LINKING LAND USE, LAND COVER, AND LAND OWNERSHIP AT THE PARCEL SCALE IN THE MIDWEST UNITED STATES

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Abstract

Land ownership institutions play an important role in how land-use decisions translate to land cover. This research addresses three tightly linked but independent research questions to better understand the relationships between land use, land cover, and land ownership in the Midwest United States. The first research objective is to describe how ownership parcels split during the period of 1928 to 1997. A spatial database of ownership parcels was developed for six time points for two townships in Indiana. A method for describing the spatiotemporal pattern was then developed using spatial metrics to describe parent and child parcels for each parcelization event during the time period. Using a transition matrix approach, the research finds that there are common patterns of parcelization. The notion of a land-use portfolio is used to address the relationship between land use and land cover. Landowners were interviewed and asked to draw maps of the land use on their parcel. These maps were then digitized and incorporated with land-cover data derived from aerial photography in a GIS. The correspondence of land use and land cover was then assessed quantitatively. The general finding is that a more complex land-management portfolio does lead to more land-cover fragmentation but not equally across portfolio types. To address property-rights arrangements outside of a one household–to–one parcel scenario, the notion of intentional communities is used to describe scenarios where multiple people own land in common. Data were first collected on how communities legally own their land and then examined for differences in land-cover patterns between land ownership types. Results suggest that type of land ownership may be a useful way to categorize communities but does not explain much of the variance in terms of land-cover patterns.

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1 Introduction

Land-use and land-cover change has been identified as a primary component in the human dimensions of global environmental change. Addressing the causes of these changes is not simple because the causes are often the result of many individual actions that aggregate in complex ways. One cause of global climate change, as well as other negative impacts such as species extinction, is the removal and fragmentation of forests. This form of land-use and land-cover change must be understood as the complex interaction of many individual agents making individual decisions. In the past 30 years, much has been learned about how macro-level forces affect individual land managers and how those land managers make decisions. The role of institutions in filtering the effects of macro forces on land managers and structuring the interaction between agents in the landscape has been clearly recognized as having an important spatial component. The study of property rights and natural resources has explored the formal and informal rules structuring the relationship between humans and the land. However, the spatial aspects of land tenure that determine the way in which individual decisions aggregate to landscape patterns have not been well studied in most cases. My research focuses on those spatial interrelationships between patterns of land tenure and patterns of land cover.

The overarching objective of this research is to examine how patterns of land ownership and land tenure affect the way in which individual land-use decisions produce landscape outcomes. Research in the field of land-use and land-cover change has elucidated many of the factors that act across scales to affect the decisions of individuals but tying those factors to the landscape in a spatially explicit way has proven difficult. Bottom-up approaches in land-use and land-cover change research have built a valuable body of case study literature, but scaling these findings up to landscape and regional outcomes continues to be challenging. This research will use the perspective of social-ecological systems to show how the spatial pattern provided by formal and informal rules of land ownership organizes the building blocks of the landscape into patterns that have ecological consequences for humans and other species. To accomplish this, the scale of individual land ownership must be the primary focus.

In the predominantly privately owned landscape of the Midwest United States, the corresponding spatial unit of analysis is the ownership parcel. In the simplified graphic below (Figure 1.1), the relationship between agents, institutions, management units, parcels, and the landscape is shown. The first step in addressing the broad research objective is a spatial analysis of the ways in which parcels are fragmented or parcelized. The results and interpretation of this analysis facilitate a better understanding of the possible path dependencies that occur in the spatial patterns of land ownership. The next step is to analyze the land-use and land-cover decisions made on individual parcels. This research direction will allow generalizations to be drawn about the relationship between parcel characteristics and land-cover outcomes. Examining the simplifying assumption that there is a one-to-one correspondence between decision maker and ownership parcel will be the third research focus. The concept of intentional communities provides a useful lens with which to look at a broad spectrum of land ownership arrangements that stray from the one owner, one parcel scenario. These land-tenure institutions are the sets of rules that give rights and responsibilities about how the land may be used.

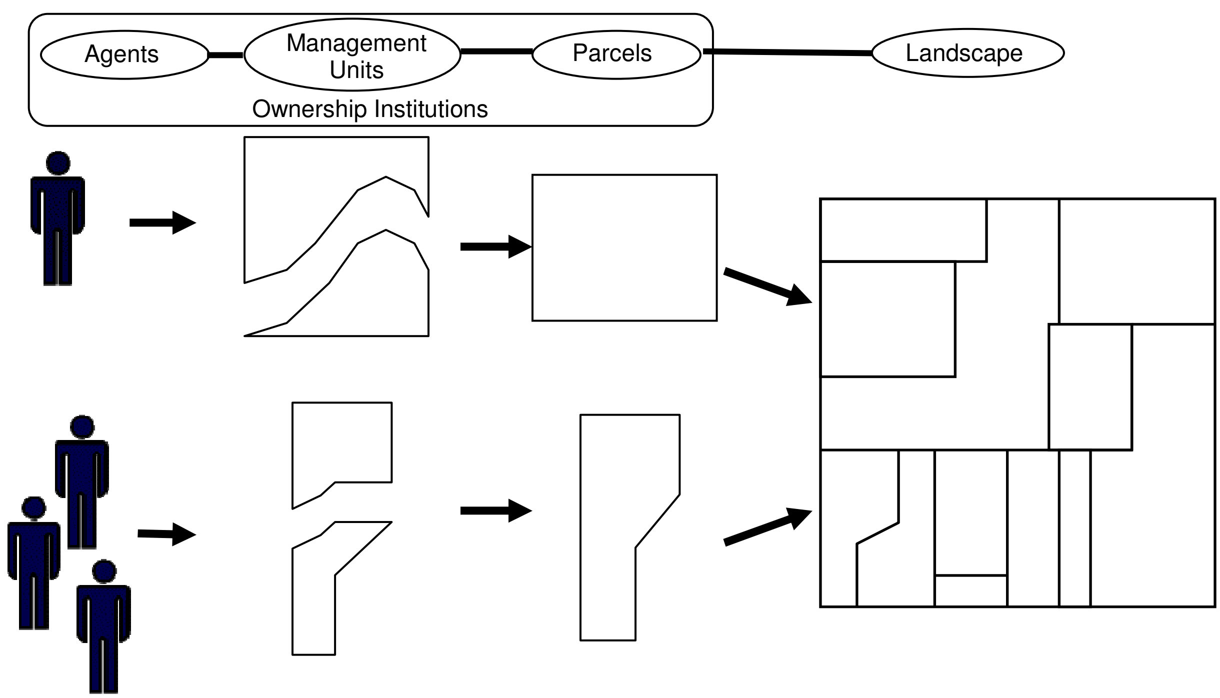

Figure 1.1 Relationship between agents, institutions, management units, parcels, and the landscape.

1.1 Background: Linking Land Use, Land Cover, and Land Ownership

1.1.1 Land change science

Humans have significantly altered the workings of the Earth system to the extent that the global ecosystem is currently in a no-analogue state (Steffen 2004). That is, we can no longer look back at the history of the system for a simple predictive understanding of the future consequences of our actions. Contributing as much carbon dioxide to the atmosphere as the combustion of fossil fuels over the last century and a half, land-use and land-cover change has emerged as a major issue in global environmental change research (Turner et al. 1995). Terrestrial ecosystems, primarily forests, are a major carbon sink that stores an estimated 39% of global carbon. Degradation, fragmentation, and removal of this land cover is responsible for about 20% of current emissions (World Resource Institute 2000). The ecological consequences of the degradation of remaining forests on plant and animal habitats are severe. Forests contain a majority of the terrestrial ecological regions that have been deemed most important to biodiversity, making their removal potentially catastrophic in the still largely undocumented area of biodiversity (Olson and Dinerstein 1998). Over the last few decades, land change science has increased the understanding of the causes, impacts, and consequences of land-use and land-cover change (Turner et al. 2007).

Environmental impacts, including land-use and land-cover change, have historically been seen as linear processes that can be addressed as they approach critical levels (Levin 1999). The gradual and smooth degradation of ecosystems may be undermining the resilience and stability of those systems to the point at which a catastrophic shift can occur (Scheffer et al. 2001). Ecosystems may have multiple stable states such that altering them beyond some threshold will result in a permanent shift (Levin 1999). In terms of land-use and land-cover change, forest fragmentation may produce a landscape where extinction occurs much earlier than is predicted by the linear loss of habitat (Cassagrandi and Gatto 1999). The recognition of global and landscape ecological consequences has been an important and necessary first step, but tying these emergent outcomes to the actions of individual decision makers is a much more difficult challenge (Nassauer 1997). Cross-scale approaches are needed to connect global-scale research to the rich local-scale case study literature.

Linking global-scale environmental change to local-scale management issues is one of the most important and difficult challenges in research on the human dimensions of global environmental change (Geoghegan et al. 1998, Moran and Brondizio 1998, Janetos 2004). Great strides have been made in land change science in identifying the proximate and underlying causes of land-use and land-cover change and linking these components in pathways (Lambin et al. 2003) and syndromes (Petschel-Held 2001) important to global environmental change. Because the important outcomes are global in nature but the causes are often local, land-use and land-cover change studies have had to deal with geographic breadth as well as depth. While regions such as the Amazon have garnered more thorough attention because of their importance in current deforestation processes, land-use and land-cover change studies using comparable methods have been undertaken in diverse contexts ranging from Thailand (Rindfuss et al. 2003), to Kenya (BurnSilver et al. 2003), to China (Seto et al. 2002), to Nepal (Haack et al. 2002). The approach of linking observable patterns in the landscape and underlying social or ecological processes has proven flexible enough to be useful across geographic contexts and scales. The spatial boundaries of land ownership can often provide an important connection between pattern and process that facilitates linking land-management decisions of individuals to the landscape.

From the beginning of the attempt to generalize about land-use and land-cover change processes, factors such as population, affluence, and technology have been posited as broad-scale drivers that affect fine-scale decisions about land use. The list of underlying causes has been further developed to include drivers such as institutional and cultural causes along with these demographic, economic, and technological causes (Geist and Lambin 2002). At the broad scale, these factors are often connected to aggregate measures of land-use and land-cover change, but the growing body of case study literature shows that there are not simple connections between these underlying causes and the proximate causes of change. Findings that neither population nor poverty alone can explain patterns of land-cover change (Lambin et al. 2001) suggest that much of the policy aimed at addressing land-use and land-cover change is based on oversimplifications of both human and ecological systems (Lambin et al. 2001). In a meta-analysis of the underlying and proximate causes of land-use and land-cover change, Geist and Lambin (2002) were able to generalize only as far as that there are most often three to four interacting underlying causes that manifest in two to three proximate causes of change and that most of these combinations are region specific. Geist et al. (2006) provide an in-depth history of the development of the idea of underlying and proximate causes in land-use and land-cover change studies. In this in-depth meta-analysis, the authors go as far as saying that "no factor ever works in isolation" (Geist et al. 2006 p. 62). Understanding land-use and land-cover change in terms of underlying and proximate causes has been and continues to be instructive, but the impossibility of broad generalization across geographic contexts has led to the descriptions of pathways (Lambin et al. 2001, Mustard et al. 2004), syndromes (Lambin et al. 2003), and trajectories (Geist et al. 2006) of change.

Relating the physical patterns of land cover, often observed and measured with remote sensing, to the underlying social processes has elucidated the relationship between land use and land cover as well as illuminated complexities in their relationship. While the distinction between land use and land cover is frequently acknowledged, in practice the two are usually not measured as separate variables. This simplification has been successful and appropriate in many frontier scenarios where changes in land use and land cover can be clearly associated. Because the particular combinations of drivers have been found to be largely regional (Geist and Lambin 2002), the conflation of land use and land cover can mask important causal links that are necessary for a better understanding of these processes in more industrialized, exurbanizing contexts where there is high heterogeneity in agent characteristics (Fernandez et al. 2005). To advance the program of "socializing the pixel" and "pixelizing the social" that has become so integral to land change science (Geoghegan et al. 1998), these processes may need to be further separated.

Even though satellite imagery has been available for more than three decades, the application of spatial thinking has only recently gained traction in social science disciplines outside of geography (Rindfuss and Stern 1998). While this goal of assessing change across numerous different social and ecological contexts does not have a long history, it has led to the development of comparable methodologies based on remote sensing and spatial analysis (Turner et al. 2007). Described as "socializing the pixel" and "pixelizing the social," these methodologies aim at finding spatial and temporal patterns in land cover derived from remote sensing and linking them to underlying social processes (Geoghegan et al. 1998). These two related but separate tasks refer to "mining the pixel" for social meaning in the composition and pattern of land cover and predicting land-cover change based on various theoretical formulations of human behavior (Geoghegan et al. 1998). Issues of scale, resolution, and path dependence have become central to the implementation of these approaches (Rindfuss and Stern 1998), requiring the integration of previously disparate data sources. Along with remote sensing, household survey, and forest measurement data, laboratory-based experimental approaches to understanding the relationship between institutional factors and forest management are also being employed (Ostrom and Nagendra 2006). Modeling approaches integrating these sources of data have advanced at both the system level and the level of individual decision makers (Turner et al. 2007).

The modern field of landscape ecology has largely grown from this foundation of linking patterns in the landscape to underlying process (Geoghegan et al. 1998). The European roots of landscape ecology have taken a more holistic approach to man-in-nature (Naveh and Lieberman 1994) while North American landscape ecology has excelled in developing methods for quantitatively describing spatial patterns in the landscape (Turner et al. 2001). Wu (2006) suggests that partly because of these seemingly disparate traditions, the field of landscape ecology is well suited to deal with the heterogeneity that is necessary for sustainability studies. Landscape ecology has played a major role in the study of land-use and land-cover change both in terms of underlying theoretical relationships of pattern and process and through the provision of tools to describe spatial heterogeneity in the landscape.

1.1.2 **Land ownership and institutions**

Institutions are defined here as the rules-in-use that structure human interactions. These rules can be formally or informally employed and the agents involved can be individuals or groups. Institutional analysis as used in this dissertation research draws on components of the Institutional Analysis and Development framework (Ostrom et al. 1994) to examine the institutions related to property rights and their role in structuring land cover. Rules confer both rights and responsibilities. The types of rules that exist can be viewed as varying both horizontally and vertically (Ostrom 2005). Thinking about variation in rules in a horizontal sense allows examination of the structure at any given scale of analysis. Any one scale must be understood in the context of the structure imposed by broader scales. This hierarchical organization of rules is captured by the vertical division of rules into operational, collective, and constitutional levels (Ostrom et al. 1994).

Research taking this perspective has suggested that rules can be categorized horizontally into seven types: position, boundary, authority, aggregation, scope, information, and payoff (Ostrom et al. 1994). While each type of rule may exist in a given scenario, some types will be more important for answering some questions. Especially important for this research are rules that create positions for participants in institutions structuring land ownership. Schlager and Ostrom (1992) describe how sets of rights can be used to define positions important in property-rights arrangements dealing with natural resources. The types of rights must be differentiated from the type of entity in which the rights are vested (McKean 2000). In terms of the positions defined by Schlager and Ostrom (1992), these rights may be vested in agents ranging from individuals to corporations to governments.

The concept that an individual simply owns or does not own a piece of land is a dominant one in much of Western thought. The term "land ownership" is often used to mean unlimited rights over a piece of land or what is legally known as holding an estate in fee simple. To more clearly understand how agents own land, ownership must be understood as a bundle of rights rather than a simple dichotomy. Within the bundle of rights that constitute land ownership are the right to alienation, the right of occupation, and use rights. These rights are separable, meaning that the rights can be distributed among different individuals for a single piece of land.

