification based on the most important use indicate that the groups have significantly different measures for several metrics. As evident in Table 6.4, the most statistically significant difference in the metric values among the groups is NUMP with a p-value of 0.014. Other significantly different metrics are PER_FOR with a p-value of 0.016, LPI with a p-value of 0.022, and SIEI with a p-value of 0.023. The IJI, MNN, and MPI metrics are not significantly different among these groups.

Table 6.4. Results and P-Value Significances of Kruskal-Wallis Tests of Differences in Metrics among Groups Based on the Most Important Uses

	PER_FOR	NUMP	LPI	MPI	MNN	IJI	SIEI
Chi-Square	18.8	19.19	17.9	9.3	14.0	4.7	17.8
df	8	8	8	8	8	8	8
Asymp. Sig.	**0.016**	**0.014**	**0.022**	0.321	0.082	0.790	**0.023**

Note: Correlations significant (2-tailed) at the 95% confidence level are in bold.

Similar results are evident for differences in the metrics that indicate forest fragmentation among the forest use groups created based on likely similarities in landowner views of forest management. As evident in Table 6.5, the PER_FOR, LPI, and NUMP tend to be the most different metrics among the groups. These relationships have p-value significances of about 0.00. Differences in SIEI are also significant with p-values of about 0.01. Unlike the results for the other classification, the mean MNN values for groups in this classification tend to be different with a p-value significance of 0.02. As with the previous classification, the IJI and MPI measures are not significantly different among these groups. For most of the metrics, the groups that were created based on likely landowner similarities have more significantly different metrics than the groups created based on the most important use.

Table 6.5. Results and P-Value Significances (2-tailed) of Kruskal-Wallis Tests of Differences in Metrics among Groups Based on Likely Similarities in Landowner Views of Forest Management

	PER_FOR	NUMP	LPI	MPI	MNN	IJI	SIEI
Chi-Square	25.32	25.43	25.0	14.0	18.9	12.9	22.0
df	8	8	8	8	8	8	8
Asymp. Sig.	**0.001**	**0.001**	**0.002**	0.081	**0.015**	0.115	**0.005**

Note: Correlations significant at the 95% confidence level are in bold.

The Kruskal-Wallis tests indicate that differences in forest use are associated with significantly different measures of PER_FOR, LPI, NUMP, and SIEI. The tests do not specify which uses are associated with high or low levels of forest fragmentation. In order to understand better how the use groups differ, measures of central tendency and dispersion in the metrics of forest fragmentation by group are presented and discussed in the next section and in the Appendix.

3.2. Discussion of Descriptive Statistics for Groups

3.2.1. Classification 1: Most-Important-Use Groups

This section further discusses differences between the groups created based on the most important forest use (those listed in Table 6.3). Table A.3, in the Appendix, presents descriptive statistics for the seven metrics that indicate forest fragmentation for all the groups in this classification. The group with the lowest mean (59) and median (58) percentage of landscape covered by forest is the riding/grazing group. The highest mean (82) and median (87) values are for the buffer group. These results indicate that larger amounts of forest are likely in areas where hiking or waking, aesthetics, spiritual, and especially buffering are important forest uses. Relatively small amounts of forest are likely on parcels where riding and grazing animals are important uses.

The mean values for the percentage of landscape area covered by the largest patch of forest (LPI) tend to be similar to the values for the percentage of landscape area covered by forest (PER_FOR). The lowest mean LPI value is for the riding/grazing group (53). Although the riding/grazing group also has a low median value, the lowest median value (53) is for hunting. As with the measures of the percentage of landscape area covered by forest, the highest mean (79) and median (87) values for LPI are for the buffer group. These results imply that on parcels where landowners view buffering as an important forest use, much of the parcel is covered by one continuous patch of forest. A relatively small area of continuous forest tends to cover parcels where riding and animal grazing are considered important uses.

The buffer group has the lowest mean number of forest patches (2), and the riding/grazing group has the highest (6). Other groups with relatively large numbers of patches of forest are collecting tree/non-tree products and timbering. The groups with high and low mean and median measures of the number of forest patches tend to be opposite those for the percentage of area covered by forest and LPI. Forest that almost completely covers a parcel tends to occur in a low number of patches.

The mean nearest-neighbor value (MNN) indicates how isolated or far apart the patches of forest are on a landscape. The lowest mean (17) and median (8) MNN values are for the hiking/camping group. Other groups with low values are buffer, aesthetic/spiritual, and collecting tree/non-tree products. This indicates that forest patches in these groups tend to be relatively near each other. The highest mean (35) and median (35) values are for the riding/grazing group. This indicates that the clumps of forest that occur on parcels where riding and grazing are important forest uses, the forest occurs in more isolated patches.

The measures of forest mean patch interspersion (MPI) also provide an indication of how isolated or interspersed the forest patches are. Unlike MNN, MPI takes the size of the patches into account. The mean values for MPI range from 36 for the buffer group to 185 for the group collecting tree/non-tree products. The median values range from 8 for the hiking/camping group to 85 for the collecting tree/non-tree products group. The low values for the buffer group do not indicate that forest associated with these uses are not well interspersed. The low values occur because landscapes composed of one or few patches of forest have lower MPI values. The relatively high mean MPI values imply that, although forest commonly used for collecting tree and non-tree products, wildlife watching, and erosion control/watershed protection may be dispersed into several patches, the patches tend to be relatively well interspersed with each other.

The forest interspersion and juxtaposition index (IJI) indicates how likely a patch of forest is to be adjacent to other types of land use and land cover. The groups hunting, buffer, and hiking/camping have mean IJI values that are lower than the mean for all cases. The lowest mean (32) and median (23) values are associated with the hunting group. The highest mean value (49) is for the wildlife watching group, while the highest median value is for timbering (56). The higher IJI values indicate that parcels, on which these uses are important, tend to have a relatively wide variety of land uses and land covers adjacent to the forest patches.

The Simpson's landscape evenness index (SIEI) indicates how evenly distributed the types of land use and land cover are in a landscape. The groups with high and low mean and median SIEI values tend to be opposite the groups with high and low percentages of landscape covered by forest and LPI. The buffer, aesthetics/spiritual, collecting tree/non-tree products, hiking/camping, and hunting groups have mean measures of SIEI that are lower than the mean and median values for all cases. The lower the SIEI value, the more the landscapes are dominated by one land use or land cover. The lowest mean measure of the SIEI is for the buffer group (0.38). The highest mean value is for the riding/grazing group (0.65). The results indicate that on parcels where agriculture is an important use of the forest, the landscapes tend to be more evenly covered by a variety of land uses and land covers, and on parcels where buffer is an important use, forest tends to dominate.

3.2.2. Classification 2: Landowner-Similarity Groups

The same descriptive statistics are calculated for the groups in the classification created based on likely similarities in landowner views of forest management. One of the largest differences between this classification system and the one based on the most important use is that the riding and grazing groups are separate. This classification system also differs from the first in that there is no collecting tree and non-tree products group. The statistics for metrics of forest fragmentation by these groups are presented in Table A.4 in the Appendix.

The mean percentages of landscape area covered by forest for the grazing and riding groups are relatively low. That is, they are lower than the mean value for all 251 sampled cases. In addition to the grazing and riding groups, the erosion control/watershed protection, and wildlife watching groups have relatively low medians. The lowest mean (57) and median (61) values are for the grazing group. The buffer and aesthetics groups share the highest mean value of 82. Although the buffer group also has a relatively high median value (86), the aesthetics group has the highest value (88). These results suggest that larger areas of forest are likely on parcels commonly used for buffering or aesthetics and smaller areas of forest are likely on landscapes used for grazing.

The mean and median values for the groups' LPI metrics are similar to the values for the percentage of landscape area covered by forest (PER_FOR). Grazing and riding are the only groups with mean and median values that are markedly low. The grazing group has the lowest mean (52) and median (53) values. The buffer group's mean value (81.4) is the highest, but it is only slightly higher than that of the aesthetics (81.1) group. These results indicate that the forest associated with the buffer and aesthetics groups tends to occur mostly in one large patch, that the largest patches of forest on parcels used for grazing tends to be relatively small, and that forest commonly used for purposes other then buffering, aesthetics, grazing, or riding tends to occur in at least one moderately large patch.

Groups with high and low numbers of forest patches tend to be opposite those with high and low percentages of landscape area covered by forest. The buffer group has the lowest mean (2) and median (1) numbers of forest patches, and the grazing group has the highest mean (6) and median (5). Other groups with relatively high numbers of forest patches are wildlife watching and riding. These means also suggest that forests that are used for buffering tend to consist of a small number of large patches, while forest used for grazing, and, to a lesser degree, riding, tends to be split into a larger number of smaller patches.

The buffer group has the lowest mean (16) and median (0) measures of MNN. In addition to the buffer group, the aesthetics, erosion control/watershed protection, hiking, and timbering groups have lower than average mean MNN values. The aesthetics, buffer, and erosion control/watershed protection groups also have lower than average median values. The forest patches in these groups tend to be relatively close together. The hunting, riding, wildlife watching, hiking, and timbering groups all have median values that are about equal to the median for all cases. The forest patches in these groups tend to be relatively far apart. The grazing group is the only group that has a median value that is higher than the median for all cases, and it also has the highest mean value (36). Distances between forest patches tend to be largest on parcels used for grazing.

The buffer group also has the lowest mean (26) and median (0) values for MPI. It may have low values because of the high number of cases with only one forest patch that are included in the group. The riding, wildlife watching, hunting, and timbering groups have relatively high mean values. The highest mean (164) and median (68) values are for timbering. This indicates that the forest patches on parcels used for timbering are relatively well interspersed with each other.

The hunting group has the lowest mean and median forest IJI values. Other groups with relatively low mean and median IJI values are hiking, buffer, aesthetics, and timbering. Groups with relatively high mean values are grazing, riding, and erosion control/watershed protection. The highest mean value is for the wildlife watching group. The wildlife watching group also has a high median value (58), but the highest median value (59) is for the erosion control/watershed protection group. High IJI values indicate that a wide range of land uses and land covers are adjacent to the forest patches. Therefore, the widest ranges of land uses and land covers tend to be adjacent to forest patches in the wildlife watching and erosion control/watershed protection groups. The results also indicate that a relatively wide variety of land uses and land covers exist adjacent to forest on parcels in the riding and grazing groups. The groups with relatively low IJI values, particularly hunting, have few types of land use and land cover adjacent to the forest patches.

The groups with low IJI values also tend to have low evenness or SIEI values. The aesthetics, buffer, hiking, hunting, and timbering groups have relatively low mean and median SIEI values, but the buffer group has the lowest mean value (0.36). The grazing group has the highest mean (0.63) and median (0.68) values. The relatively high SIEI values indicate that the land-use and land-cover types tend to be evenly distributed, and no single type dominates. The land use and land cover on parcels with low evenness values consists primarily of a single type that encompasses most of the landscape. Given the other results, this one type is most likely forest cover.

3.3. Similarities in Both Classifications

Table 6.6 provides an overview of the relative differences in the mean metric values among the groups that are based on the most important use (labeled classification 1) and the groups that are based on likely similarities in landowners' views of forest management (labeled classification 2). Table 6.6 lists the groups with the highest mean values, higher than the average mean for all cases, lower than the average mean for all cases, and lowest mean values for each of the seven indicators of forest fragmentation. This table highlights similarities and differences between the mean values for the groups within each classification and between the classifications.

Table 6.6. Comparison of Low and High Group[1] Mean Values for Each Metric

Metric	Classification2	Lowest Mean	Mean lower than the mean for all cases	Mean higher than the mean for all cases	Highest Mean
PER_FOR	1	Gr	H, T, Es	Ww, NT, Hc, As	B
	2	G	R, Ww3	Es, T, H, Hc, As	B
LPI	1	Gr	H, T	Es, Ww, Nt, Hc, As	B
	2	G	R	Ww, Es, H, T, Hc, As	B
NUMP	1	B	Hc H, As, Ww, Es	Nt, T	Gr
	2	B	As, Es, H, Hc, T	Ww, R	G
MNN	1	Hc	B, As, Nt	T, Es, H, Ww	GR
	2	B	As, Es, Hc, T	H, R, Ww	G
MPI	1	B	As, H, T, Gr	Hc, Ww, Es	NT
	2	B	Es, As, G, Hc	R, Ww, H	T
IJI	1	H	B, Hc, As, Gr, T	Es, Nt	Ww
	2	H	Hc, B, As, T	G, R, Es	Ww
SIEI	1	B	As, Nt, Hc, H	T3, Es, Ww	GR
	2	B	As, H, Hc, T	Es, Ww, R	G

[1] Groups: R = riding; G = grazing; H = hunting; T = timbering; Ww = wildlife watching; Nt = harvesting tree and non-tree products; Hc = hiking or walking and camping; Es = environmental services (wind break, erosion control, watershed protection; B = buffer; As = aesthetics and spiritual.
[2] Classifications: 1 is the classification based on the most important uses; 2 is the classification based on likely similarities in landowner views of forest management.
[3] Approximately equal to the mean for all sampled cases.

Groups in both classification systems have LPI measures that are very similar to the measures of the percentage of landscape area covered by forest. This may be because the landscapes included in this analysis are relatively small, and the largest patches of forest may cover all or most of the landscapes' area. Groups with relatively high mean numbers of forest patches tend to have relatively high mean landscape SIEI measures and relatively low measures of the mean percentages of landscape covered by forest and LPI.

An opposite trend is evident for groups with relatively low mean numbers of forest patches. The mean measures of SIEI and number of forest patches may be similar because a relatively large number of forest patches is typically associated with smaller-sized patches. The larger number and smaller size of the patches allow various land uses and land covers to mingle better and to be more evenly distributed across the landscape. The groups with relatively high mean measures of the number of forest patches and SIEI tend to have low measures of the percentage of landscape covered by forest and LPI because evenness is the opposite of dominance. High percentages of landscape covered by forest and LPI indicate landscapes that are dominated by forest. High LPI values in particular indicate landscapes composed almost exclusively of one large patch of forest. Such landscapes are dominated by forest and have low levels of evenness.

The groups with high mean MNN values tend to be similar to the groups with high mean numbers of forest patches and high mean SIEI values. An opposite trend is observed for the groups with relatively low mean MNN values. A larger number of forest patches allows a larger mean distance between patches and a more even distribution of land-use and land-cover types across the landscape. The largest differences in the mean values between comparable groups in the two classification systems are for the MPI values. Interpretation of the MPI values is complex because different configurations of land use and land cover may have the same values. Landscapes entirely covered by one patch of forest, such as many in the buffer group, have extremely low MPI values. Landscapes with little forest that is not well interspersed, such as some of those in the grazing group, also have low MPI values.

For most of the metrics, the means for the buffer groups tend to be opposite the grazing (or grazing and riding) groups. When the buffer group has a high mean value, the grazing (or grazing and riding) group has a low value, and vice versa. The buffer group tends to be associated with parcels that have large amounts of forest, few numbers of forest patches, short distances between any forest patches, and large areas covered by the largest patch of forest. Because the landscapes in the buffer group tend to be dominated by forest, they have low SIEI values and uneven distributions of land use and land cover.

The buffer and grazing (or grazing and riding) groups generally have the most extreme mean values for all metrics except for IJI. The mean IJI values may be different because they are not as affected by the number and size of the patches in the landscape as the other metrics. Although it does not have the lowest mean IJI, the buffer group's IJI value is relatively low. The low IJI value indicates that on parcels where buffer is an important use, forest patches tend to be adjacent to few other types of land uses and land covers.

The aesthetic (including spiritual uses) group has the second highest mean percentage of area covered by forest and LPI. The aesthetic group also has a low number of forest patches, MNN, MPI, and SIEI. The low mean SIEI value reflects that relatively large patches of forest dominate the landscapes. This indicates that there tends to be a large amount of forest in a few large, closely spaced patches on parcels where aesthetics or spiritual uses are important. These parcels also tend to have an uneven distribution of land uses and land covers. In general, the mean IJI values for the groups indicate that patches of forest used for aesthetic purposes tend to be adjacent to a moderate variety of other land uses and land covers. This may reflect that aesthetics is an important use of forest on parcels with a variety of other land uses and land covers. For example, aesthetics may be important on parcels where both residential and agricultural uses occur.

Many of the metrics for the hiking (including walking and camping) group are similar to those of the aesthetic group. Forests that are used for hiking tend to occur in a few closely spaced patches that cover a large percentage of the landscape. The relatively low mean IJI values for this group indicate that forest patches tend to be adjacent to few other types of land use and land cover. The low SIEI value further suggests that forest cover dominates parcels in this group.

Parcels for which erosion control/watershed protection is an important use of the forest have moderate amounts of forest comprised of fewer, relatively large patches (based on LPI values). The moderate SIEI values indicate that the distribution of land uses and land covers tends to be moderately even. The MPI values indicate that the forest patches are fairly well interspersed with each other. The relatively high mean values for IJI suggest that these forest patches are adjacent to several types of land uses and land covers. In addition to areas of developed and agricultural lands, forests that are used for watershed protection are likely to border a body of water such as a pond or stream.

The mean values for the timbering groups generally indicate these parcels have moderate amounts of forest, moderate numbers of forest patches, and moderate distances between forest patches (as evident in the mean MNN). The landscapes on which timbering is an important use of the forest tend to have moderately even distributions of types of land uses and land covers given the mean SIEI value. The IJI values indicates that the forest patches tend to be adjacent to a wider variety of types of land use and land cover than the forest used for buffering and hiking but less variety than the forest used for grazing and riding. The high MPI value indicates that, although there may be a moderately large number of forest patches on landscapes where timbering is an important use, the patches are well interspersed with each other.

Generally, parcels in the wildlife watching group tend to have average amounts of forest cover with a moderate number of patches. The mean LPI value indicates that the largest forest patch covers a slightly larger percentage of the landscape than average. The wildlife watching group has relatively high MNN, MPI, and SIEI values. Although landscapes of parcels on which wildlife watching is an important use tend to have a relatively high number of forest patches, distances between forest patches, and evenness in the landscape, the forest patches tend to be relatively well interspersed with each other. One of the most interesting results is that the wildlife watching group has the highest mean IJI value of all the groups in both classifications. This indicates that forest patches associated with wildlife watching tend to be adjacent to the widest variety of other land-use and land-cover types. The wide variety of land-use and land-cover types that are adjacent to the forest patches are relatively evenly distributed across the landscape. These results may reflect that forest used for wildlife watching occurs on parcels with a variety of dominant land uses.