Dividing up the rights associated with land ownership allows for many possible property-rights arrangements. Scenarios can be constructed where the distribution of rights in a private-rights regime and a common-pool rights regime are indistinguishable. As such, property rights allow for a continuum from private to public ownership. The only difference may be in how the rules are distributed vertically. That is, in a private-rights regime, the state may make collective and constitutional rules that govern the individual while in a common-property regime a community may have collective and constitutional powers. The rules structuring the operational level of rule making are, however, identical.

The connection between land-tenure institutions and land-cover change has been examined most frequently in contexts where a shift from subsistence to commercial activities is taking place. Fox (2002) describes the increased importance of well-known boundaries between villages and the role of national policy in Cambodia as land use changed from subsistence swidden to commercial monocrop agriculture. Testing the relationship between clear title to land and forest conservation, Walker et al. (2002) found decreased participation in logging by households with land titles along the Transamazon Highway in Pará, Brazil. A similar finding in Bolivia suggests that security in forest property rights tended to lead land managers to engage more in sustainable forestry practices rather than clearing forest for other land uses that produce a higher short-term return (Andersson 2002). In a comparison of private- and common-property forests in Honduras, Tucker (1999) found that any difference in forest condition was more related to historical conditions and the preferences of forest owners. In Mexico, community management of forests has been more sustainable than outside management

(Klooster 1999) but the importance of rules internal to the community were more important than formal land tenure in stopping illegal forest practices from occurring (Klooster 2000).

1.1.3 Ownership parcelization and land cover

Path-dependent relationships have been identified in areas where successive periods of land fragmentation occur over several generations. As the size of land holdings declines over time, the land-use choices become more constrained. Leach (1968) found that successive land-ownership fragmentation in Sri Lanka resulted in parcels that were too small to sustain household production and were ultimately abandoned. Yet in other areas informal institutions have maintained the sustainability of land uses. Cole and Wolf (1974) found that a minimum farm size in the Italian Alps was maintained by the nature of inheritance laws in the region, thus allowing agricultural land uses to persist. These path-dependent linkages between land-ownership fragmentation and land use are of particular interest in the analysis of south-central Indiana.

The land-use and land-cover implications of ownership patterns have been addressed by a few researchers in a spatially explicit manner. Using a time series of parcel data for one township in western Ohio, Medley et al. (2003) found that rural parcels with less frequent ownership change experienced forest expansion while high ownership turnover was related to forest loss. For a study site in Michigan, Drzyzga and Brown (2002) provide evidence for the largely untested claim that parcelization does increase fragmentation of the forested landscape. Brown (2003) also uses parcel data to characterize county-wide processes in order to explain differences in reforestation rates in upper Midwest states. For an area in Ohio that sits on the boundary between the rectangular survey system and the metes and bounds system, land divided into regular rectangular parcels was more easily accessed by roads and subdivided than the irregularly shaped parcels of the metes and bounds system (Thrower 1966). Batistella et al. (2003) describe a similar situation in the Brazilian state of Rondônia, where the land in one settlement was divided according to a rectangular survey and the land in the other with a survey that followed the contours of the land. Over the study period of 1988 to 1998, the settlement designed in accordance with topography had forests that were less fragmented and more complex in shape and provided more interior habitat (Batistella et al. 2003). Turner et al. (1996) conducted a similar comparison of land-cover change in two locations in the United States, each containing areas of public and private ownership. Land-cover change patterns and rates were significantly different between both the locations and ownership regimes (Turner et al. 1996). For 66 watersheds in the state of Oregon, Stanfield et al. (2002) found positive relationships between parcel size and forest patch size, stand age variation and ownership variation, and ownership connectivity and forest patch connectivity.

Forestry researchers have also recognized the implications of parcelization to forests on privately held land. A 1994 survey of non-industrial private forest (NIPF) owners in the United States revealed that there are an estimated 9.9 million NIPF owners, with 90% owning less than 100 acres of forest land and an average holding of 24 forested acres (Birch 1996). The overall number of NIPF owners increased by 20% between 1978 and 1995 (Agrow 1996). NIPF owners also exhibit a very high turnover rate with more than 40% having acquired their land during this period (Agrow 1996). High ownership turnover is increasing the diversity of decision makers, as owners of more than 90 million acres of forest are age 65 or older and new owners are increasingly coming from urban backgrounds (Sampson and DeCoster 2000).

Various forms of urban sprawl have been recognized as contributors to landscape fragmentation. Development in the form of common-interest developments has been the dominant form of new housing built in the last decade (McKenzie 1994). Although less prevalent in terms of overall population, exurban development supports a lower population density than suburban development and therefore has a potentially higher per capita impact on land cover. The driving forces of exurban development are being studied from several perspectives, including their land-cover change implications (Gobster and Haight 2004). Generalizing preferences of exurban landowners and quantifying parcelization at an aggregate level in this regime will provide insight into the effects of land ownership on land cover, but parcel-scale changes have yet to be addressed.

The relationship between parcelization and land-use change is particularly apparent at the exurban fringe where the rate of land-use and land-cover change is typically more rapid than in rural areas (Evans et al. 1999). The transition of parcels from old farms to lots subdivided for high- or low-density residential development affects tree canopy cover and greenspace with resulting effects on ecosystem function (Gobster and Haight 2004). Considerable research has been conducted on the effects of parcelization in urban and suburban areas, and now there is an emerging recognition of the role of parcelization in rural areas (Gobster and Haight 2004) as the rate of parcelization in many rural areas of the United States is increasing (Sampson and DeCoster 2000).

Despite recent work on the drivers and effects of parcelization (Drzyzga and Brown 2002, Gobster and Haight 2004), the spatial structure of land ownership change is still not clearly understood in part because of the complexity of the parcelization process in different geographic settings. Interactions of both social and geographic factors result in parcelization, yet these interactions are highly complex and often tied to very specific household events (Mehmood and Zhang 2001). At the household level, life-course events such as retirement or a death in the family may lead a household to move or sell a portion of its land holdings. At the same time, the demand for real estate can motivate a landowner to sell land holdings, as in the case of the development of former farm fields into residential subdivisions. The interplay between these household and market forces produces a complex and difficult-to-predict process in many locations.

Parcelization can result in spatial changes that are associated with the transition from one land use to another (Gobster and Rickenbach 2004). For example, a large parcel that is dominated by agriculture may be split into several smaller parcels that are no longer of sufficient size to sustain the pre-parcelization land use such as agriculture or harvesting timber (Leach 1968, Luloff et al. 2000, Mehmood and Zhang 2001). However, the direction of causality between land-use/land-cover change and parcelization can flow in both directions. For example, land-use changes at the suburban fringe can lead to the subdivision of exurban areas. But these relatively clear examples risk oversimplifying the complex relationship between parcelization and land-cover change evident in many locations. Diverse drivers and processes often operate in a single location, complicating the identification of clear causal relationships, and no single type of parcelization event will necessarily result in a predictable type of land-cover change.

Across the many geographic contexts where understanding land-use and land-cover change has been studied, a great variety of formal and informal land-tenure institutions exist. Methods for representing tenure in spatially explicit ways can be challenging and no single spatial unit works in all cases (see Liverman et al. 1998, Fox et al. 2003 for numerous examples). This spatial linkage is generally simplified in industrialized nations where forms of private property held at the household level are common and the ownership parcel is clearly defined. While connecting a household to the landscape with parcel boundaries at any given time is relatively simple in such cases, both household members and parcel boundaries may change over time, complicating matters (Evans et al. 2001, Evans and Moran 2002).

Still in the realm of private ownership, but receiving much less academic attention, is land owned collectively by a group of people. At the present time, the number of intentional communities in the United States is on the rise. According to the Fellowship for Intentional Community (2005), more than 1,000 communities in North America provided detailed information for the most recent edition of the Communities Directory. Reviewing the history of communal movements in the United States, Zablocki (1980) points out that although communal organization has never played a dominant role in American society, not a single year has passed in which no new intentional communities were initiated. Kanter (1972) has divided the history of intentional communities in the United States into three periods based on common core beliefs. The current wave began in the 1960s and is largely based on environmental or ecological motivations. Another characteristic of the current period of intentional communities is a move toward balancing individual and collective needs. The increase in the focus on the individual has resulted in institutions where some parts of life are lived collectively but others are controlled by the individual. New community types, such as ecovillages and cohousing, focus on relatively specific applications of communal structure while leaving the governance of other facets of life to the individual. Understanding the land-cover implications of these property-rights arrangements has not been addressed at all in the United States.

1.2 Research Objectives

Working from the above foundations, three research objectives will be addressed. Each research objective is described in more detail below and then connections between the objectives are addressed.

1.2.1 **Characterizing spatial patterns of land ownership at the parcel level in south-central Indiana, 1928–1997**

Tools to better characterize the process of parcelization may lead to a better understanding of the role of parcelization in social-ecological systems. Of particular interest is the potential path dependence of parcelization trajectories. In this context, parcels can be considered to have a particular "life history" during which they undergo different types of fragmentation or in some cases agglomeration. Chapter 2 describes and interprets the process of parcelization in a peri-urban region of south-central Indiana. Parcelization events are tracked to describe how the social and physical landscapes have evolved over a period of 70 years in Monroe County, Indiana. A typology is first developed to quantitatively describe parcelization that occurred in Monroe County from 1928 to 1997 using area measures of the parent and child parcels. This parcelization typology provides a means to characterize individual parcelization events between two time points. The purpose of this typology is to facilitate the exploration of processes leading to parcelization and the potential landscape implications associated with different types of ownership changes. The second objective is to use the typology to ascertain if patterns in parcelization exist over time. These patterns, composed of successive parcelization types called parcelization trajectories, facilitate the assessment of path dependence in ownership parcelization and are akin to the life history of a parcel.

1.2.2 Land-use portfolios and the management of private landholdings in south-central Indiana

To address the second research objective, the parcel is the spatial unit that connects the decision maker to the landscape but is treated as a portfolio defined in terms of the variety of land uses identified by the land manager. For example, one landowner might identify two management units on a parcel, one forest management unit and one pasture management unit. A second landowner might identify three management units on a parcel, one forest management unit and two pasture management units. From a more institutional perspective, the parcel can be understood as the scale at which one set of ownership rules, such as legal access or alienation, apply (Schlager and Ostrom 1992). At a finer scale, areas of differing land use, or management units, can be described as the spatial units to which different sets of rules are applied by the household. A portfolio can then be understood as the sets of rules that the household uses to manage the land. The overall goal of Chapter 3 is to present parcel-level land-use portfolios as a way to better understand the relationship between land-use strategy and land-cover patterns. Three specific research questions will be addressed in this chapter to better understand this connection in south-central Indiana.

1.2.3 Land ownership and land cover in intentional communities of the eastern United States

Chapter 4 examines intentional communities in the eastern half of the United States as examples of land-ownership arrangements that do not easily fit into the private versus public dichotomy and may have value in addressing issues of land-use and land-cover change in an urbanizing context. The notion of intentional community, a term now widely adopted by a variety of groups (Schaub 2005), encompasses much of the spectrum between the two endpoints of private and public ownership. The term "intentional community" will be used here to refer to a group of people who have come together with a goal of residing on land somehow owned in common. The scholarly attention that intentional communities have received has been almost exclusively focused on the shared goals and values of the members of the communities and has not addressed the relationship of the community to the physical landscape. Land ownership provides a useful way to bridge from the characterization of the ideology of the communities to these increasingly important social-ecological relationships. This chapter will address whether the legal type of land ownership in intentional communities is related to the fragmentation of land cover within community boundaries. The necessary first step in addressing this question is to identify the legal types of land ownership used by intentional communities. Then, the relationship of the legal type of land ownership with community characteristics will be tested.

1.3 Linking Land Use, Land Cover, and Land Ownership at the Parcel Scale

Each of the three research objectives will be dealt with in a separate chapter of the dissertation. While these three chapters have been written as stand-alone papers that address the specific research objectives defined above, the common theoretical foundations connect the chapters in a logical progression. The common approach of linking pattern to process manifests as similar methods providing comparable outcomes.

Although the research objectives are stated above as independent, it is important to highlight the fact that the three following chapters are tightly connected and shape one another. In connecting land managers to the landscape in the Midwest United States, an obvious complication is that the spatial footprint of the land manager, the ownership parcel, changes over time. From the description of how that footprint changes, addressed in Chapter 2, arises the question of why parcels are split in a particular pattern. Part of that answer will likely come from understanding how land managers view the spatial distribution of activities on their land. Chapter 3 will first quantify the spatial distribution of management activities as a means of describing which types of management activities frequently occur together. These land-use patterns will then be compared to land-cover patterns to assess how tightly the two are linked on single-household parcels. Taking a broader perspective on who is managing the land is achieved by the examination of land owned by groups, rather than individuals or households, in Chapter 4. Intentional communities can be understood as a group of landowners adding more institutional layers to connect a group, rather than an individual or household, to a parcel or parcels of land. Beyond this difference in the ownership institution, the core questions and methods used in Chapters 2 and 3 also apply to these collective property-rights arrangements.

In terms of theoretical foundations, the primary connection running through all of the chapters is the use of the ownership parcel as a meaningful spatial unit of analysis. Connecting decision makers to the landscape has been a difficult challenge in land-use and land-cover change studies. While the assumption of one household to one parcel is reasonable in a context such as the Midwest United States, each chapter examines a different aspect of this spatial relationship. The second chapter addresses how parcel boundaries change over time. The third chapter treats the parcel as a portfolio of land uses to examine the building blocks of the parcel. The fourth chapter then deals with how communities own land, which may be one or many parcels, and the resulting patterns of land cover.

Expressed in terms of human institutions, the parcel is the basic unit of ownership and can be used as a meaningful footprint of many property rights that potentially have landscape impacts. One overall goal is a better understanding of parcel-scale land-cover dynamics derived from looking at how parcels change over time (Chapter 2), the building blocks of parcels (Chapter 3), and how groups of parcels are owned by communities (Chapter 4). The focus on institutions is limited to formal property rights in the sense that legal land ownership, the ownership parcel, is used in each case. Some attention is given to informal household rules in the third chapter, where management units are defined by the users of the land. Underlying each chapter, then, is the fact that institutional analysis is flexible enough to deal with both formal and informal rules if the property rights, resource characteristics, and spatial extents can be identified.

Methodologically, the three chapters share the approach of “starting with the land” (Rindfuss et al. 2004). Both the physical land-cover outcomes and the human social causes must be addressed in any land-use and land-cover change study, but Rindfuss et al. (2004) describe the question of where to start as with “people or land.” This research begins with a piece of the land delineated by parcel boundaries. In the case of intentional communities, the choice to begin with the land is unique in that nearly all other research on this topic has focused heavily on the people. The chapters quantitatively describe spatial patterns in the landscape and examine the connection of these patterns to social processes. The spatial characteristics of the parcels are described using simple spatial metrics in each chapter. In the second chapter, these spatial metrics are used to examine patterns of change in the parcel boundaries over time. In the third chapter, these same spatial metrics are calculated for land use and land cover and are used to assess the coincidence of these two measures. These spatial metrics are used to quantify land-cover patterns in the fourth chapter to assess whether or not these patterns are linked to types of land ownership used by intentional communities.