The fairly low amount of forest in the hunting group consist of relatively small numbers of patches that are moderately well interspersed. Landscapes in this group tend to have very low IJI values. The lack of diversity or evenness in land use and land cover is also evident in the relatively low SIEI values. These results imply that there are few other types of land use or land cover commonly found on parcels where hunting is an important use of the forest. However, it should be noted that there are relatively high measures of dispersion associated with many of the metrics for the hunting groups in both classifications, and these groups may be the least well-defined group in both classifications.

The collecting tree and non-tree products group occurs in one classification. Perhaps the most noteworthy result for this group is that the forest patches tend to be well interspersed with each other given its relatively high mean MPI. The results indicate that collecting tree and non-tree products is associated with moderately high amounts of forest that occur in moderate numbers of forest patches that are well interspersed with each other so that the landscape is not very even.

3.4. Correlations between Fragmentation Metrics and Importance of Uses

Respondents' importance ratings for the forest uses are correlated with the seven metrics of forest fragmentation on a case-by-case basis. Table A.5, in the Appendix, presents an overview of significant correlations. Many of the correlations between the uses and PER_FOR are extremely similar to the correlations between the uses and LPI. The importance ratings for hiking/walking, aesthetics, spiritual, and buffer uses are positively correlated, at the 99% confidence level, with PER_FOR and LPI. PER_FOR and LPI also have positive correlations with the importance ratings of wildlife watching and camping, but these correlations are only significant at the 95% confidence level. The correlations between both PER_FOR and LPI and the importance of grazing as a forest use are negative with p-value significances of approximately 0.00. The importance ratings of hiking/walking, buffer, and aesthetics are each negatively correlated with landscape SIEI at the 99% confidence level. The importance of grazing is positively correlated with SIEI at the 99% confidence level.

The correlations between the importance ratings for each of the forest uses and NUMP tend to be almost opposite the correlations between the importance of the uses and both PER_FOR and LPI. The importance ratings for hiking/walking, buffer, aesthetics, wildlife watching, and spiritual uses are all negatively correlated with NUMP at the 99% confidence level. The importance of grazing is also correlated with NUMP at the 99% confidence level, but this relationship is positive. Forest MNN is negatively correlated, at the 99% confidence level, with the importance of hiking/walking, buffer, and aesthetics. It is negatively correlated, at the 95% confidence level, with the importance of wildlife watching and spiritual uses and, it is positively correlated, at the 99% confidence level, with the importance of grazing.

Forest MPI is negatively correlated with the importance ratings given to aesthetic and buffer uses of the forest, at the 99% confidence level, and it is negatively correlated with spiritual uses at the 95% confidence level. It is interesting to note that the importance rating for timbering is positively correlated, at the 95% confidence level, with forest MPI. However, relationships between the importance of forest uses and MPI are more difficult to interpret because low MPI values are associated with different types of landscapes.

Analysis of similarities and differences between mean values for the metrics in both classifications of parcels based on forest uses indicates some general trends that occur across the seven metrics that indicate forest fragmentation. The groups' mean PER_FOR values are extremely similar to the mean LPI values, and the two metrics provide almost redundant information. Groups with high values for PER_FOR and LPI tend to have low values for NUMP, SIEI, and MNN, and vice versa. If a parcel has a relatively high NUMP value, it is likely that it also has high SIEI and MNN values and low PER_FOR and LPI values. This research also illustrates difficulties associated with comparing MPI values across landscapes with large differences in NUMP. Landscapes with relatively high NUMP values tend to have higher MPI values than landscapes with high LPI values but low NUMP values.

3.5. Regression Models

Table 6.7 presents the results of ordinal regression models with the seven metrics of forest fragmentations as the dependent variables and the significantly correlated socioeconomic variables from the interviews with the landowners (given in Table 4.7), LANDUSE (types of land uses), and FORUSE (group created based on likely similarities in landowners' view of forest management) as independent variables.

Table 6.7. Ordinal Regression Models with Metrics as the Dependent Variables and the Significantly (2-tailed) Correlated Socioeconomic Variables (given in Table 4.7), LANDUSE, and FORUSE as the Independent Variables

Model for	-2 Log Likelihood	Chi-Square	df	Sig. (2-tailed)	Nagelkerke Pseudo R-Square
PER_FOR	283.348	170.735	26	0.000	0.639
LPI	353.808	147.687	26	0.000	0.567
NUMP	334.198	150.468	31	0.000	0.588
MNN	335.847	88.950	27	0.000	0.415
MPI	419.789	89.817	27	0.000	0.399
IJI	546.561	46.521	18	0.000	0.207
SIEI	388.514	123.447	27	0.000	0.508

Similar to the models discussed in the other chapters, the significance values for the models are all quite high at least in part because of the large numbers of independent variables included in the models. The pseudo R-square values provide more useful information than the significance values. There is a wide range in pseudo R-square values for the models, but the pseudo R-square values are quite high for most of the models. They are over 0.50 for PER_FOR, LPI, NUMP, and SIEI. Similar to the results in the previous chapters, the model for PER_FOR performs the best, and the model for IJI performs the worst.

Table 6.8 presents a comparison of pseudo R-square values for the models considered in this chapter and in Chapters 4 and 5. As in the previous chapter, the models labeled Model 1 include the variables POPDEN, SLOPE, and HWY37 as the independent variables and the metrics as the dependent variables. The models labeled Model 2 in the table are the same as those labeled Model 1 expect that they include as independent variables the socioeconomic data from the interview with landowners that are significantly correlated with the metrics and listed in Table 4.7. Those labeled Model 3 are the same as Model 2 except that they include LANDUSE as an independent variable and, those labeled Model 4 are the same as those in Model 3 except that they include FORUSE as an independent variable.

Table 6.8. Comparison of Nagelkerke Pseudo R-Square Values for Models with Metrics as the Dependent Variables and Different Independent Variables for Each Model (Model 1: SLOPE, POPDEN, and HWY37. Model 2: same as Model 1 with added socioeconomic variables that are significantly correlated with the metric [given in Table 4.7]. Model 3: same as Model 2 plus LANDUSE. Model 4: same as Model 3 plus FORUSE)

Dependent Variable	Model 1	Model 2	Model 3	Model 4
PER_FOR	0.467	0.533	0.694	0.639
LPI	0.423	0.479	0.611	0.567
NUMP	0.270	0.458	0.562	0.588
MNN	0.239	0.338	0.398	0.415
MPI	0.049	0.300	0.355	0.399
IJI	0.131	0.149	0.190	0.207
SIEI	0.323	0.409	0.501	0.508

Table 6.8 shows that the addition of the type of forest use (FORUSE) only slightly improved the performance of most of the models. The performance of the models for PER_FOR and LPI actually worsened with the inclusion of the type of forest use as an independent variable.

4.0. Discussion

The forest use rated as the most important by most landowners in the sample is hiking/walking. The landowners also frequently rated wildlife watching and aesthetics as the most important forest uses. They rarely identified harvesting non-wood products and spiritual uses as the most important forest use. Timbering was rated as the most important by a moderate number of landowners.

Similar to many areas, the spatial patterns of land use and land cover in Monroe County have been affected by the process of urbanization or, more specifically suburbanization. In the process of suburbanization, rural areas consist of increasingly smaller sized parcels, smaller areas of agriculture, and larger areas of developed land. The process of suburbanization affects the types of land uses and land covers that occur in a landscape, the proportions of the landscape occupied by each type and the spatial arrangement of the types of land uses and land covers. This research finds that landowners commonly rated forest uses that tend to be most compatible or beneficial to more urban as opposed to agricultural uses of the parcel as the most important.

The landowners' decisions not to use the forest for agricultural purposes impact the composition and configuration of the landscape. Generally, the largest amounts of forest that are least fragmented are associated with buffering, aesthetics, and hiking/walking uses of the forests. The lowest amounts of forest that are most fragmented are associated with grazing and riding as important uses of the forest on the parcels.

The results of the Kruskal-Wallis tests further reveal several relationships between metrics of forest fragmentation and forest uses. The PER_FOR and the LPI metrics tend to be quite different on parcels where the forest is used primarily for different purposes. The LPI and the degree of evenness in the distribution of land uses and land covers tend to be significantly different among parcels that are associated with different primary forest uses, but differences between these metrics tend to be less significant than differences between the NUMP and the PER_FOR. The MPI and the IJI metrics are not significantly different among parcels associated with different uses of the forest. Differences in the MNN metrics are somewhat significant among parcels with different forest uses.

In general, the correlation results indicate that grazing, aesthetics, spiritual, hiking/walking, and buffer uses have relatively extreme impacts on the composition and configuration of the forest, while other recreational uses have more moderate impacts. Parcels on which aesthetics, spiritual, hiking/walking, and buffer uses are highly important tend to have larger areas of forest that are better connected, with less forest fragmentation, and potentially better forest functions and resilience than other parcels. An opposite trend is evident with an increase in the importance of grazing as a forest use. Parcels on which grazing is an important use of the forest tend to have less area covered by forest, smaller forest patches that are more widely spaced, and more even distributions of land use and land cover. These characteristics are associated with a larger amount of forest fragmentation and less forest resilience. The other forest uses are associated with moderate amounts of forest that are moderately well interspersed on landscapes with somewhat even distributions of land uses and land covers.