Another common thread among the three chapters is the geographic context. While each chapter does have some overlap with the others in the geographic extent of the study area, none is exactly the same as another. Ranging from looking at only one township to an entire county to much of the eastern United States, all of the chapters are focused on the same types of exurbanizing processes. Broadly speaking, this entire region has to some extent gone through a forest transition where much of the pre-European forests were cleared for agriculture. Areas less suitable for agriculture were abandoned decades ago and are therefore now generally more forested while more agriculturally suitable areas currently have less forest. Monroe County, Indiana, the study area for Chapters 2 and 3, has largely gone through this forest transition. The wide geographic distribution of the communities examined in Chapter 3 means that they occur in contexts ranging from suburban to rural areas. By definition, though, all of the communities included in the study are residential with "off-farm" employment and therefore fit into the exurban framework.

Each of the three following chapters will present background, data and methods, results, and discussion for the research objectives described above. Chapter 5 will revisit these connections and discuss how the findings in Chapters 2–4 can be synthesized to better understand the relationship between land ownership and land cover in the Midwest United States.

2 Characterizing Spatial Patterns of Land Ownership at the Parcel Level in South-Central Indiana, 1928–1997

Based on an article written by Shanon Donnelly and Tom P. Evans
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2.1 Introduction

Many areas of the United States are experiencing parcelization of land ownership, a process that has dramatic implications for how landscapes are managed and how socioeconomic changes ultimately affect the pattern, composition, and characteristics of the landscape. In landscapes dominated by private small-holders, land ownership is a fundamental link tying landowner attributes to specific land-use and land-cover change trajectories. Yet the pattern of land ownership is highly dynamic in many locations, complicating efforts to create this landowner-landscape linkage over time. There is ample evidence suggesting that parcel size is an indicator of certain land-use regimes. Small, dense parcels are common in urbanized areas while larger land holdings are more commonly associated with rural land uses. But there is a complex array of parcel dynamics within this broad characterization of parcel configurations. The relationship between parcelization and land-use change is particularly apparent at the exurban fringe where the rate of land-use and land-cover change is typically more rapid than in rural areas (Evans et al. 2001). The transition of parcels from old farms to lots subdivided for high- or low-density residential development affects tree canopy cover and greenspace with resulting effects on ecosystem function (Gobster and Rickenbach 2004). Considerable research has been conducted on the effects of parcelization in urban and suburban areas, and now there is an emerging recognition of the role of parcelization in rural areas (Gobster and Rickenbach 2004), as the rate of parcelization in many rural areas of the United States is increasing (Sampson and DeCoster 2000).

Despite recent work on the drivers and effects of parcelization (Drzyzga and Brown 2002, Gobster and Rickenbach 2004), the dynamics of land ownership change are still not clearly understood in part because of the complexity of the parcelization process in different geographic settings. Interactions of both social and geographic factors result in parcelization, yet these interactions are highly complex and often tied to very specific household events (Mehmood and Zhang 2001). At the household level, life-course events such as retirement or a death in the family may lead a household to move or sell a portion of its land holdings. At the same time, the demand for real estate can motivate a landowner to sell land holdings, as is the case of the development of former farm fields into residential subdivisions. The interplay between these household and market forces produces a complex and difficult-to-predict process in many locations.

The parcelization process is particularly challenging to understand and predict in semi-rural exurban areas. Here the pressure of suburban development is not as dominant as in areas immediately adjacent to existing urban development, and the parcelization process is particularly tied to household events such as retirement, inheritance, and changes in household composition. Clearly, economic factors are relevant in this context, as in the case with agricultural leasing, but the parcelization process is less dictated by simple spatial diffusion as in the case with suburban expansion where accessibility is a more dominant factor.

Parcelization can result in spatial changes that are associated with the transition from one land use to another (Gobster and Rickenbach 2004). For example, a large parcel that is dominated by agriculture may be split into several smaller parcels that are no longer of sufficient size to sustain the pre-parcelization land use such as agriculture or harvesting timber (Leach 1968, Luloff et al. 2000). Of particular interest is the potential for parcelization to lead to a path dependence in land use and resulting land cover because the splitting of parcels is a much more common process than the agglomeration of parcels.

In this chapter, I describe and interpret the process of parcelization and associated land-cover change in a peri-urban region of south-central Indiana. We track parcelization events to describe how the social and physical landscapes have evolved over a period of 70 years in Monroe County, Indiana. We use the quantitative results from this analysis to propose a typology of rural parcelization applicable to the south-central Indiana context.

The purpose of this typology is to facilitate the exploration of processes leading to parcelization and the potential landscape implications associated with different types of ownership changes. The typology also allows a method to characterize the temporal patterns of parcelization. The notion of the life history of a parcel is presented as a means to integrate the empirical findings with social changes that occur at the household level.

2.2 Drivers of Parcelization

A number of researchers have addressed the process of parcelization and its role in land management and land use. Mehmood and Zhang (Mehmood and Zhang 2001) divide the factors contributing to the decreasing size of forested parcels in the United States into supply and demand factors. Supply-side factors that contribute to parcelization include mortality rate, taxes, and uncertainty about environmental regulations. DeCoster (1995) describes the process in which the need to pay inheritance taxes upon the death of a family member leads to the sale of part or all of a parcel. Empirical evidence shows that an estate tax does decrease the chances of a farm or business being transferred to an heir (Brunetti 2003). As general-demand factors, lifestyle and urbanization are cited as drivers of parcelization (Mehmood and Zhang 2001). By lifestyle, these authors refer to the increasing desire to live in or near a forest and therefore presumably in a rural setting. For a study area in Oregon, research shows that property values are positively affected by proximity to forest (Kim and Johnson 2002). While Mehmood and Zhang (2001) tested their model of parcelization using changing parcel sizes across the entire United States (excluding Alaska), Gobster and Rickenbach (2004) formulated a list of drivers based on information gathered from interviews with landowners in Wisconsin's Northwoods. These authors group the forces driving parcelization of forested land into economic, demographic, values and motivations, globalization and technology, natural capital, and policy-related categories.

A particular focus of parcelization research has been on the influence of inheritance on land-ownership fragmentation. Binns (1950) hypothesized that inheritance will always lead to an increased degree of parcelization, yet studies in many contexts suggest that household and institutional contexts impose limits on the process of parcelization.

Downing (1977) identified a minimum farm threshold size beyond which parcelization ceased to be economically viable. And inheritance laws in the Italian Alps have limited the parcelization of land ownership below a specific size (Cole and Wolf 1974).

A decrease in average parcel size coincided with an increase in residential land use in a study of selected townships in Michigan (Drzyzga and Brown 2002). However, the authors warn against assuming a simple causal relationship, as the county-level rankings of parcelization rate and increase in residential use did not show a statistically significant relationship. The descriptive analysis showed that parcelization rates were greater farther from the city in Grand Traverse, Michigan from 1970 to 1990 (Drzyzga and Brown 2002). Although untested, these authors speculate that improved transportation or a decrease in the importance of access to the city explains this trend. Although they admit that they are unable to find support in the literature, Mehmood and Zhang (2001) also examined rural parcelization and found that the development of a local forest industry was not a significant predictor of parcelization, but the presence of a cost-share program was.

2.3 Links between Parcelization and Land-Cover Change

The land-use and land-cover implications of ownership patterns have also been addressed using spatially explicit methods. Using a time series of parcel data for one township in western Ohio, Medley et al. (2003) found that rural parcels with less frequent ownership change experienced forest expansion while high ownership turnover was related to forest loss. For a study site in Michigan, Drzyzga and Brown (2002) substantiate the largely untested claim that parcelization does increase fragmentation of the forested landscape. Brown (2003) also uses parcel data to characterize county-wide processes in order to explain differences in reforestation rates in upper Midwest states. For an area in Ohio that sits on the boundary between the rectangular survey system and the metes and bounds system, Thrower (1966) shows that with all other social and biophysical factors controlled for, the land divided into regular rectangular parcels is more easily accessed by roads and subdivided than the irregularly shaped parcels of the metes and bounds system. Batistella et al. (2003) describe a similar situation in the Brazilian state of Rondônia where the land in one settlement was divided according to a rectangular survey and the other with a survey that followed the contours of the land. Over the study period of 1988 to 1998, the settlement designed in accordance with topography had forests that were less fragmented and more complex in shape and provided more interior habitat (Batistella et al. 2003). Turner et al. (1996) conducted a similar comparison of land-cover change in two locations in the United States, each containing areas of public and private ownership. Land-cover change patterns and rates were significantly different between both the locations and ownership regimes (Turner et al. 1996). For 66 watersheds in the state of Oregon, Stanfield et al. (2002) found a positive relationship between parcel size and forest patch size, stand age variation and ownership variation, and ownership connectivity and forest patch connectivity.

Forestry researchers have also recognized the implications of parcelization to forests on privately held land. A 1994 survey of non-industrial private forest (NIPF) owners in the United States revealed that there are an estimated 9.9 million NIPF owners, with 90% owning less than 100 acres of forest land and an average holding of 24 forested acres (Birch 1996). The overall number of NIPF owners increased by 20% between the years of 1978 and 1995 (Agrow 1996). NIPF owners also exhibit a very high turnover rate with more than 40% having acquired their land during this period (Agrow 1996). Furthermore, owners of more than 90 million acres of forest are age 65 or older, and new owners are increasingly coming from urban backgrounds (Sampson and DeCoster 2000).

Path-dependent relationships have been identified in areas where successive periods of land fragmentation occur over several generations. As the size of land holdings declines over time the land-use choices become more constrained. Leach (1968) found that successive land-ownership fragmentation in Sri Lanka resulted in parcels that were too small to sustain household production and were ultimately abandoned. Yet in other areas informal institutions have maintained the sustainability of land uses. Cole and Wolf (1974) found that a minimum farm size in the Italian Alps was maintained by the nature of inheritance laws in the region, thus allowing agricultural land uses to persist. These path-dependent linkages between land-ownership fragmentation and land use are of particular interest in our analysis of south-central Indiana.

The above research has begun to examine the relationship of ownership patterns and land-cover change, but there has been relatively little research focused on parcelization in rural areas of the United States. Yet it is these rural areas that are responsible for the net increase in forest cover that characterizes much of the eastern United States, including south-central Indiana. The process of parcelization clearly poses methodological challenges in linking households to discrete landscape outcomes. However, it is also clear that parcelization is a critical process that changes how landscapes are managed over time. The following sections present an analysis of parcelization in south-central Indiana to provide insight into this dynamic process.

2.4 Study Area and Data

2.4.1 Study area

The study area for this research lies in south-central Indiana. This part of the state was primarily forested prior to the arrival of European settlers in the early 1800s. These settlers cleared substantial areas of land for agricultural production (crops and pasture) and for forest products used for construction materials. It is estimated that in the early 1800s more than 87% of the state was covered with forest of some type across a wide range of topographic zones (Lindsey et al. 1965, Lindsey 1997). The process of land clearing continued until the early 1900s, at which time areas marginal for agricultural production were gradually abandoned, allowing forest regrowth. The combination of agricultural clearing and timber extraction reduced Indiana's forested land to approximately 560,000 ha (1,390,000 acres), or about 6% of the state by the early 1920s (Nelson 1998). Since that time, the extent of forest cover has increased to over 1.6 million ha (4 million acres) (Nelson 1998). Indiana retains only an estimated 0.06% of its original forest cover from the time of European-American settlement (Davis 1993, Lindsey 1997). The majority of forest cover in the state is relatively young successional forest covering approximately 18%–20% of the state.

The two townships examined here, Indian Creek and Van Buren, cover an area of approximately 10 km x 20 km located in southwest Monroe County, Indiana (Figure 2.1). Private landholders are the primary actors in the landscape with a general trend of urban to rural land uses from northeast to southwest corners of the study area. The topography of the area is characterized by a series of rolling hills with bottomland areas suitable for agricultural production interspersed between ridges/hills that are largely forested. Forest cover composed 36% of the landscape in 1939 and 54% by 1998 (Figure 2.2). A general pattern of afforestation has occurred in steeply sloped areas while areas with shallow topography remain in some type of agricultural land use. Landowners are a mix of households that derive a portion of their household income from extractivist practices (agriculture, farming, haying, timber harvesting) and other households that derive all their income from non-farm activities (Evans et al. 2001, Koontz 2001).

The spatial pattern of changes in land ownership is fundamentally related to the method in which the land was originally allocated. The first federal surveys in this region began with the Land Ordinance of 1785, which laid out a survey system that divided the western public lands, of which Indiana was a part, into a rectangular grid (White 1983). Beginning from the western boundary of Pennsylvania and generally spreading westward, the land was divided into six-mile-by-six-mile squares that were known as townships. These townships were in some cases further divided into square-mile sections. The aggregation of these square cadastral units provided the basis for organization into counties and states. The regular grid was laid down without concern for topography or any physical traits of the land. Originally sold as whole townships or sections, these areas were often subdivided into 40-acre (quarter-quarter sections) or 80-acre parcels and sold or otherwise distributed to settlers.

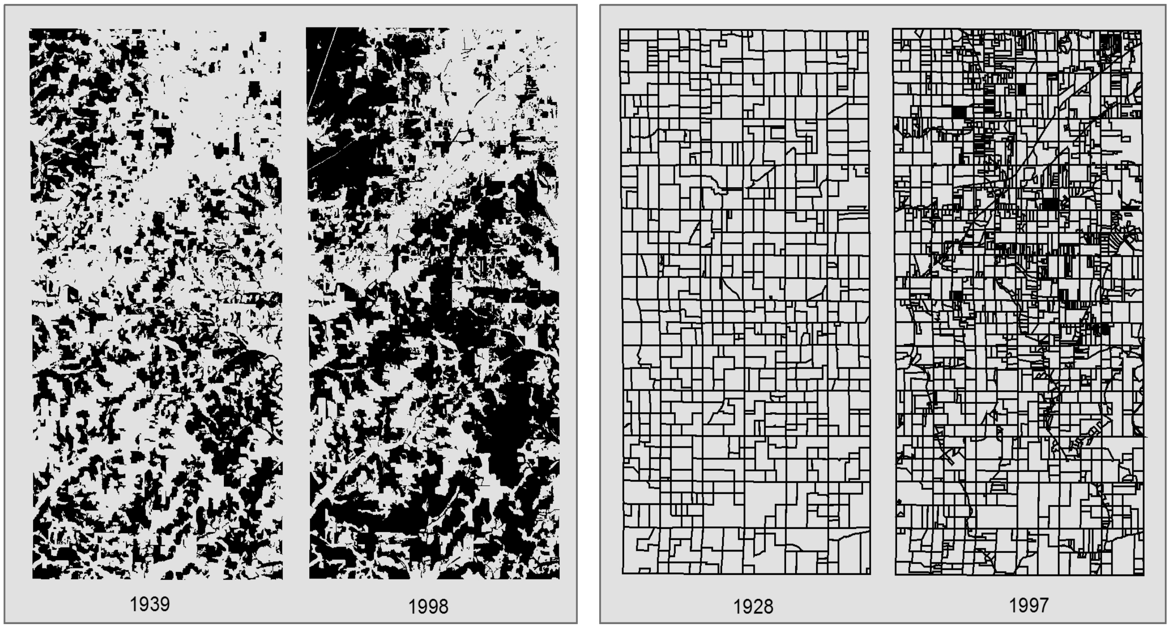


Figure 2.1 Change in forest cover (shaded areas) and ownership boundaries in Indian Creek and Van Buren Townships, Monroe County, Indiana.