The regression results suggest that models that include the type of forest use conducted on the parcel perform fairly well. However, the addition of FORUSE as a categorical variable in the ordinal regression models only slightly improves the performance of the models as compared with the models that include the socioeconomic variables that are significantly correlated with the metrics (those given in Table 4.7) and LANDUSE.

5.0. Conclusion

Socioeconomic processes have impacted the spatial patterns of the landscape in Monroe County, Indiana. The spatial patterns of land use and land cover in the landscape reflect changes in the dominant economic activities that have occurred in the area over time. The shift away from agricultural production to first industrial production and, more recently post-industrial activities, has allowed forest to regrow and become better connected in recent years.

Changes in the way landowners view forests have also changed over time and have also affected spatial patterns of land uses and land covers. During the period of initial settlement, landowners tended to view forests as an obstacle to be removed. Later, they valued forests as a harvestable resource. More recently, the non-consumptive benefits of forests have become important. The results of this research indicate that most contemporary landowners value their forests, in large part, because of the positive externalities, beauty, and recreational opportunities they offer. An externality is any action that affects the welfare of or opportunities available to an individual or group without direct payment or compensation, and may be positive or negative (Pretty et al. 2001). Positive externalities and forest benefits associated with aesthetics, buffering, and recreation are commonly important to the landowners in the study area.

The results of this analysis are similar to those of previous research. For example, these results support the work of Erickson et al. (2002), who have suggested that the proliferation of non-agricultural land uses on parcels may have some positive consequences for forest connectivity and, that landowners are likely to consider more than their own economic interests and make land and forest use decisions that increase the visual quality, environmental functions, and recreational potential on their parcels.

The results of this research support the assumption that there are connections between forest uses and forest fragmentation. This implies that forest management programs, which limit particular uses, may impact the overall forest functions and resilience. However, conservation programs that target landowners who value their forest for similar purposes may bring together landowners with similar management objectives and facilitate voluntarily cooperate in efforts to achieve common land management goals. Such policies provide opportunities for individuals who want to retain control over their land to work cooperatively with other landowners to manage the forest landscape as a larger unit. Policies that encourage individual cooperation may be able to adjust to meet changing socioeconomic and biophysical circumstances faster and more cost-effectively than traditional approaches to conservation such as zoning.

The results indicate that knowledge of individual's forest use preferences may be more useful information to include in efforts to encourage participation in ecosystem management programs than for efforts to improve land-use and land-cover models. The results support the proposition that some ecosystem management policies should emphasize benefits of conservation programs such as wildlife restoration, improvement of visual quality, and recreation (Erickson et al. 2002). Landowners who use the forest for aesthetics, buffering, and walking may be more apt to join conservation programs that include improvement of the visual quality of their land than they are to join traditional programs. Improving participation in conservation programs is a way to implement ecosystem management, eventually increase forest connectivity, and ultimately improve the overall functions and resilience of the forest.

A number of factors affect the composition and configuration of land use and land cover on a landscape. Future studies will expand upon the results of this research and will take other biophysical and socioeconomic factors into account when analyzing relationships between socioeconomic characteristics and forest ecosystem function. Analysis of relationships between similar variables across other scales will also be explored in future research.

CHAPTER 7
CONCLUSIONS

1.0. Overview of Research and Results

This dissertation addresses the research needs that were identified in Chapter 1 through a case study of Monroe County, Indiana. In general, this research uses theory and methodology from geography, resource management, and landscape ecology to analyze relationships between socioeconomic variables and spatial patterns of land use and land cover on non-industrial private parcels. Although Monroe County is a unique location, it shares characteristics with many areas of the world. As discussed in Chapter 2 historical changes and socioeconomic processes have affected the amount of forest cover and its distribution in Monroe County.

A classification of a remote sensed image is used as a basis for calculating metrics of landscape composition and configuration with the use of a geographic information system. These metrics indicate the degree of forest fragmentation in the landscape. The metrics are calculated for a sample of individual, privately owned parcels that were chosen to represent all the parcels within Monroe County. Information that pertains to land and forest use decisions on the sampled parcels was collected during interviews with the landowners. Relationships between variables that are related to land and forest use decisions and the metrics of spatial patterns on the parcels are determined through statistical tests.

This dissertation explores whether the process of land parcelization is evident in patterns of land use and land cover in the landscape of south-central Indiana. It investigates whether landowners, who make decisions based on discrete partitions in the landscape, affect spatial patterns and whether these partitions result, in some cases, in discrete land-use and land-cover edges. Metrics that indicate spatial patterns are calculated for areas of developed, agricultural, and forest land around the boundaries of each parcel. The variances of the metric values for areas near the parcel boundaries are compared with the values for areas at increasing distances from the parcel boundaries. It is hypothesized that the highest variance occurs for landscapes of areas near the parcel boundaries, that distinct changes in variance occur between these landscapes and landscapes that include areas at a distance from the boundaries, and that variance is comparatively low and changes little for landscapes encompassing areas at larger distances from the boundaries.

The results of this research suggest that, in Monroe County, Indiana, changes in the composition of the landscape, particularly in the amount of area covered by agriculture and forest, correspond with parcel boundaries. Changes in the configuration of agricultural and, to a lesser extent, developed lands also occur near parcel boundaries. The results support the hypothesis that the grid-based system of parcelization has affected spatial patterns of land use and land cover in the landscape. The results also illustrate the potential impact socioeconomic and political systems may have on spatial patterns in a landscape, how land management decisions persist in the landscape, and the usefulness of considering parcels as units of landscape study.

This dissertation also explores links among spatial patterns of forest cover and socioeconomic variables that affect individuals' land-use decisions. The specific factors included in this analysis are: differences in the size of the parcel, whether or not the current owner shares similar land uses and management beliefs as the former owner, how the parcel was acquired, the length of time the parcel has been owned, the importance of the parcel for income generation, whether or not the parcel will be inherited by an heir, highest level of education of landowner, age of landowner, income of landowner, distance of parcel from the central business district of Bloomington, distances to the two main highways, mean slope, and past land uses that have affected the parcel. These variables indicate differences in the knowledge, experiences, and preferences of the landowners and represent factors that may constrain landowners' land and forest use decisions.

It is hypothesized that larger amounts of forest that is less fragmented occur on parcels with shorter periods of ownership by an individual and his or her family and on parcels that are less important for generating income for the landowner. It is also hypothesized that there are significant differences in the spatial characteristics of forest on parcels that have and have not had similar land uses and management beliefs over subsequent owners, have and have not been inherited or obtained from a family member, have and do not have owners who anticipate transferring the parcel to an heir, and have or have not been affected by tilling, quarrying, and drilling. Significant correlations are expected between education, income, distance measures, parcel size, length of time parcel has been owned, age of owner, mean slope and the metrics that indicate forest fragmentation. It is expected that models of spatial patterns of land use and land cover can be improved with the addition of parcel-level socioeconomic data.

The results indicate that forests have played an integral part in the history of south-central Indiana. The forests have been viewed as obstacles to settlement and as resources to exploit. Over much of the history of Monroe County, forests competed directly with agriculture or were harvested as a type of crop. More recently, forests have become valued for environmental and aesthetic purposes. Land and forest use activities and management policies have varied with the changing views of the forest.

Differences in factors affecting landowners' land-use decisions impact spatial patterns that indicate forest ecosystem functions. The results of this research suggest that the decision to engage in agricultural production or not to engage in agricultural production on a parcel significantly affects the spatial patterns of land use and land cover on a landscape. Variables related to whether or not a parcel is used for agricultural production appear to be the most significantly related to metrics that indicate forest fragmentation. Generally, the longer a parcel has been owned, the more important it is for income generation, and the larger the parcel (all indicators of greater dependence on agricultural production), the more fragmented the forest. Whether or not a parcel has ever been affected by tilling impacts the spatial patterns of the forest cover as does quarrying and drilling to a lesser degree. This suggests that even past agricultural land uses affect current spatial patterns of land use and land cover in a landscape.

Other socioeconomic variables that tend to be significantly correlated with the most of the metrics of forest fragmentation are the age of the landowner and the highest level of education achieved by the landowner. Whether or not a parcel was inherited or obtained from a family member and the income of the landowner are not significantly correlated with any of the metrics. This research confirms that variables, which are commonly assumed to be highly correlated with level of forest fragmentation in a landscape, are highly correlated with metrics of fragmentation in the study area. These variables include the degree of slope, distance to the main north-south highway in the county, and the population density of the neighborhood of each parcel.

The regression models indicate that the variables SLOPE, POPDEN, and HWY37 explain a relatively large portion of variability in most of the metrics that indicate forest fragmentation. However, the addition of socioeconomic variables that affect landowners' land and forest use decisions improves the performance of the models for all the metrics except IJI. This is not surprising because IJI is not significantly correlated with any of the variables that were obtained from the interviews with the landowners. The models that include the variables from the interviews that are significantly correlated with the metrics perform at least fairly well in predicting the values for all the metrics except IJI. The models for PER_FOR, LPI, NUMP and SIEI perform particularly well. The results indicate that models of land use and land cover should include socioeconomic data relevant to land-use decisions including the age and level of education of the landowner, length of time a parcel has been owner, and the importance of the parcel for income generation for the owner.

Chapter 5 tests the following hypotheses:

- There are significant differences in the means of metrics that indicate forest fragmentation on parcels with different land uses.
- Parcels with different combinations of land uses have significantly different mean indicators of forest fragmentation.
- Parcels used for forestry have larger amounts of forest that is less fragmented.
- Parcels used mostly for residential purposes have moderate amounts of forest that is moderately fragmented.
- Parcels used primarily for agricultural purposes have the least amount of forest that is the most fragmented.
- Models of spatial patterns of land use and land cover can be improved with the addition of parcel-level socioeconomic data, specifically by including the types of land uses conducted on the parcel.

The results confirm that parcels used for agricultural purposes tend to have the least amount of forest that is relatively highly fragmented, parcels used for residential purposes have a moderate amount of forest that is moderately fragmented, and parcels used for forestry have a large amount of forest that is not very fragmented.

Different land uses on parcels are associated with significant differences in many of the metrics that indicate forest fragmentation, particularly the percentage of area covered by forest, the largest patch of forest, the number of forest patches, distances between forest patches, interspersion of forest patches, and the degree of evenness in the types of land uses and land covers in the landscape. Measures of the degree of diversity in land-use and land-cover types that are adjacent to forest patches are less likely to be significantly different on parcels with dissimilar land uses.

In general, parcels used for both forest and residential uses are not significantly different, in terms of the metrics that indicate forest fragmentation, from those used only for forest. Many of the metrics are not significantly different between parcels used for both agriculture and residential uses and those used only for agriculture. The combination of forest and agricultural and the combination of agricultural and residential uses are the use combinations that have metrics that are most different from each other.

The results suggest that different combinations of land uses that may occur on a parcel impact the degree of forest fragmentation. Of the seven metrics of forest fragmentation that are included in this analysis, only forest IJI tends not to differ significantly among parcels that have forest or residential use in common. Parcels that have agricultural land use in common have similar results except that the differences in forest IJI are more significant and the differences in landscape SIEI are less significant. Although parcels may have a land use in common, the amount of forest cover, its spatial arrangement, and its degree of fragmentation are likely to vary if the other types of land use that occur on the parcel differ.

The differences in fragmentation are most obvious with parcels that are or are not used for agricultural purposes. These results support research (Dean and Smith 2003) that found that a parcel-level analysis was especially suited for analysis of agricultural landscapes because they have an inherent parcel structure and that variability in land use and land cover becomes more significant in more developed areas.

Parcels that are used for both forest and residential uses tend not to have significant differences in metrics of forest fragmentation from parcels used only for forests. This indicates that residential uses tend to have similar impact on the spatial patterns of land use and land cover as forest use in the study. This may be because the impact of residential use on the spatial patterns is too small to detect in the landscapes created from the Landsat Thematic Mapper imagery. However, parcels that are used for both residential and forest uses tend to have significant differences in IJI from parcels used only for forest. In addition, parcels used for both residential and agricultural uses tend to have significant differences in IJI from those used only for agricultural purposes. Because significant differences in one metric are evident among parcels used for residential uses and those that are not used for residential purposes, it is likely that the grain of the data would have been sufficient to detect significant differences in the other metrics among the parcels.

One of the characteristics of urban sprawl or the spread of developed land uses into rural areas is the relatively high level of diversity of land uses that are adjacent to each other. It is likely that parcels used for residential purposes occur in more suburban areas, where a relatively wide variety of land uses and land covers are adjacent to each other. Therefore, variation in forest IJI may be an early indication of urban pressure in an area.

Differences in land uses are associated with differences in many aspects of the spatial patterns of forest cover and thus forest functions and resilience on rural or semirural parcels in Monroe County, Indiana. The results generally support the assertion that regulating land uses on parcels is an effective means of managing forest fragmentation. Regulations that focus on forest and agricultural uses may have significant impacts on the spatial patterns in a landscape, which indicate forest fragmentation and function.

The regression analysis indicates that the performance of fine-scale models of spatial patterns of land use and land cover and forest fragmentation would improve if socioeconomic variables were included. The variables that appear to explain the most variation in the metrics are measures of slope, accessibility (to the main north-south highway not to the central business district of the city), neighborhood population density, age of the landowner, highest level of education achieved by the landowner, the importance of the parcel for income generation (not the landowner's income), the size of the parcel, how long the parcel has been owned by the current owner's family, and whether or not the parcel has ever been tilled.

Chapter 6 focuses on the following questions: what forest uses are considered to be the most important by the largest number of private landowners; which uses are associated with high and low levels of forest fragmentation; do measures that indicate forest fragmentation significantly differ among landscapes associated with different forest uses, are they significantly correlated with the degree of importance landowners assign to the uses, and does including the types of forest use that are conducted on parcels improve models of forest fragmentation?

It is expected that parcels with different types of forest uses have significantly different metrics of forest fragmentation, the degree of importance landowners assign to various forest uses is significantly correlated with measures of forest fragmentation, and models of forest fragmentation can be improved with the addition of parcel-level socioeconomic data that specifically include the types of land and forest uses that are conducted on the parcel. The questions are addressed in a case study of non-industrial, privately owned parcels of land in Monroe County, Indiana.

The forest use rated as the most important by most landowners in the sample is hiking/walking, with wildlife watching and aesthetics also frequently rated as the most important use. Harvesting non-wood products and spiritual uses were least frequently identified as the most important use. Generally, the largest amount of forest that is least fragmented is associated with buffering, aesthetics, or hiking/walking. The lowest amount of forest that is most fragmented occur on parcels where grazing or riding is important.

The amount of forest cover and the number of forest patches tend to be significantly different on parcels where the forest is used for different purposes. The percentage of area covered by the largest patch of forest and the degree of evenness in the distribution of land uses and land covers tend to be significantly different among parcels that are associated with different forest uses, but differences between these metrics tend to be less significant than differences between the number of forest patches and the percentage of area covered by forest. Differences in the mean distances between nearest-neighboring forest patches are somewhat significant among parcels with forest used for different purposes. The MPI and the IJI metrics are not significantly different among parcels associated with different uses of the forest.

In general, the correlation results indicate that grazing, aesthetics, spiritual, hiking/walking, and buffer uses have relatively extreme impacts on the composition and configuration of the forest while other recreational uses have more moderate impacts. Parcels on which aesthetics, spiritual, hiking/walking, and buffer uses are highly important tend to have larger areas of forest that are better connected, with less forest fragmentation, and potentially better forest function and resilience than other parcels. An opposite trend is evident with an increase in the importance of grazing as a forest use. Parcels on which grazing is an important use of the forest tend to have less area covered by forest, smaller forest patches with larger distances between them, and more even distributions of land use and land cover occurring over the landscape. These characteristics are associated with a larger amount of forest fragmentation and less forest resilience. The other forest uses are associated with moderate amounts of forest that are moderately well interspersed on landscapes with somewhat even distributions of land uses and land covers.

The regression model results indicate that adding landowners' forest uses or the variable FORUSE to the independent variables in the models of forest fragmentation does not greatly improve the performance of the models. The results indicate that data on individual's forest use preferences may be more useful for efforts to encourage participation in ecosystem management programs than for efforts to improve land-use and land-cover models.

2.0. Results Related to Socioeconomic Processes

The results of this analysis are similar to those of previous research. For example, these results support the work of Erickson et al. (2002) who have suggested that the proliferation of non-agricultural land uses on parcels may have some positive consequences for forest connectivity and that landowners are likely to consider more than their own economic interests and make land and forest use decisions that increase the visual quality, environmental functions, and recreational potential on their parcels.

The contemporary patterns of land use and land cover in the landscape of Monroe County reflect socioeconomic processes that have occurred in the area. For example, the spatial patterns of land use and land cover have been impacted by changes in the dominant economic activity in the area. After the initial division and privatization of the land in the county, most owners attempted to completely clear the land of forest in order to use the land for agriculture. Later, much of the remaining forest was harvested for timber. These processes resulted in an almost total loss of forest, fragmentation of the remaining forest, and large areas of agriculture in the county. The shift away from agricultural production to first industrial production and, more recently post-industrial activities, has allowed for the regrowth of secondary forest on some parcels. This research highlights the associations between the types of economic activities that are conducted on private parcels and forest fragmentation.

Changes in the way landowners view forests have also affected spatial patterns of land uses and land covers. During the period of initial settlement, landowners tended to view forests as an obstacle to be removed. Later, they tended to value forests as a harvestable resource. More recently, uses of forests such as aesthetics, buffering, and recreation have become important to many landowners. The results of this research indicate that most contemporary landowners value their forests, in large part, because of the positive externalities, beauty, and recreational potential they offer. An externality is any action that affects the welfare of or opportunities available to an individual or group without direct payment or compensation, and may be positive or negative (Pretty et al. 2001). Landowners who consider uses such as aesthetics, buffering, and hiking to be important tend to have the largest areas forests that are the least fragmented and, those who value their forests mostly for more traditional agricultural uses tend to have the least amount of forest that is the most fragmented.