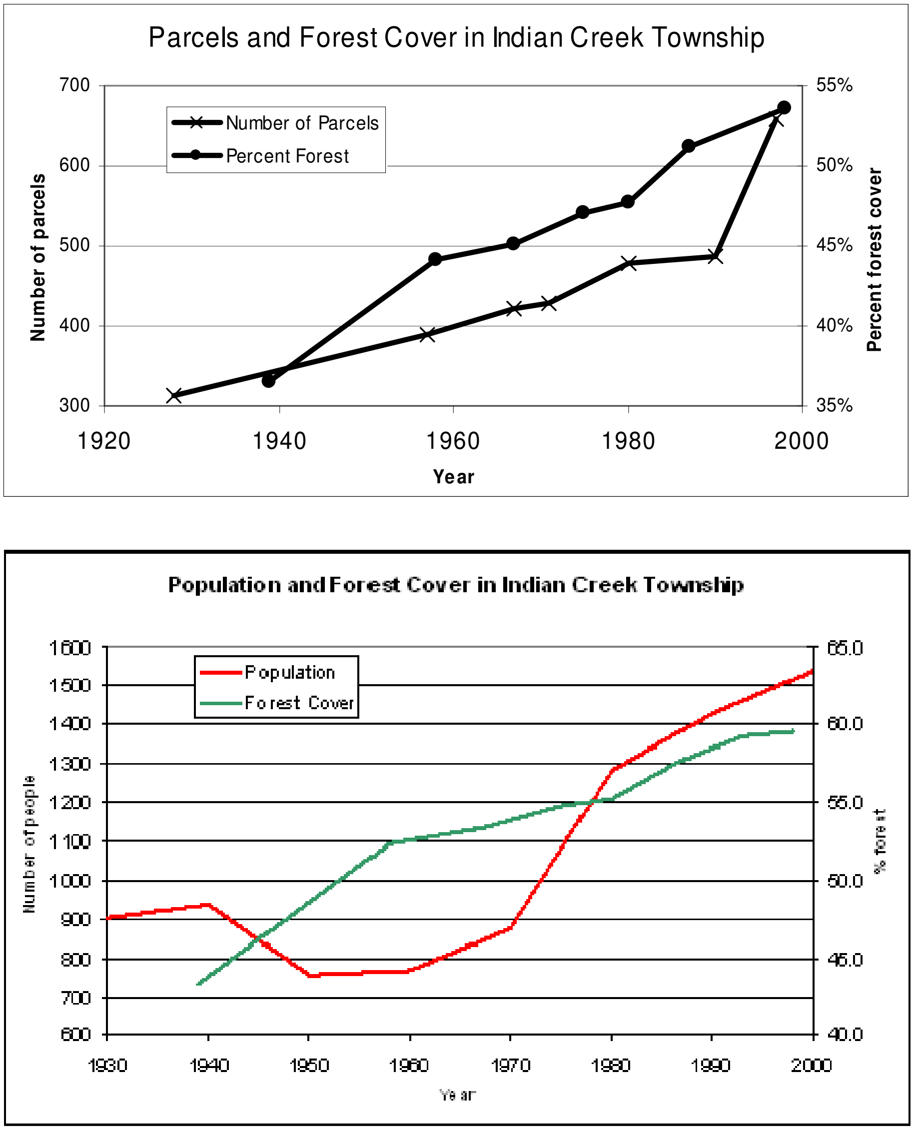


Figure 2.2 Number of parcels, percent forest cover, and population in Indian Creek Township, Monroe County, Indiana.

2.4.2 **Data**

The production of the time series of land ownership began with a digital spatial database of 1997 parcel boundaries provided by the Monroe County government. Commercially produced plat books were obtained for the years 1928, 1957, 1967, 1971, 1980, and 1990. Beginning with the 1997 data, the scanned and registered 1990 plat book was compared to the 1997 dataset and changes in ownership boundaries were made by adding or removing boundaries as necessary. This process was continued in reverse chronological order to ensure that the common parcel boundaries coincided throughout the time period with the most spatially accurate data and thereby removing the possibility of gaps or overlaps in the spatial dataset. The first and last names of the owner of each parcel was coded and recorded in each time point. In residential subdivisions where parcels were less than five acres, individual parcel boundaries and ownership were not available from the plat books and were therefore coded as "high density suburban residential" ownership.

2.5 Methods

2.5.1 **Parcelization typology**

Working from the notion that the spatial characteristics of a parcelization event are the result of an underlying social process, the variety of known social processes along with observed spatial patterns in the data provide a starting point for the categorization of parcelization types. For instance, a parcelization event precipitated by inheritance would likely be characterized by the initial parcel being split into a small number of equally sized parcels. We use the terms "parent" and "child" parcels to refer to parcels before and after a parcelization event such that multiple child parcels result from the fragmentation of a parent parcel.

The spatial characteristics of the parent parcel and child parcels involved in a parcelization event can be used to describe and classify those events into general types that can then be more easily interpreted. With the goal of classifying parcelization events using the most efficient metrics, the area of the parent parcel, the number of child parcels, and the range in the area of the child parcels normalized by the area of the parent (range ratio) are used to build a parcelization typology. The range ratio uses only the smallest and largest child parcel areas. After multiplying the ratio by 100, the possible values vary from 0 to 100 with small values for similarly sized child parcels and large values for dissimilarly sized child parcels.

The Two Step clustering algorithm in SPSS was used to classify all of these parcelization events into five classes using these descriptors of parcel splits. The Two Step Cluster includes both categorical and continuous variables in the same analysis to group similar data observations. The algorithm first groups the cases into "pre-clusters" based on any categorical variables and then applies an agglomerative hierarchical clustering method with the remaining continuous variables. The number of child parcels was treated as a categorical variable and thus provided the grouping into pre-clusters. The hierarchical clustering then proceeded using the area of the parent and the range ratio of the child parcels as continuous variables. After trying both automatic determination of the number of clusters and manual setting of the final number of clusters to several values, we determined that five clusters provided a good balance of capturing unique configurations of parcel splits while retaining a manageable number of clusters to interpret.

Along with patterns in the quantitative empirical data, other data considerations also dictate that some parcelization types be added to capture events that are known to exist but cannot be detected with the parent-child metrics described above. One such type arises when a parent parcel is subdivided by a developer. Commercial plat maps generally do not or cannot record parcels smaller than five acres and simply label the entire parent parcel as a subdivision. Another category of changes in land ownership not captured by the parent-child metrics is when parcels are combined. Although fragmentation of ownership is the dominant trend and the primary focus of this research, the aggregation of parcels must also be recorded in the typology developed here as it clearly affects future patterns of ownership and land use. Along with two parcelization types for residential subdivision and parcel aggregation, and a category for parcels that did not split, a total of eight parcelization types comprise the typology.

2.5.2 **Parcelization trajectories**

The parcelization typology provides a means to characterize individual parcelization events between two time points. In the same way that land cover can be described over many time points to describe long-term trajectories of land-cover change, we describe the trajectories of parcelization events to describe trajectories of land-ownership fragmentation. The purpose of this analysis is to identify what trajectories emerge and if there is a path dependence whereby one type of parcelization event predominantly results in a particular trajectory of subsequent parcelization events.

Describing the types of individual parcelization events is a first step in understanding the changing patterns of ownership. Understanding how these individual decisions about land ownership enable and constrain future decisions is a next important step. To quantify the temporal patterns in the trajectories of parcelization, a contingency table or transition matrix is produced that records what type of parcelization events occur in immediate succession. Expected values for each cell in the matrix are calculated by multiplying the probability of the earlier type of parcelization by the probability of the latter type of parcelization. The difference between observed and expected probabilities derived from the transition matrix allow an estimate of standard error that is used to calculate an adjusted standardized residual expressed in standard deviation units above or below the mean. The adjusted standardized residual is provided for each cell in the matrix as a way of describing the statistical significance of the frequency of occurrence of that transition type. A positive significant value suggests that the two parcelization types are related and occur more frequently than expected. The sample for this analysis is all consecutive parcelization events.

2.6 Results

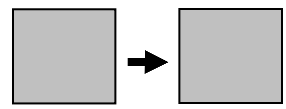
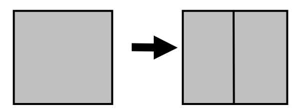
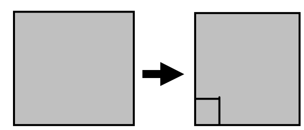
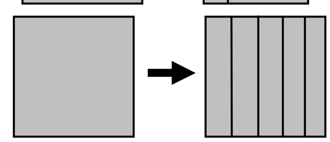
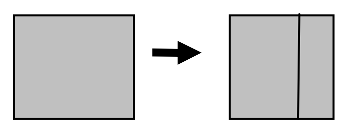
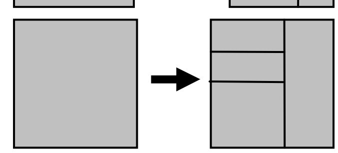
2.6.1 Parcelization typology

The cluster centroids for each of the three parent-child metrics resulting from the TwoStep clustering algorithm are presented below (Table 2.1). These clusters define the five types of parcelization in the typology that are based on the parent-child metrics. Generalized descriptions and stylized illustrations of these parcelization types are given in Table 2.1.

The total number of parcelization events that were used in the cluster analysis was 1,011, with the number of parcelization events in any type ranging from 71 (Type 5) to 353

(Type 1). In addition to the five categories derived from the quantitative data and shown in Table 2.1 (categories 1–5), categories for no split (Type 0, also shown in Table 2.1), aggregation (Type 6), and subdivision into parcels smaller than 5 acres (Type 7) are included in the trajectory analysis below.

Table 2.1 Generalized examples of parcelization types derived from cluster analysis.

Type (n)	Parent area (ha)	Range ratio	Number of Child parcels (n)	Example
0 (4,393)	Small (18)	NA	NA	
1 (353)	Small (17)	Low (30)	Low (2)	
2 (269)	Large (32)	High (80)	Low (2)	
3 (92)	Large (36)	Low (41)	High (5-13)	
4 (226)	Small (26)	Med (51)	Low (3)	
5 (71)	Large (36)	Med (53)	Low (4)	

2.6.2 **Parcelization trajectory**

Identifying patterns in the historical order of parcelization events that have created the current set of ownership boundaries facilitates an analysis of the historical path dependence in land ownership and land cover. The relationship between different parcelization types is analyzed here using a transition matrix (Table 2.2), where the rows represent the parcelization type occurring between the first two time points (t_1 and t_2) and the columns represent the parcelization types occurring between the next two time points

(t_2 and t_3). Because the parcelization types are themselves transitions, it may be clearer to describe the transition matrix as recording the sequence of parcelization types at successive time points. Each cell in the transition matrix contains the observed count and the standardized residual. Transitions that occur more frequently than expected (standardized residual greater than 2.0) are highlighted in gray and transitions that occur less frequently than expected (standardized residual less than -2.0) are highlighted in black.

Table 2.2 Transition matrix of parcelization types with positive standardized residuals greater than 2.0 in gray and negative standardized residuals less than -2.0 in black.

			Type at t_1+1								
			0	1	2	3	4	5	6	7	Total
Type at t_1	0	Count	4,850	318	180	408	342	184	348	139	6,769
		Std. residual	4.5	-1.5	-0.3	-0.6	0.8	0.7	-6.3	-8.5	
	1	Count	327	33	11	15	24	6	77	24	517
		Std. residual	-1.1	1.3	-0.8	-3.0	-0.2	-2.0	6.5	0.6	
	2	Count	171	29	5	9	8	0	19	14	255
		Std. residual	0.0	4.4	-0.7	-1.7	-1.2	-2.6	0.2	1.1	
	3	Count	435	42	6	35	11	28	72	42	671
		Std. residual	-0.7	1.3	-2.9	-1.0	-3.8	2.6	3.4	2.7	
	4	Count	391	14	22	61	24	0	30	55	597
		Std. residual	-0.5	-3.0	1.4	3.9	-0.9	-3.9	-2.0	6.1	
	5	Count	140	5	1	8	2	0	7	27	190
		Std. residual	1.1	-1.5	-1.8	-1.1	-2.4	-2.2	-1.8	6.8	
	6	Count	388	49	36	60	62	19	67	44	725
		Std. residual	-4.5	2.0	3.6	2.2	4.5	0.1	2.1	2.5	
	7	Count	117	28	16	35	19	25	109	76	425
		Std. residual	-10.0	1.4	1.3	1.7	-0.4	4.2	14.2	13.9	
Total		Count	6,819	518	277	631	492	262	729	421	10,149

Note: Std., Standardized

From the number of counts, it is clear that between any two sets of time points, most parcels do not split. Type 0 in Table 2.2 represents parcels that do not split, and as such, any combinations containing this type have the highest overall frequencies. Two successive periods with no parcelization events (0-0) happened more frequently than expected while no other transition type beginning with parcelization Type 0 happened more frequently than expected. To generalize, there is not a dominant type of parcelization that occurs after a parcel has gone through two successive time points without splitting.

A time period with no parcelization event followed by either an aggregation (0-6) or a split into parcels smaller than five acres (0-7) happened less frequently than expected. This was also the case for these transition types in reverse order. Parcels that were aggregated in the earlier time period tended to be dynamic (either split or aggregated) in the next time point, while parcels that do not split do not often go directly to aggregation or to smaller lot subdivisions. Taken together, these findings can be generalized to say that aggregation of parcels is likely followed by some sort of parcelization.

Parcelization Type 5 had the fewest occurrences over the study period, so it is not surprising that several of the transition types involving this type of parcelization had very few occurrences. Almost no transitions occurred from 2, 4, or 5 to 5 or from 5 to 2 or 4. The lack of these transition types can be attributed to the fact that child parcels resulting from the earlier parcelization type are not of suitable size to be parent parcels in the latter parcelization type. In fact, this pattern can be seen with most of the parcelization types based on the parent-child metrics where parcelization in the earlier time period leads to fewer than expected occurrences of parcelization in the latter time period. Exceptions to this pattern occur where at least one of the child parcels is large and may still be suitable for further parcelization. These results give strong support for the idea of a path dependence in the parcelization history of a parcel.

One caveat that should be recognized with this analysis is that time periods for which parcel data were available were not evenly spaced through history and ranged from 7 to 29 years in length. The longer the time period, the more likely multiple parcelization events occurred between time points. In the discussion below, the attempt to tie parcelization types to underlying social processes relies on the assumption that only one type of parcelization has occurred. The two cases where the occurrence of multiple parcelization events is most likely are in Types 5 and 6. Multiple parcelization events, Type 1 and Type 2 for example, during the same time period would be classified as Type 5 according to the parent-child metrics. The combination of parcel aggregation, Type 6, and other parcelization types would also not be recognized in the parent-child metrics.

2.7 Discussion

An examination of the spatial pattern of parcelization allows for a categorization of parcelization events. Existing literature and qualitative information from a 1997 household survey in the study area inform our interpretation of these categories in terms of underlying social processes and demographic events in the study area. The parcelization trajectory that is based on the transition matrix results provides a way of looking at the historical development and path dependence of changing ownership boundaries. Although the trajectory is clearly not a complete historical description of the parcel, we use the idea of a life history of the parcel as a way to emphasize its historical development where the social processes influencing parcelization are akin to the influences shaping the life history of an organism.