Fine-scale migration patterns also impact spatial patterns in the landscape. When most landowners lived and worked on their parcels by conducting agricultural activities, large, well-connected areas of agriculture spread over the county and only small, highly fragmented patches of forest remained. As people moved to the cities, for industrial work, the amount of land used for agriculture decreased, the amount of forest land increased, and forest became better connected. Most recently, the importance of post-industrial activities has increased and people have tended to move out of the city and into more rural areas. This process of migration is tied to the process of urbanization.

Similar to many areas, the spatial patterns of land use and land cover in Monroe County have been affected by the process of urbanization or, more specifically suburbanization. In the process of suburbanization, rural areas consist of increasingly smaller sized parcels, smaller areas of agriculture, and larger areas of developed land that is most often used for residential purposes. The process of suburbanization affects the types of land uses and land covers that occur in a landscape, the proportions of the landscape occupied by each type and the spatial arrangement of the types of land use and land covers. For example, suburbanization may result in clustering of developed areas because of the availability of utilities such as sewer lines or roads.

Suburbanization tends to increase the economic value of the land, increase the taxes that must be paid on the land, and increase pressure on the landowners to sell the land to developers. One landowner may subdivide or sell his or her land for development while a neighboring landowner continues to use his or her land for agriculture. In this situation, agricultural land use may stop abruptly at the boundary of a parcel and a relatively large variety of land use and land covers may be adjacent to each other.

Urbanizing or suburbanizing of rural areas is tied to landowners' desire for the benefits of living in a "country" setting such as the aesthetics, buffering, wildlife watching, and hiking uses of forests. This preference for living in the country but working in town is reflected in the results of this research. Most respondents were not dependent on their land for income generation and most valued their forests for aesthetics, buffering, and hiking or walking through. The forest uses that were found to be the most common in this research tend to complement residential land use. The areas of developed land tend to occupy very small proportions of the sampled parcels, and relatively well-connected areas of forest tend to occupy relatively large proportions of the parcels.

The processes affecting the landscape in Monroe County may be somewhat unique when compared with other areas. Much of the county has steep topography. Therefore, the county is not like many Midwestern U. S. counties that are mostly flat and dominated by broad-scale agricultural production. The county is not directly accessible by a major interstate highway. Bloomington and other nearby urban areas provide a market for specialized agricultural products that help to make relatively small-scale agriculture economically viable.

The county is affected by urban growth associated with a city, but land prices remain relatively inexpensive. This allows many owners to purchase land to be used only for recreational purposes such as riding or hunting and not for residences or agricultural production. Recreation and tourism associated with forest uses are important industries in the county. Parcels that are used for residential purposes usually consist of single-family homes with very large areas of lawn. Often wooded areas are included on the lawns. The large lots are tied to the low population density in the study area.

There may be a threshold associated with the density of development or population and the amount forest and its fragmentation. Up to a certain density, suburban areas may be associated with larger amounts of forest that is less fragmented than areas that are dominated by agricultural uses. The results of this research indicate that differences in the metrics between parcels that are used for residential purposes and those that are used for forests are not significant. However, if urbanization continues and the study area is developed for high densities, then the amount of forest and its connectivity may decrease, and parcels with residential uses may differ significantly in the metrics of forest fragmentation from those used for forests.

Monroe County has multiple jurisdictions of land and forest management. In addition to the large number of private landowners, there are state and federal forest managers and city and county land-use planning and zoning. It is extremely difficult to coordinate between all the managers and management plans. Policymakers in the study area try to balance the private property rights of the landowners with the need to protect the public benefits provided by forests. The tools most often employed to protect the public good are land-use planning and zoning ordinances. The results of this research support the assumption that different land uses have different impacts on the spatial patterns of land use and land cover and that regulating land uses may be an effective method of controlling human impacts on forest fragmentation. However, the use of zoning as a means of implementing ecosystem management and protecting forests is not without problems.

Land-use planning and zoning can be very controversial and, because of legal challenges, may not ever be completely implemented. In addition, the process by which comprehensive plans and zoning ordinances are amended or changed tends to be cumbersome. Zoning ordinances may be too expensive and not be flexible enough to effectively implement ecosystem management. Therefore, supplementing traditional methods of landscape or ecosystem management with new, fine-scale, participatory policies may be more effective.

3.0. Results Related to Ecosystem Management

Christensen et al. (1996) suggested that ecosystem management might be simply defined as managing ecosystems so as to assure their sustainability. Research indicates that a number of changes in the way ecosystem management is implemented would greatly improve the chances of successfully achieving the stated goals. Interdisciplinary academic research contrasts with the compartmentalized nature of policy, law, and administration used to implement ecosystem management. Although interdisciplinary research on landscape and ecosystem management has incorporated a variety of socioeconomic and biophysical specialists, lawmakers and policymakers are typically not involved with all stages of this research. Sciences need to be integrated, not separated, from policy and law at the "design" stage in order to effectively implement recommendations given by interdisciplinary researchers.

There is a need for changes in the professional emphasis for most policymakers and agencies or, in other words, there is a need for a new modus operandi in many agencies that incorporate ecosystem management (Danter et al. 2000). Specific changes include:

- Shifting the scientific basis to more squarely rest on fields such as conservation ecology or landscape ecology
- Focusing on sustaining system functions rather than protecting specific plants or animals
- Recognizing that the systems are dynamic rather than static and have nonlinear processes
- Focusing on leading conservation efforts and providing information and support to a variety of stakeholders rather than imposing regulations
- Reorganizing the way goals are accomplished so that integrated, diverse groups work cooperatively
- Conveying explicit goals for programs and policies
- Communicating horizontally and vertically (both top-down and bottom-up) across specialties within an organization and between organizations
- Providing a forum for discussion with all stakeholders
- Remaining consistent in messages and procedures related to goal achievement
- Demonstrating commitment to and confidence in the process
- Emphasizing scientific research, data collection, and monitoring of the state of the system and progress toward explicitly stated goals
- Making non-subjective, quantitative data a vital part of determining the states of the systems and ongoing monitoring of changes in the systems
- Determining ways to measure success

Many of the proposed changes refer to the type of information that is collected and how it is communicated. This research has illustrated how landscape ecological methods can be used with remote sensing and GIS to obtain quantitative data on the state of forest resources. It also presents various landscape ecological metrics that may used to compare the state of forests in different areas in order to identify areas in most need of conservation. They may also be used in order to compare the same area over time in order to monitor changes. The data collected by using this process may also be used to evaluate the success of various management policies.
Some advocate consolidating powers of regulation and landscape management at a relatively broad scale such as at the state level. While there is a need for management of resources at the state level, particularly for geographically large systems such as watersheds, there is also a need for policies that focus on management at fine scales including individual parcels. Polycentric, or nested institutions, offer advantages over managements that centralize power at one level. Research (Ostrom et al. 1993, Gibson et al. 1998) has identified several advantages offered by polycentric management approaches. Advantages include that they:

- Offer more options to achieve conservation goals than "one-size-fits-all" type policies
- Are more adaptable to changes in systems
- Allow for easier gathering of information on the state of the landscape and easier monitoring of smaller geographic areas
- Encourage better cooperation
    - Reduce conflict because management of smaller areas is likely to incorporate a smaller number of individuals and groups.
    - Those involved in management are likely to have frequent interaction and develop trust between them.

Fine-scale or parcel-level management is an integral part of the polycentric management approach and individuals and small groups should participate in ecosystem management efforts.

Researchers (for example Rigg 2001, Moore and Koontz 2003, Hurley et al. 2002) suggest that ecosystem management may be more successful if interested individuals and groups are given a greater opportunity to participate in drafting and implementing management policies. Most successful efforts to include individuals and groups in management programs:

- Begin collaborating early and continue collaborating throughout the decision-making process
- Clearly define the rights, needs, roles, and responsibilities among groups
- Establish explicit protocols
- Offer a variety of incentives to attract participation
- Offer interactive educational programs
- Offer different types of technical assistance
- Mediate and develop consensus between individuals and groups with different views and preferences
    - Identify how and where the various understandings of forest management overlap and diverge
    - Identify shared goals, definitions, and measures of success

This research supports the proposition that offering a variety of incentives, educational programs, and types of technical assistance would facilitate greater landowner participation in management efforts.

Programs that target several specific types of landowners based on the size of their parcel, the length of time they have owned the parcel, the importance of the parcel for income generation, the age of the landowner, the level of education of the landowner, and the types of land and forest uses on the parcel may bring together landowners with similar management objectives and lead to voluntarily cooperation in efforts to achieve common land management goals. Such policies provide opportunities for individuals who want to retain control over their land to work cooperatively with other landowners to manage the forest landscape as a larger unit.

Because a number of processes that operate at a variety of scales are related to ecosystem functions, it is impossible to completely address all aspects of the function of the system in a single policy. According to hierarchy theory, processes occurring at finer scales tend to be less complex than those occurring at broader scales. Management of smaller geographic areas is likely to encompass fewer variables with less interaction among processes and levels than management that encompasses broader scales. Fine-scale management requires information on fewer variables, is easier to model, and is less difficult and costly to monitor than similar efforts to manage at broader scales. Smaller, local management efforts are more likely to have a better understanding of a particular situation and be better able to adapt to changes or to adjust policies as more information becomes available (Guruswamy 2001).

Fine-scale management presents advantages over management that occurs only at broader scales. Policies that encourage individual cooperation may be able to adjust to meet changing socioeconomic and biophysical circumstances faster and more cost-effectively than traditional approaches such as zoning. It is more likely that goals will successfully be achieved if they refer to relatively small, well-defined geographic areas with easily recognized boarders (Gibson et al. 1998). Small conservation projects that are part of larger programs can achieve a series of small successes. The small successes create a sense of control, reduce frustration and anxiety, and foster continued enthusiasm for the project on the part of the public, scientists, and politicians. The fine-scale conservation projects offer a number of what may be considered relatively inexpensive experiments in management from which other managers may learn what is likely to work for other areas.

4.0. Directions for Future Research

A number of both biophysical and socioeconomic processes have affected the landscape of Monroe County. Future research will expand upon the results of this research and will take other biophysical and socioeconomic factors into account when analyzing relationships between socioeconomic characteristics and spatial patterns in a landscape. Future research will also compare the results of this research to similar research conducted at different spatial scales and further explore relationships between variables by using different statistical tests and models.

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APPENDIX

Table A.1. Information on Metrics Used in This Research

Code	Metric Name	Range and Units	Formula	Interpretation
SIEI	Simpson's Evenness Index for the landscape	≥ 0 and ≤ 1 no units; relative measure	$\frac{1-\sum_{i=1}^{m}(P_i)^2}{1-\left(\frac{1}{m}\right)}$	Measure of landscape composition that indicates the relative patch abundance. Considers the number of patches in each type relative to the maximum value for the number of patch types. Results range from near 0, for low evenness with high single-type dominance, to 1, which indicates equal abundance of all land-use and land-cover types or maximum evenness.
PER_FOR	Percentage of the landscape covered by forest	0–100 percent	$\frac{\sum_{j=1}^{n} a_j}{A}100$	Measure of landscape composition. The higher the value the more forest.
LPI	Largest patch index for forest	0–100 percent	$\frac{\max_{j=1}^{n}(a_{ij})}{A}(100)$	Measure of the percentage of landscape accounted for by largest patch of forest. Approaches 0 when the largest patch of forest is small relative to the landscape. Equals 100 when the entire landscape consists of a single patch of forest.
IJI	Interspersion and juxtaposition index for forest	0–100 percent	$\frac{-\sum_{k=1}^{m'}\left[\left(\frac{e_{ik}}{\sum_{k=1}^{m'} e_{ik}}\right)\ln\left(\frac{e_{ik}}{\sum_{k=1}^{m'} e_{ik}}\right)\right]}{\ln(m'-1)}(100)$	Quantifies unique patch type adjacencies to measure the extent a patch of forest is interspersed with other patch types. Higher values result from landscapes in which patch types are well interspersed or are equally adjacent to each other. Low values characterize landscapes in which the patch types are poorly interspersed.
MNN	Mean nearest-neighbor distance for forest	≥ 0 meters	$\frac{\sum_{j=1}^{n'} h_{ij}}{n'_i}$	Measure of patch isolation and landscape configuration. The mean nearest-neighbor distance is the average of the shortest distances between forest patches. It assumes that there are at least two patches of forest in the landscape. It measures edge to edge and does not take the size of the patches into account.

(continued)

Code	Metric Name	Range and Units	Formula	Interpretation
MPI	Mean proximity index for forest	≥ 0 no units; relative measure	$\frac{\sum_{j=1}^{n}\sum_{s=1}^{n}\frac{a_{ijs}}{(h_{ijs})^2}}{n_i}$	Measure of the degree of isolation and fragmentation. Quantifies size and distance of neighboring forest patches to distinguish sparsely distributed, small forest patches (with low values) from clusters of large or closely spaced forest patches (with high values).
NUMP	Number of forest patches	≥ 1 counts	n_i	It is the number of forest patches in the landscape.

Source: Adapted from McGarigal and Marks 1994.

Formula abbreviations:

$j = 1, \ldots, n$ patches

A = total landscape area (m^2)

$k = 1, \ldots, m$ or m' patch types or classes

$i = 1, \ldots, m$ or m' patch types or classes

e_{ik} = total length (m) of edge in landscape between patch types or classes (distinguished by i and k)

m = number of patch types or classes present in the landscape, excluding the landscape border if present

m' = number of patch types or classes present in the landscape, including the landscape border if present

a_{ijs} = area (m^2) of patch ijs within specified neighborhood (m) of patch ij

h_{ijs} = distance (m) between patch ijs (located within 1,000,000 m of patch iji) and patch ij, based on edge-to-edge distance

h_{ij} = distance (m) from patch ij to nearest-neighboring patch of the same type (class), based on edge-to-edge distance

n' or n'_i = number of patches in the landscape of patch type (class) i that have nearest neighbors

n_i = number of patches in the landscape of particular type (class)

a_{ij} = area (m) of patch ij

P_i = proportion of the landscape occupied by patch type (class) I

Table A.2. Ordinal Rankings for Metrics and Numbers of Cases in Each Class

Metric	Rank	Range	N	Metric	Rank	Range	N
PER_FOR	1	0–25	23	NUMP	1	1	84
	2	26–33	40		2	2–25	89
	3	47–80	88		3	6–10	53
	4	80–100	100		4	11–34	25
IJI	1	0–9	57	MNN	1	0	84
	2	11–40	55		2	1–35	71
	3	41–75	85		3	36–50	65
	4	76–100	54		4	51–134	24
MPI	1	0	84	LPI	1	1–25	44
	2	1–49	76		2	26–53	40
	3	50–249	64		3	54–84	86
	4	250–884	27		4	85–100	81
SIEI	1	0.20–0.24	55				
	2	0.25–0.59	73				
	3	0.60–0.79	82				
	4	0.80–0.99	41				

Table A.3. Descriptive Statistics of Metrics of Forest Fragmentation for Groups Based on the Most Important Forest Use

	N	Mean	Median	Range	Std. Dev.	Variance
			PER_FOR			
arag	20	58.64	58.57	67.05	22.49	505.80
as	28	79.26	84.44	70.88	19.82	392.75
bf	16	82.18	87.43	57.42	17.52	306.99
ew	23	66.21	66.61	76.72	21.18	448.53
hkcp	38	77.48	83.35	69.97	18.81	353.95
ht	38	62.18	71.46	88.34	33.68	1134.33
nttf	16	74.93	85.44	80.38	24.37	593.80
tm	18	65.75	72.96	88.29	29.23	854.26
ww	29	68.61	71.61	79.01	21.43	459.35
All cases	251	66.81	72.00	96.72	26.55	704.67
			LPI			
arag	20	53.34	56.72	87.18	28.03	785.84
as	28	77.37	83.16	75.62	21.70	471.05
bf	16	78.83	86.79	78.31	22.83	521.17
ew	23	63.25	65.98	85.46	24.96	622.89
hkcp	38	74.57	82.19	81.05	22.43	503.11
ht	38	55.02	52.90	97.44	37.89	1435.70
nttf	16	72.84	84.80	91.80	27.59	761.16
tm	18	61.39	70.68	95.15	33.65	1132.28
ww	29	65.68	70.73	89.30	24.28	589.64
All cases	251	63.10	69.84	99.14	30.18	910.74
			NUMP			
arag	20	6.05	5.00	17.00	4.58	21.00
as	28	3.36	2.00	16.00	3.82	14.61
bf	16	2.56	1.50	10.00	2.63	6.93
ew	23	4.52	3.00	10.00	3.45	11.90
hkcp	38	3.03	1.50	15.00	3.48	12.13
ht	38	3.03	1.50	15.00	3.48	12.13
nttf	16	4.88	3.50	14.00	4.57	20.92
tm	18	5.78	4.50	14.00	5.12	26.18
ww	29	3.93	2.00	19.00	4.02	16.14
All cases	251	4.54	3.00	33.00	4.44	19.74

(*continued*)

Table A.3. Descriptive Statistics of Metrics of Forest Fragmentation for Groups Based on the Most Important Forest Use (*cont'd*)

	N	Mean	Median	Range	Std. Dev.	Variance
			MNN			
arag	20	35.29	34.93	70.00	16.26	264.37
as	28	21.28	21.21	60.00	21.80	475.03
bf	16	20.92	15.00	69.52	24.49	599.94
ew	23	27.66	30.00	60.00	17.02	289.75
hkcp	38	17.46	7.50	67.08	19.57	382.89
ht	38	30.28	30.00	93.75	26.75	715.42
nttf	16	21.88	25.41	51.21	17.06	291.12
tm	18	26.97	32.00	62.19	21.51	462.54
ww	29	32.91	30.00	134.16	33.03	1090.73
All cases	251	26.76	30.00	134.16	23.17	536.80
			MPI			
arag	20	82.30	35.89	395.71	95.43	9106.22
as	28	70.16	12.27	448.39	113.18	12808.81
bf	16	35.95	10.48	129.95	47.18	2225.89
ew	23	127.57	64.73	732.50	177.12	31371.72
hkcp	38	91.26	8.05	760.00	158.69	25182.93
ht	38	77.10	8.70	506.05	147.68	21810.80
nttf	16	184.90	85.30	769.75	237.59	56448.52
tm	18	79.50	34.22	323.02	105.74	11180.44
ww	29	118.72	49.19	883.50	209.55	43912.38
All cases	251	83.01	21.74	883.50	146.29	21402.22
			IJI			
arag	20	45.44	43.34	90.32	27.60	761.93
as	28	44.59	46.10	98.52	38.69	1496.80
bf	16	35.17	20.53	97.66	39.95	1596.18
ew	23	46.34	38.80	94.34	30.63	938.31
hkcp	38	39.19	40.77	96.27	33.58	1127.48
ht	38	31.54	23.52	92.53	32.79	1074.96
nttf	16	46.27	52.25	81.39	25.81	666.21
tm	18	46.21	55.59	98.92	31.21	974.23
ww	29	48.81	48.65	99.81	33.72	1137.07
All cases	251	46.22	46.00	99.81	32.80	1075.61