Gobster and Rickenbach (2004) categorize the responses of participants in a study in Wisconsin into three major types of events leading to parcelization. Urban sprawl resulting in permanent residential development was the most common type of parcelization with second home development and exurban growth also noted as household-scale decisions driving parcelization. These types of household-level events present examples of important trigger points for parcelization. A relationship between parcelization and other household social processes can also be posited. For example, when a couple decides to retire they may choose to subdivide their parcel, keeping a small area for their residence and selling the remaining portion. In this case, a large parent parcel is split into two parcels of unequal sizes, one small and one large (Figure 2.3a). The outcome of this process corresponds to Type 2 in the typology presented in Table 2.1. A similar outcome might result from children moving out of the household or the household switching from agricultural employment to off-farm employment or some other reason. From the trajectory analysis it is also clear that this type of parcelization, where a small parcel is delineated leaving a relatively large portion of the parent parcel intact, is important because further parcelization is more likely to occur. The potential directions that the life history of the parcel may take are not as limited as if all the child parcels were much smaller.

The death of a landowner also presents the opportunity for several types of change in ownership and parcelization. Inheritance has been identified as an important event that can lead to different child parcel configurations. In the case of a couple with two adult-age children, the couple may split a parcel leaving each child an equal-sized parcel (Figure 2.3b). The parcelization outcome of this process corresponds to a Type 1 split in Table 2.1. This demographic aspect of parcelization can be identified where the family name of the child parcel is the same as the parent parcel owner. The utility of this sort of analysis is limited by the fact that any change in family name, such as marriage, would make this underlying process impossible to identify from data derived from standard plat maps. Parcelization resulting from inheritance might also occur where a landowner passes on some portion of a parcel while he or she is still living. The spatial pattern associated with this process might be better described as a Type 2 or 4.

In a survey of forest owners in the southern United States, Granskog et al. (2002) found that in cases where land was passed on through inheritance and federal estate tax was due, 44% of respondents reported selling timber from the land or a portion of the land itself to pay the tax with about one-quarter of forest land sold being converted to a non-forest use. Extending the findings from the regional to the national scale, Granskog et al. (2002) estimate that around 2.6 million acres of forest land would have to be harvested or 1.4 million acres of forest land would need to be sold each year to pay estate taxes. Clearly, an estate tax can have an impact on the land-cover and land-ownership patterns that result from the change of ownership occurring with inheritance. Because selling land is one of several strategies that can be combined to pay estate taxes, connecting this process to a particular spatial pattern of land division is difficult. In terms of connecting the typology presented here to underlying processes, if land had to be sold to pay an estate tax, this would likely be done in the simplest form such that one parcel large enough to generate the necessary income would be delineated. If only one heir inherited the remainder of the parcel, then parcelization Type 2 or 4 would be most likely, whereas if the inheritance involved several heirs, parcelization Type 4 or 5 would be more likely.

Outmigration is another trigger point where parcelization may occur as might be the case with a retiring couple deciding to move further from the city or a household moving closer to the city to reduce commute times. When a parcel is sold to a new owner, market forces present opportunities for changes in parcel configuration. The parcel may be purchased by an owner who uses the parcel in the same manner as the previous owner, or the parcel may be subdivided at the time of sale or after the sale. Figure 2.3c depicts a case where a parcel is purchased by a developer who then subdivides the parcel into much smaller residential lots. The change in intended use clearly has potential land-cover implications. Even if a particular parcel is not developed for residential purposes and the land cover remains unchanged, the change in land use in surrounding parcels affects future use possibilities. Tying parcelization to these types of driving forces provides an effective foundation for relating the landscape fragmentation to potential stakeholder and policy initiatives. However, predicting what type of parcelization will occur is very difficult. Results from the trajectory analysis show that when a parcelization event does happen following a period without parcelization, there is no dominant pattern of what type of parcelization will occur.

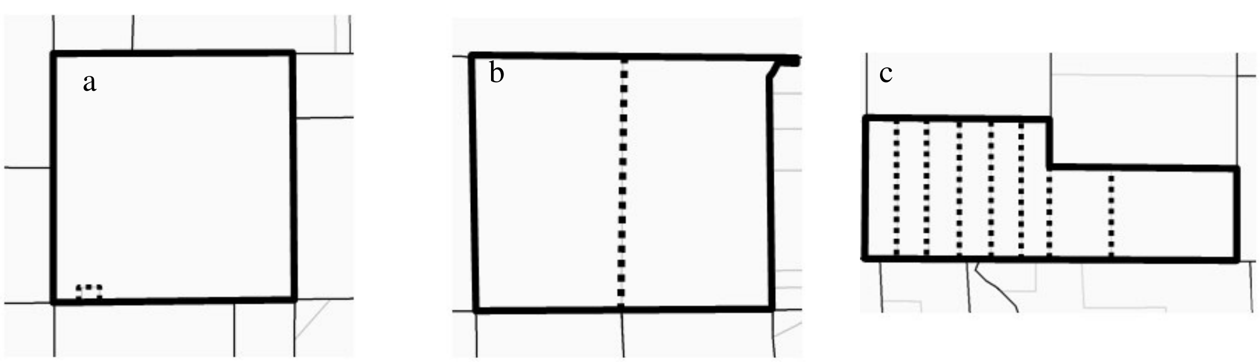


Figure 2.1 Representative examples of unequal (a), equal (b), and multiple (c) parcelization events from Monroe County, Indiana, ownership data. Solid lines represent

parcel boundaries at earlier time point and dashed lines represent parcel boundaries at later time point.

Along with household-scale triggers that influence parcelization, physical factors, such as the size of the parent parcel, can affect what types of parcelization events are more or less likely to occur. It is a common process worldwide that when split among heirs, parent parcels of sufficient size for agricultural use are no longer viable for that same use. Likewise, a large parcel may be less likely to split in certain ways because of its size. A clear example of this path dependence is provided by the transition matrix results where a parcel that does not split during an earlier time period is very unlikely to split into a small-parcel residential subdivision at the latter time point. Results also suggest that most types of parcelization result in less than expected frequencies of further parcelization. In the same way, aggregation of parcels is followed by parcelization more frequently than expected. This clear pattern in the data suggests that aggregation may be undertaken as an intentional precursor to dividing land in a different way. One example of this process is where two small parcels are combined and then divided into a number of smaller residential lots.

Table 2.3 summarizes how parcelization events might be tied to underlying social processes at the household level. Rather than a simple one-to-one correspondence, we suggest that particular household social processes are more or less likely to be related to particular parcelization types. Clearly, different social processes may result in the same types of parcelization.

Table 2.3 Potential relationships between parcelization types and household social processes.

		Household social process			
		Inheritance	Inheritance with estate tax	Retirement	Outmigration
Parcelization process	Type 1	***	*	*	*
	Type 2	*	***	***	*
	Type 3	**	**	*	***
	Type 4	**	***	***	***
	Type 5	*	***	**	**

Type 6	*	*	*	***

Note: * = less likely, *** = more likely

The historical context also provides useful information in interpreting which processes lead to a particular type of parcelization. For example, a Type 2 parcelization event occurring in the 1940s might more likely have been a family getting out of farming and selling off all but a small piece of their land to use as residential than the same type of split in the 1980s, because almost no land in the study area was used for agriculture by this point. Along with the actual date at which a parcelization event occurs, the relevant processes also change as the urban fringe moves from east to west across the study area. The number of long-time residents likely decrease as exurban development increases with processes such as inheritance becoming less prominent. While parcelization events are not stratified by time period in this analysis, further research could test hypotheses relating specific historical processes to types and trajectories of parcelization.

2.8 Conclusion

Land cover is shaped by a combination of individual decisions, macroscale social factors and biophysical conditions. The spatial analysis of ownership patterns can provide much needed insight into these relationships. Land ownership is the link between land-management decisions and landscape outcomes, and the dynamic nature of land ownership often results in changes in land-management strategies. Understanding the process of parcelization can provide insight into the spatial pattern of land cover, and the potential path dependence of land-use trajectories in the context of different parcelization events. In this research, cluster analysis was used to analyze parcelization events observed in south-central Indiana from 1928 to 1997. The results of this clustering procedure were used to develop a parcelization typology that included five types of parcel splits and one type of parcel aggregation. The most common type of parcelization event is where a parent parcel is split into two child parcels of similar sizes. Patterns in the historical relationship of these parcelization types were analyzed using a transition matrix. Results from the transition matrix suggest that (1) no dominant type of parcelization event was found among parcels that had not split in the preceding time interval, (2) a path dependence to parcelization events is determined in part by the size of parcels resulting from earlier parcelization, and (3) the aggregation of parcels often precedes a parcelization event at the subsequent time interval. The path dependence demonstrated in these findings has methodological implications for studying macroscale landscape outcomes that are the product of household-level land-management strategies. Fundamentally, it is more challenging to link household decision making to distinct landscape outcomes in areas where land ownership is highly dynamic compared to areas where land ownership is relatively stable. In addition, the parcelization of land ownership has important policy and planning implications because of the relationship between parcel size and changes in land use and land cover.

3 Land-Use Portfolios and the Management of Private Landholdings in South-Central Indiana

3.1 Introduction

Great strides have been made in land change science in identifying the proximate and underlying causes of land-use and land-cover change and linking these components in pathways (Lambin et al. 2003) and syndromes (Petschel-Held 2001) important to global environmental change. One of the enduring challenges in this field is to connect fine-scale decision making to physical outcomes at broader landscape and global scales (Janetos 2004). Relating the physical patterns of land cover, often observed and measured with remote sensing, to the underlying social processes has elucidated the relationship between land use and land cover as well as illuminated complexities in their relationship. While the distinction between land use and land cover is frequently acknowledged, in practice the two are usually not measured as separate variables. This simplification has been successful and appropriate in many frontier scenarios where changes in land use and land cover can be clearly associated. In more industrialized contexts, especially in exurbanizing landscapes where there is high heterogeneity in agent characteristics, the conflation of land use and land cover can mask important causal links that are necessary for a better understanding of these processes (Fernandez et al. 2005). To advance the program of "socializing the pixel" and "pixelizing the social" that has become so integral to land change science (Geoghegan et al. 1998), these processes may need to be further separated.

In examining land-use and land-cover change as components of global climate change, the issue of scale is an ever-present challenge in both the human social components and the biophysical components of the system. Households are often the social level of organization at which land-use intentions manifest into land-cover changes and are therefore of primary interest. Remote sensing has developed into a powerful means of measuring the physical properties of the surface of the Earth at this relatively fine scale. In the same way that small land-cover changes both affect and are affected by the broader ecological context, households must be put in the broader context of many layers of human institutions that provide incentives and constraints to decision makers (Ostrom et al. 1994). One common approach in land-use and land-cover studies has been to link household attributes to land-cover change processes and outcomes where demographic, economic, and attitudinal characteristics are collected through surveys and questionnaires. This approach has been used successfully in geographic contexts including the Brazilian Amazon (Brondizio et al. 2002), the Yucatán (Abizaid and Coomes 2004), and the Midwest United States (Brown and Robinson 2006, Frimpong et al. 2006).

Inherent in this method is the challenge of spatially linking the household actors to landscape partitions. Across the many geographic contexts where understanding land-use and land-cover change has been studied, a great variety of formal and informal land-tenure institutions exists. Methods for representing tenure in spatially explicit ways can be challenging, and no single spatial unit works in all cases (see Liverman et al. 1998, Fox et al. 2003 for numerous examples). This spatial linkage is generally simplified in industrialized nations where forms of private property held at the household level are common and the ownership parcel is clearly defined. While connecting a household to the landscape with parcel boundaries at any given time is relatively simple in such cases, both household members and parcel boundaries may change over time, complicating matters (Evans et al. 2001, Evans and Moran 2002).

The advantages and disadvantages of farms composed of spatially non-contiguous holdings have long been debated. With some exceptions, the general reasoning has been that the variety of biophysical conditions provided by fragmented holdings are adaptive in traditional agriculture (examples include Netting (1972) and Forbes (1976)) but not well suited to modern, mechanized farming methods (Bentley 1984). While still employing the ownership parcel as an important spatial unit, this debate points out that land-use variety at numerous scales influences management choices on a single parcel. This reasoning can be extended to exurban contexts where biophysical characteristics, such as topography and soil conditions, are clearly still important, but the links with land-use decisions are becoming much less clear (Rickenbach and Gobster 2003). The variety in such a context may be in terms of subparcel units rather than multiple separate parcels.

In areas where the dominant process of land-use change is toward non-extractive uses, such as low-density urbanization in industrialized countries, the "natural" land cover, such as forest, may have a primarily non-monetary value. The relationship between sprawl and forests (MacDonald and Rudel 2005) has been a concern for foresters for more than a decade (DeCoster 1995, Agrow 1996) as an increasing proportion of land is divided into smaller parcels with an increasing heterogeneity of motivation (Klosowski et al. 2000, Kurttila et al. 2001). While exurbanization may or may not lead to a decrease in overall amounts of forest, exurban populations are marked by a decreased correspondence of socioeconomic characteristics and land-use preferences (Fernandez et al. 2005) complicating the creation of policy to effect particular land-use outcomes. This decoupling is also problematic for any direct connection between household survey data and land-cover outcomes derived from remote sensing data and suggests that land use and land cover need to be treated as separate variables in exurban landscapes. In an area in the Upper Midwest United States characterized by an exurban mix of traditional land uses, large residential parcels, and forest regrowth from land abandonment, Brown et al. (2000) found that 60% of variation in transitions between forest and non-forest could be explained by looking at parcel-scale land-use variables. The separation of land use and land cover, even when using a highly simplified classification where one of three land uses was assigned to each parcel, can provide information beyond a combined land-use/land-cover approach.

In this research, the parcel is still the spatial unit that connects the decision maker to the landscape but is treated as a portfolio defined in terms of the variety of land uses identified by the land manager. For example, one landowner might identify two management units on a parcel, one forest management unit and one pasture management unit. A second landowner might identify three management units on a parcel, one forest management unit and two pasture management units. In terms of the land-use portfolio, these two sets of land uses are both described as *Forest/Pasture* portfolios. From a more institutional perspective, the parcel can be understood as the scale at which one set of ownership rules, such as legal access or alienation, apply (Schlager and Ostrom 1992). At a finer scale, areas of differing land use, or management units, can be described as the spatial units to which different sets of rules are applied by the household. A portfolio can then be understood as the sets of rules that the household uses to manage the land. To avoid confusion in the text, portfolio types will be italicized to differentiate them from land-use types that might have similar or identical names.

The terms "complexity" and "fragmentation" are used in this research when comparing land use and land cover. While "complexity" is clearly a very rich and potentially confusing term (Manson 2001), using "fragmentation" to describe the composition and configuration for both land use and land cover may also be misleading in the context of trying to understand land use and land cover as linked but separate processes. Land-cover fragmentation, especially forest fragmentation, is often considered an ecological problem, while land-use fragmentation might well be desirable in the sense of land managers responding in a more subtle way to the physical conditions on their land. In an attempt to alleviate the ambiguity of using the term "complexity," land-use portfolios will be described using the term "land-management complexity" rather than just "complexity." Here, "land-management complexity" is described in terms of both composition and configuration of land use in a portfolio while also recognizing that the relationships between the constituent land uses is important for understanding the portfolio as an emergent whole. While it may be a stretch to think of each portfolio as a system, this notion of "land-management complexity" exhibits several of the characteristics Manson (2001) uses to define the category of "aggregate complexity." In particular, diversity is achieved largely through a variety of connections between components rather than a variety in the types of components themselves.

The overall goal of this chapter is to present parcel-level land-use portfolios as a way to better understand the relationship between land-use strategy and land-cover patterns. Three specific research questions will be addressed in this paper to better understand this connection in south-central Indiana. First, do land owners in south-central Indiana manage parcels as a single entity or as a portfolio of subparcel units? Second, is land-management complexity, defined in terms of the size, shape, location, and variety of land-use patches, related to land-cover fragmentation in this area? And finally, are there specific differences between land-use portfolios in terms of land-use and land-cover metrics that can help elucidate the relationship between land-management intentions and land-cover outcomes?