(*continued*)

Table A.3. Descriptive Statistics of Metrics of Forest Fragmentation for Groups Based on the Most Important Forest Use (*cont'd*)

	N	Mean	Median	Range	Std. Dev.	Variance
			SIEI			
arag	20	0.65	0.70	0.81	0.24	0.06
as	28	0.41	0.43	0.80	0.27	0.07
bf	16	0.38	0.38	0.88	0.26	0.07
ew	23	0.59	0.63	0.75	0.22	0.05
hkcp	38	0.44	0.42	0.89	0.28	0.08
ht	38	0.45	0.50	0.76	0.27	0.07
nttf	16	0.41	0.36	0.83	0.27	0.07
tm	18	0.51	0.59	0.88	0.33	0.11
ww	29	0.55	0.62	0.99	0.25	0.06
All cases	251	0.51	0.59	0.99	0.28	0.08

Table A.4. Descriptive Statistics for Metrics of Forest Fragmentation for Groups Based on Likely Similarities in Landowner Views of Forest Management

	N	Mean	Median	Range	Std. Dev.	Variance
			PER_FOR			
ag	**27**	57.49	61.43	87.95	23.34	544.94
ar	**20**	64.13	66.04	88.34	25.68	659.68
as	**26**	82.58	87.54	63.47	16.56	274.27
bf	**22**	82.58	86.38	80.50	18.62	346.66
ew	**16**	71.31	70.05	75.88	21.62	467.59
hk	**23**	75.28	82.41	75.50	21.70	470.69
ht	**20**	73.45	82.68	86.80	26.17	684.95
tm	**39**	72.31	77.54	88.29	22.94	526.26
ww	**23**	66.81	71.61	80.38	24.74	612.28
All cases	251	66.81	72.00	96.72	26.55	704.67
			LPI			
Ag	27	52.08	52.95	94.46	27.80	773.10
Ar	20	59.72	63.91	97.44	29.90	894.11
As	26	81.06	84.75	75.62	18.46	340.88
Bf	22	81.38	86.38	89.24	20.42	417.18
Ew	16	68.75	70.05	88.89	25.15	632.58
Hk	23	71.70	80.63	84.60	25.73	661.81
Ht	20	68.82	80.96	92.93	30.55	933.03
Tm	39	69.44	77.54	95.15	26.58	706.35
Ww	23	63.81	68.65	91.80	27.87	776.72
All cases	251	63.10	69.84	99.14	30.18	910.74
			NUMP			
Ag	27	6.48	5.00	17.00	5.24	27.49
Ar	20	4.90	4.00	12.00	3.60	12.94
As	26	2.50	1.50	10.00	2.61	6.82
Bf	22	1.77	1.00	6.00	1.45	2.09
Ew	16	3.38	1.50	10.00	3.18	10.12
Hk	23	3.87	2.00	14.00	4.09	16.75
Ht	20	3.80	2.50	10.00	3.29	10.80
Tm	39	4.46	3.00	14.00	4.22	17.83
Ww	23	4.87	3.00	19.00	4.81	23.12
All cases	251	4.54	3.00	33.00	4.44	19.74

(*continued*)

Table A.4. Descriptive Statistics for Metrics of Forest Fragmentation for Groups Based on Likely Similarities in Landowner Views of Forest Management (*cont'd*)

	N	Mean	Median	Range	Std. Dev.	Variance
			MNN			
ag	27	35.97	38.58	84.85	21.86	477.81
ar	20	28.91	30.00	60.00	19.45	378.26
as	26	17.70	10.61	60.00	19.55	382.11
bf	22	15.77	0.00	69.52	24.00	576.17
ew	16	18.05	13.35	45.00	19.12	365.62
hk	23	20.71	30.00	67.08	20.12	404.92
ht	20	27.18	30.00	93.75	23.76	564.52
tm	39	23.41	30.00	62.19	19.26	370.78
ww	23	33.76	30.00	134.16	33.70	1135.83
All cases	251	26.76	30.00	134.16	23.17	536.80
			MPI			
Ag	27	73.23	32.13	440.88	111.90	12521.86
Ar	20	94.70	36.28	643.36	156.82	24592.38
As	26	71.36	6.05	448.39	117.66	13843.21
Bf	22	26.23	0.00	186.64	51.75	2677.85
Ew	16	44.62	14.18	167.25	60.01	3600.92
Hk	23	82.81	20.23	405.74	125.25	15688.27
Ht	20	116.66	50.02	506.05	163.98	26890.66
Tm	39	164.09	68.27	883.50	230.48	53121.23
Ww	23	99.59	29.55	769.75	172.80	29860.03
All cases	251	83.01	21.74	883.50	146.29	21402.22
			IJI			
Ag	27	46.37	46.08	97.66	27.96	781.80
Ar	20	47.30	50.47	99.47	31.45	988.90
As	26	42.87	45.53	98.52	38.72	1499.06
Bf	22	39.29	31.39	96.27	37.35	1395.07
Ew	16	53.07	59.37	99.81	35.05	1228.52
Hk	23	32.18	20.99	93.28	30.32	919.22
Ht	20	28.52	10.07	98.52	34.94	1220.75
Tm	39	43.03	46.02	98.92	28.54	814.62
Ww	23	56.81	57.95	99.11	30.06	903.53
All cases	251	46.22	46.00	99.81	32.80	1075.61

(*continued*)

Table A.4. Descriptive Statistics for Metrics of Forest Fragmentation for Groups Based on Likely Similarities in Landowner Views of Forest Management (*cont'd*)

	N	Mean	Median	Range	Std. Dev.	Variance
			SIEI			
Ag	27	0.63	0.68	0.84	0.22	0.05
Ar	20	0.56	0.66	0.95	0.29	0.08
As	26	0.38	0.36	0.80	0.27	0.07
Bf	22	0.36	0.36	0.82	0.24	0.06
Ew	16	0.52	0.63	0.92	0.30	0.09
Hk	23	0.44	0.46	0.89	0.28	0.08
Ht	20	0.44	0.44	0.84	0.26	0.07
Tm	39	0.48	0.53	0.88	0.28	0.08
Ww	23	0.54	0.62	0.99	0.25	0.06
All cases	251	0.51	0.59	0.99	0.28	0.08

Table A.5. Significant Kendall's Tau Correlations between the Metrics of Forest Fragmentation and the Landowners' Importance Ratings for the Forest Uses (N = 251)

Metric	Forest Use	Sign	Kendall's Tau p-value
PER_FOR	Aesthetics	Positive	**0.000**
PER_FOR	Hiking	Positive	**0.000**
PER_FOR	Buffer	Positive	**0.002**
PER_FOR	Grazing	Negative	**0.003**
PER_FOR	Spiritual	Positive	**0.007**
PER_FOR	Wildlife Watching	Positive	0.018
PER_FOR	Camping	Positive	0.025
LPI	Aesthetics	Positive	**0.000**
LPI	Hiking	Positive	**0.000**
LPI	Buffer	Positive	**0.001**
LPI	Grazing	Negative	**0.002**
LPI	Spiritual	Positive	**0.006**
NUMP	Wildlife Watching	Positive	0.015
NUMP	Camping	Positive	0.025
NUMP	Aesthetics	Negative	**0.000**
NUMP	Buffer	Negative	**0.001**
NUMP	Grazing	Positive	**0.001**
NUMP	Wildlife Watching	Negative	**0.001**
NUMP	Spiritual	Negative	**0.001**
NUMP	Hiking	Negative	**0.004**
NUMP	Collecting Tree Products	Positive	0.052
MNN	Aesthetics	Negative	**0.002**
MNN	Hiking	Negative	**0.002**
MNN	Buffer	Negative	**0.002**
MNN	Grazing	Positive	**0.003**
MNN	Spiritual	Negative	0.015
MNN	Wildlife Watching	Negative	0.029
MPI	Aesthetics	Negative	**0.007**
MPI	Timbering	Positive	0.019
MPI	Spiritual	Negative	0.043
MPI	Buffer	Negative	0.047
IJI	Hunting	Negative	0.031
SIEI	Grazing	Positive	**0.001**
SIEI	Aesthetics	Negative	**0.001**
SIEI	Hiking	Negative	**0.004**
SIEI	Buffer	Negative	0.015
SIEI	Camping	Negative	0.047

Note: Correlations significant (2-tailed) at the 99% confidence level are in bold.