3.2 Study Area and Data

3.2.1 **Monroe County, Indiana**

The study area for this research lies in south-central Indiana (Figure 3.1). This part of the state was primarily forested prior to the arrival of European settlers in the early 1800s. These settlers cleared substantial areas of land for agricultural production (crops and pasture) and for forest products used for construction materials. It is estimated that in the early 1800s more than 87% of the state was covered with forest of some type across a wide range of topographic zones (Lindsey et al. 1965, Lindsey 1997). The process of land clearing continued until the early 1900s at which time areas marginal for agricultural production were gradually abandoned, allowing forest regrowth. The combination of agricultural clearing and timber extraction reduced Indiana's forested land to approximately 560,000 ha (1,390,000 acres), or about 6% of the state by the early 1920s (Nelson 1998). Since that time, the extent of forest cover has increased to over 1.6 million ha (4 million acres) (Nelson 1998). Indiana retains only an estimated 0.06% of its original forest cover from the time of European–American settlement (Davis 1993, Lindsey 1997). The majority of forest cover in the state is relatively young successional forest covering approximately 18–20% of the state.

The county examined here, Monroe County (Figure 3.1), covers an area of approximately 23 by 15 miles with the city of Bloomington near its center. Private landholders are the primary actors in the landscape with a general trend of urban to rural land uses at increasing distances from Bloomington. The topography of the area is characterized by a series of rolling hills with bottomland areas suitable for agricultural production interspersed between ridges/hills that are largely forested. A general pattern of afforestation has occurred in steeply sloped areas while areas with shallow topography remain in some type of agricultural or residential land use. A large reservoir, Monroe Lake, was created in the 1960's in the southeaster portion of the county. Public lands owned by the state and federal government also occur in the part of the county. Landowners are a mix of households that derive a portion of their household income from extractavist practices (agriculture, farming, haying, timber harvesting) and other households that derive all their income from non-farm activities (Evans et al. 2001, Koontz 2001).

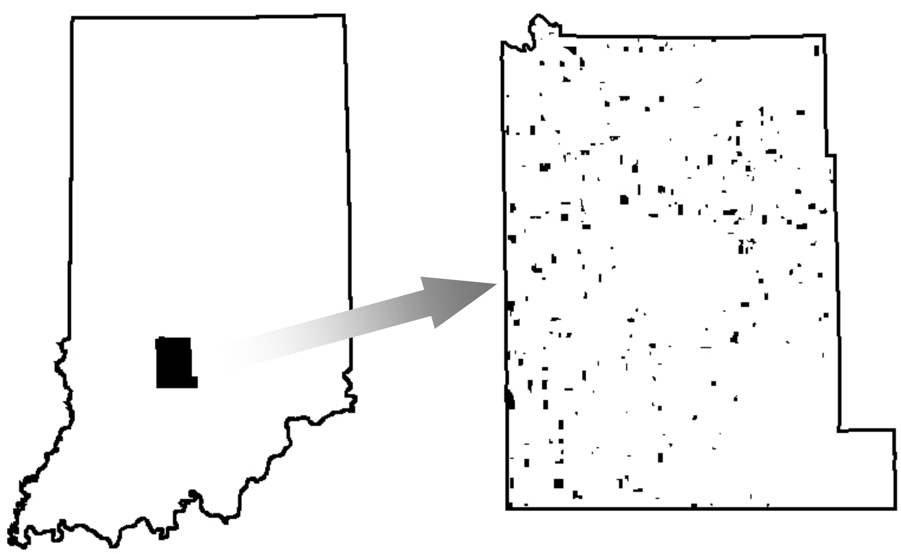


Figure 3.1 Location of Monroe County, Indiana, USA, and sample parcels.

The spatial pattern of changes in land ownership is fundamentally related to the method in which the land was originally allocated. The first federal surveys in this region began with the Land Ordinance of 1785, which laid out a survey system that divided the western public lands, of which Indiana was a part, into a rectangular grid (White 1983). Beginning from the western boundary of Pennsylvania and generally spreading westward, the land was divided into six-by-six-mile squares that were known as townships. These townships were in some cases further divided into square-mile sections. The aggregation of these square cadastral units provided the basis for organization into counties and states. The regular grid was laid down without concern for topography or any physical traits of the land. Originally sold as whole townships or sections, these areas were often subdivided into 40-acre (quarter-quarter sections) or 80-acre parcels and sold or otherwise distributed to settlers. While much subdivision has occurred since the inception of the grid, parcels are still generally rectangular in shape.

3.2.2 Household survey and land-use data

Quantifying the land-use or management intentions of landowners in the study area was achieved through household interviews with structured and unstructured questions that collected several types of data including demographic, land-use history, preferences, and spatial location of a land use. Interviews were conducted in the homes of respondents using teams of two researchers with each interviewer having participated in a substantial amount of training prior to data collection as well as weekly team meetings during the collection process. To collect the spatial data on land use, a respondent was provided with an outline of the ownership parcel and asked to draw *management units*, defined here as areas of the ownership parcel that are managed for uses distinct from other uses. One management unit may contain non-contiguous areas. After the respondent had drawn all management units on the parcel, information was collected about any management unit that met at least one of the following criteria: comprised at least 20% of the parcel, required at least 20% of the time spent on the parcel by the respondent, or was forested. Management activities, called *direct activities* in the survey, were recorded if they met any of the following criteria: distinctive linear feature, covered an area greater than 120 m x 120 m, involved land conversion, or involved forest activities. Multiple direct activities could occur in one management unit. Temporal duration of management activities was also collected to provide information on the land-use history of an area. For this research, a single land use was assigned to each management unit based on the dominant management activity at the time of the survey. Further description of data collection methods are provided in Koontz (2001) and an example map is shown in Figure 3.2.

The survey employed in this research has the explicit aim of separating land use from land cover by addressing the multiple levels of rules that comprise the institutional context that influences the land-use decisions of the household. In these terms, land uses can be thought of as the spatial units to which particular rules apply and therefore must be collected from the decision makers separately from the physical description of the condition of the land. An example of separating management strategy from existing land cover in a single area of forest might be recognizing two management units where timber is harvested from one part of the forest and no harvesting is allowed in another part. Land-use data were collected in Monroe County from a household survey lasting anywhere from one to three hours, during which respondents were asked to draw a map of where and how they used the land on a boundary map of their parcel overlaid on a map of topographic relief. Sketch maps, as a source of spatial data, have been used in land-use and land-cover studies as a means to access perceptions held by decision makers or otherwise unavailable data. Examples include sketch maps of soil types drawn by Honduran farmers (Kammerbauer and Ardon 1999) and the effects of development interventions in Nepal (Rao and Pant 2001). In general, these maps have been integrated with land cover (and sometimes land use) derived from aerial photography.

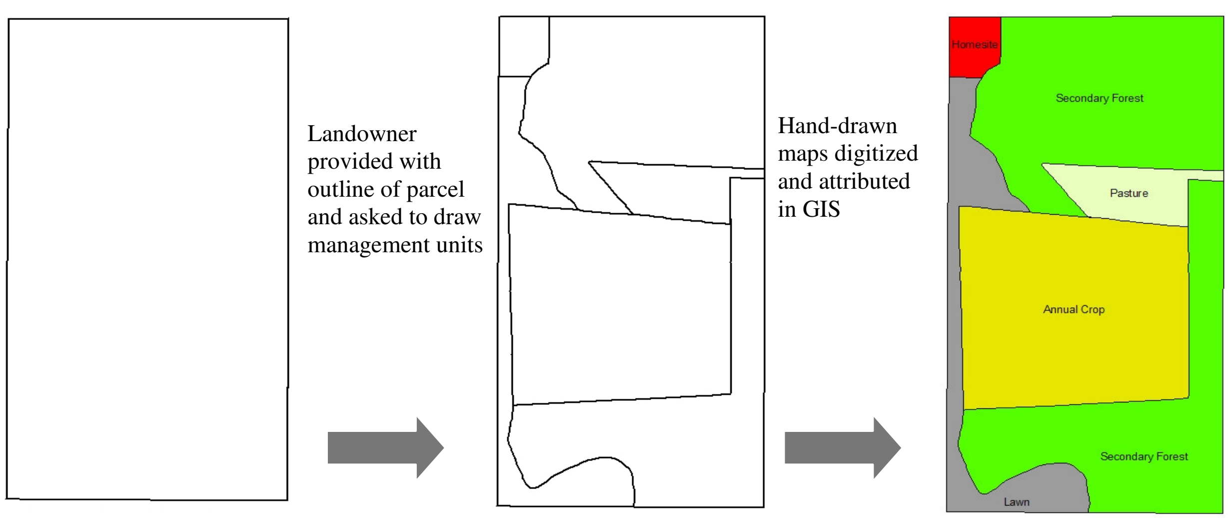


Figure 3.2 Example of hand-drawn land-use map.

The sample of respondents was drawn from the digital spatial database of parcels in Monroe County maintained by the county tax assessor in 1998. Excluding parcels smaller than 5 acres, the database contained 7,780 parcels. Upon examination of the histogram of parcel areas, seven size classes were designated and used to draw a stratified random sample. During the data collection process, the number of respondent parcels in each size class was monitored, and adjustments were made to the sampling list to maintain a representative sample with a minimum of 15 cases in each size class. After a parcel from a particular landowner had been selected, all other parcels owned by that owner were removed from the population to avoid redundancy in responses. Fifty-two percent (52%), or 250 of 484, of the landowners contacted agreed to participate in the study. After processing the data and finding several interviews and parcels unsuitable, a final sample size of 236 households was used in this research.

3.2.3 **Land-cover data**

Land-cover data were derived from the interpretation of digital aerial photography from 1998 and 2003. The aerial photos from 1998 were used whenever possible, with the 2003 photos used for verification or clarification. Both time points of aerial photography had a resolution of 1 m. The 1998 photos were black and white while the 2003 photos were natural color. Parcel boundaries were overlaid on the aerial photos, and forest and non-forest areas were digitized for all areas occurring in a study sample parcel. A minimum polygon width of 20 m was used, making the minimum mapping unit 400 m^2. Fifty percent (50%) canopy closure was used to define forest land cover. All remaining land cover was classified as non-forest.

Comparing the land-use and land-cover spatial datasets allows for an assessment of how directly land use can be related to land cover in this study area. As households can only make management decisions on land that they own, three spatial units are of importance in this study: land-use or management units, land-cover patches, and ownership parcels. Land-use portfolios are defined by the collections of land-use types occurring on a parcel and, thus, always have the same spatial extent as the parcel on which they occur. Portfolios are simply named by the land uses that comprise the portfolio. For example, a

Homesite portfolio is one where the entire parcel consists of a management unit for the home or residence. An example of a more fragmented parcel would be a *Forest/Pasture* portfolio where the respondent identifies two distinct management uses that in this case also have different land covers. A portfolio is comprised of as many land uses as the respondent identifies on the parcel.

3.2.4 **Spatial metrics**

From the above data, several metrics were calculated to test the relationship between a more complicated land-management strategy and land-cover fragmentation. All spatial metrics are calculated for the spatial extent of individual parcels so that a forest patch may extend across several parcels in reality but is truncated at the parcel boundary in this research.

The shape metric used is a ratio of the perimeter of the polygon to the perimeter of the circle with the same area (McGarigal and Marks 1995). This metric has a range of one, in the case of a perfect circle, to infinity where a higher value results from a more complex or less compact shape. The shape metric for a square, a more likely parcel shape in the context of the Public Land Survey System, is 1.128. While the polygon areas in this study do not cover a large range, this shape metric is robust across scales. The shape metric was calculated for the parcel (ParcelShp) and for each land-use and land-cover polygon. Mean and standard deviation values were reported for the management units (MUShp) and forest polygons (ForestShp) comprising each parcel. Counts of the number of management unit types, management unit polygons, and land-cover polygons were used to describe the fragmentation of the land use and land cover. Because the land-cover categorization was dichotomous, only the percent of the parcel in forest cover was necessary to describe the land-cover composition.

Interpreting the metrics requires recognition of the manner in which land was divided during European settlement. This rectangular survey resulted in parcel boundaries that are often straight and parcel shapes that are square or rectangular. More complicated portfolios provide the possibility for more complicated shapes because fewer of the patch boundaries correspond to the generally straight parcel boundaries. Furthermore, as adjacent management units can be of the same type, the management unit shape index can increase without any corresponding increase in the shape index of land-cover patches.

3.3 Results

3.3.1 **Characterizing land use by management unit type**

The 236 parcels included in this data were divided by the respondents into 536 management polygons of 10 different types. Examination of the land-use data (Table 3.1) shows that the most frequent type of management unit is secondary succession forest. Urban, bare soil, forest plantation, and unmanaged types occur very infrequently. Unmanaged management units were areas of sufficient size where the respondents reported undertaking no management activities. Forest management units also had the largest mean area and the most complex shapes of commonly occurring land uses. Only pasture was more fragmented than forest in terms of the number of management units per parcel. While it is no surprise that forest land use has the highest forest cover in this study area, it is notable that 10% of forest land use is non-forest land cover and that no land use is less than 17% forest land cover.

Table 3.1 Descriptive statistics for management unit types. Standard deviations are given in parentheses where appropriate.

Management unit (MU) type	Number of parcels w/ MU type	Mean polygons per MU	Mean (and SD) MU area (ha)	Percent forest	Mean (and SD) MU shape	Mean (and SD) slope (degree)
Forest (SS)	185	1.24	7.05 (9.13)	90.0	1.51 (0.40)	9.16 (7.64)
Homesite	94	1.05	1.30 (1.79)	42.6	1.34 (0.38)	5.83 (5.91)
Pasture	71	1.28	5.66 (5.79)	34.4	1.40 (0.34)	4.74 (4.67)
Perennial crop	41	1.20	6.29 (6.09)	20.5	1.40 (0.28)	3.59 (3.42)
Annual crop	29	1.14	6.64 (6.72)	17.0	1.34 (0.28)	3.00 (3.23)
Lawn	22	1	1.92 (2.05)	29.9	1.41 (0.52)	4.04 (4.27)
Unmanaged	6	1	1.16 (1.48)	65.0	2.16 (1.01)	4.29 (3.78)
Forest plantation	3	1	4.92 (4.53)	19.5	1.28 (0.34)	6.32 (5.19)
Bare soil	2	1	2.40 (2.34)	50.0	1.71 (0.64)	2.94 (4.51)
Urban	1	1	2.71 (0.00)	0.0	1.13 (0.00)	1.82 (2.14)

Note: SS, secondary succession; SD, standard deviation

In nearly all of the frequently occurring management unit types, there are on average more than one polygon per management unit (Table 3.1). This ratio is a measure of the fragmentation of the management unit type and represents a land manager considering distinct areas as part of the same management unit. Pasture, forest, perennial crop, annual crop, and homesite have ratios greater than one. The highest values are for pasture and forest at 1.28 and 1.24, respectively. Further interpretation of this ratio must consider that one parcel may have contiguous management units of the same type, delineated only in their use histories.

Of the frequently occurring management unit types, the average amount of forest cover per management unit (MU) type ranges from 90% for forest land use to 17% for annual crop land use. Unmanaged land use has the second-highest percentage of land in forest at 65%. While this is not a frequently occurring type of land use, the association of forest and unmanaged does point to the difficulties in separating land use and land cover when dealing with "natural" land cover. In the dichotomous patch-matrix model of landscape ecology, forest comprises the matrix in the study area. All other land covers are patches of non-forest in this matrix. Because of the sometimes severe topography and related history of soil degradation in this area, few large patches of non-forest exist. The overall increase in forest in this area is a reflection of the transition to land uses that, on average, have forest land cover included in non-forest land uses, such as homesite and lawn.

The average area of frequently occurring land-management polygons by type ranges from 1.30 ha (3.2 acres) for homesite to 7.05 ha (17.4 acres) for forest. Along with forest management units, extractive land uses, including pasture and crops, have larger management units while non-extractive uses, such as homesite and lawn, have smaller management unit areas. In terms of shape complexity, measured as the ratio of the perimeter of the management unit to the perimeter of a circle with the same area as the management unit, forest has the highest shape index value while homesite and annual crop land uses have the lowest index values. Averaged to the management unit type, none of the types exhibits a particularly complex shape, largely reflecting the rectangular survey system used in this area.

3.3.2 Characterizing land use and land cover by parcel

Approximately one-third (79/236) of the parcels have only one management unit, one-third (78/236) have two management units, and the remaining third have between three and nine management units per parcel (Figure 3.3). The land-use composition of these parcels will be described further in the portfolio section below.

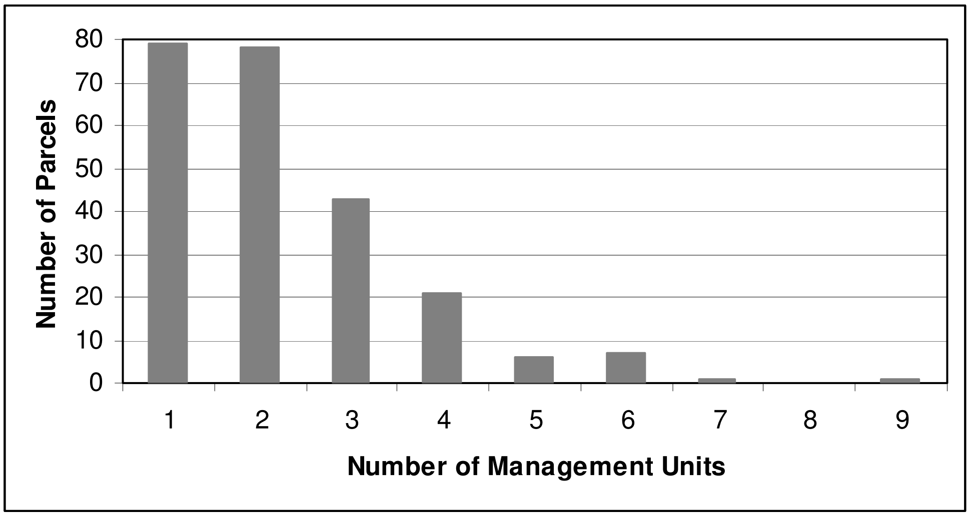


Figure 3.3 Histogram of management units per parcel.

The spatial metrics described above were calculated at the parcel scale in addition to the management unit. Relationships between these metrics were tested and the results presented in Table 3.2. Normality tests were used to determine whether parametric or non-parametric measures of correlation were appropriate. The correlation coefficient and corresponding 1-tailed p-value are presented for each pairing. Many of the relationships between the measures of land-use complexity, land-cover complexity, and parcel characteristics were significant but did not show strong correlations.

Table 3.2 Bivariate correlations with correlation coefficient and 1-tailed p-value.

MU to LC complexity	Pearson	Spearman's rho
NumMU & NumLC		0.353 (.000)
NumMUPoly & NumLC		0.399 (.000)

NumMU & ForShp		0.310 (.000)
NumMUPoly & ForShp		0.309 (.000)
NumMU & %For		-0.313 (000)
NumMUPoly & %For		-0.217 (.000)
MUShp & ForShp	0.360 (.000)	
MUShp & %For	-0.036 (.291)	
MUShp & NumLC		0.216 (.000)

Notes: NumMU, number of management units; NumLC, number of land-cover patches; NumMUPoly, number of management unit polygons; ForShp, average shape of forests; %For, percent forest; MUShp, average shape of management units on a parcel.

The number of management units (NumMU) and the number of management unit polygons (NumMUPoly) always have the same sign and statistical significance ($p < 0.05$) because the number of management unit polygons is always equal to or higher than the number of management units. As such, these values always vary in the same direction. The average shape of management units on a parcel (MUShp) always varies in the same direction and statistical significance as the number of management units and management unit polygons (see Table 3.3 in next section). It is therefore possible to describe the relationship of a more or less complicated land-use strategy to land-cover variables by collectively referring to all three of these metrics (NumMU, NumMUPoly, and MUShp). In the remainder of the chapter, reference to a more or less complicated land-use strategy is a reference to these co-varying quantities.

Other relationships that can be seen in Table 3.3 include that land-management complexity has a positive, significant relationship to land-cover complexity such that an increase in the number of management units or an increase in the shape index is correlated to an increase in the number and shape index of land-cover patches. Also, the percentage of a parcel with forest cover is not significantly related to the average shape of the management units.

3.3.3 **Characterizing land cover by portfolio type**

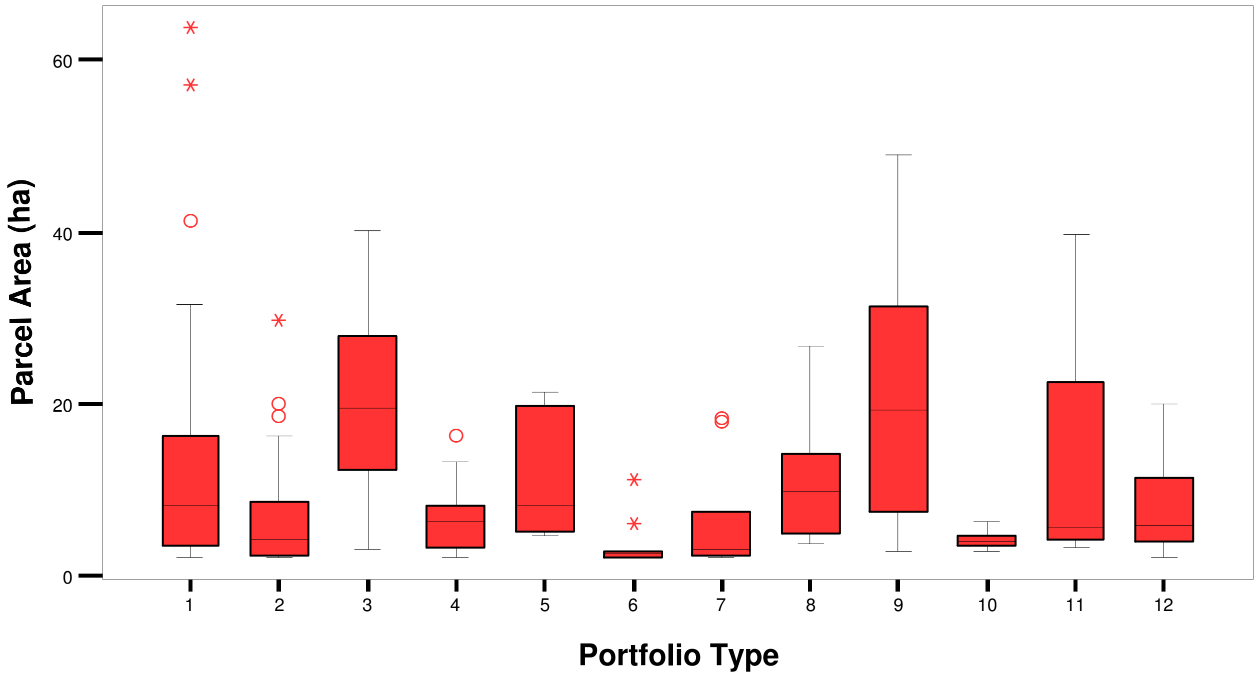
With a total of ten different management types occurring on the sample parcels, 1,024 unique combinations, or portfolios, can possibly exist. With a sample size of 236 respondents, the maximum possible variety of portfolios is further reduced. The observed number of unique portfolios in the sample is only 40, with 12 of these occurring five times or more and comprising 78.8% (186 of 236) of the sample. Those portfolios observed fewer than five times, many of which occurred only once, will be omitted from the further analysis below. Characteristics of these 12 frequently occurring portfolios are presented in Table 3.3. Means are given with standard deviation in parentheses, but care should be taken in their interpretation as the values are generally not normally distributed.

In general, the non-parametric Kruskal-Wallis (KW) statistic is used to test the null hypothesis that the mean ranks of the metrics are the same between several groups. The portfolio type is used as a grouping variable to test for differences in the ranks of land-use, land-cover, and parcel characteristics. A significant result suggests that there is a statistical difference between at least one pair of the portfolios in terms of the test variable. Only frequently occurring portfolios, those occurring five or more times, were used, resulting in a total sample of 186. The KW statistic was significant for parcel area, percent forest, number of land-cover polygons, number of management unit polygons, forest shape, and management unit shape at the $p < 0.05$ level. Of the variables tested, only parcel shape ($p = 0.064$) was not significantly different between any portfolios.

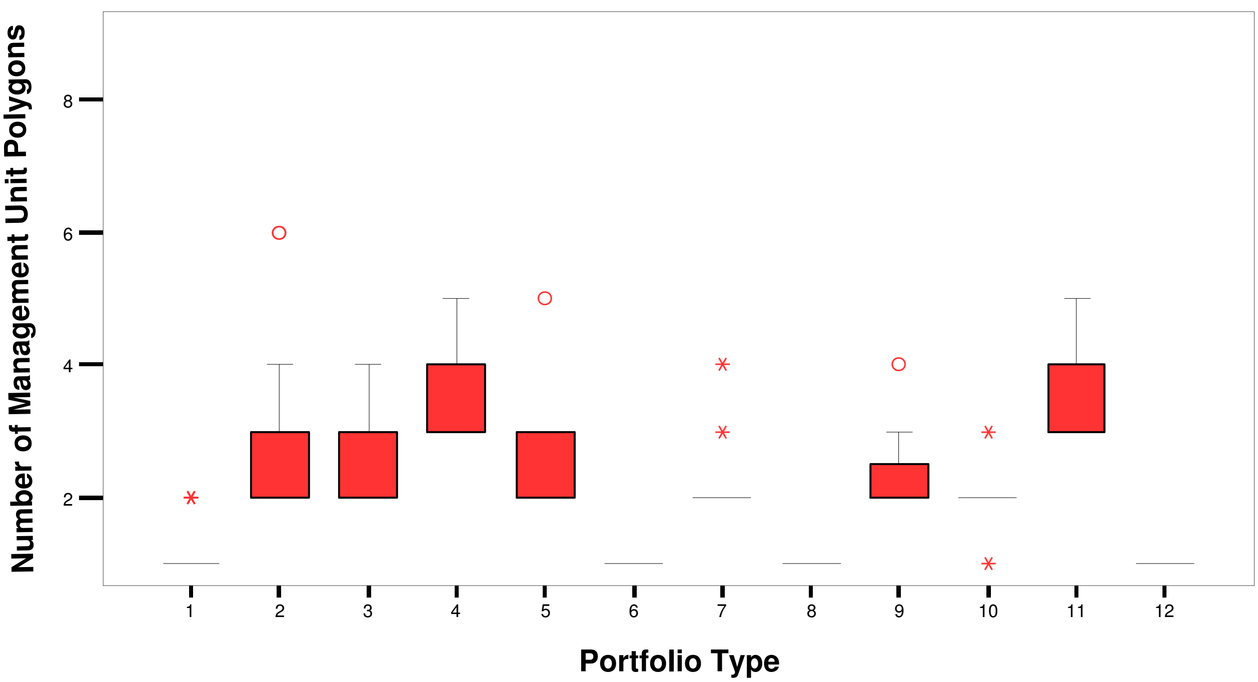
The Kruskal-Wallis tests clearly support the hypothesis that there are differences between the portfolio types in terms of spatial pattern and composition of land use and land cover, but specifying which of the frequently occurring portfolios are different requires further examination. Box plots are provided in Figure 3.4 to better illustrate the difference in distribution of each variable between portfolio types. The Mann-Whitney U (MWU) is used here to test for differences between pairs of portfolios. Table 3.4 shows the variables that are significantly different between portfolio pairs using the MWU. While parcel shape showed no significant difference with the KW test, it is included in Table 3.4 because the KW test compares the median of the subgroup to the median of the entire sample and could theoretically be different from the MWU test that compares only two portfolio types at a time.

Table 3.3 Descriptive statistics for land-use portfolios with mean and standard deviation.

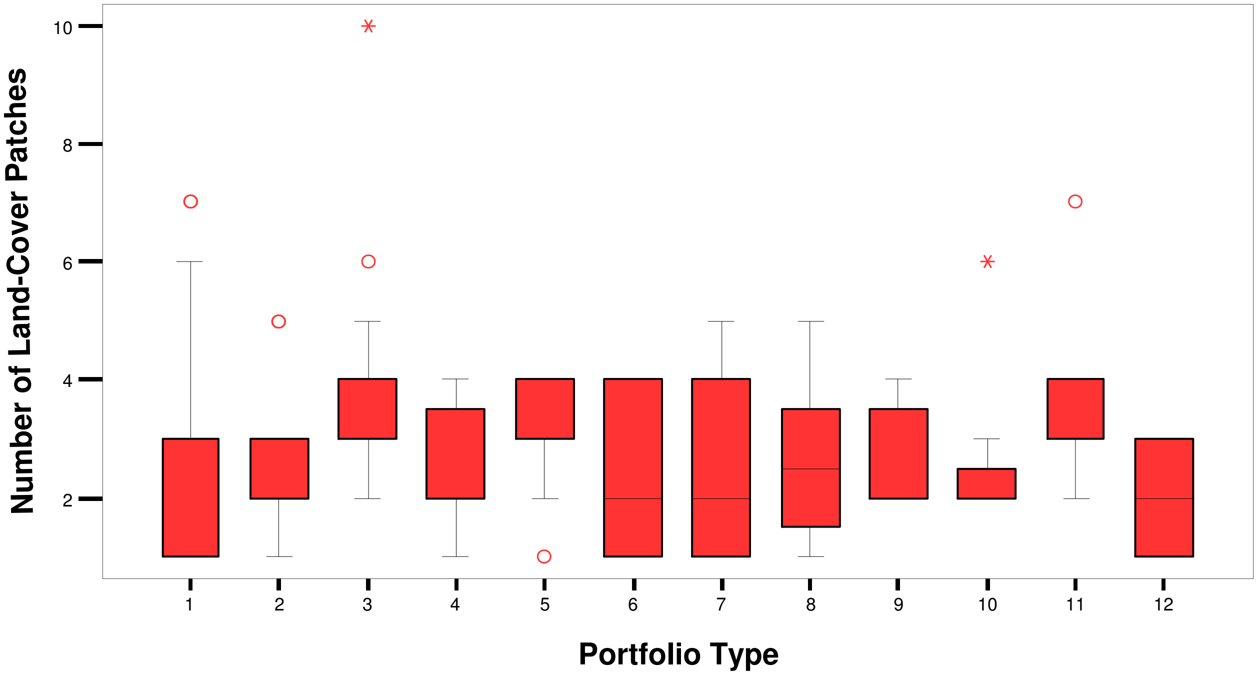
Portfolio	N	Number of management units	Percent forest	Number of land-cover patches	Area of parcel (ha)	Forest shape	MU shape	Parcel shape	Parcel slope (% < 10º)
1. Forest	53	1.02 (0.14)	93.20 (12.70)	2.20 (1.70)	12.90 (13.36)	1.42 (0.34)	1.31 (0.20)	1.31 (0.20)	60.12 (19.46)
2. Forest/ Homesite	35	1.94 (0.42)	84.81 (20.44)	2.37 (0.97)	6.88 (6.47)	1.52 (0.39)	1.51 (0.28)	1.32 (0.19)	68.34 (19.97)
3. Forest/ Pasture	21	2.10 (0.30)	65.84 (21.07)	3.81 (1.81)	19.38 (11.27)	1.78 (0.30)	1.41 (0.32)	1.25 (0.15)	77.54 (17.66)
4. Forest/ Pasture/ Homesite	11	3.09 (0.30)	56.79 (26.50)	2.64 (1.03)	6.73 (4.58)	1.46 (0.56)	1.47 (0.15)	1.39 (0.19)	83.86 (16.15)
5. Forest/ Perennial crop	10	2.00 (0.00)	53.28 (30.49)	3.00 (0.94)	11.50 (7.16)	1.60 (0.36)	1.55 (0.18)	1.41 (0.30)	84.20 (17.65)
6. Homesite	9	1.00 (0.00)	54.28 (39.70)	2.33 (1.41)	3.75 (3.05)	1.31 (0.60)	1.27 (0.09)	1.27 (0.09)	76.84 (29.02)
7. Pasture/ Homesite	9	2.22 (0.67)	29.62 (33.51)	2.56 (1.67)	6.58 (6.69)	1.17 (0.93)	1.33 (0.16)	1.44 (0.20)	96.45 (5.03)
8. Pasture	8	1.00 (0.00)	20.73 (22.62)	2.63 (1.41)	11.00 (7.61)	1.50 (1.02)	1.24 (0.14)	1.24 (0.14)	93.4 (6.83)
9. Forest/ Annual crop	8	2.25 (0.46)	61.55 (27.23)	2.63 (0.92)	20.99 (16.07)	1.54 (0.24)	1.46 (0.22)	1.22 (0.07)	84.24 (11.45)
10. Forest/ Lawn	8	1.88 (0.35)	82.67 (18.18)	2.63 (1.41)	4.19 (1.07)	1.53 (0.21)	1.40 (0.18)	1.27 (0.13)	72.69 (23.72)
11. Forest/ Perennial crop/ Homesite	7	3.00 (0.00)	52.07 (21.44)	3.86 (1.57)	14.53 (16.75)	1.71 (0.39)	1.58 (0.37)	1.42 (0.27)	82.00 (17.3)
12. Perennial crop	7	1.00 (0.00)	20.18 (28.70)	2.00 (1.00)	8.31 (6.96)	1.13 (1.26)	1.42 (0.34)	1.42 (0.34)	96.61 (3.52)

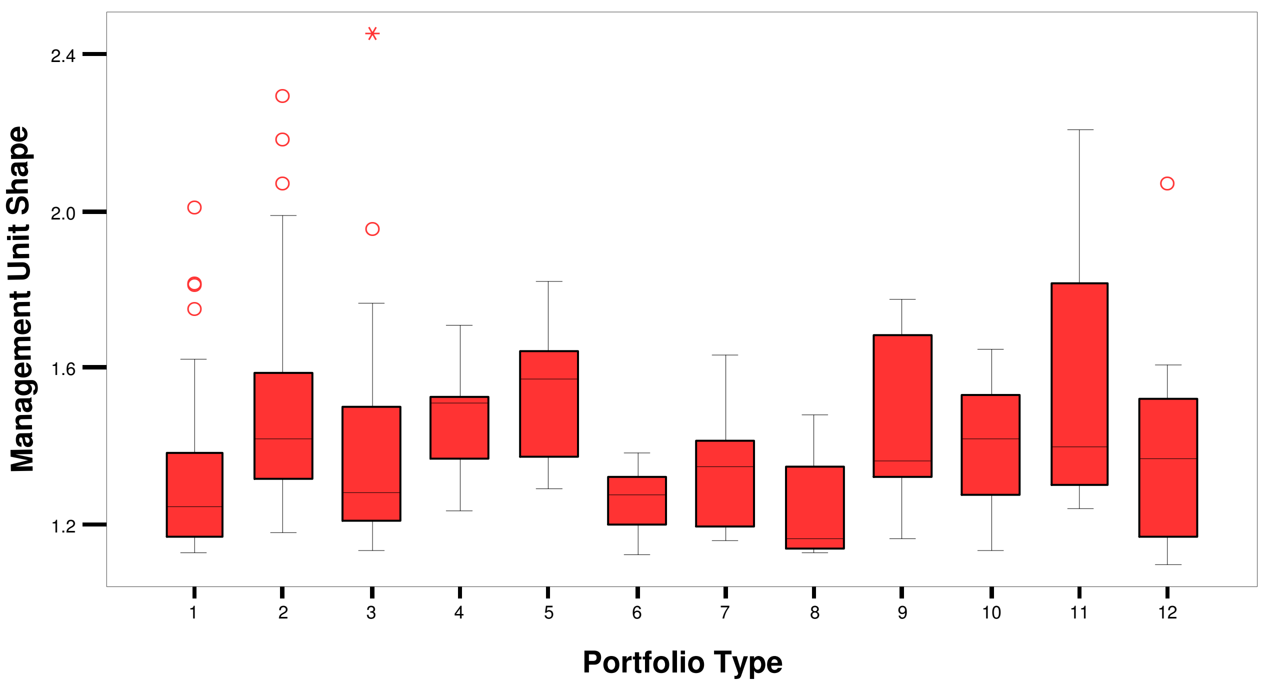


Parcel Area (ha)
60
40
20
0
1
2
3
4
5
6
7
8
9
10
11
12
Portfolio Type



Number of Management Unit Polygons
8
6
4
2
1
2
3
4
5
6
7
8
9
10
11
12
Portfolio Type


10
8
6
4
2
Number of Land-Cover Patches
1
2
3
4
5
6
7
8
9
10
11
12
Portfolio Type


2.4
2.0
1.6
1.2
Management Unit Shape
1
2
3
4
5
6
7
8
9
10
11
12
Portfolio Type

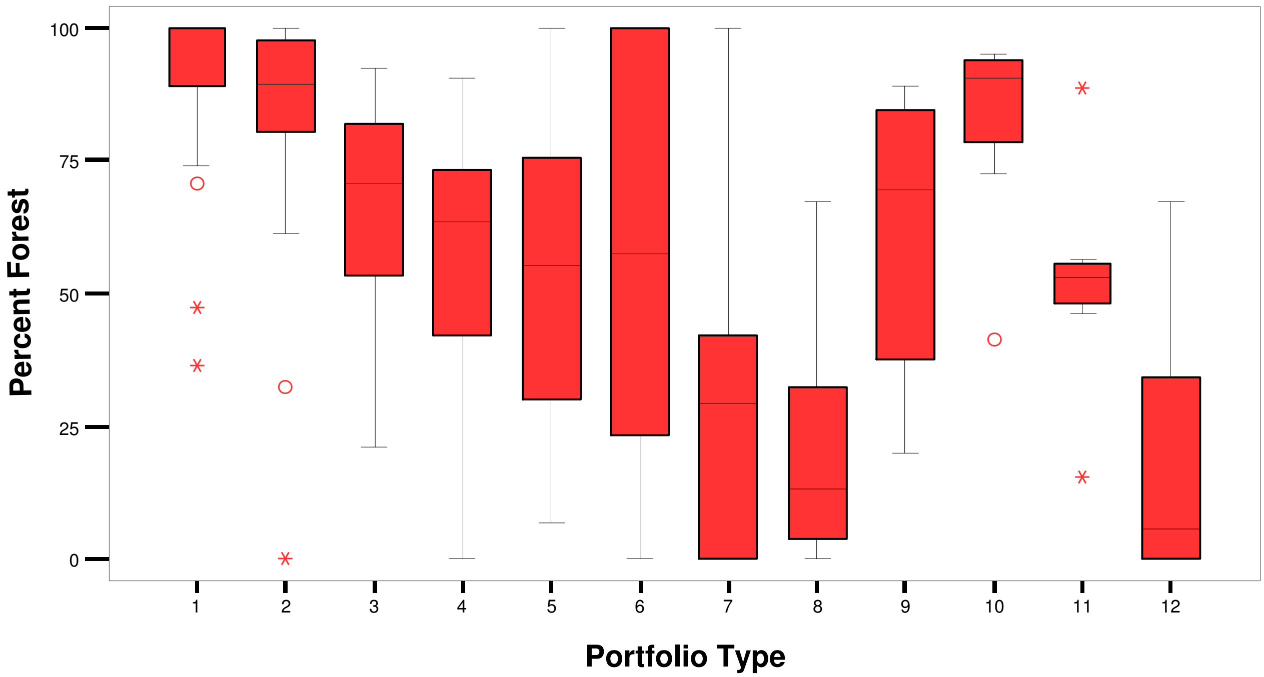


Figure 3.4 Boxplots of parcel shape, land-use metrics, and land-cover metrics grouped by portfolio types. Portfolio type numbers correspond to those in Table 3.3.

Table 3.4 Statistically significant (Mann-Whitney U with $p < 0.05$) differences between portfolio types in terms of parcel, land-use, and land-cover characteristics (a-h).

Portfolio Types	Forest	Forest/ Homesite	Forest/Pasture	Forest/Pasture/ Homesite	Forest/ Perennial crop	Homesite	Pasture/ Homesite	Pasture	Forest/ Annual crop	Forest/Lawn	Forest/ Perennial crop/ Homesite	Perennial crop
Forest												
Forest/ Homesite	abcdefg											
Forest/Pasture	abcdfg	abcde										
Forest/Pasture/ Homesite	bdefg	bfg	acf									
Forest/ Perennial crop	bcefg	abcg	e	f								
Homesite	abg	ef	acdf	ef	aef							
Pasture/Homesite	bdfg	beg	abg	befg	aeg	fg						
Pasture	bdg	abdefg	bfg	bef	bef	a	f					
Forest/Annual crop	bfg	abg	c	f	h	aef	a	bef				
Forest/Lawn	bf		abcdf	bf	a	af	bg	abfg	bf			
Forest/ Perennial crop/ Homesite	bcdefg	bcf	f		f	af	fg	bef	f	bcf		
Perennial crop	bg	bfg	acfg	bfg	bfg	g	f		bg	bfg	cfg	

Notes:
a: parcel area
b: percent forest
c: land-cover polygons
d: forest shape
e: average management unit shape
f: number of management unit polygons
g: Percent of parcel with slope less than 10º
h: parcel shape

Patterns in the results of the MWU can be described in terms of the portfolio types (rows and columns in Table 3.4) or in terms of the individual metrics (letters in Table 3.4). Some notable generalizations from these results include the following:

- The only individual metric that was significantly different between one portfolio type and all other portfolio types was the percent forest for the *Forest* portfolio. As expected, the percent forest for this portfolio type was higher than other portfolios. The boxplots show that the distribution of percent forest among *Forest* portfolios is very different than most of the other portfolios. The *Pasture* portfolio has a significantly lower percentage of forest cover than most other portfolios.

- While the *Forest/Homesite* portfolio also has a significantly higher percentage of forest than most other portfolios, the *Forest* and *Forest/Homesite* portfolios are significantly different in all variables measured. The boxplots show that while significantly different, the magnitude of differences between these two portfolios is generally not very great.

- Five pairs of portfolios are significantly different in all three land-cover metrics (number of patches, percent cover, and patch shape). The *Forest* portfolio differed from the *Forest/Homesite*, *Forest/Pasture,* and *Forest/Perennial Crop/Homesite* portfolios. The *Forest/Pasture* portfolio also differs from the *Forest/Homesite* and *Forest/Lawn* portfolios. In combination, then, the *Forest, Forest/Homesite,* and *Forest/Pasture* portfolios all differ from one another according to the land-cover metrics.

- The *Homesite* portfolio differed from *Forest/Homesite, Forest/Pasture/Homesite, Forest/Perennial Crop,* and *Forest/Annual Crop* portfolios in the land-use metrics but not the land-cover metrics. The boxplots show that this difference is because of the simplicity (lower number of simpler shaped management units) of the land use in the homesite portfolio.

- The number of both land-use polygons and land-cover polygons for the *Forest/Pasture* portfolio is significantly higher than most other portfolios, suggesting its land use and land cover are especially fragmented. The boxplots show that the number of land-cover polygons is relatively higher than the number of land-use polygons.

- In terms of parcel area, the *Forest/Pasture* portfolio is significantly larger than most other portfolio types, while the *Forest/Homesite* and *Homesite* portfolios are significantly smaller than most other portfolios. While not significantly different, the boxplots also show that the *Forest/Annual crop* and *Forest/Lawn* portfolios are larger and smaller, respectively, than most other portfolio types.

- Neither management unit shape nor forest shape varies greatly among the portfolios, as only the *Forest* portfolio has a significantly higher average shape index for forest polygons than most of the other portfolios. No portfolio shows a significant difference in the average management unit shape with a majority of other portfolio types. All portfolios were significantly different from the majority of other portfolios in terms of the number of management unit polygons. Because the values of this metric are integers ranging only from one to six, the large number of ties when rank ordering these values for the Mann-Whitney U statistic may exaggerate existing differences. In terms of topographic differences, the *Perennial Crop* portfolio and *Pasture/Homesite* portfolios are flatter than most other portfolios while the *Forest/Homesite* portfolio is steeper than most. The percent of the parcel with slope less than 10° was significantly different between the *Forest* portfolio and all portfolios except the *Forest/Lawn* portfolio

- Three pairs of portfolios were not significantly different in terms of any of the metrics, and thirteen pairs were only different in terms of one metric. The *Perennial Crop* and *Forest/Annual Crop* portfolios showed the least difference from other portfolios across all metrics.

3.4 Discussion

3.4.1 **Diversity in management strategy**

The histogram of management units per parcel (Figure 3.3) shows that most parcels, about two-thirds, are composed of multiple land uses. In addition, more than 75% of the portfolios that are managed as one land-use type are *Forest* and *Pasture* portfolios and these two land-use types have the highest polygons per management unit. So, even when a parcel has only one type of land use, there is likely some diversity in its management strategy. While this finding may not be unexpected, this variation in management has not been well documented at the parcel scale. This finding lends credence to treating parcels as portfolios of land uses rather than assigning a one-to-one relationship between parcel and land use, even when there might not be obvious variety in management strategies. Also worth noting is that all of the frequently occurring portfolio types have no more than three land-use types. Together, the findings that parcels are generally not managed as a single land-use type and that they are also not managed as a large number of different types of land use support the use of portfolios as a means to address land-management complexity at the parcel scale.

3.4.2 Land-management complexity and land-cover fragmentation

The correlations of land-use to land-cover metrics provide an initially straightforward but very general answer to the question of whether more land-management complexity is related to the fragmentation of land cover. The number of management units on a parcel is positively related to the number of land-cover patches, and the shape of those patches are negatively related to the amount of forest. In general, then, as the number of management units increase, so do the number of land-cover patches and the complexity of the shape of those patches while the amount of forest decreases. As the shapes of the management units become more complex, so do the shape and fragmentation of the forest. From these relationships, the generalization can be made that a more complex land-management portfolio does correspond to more fragmented land cover. This generalization, however, is not equally true across management portfolio types. While many of the particular complexities of these relationships are beyond the reach of this analysis, several important points will be discussed here.

While there is a general positive relationship between more land-management complexity and land-cover fragmentation, this analysis also reinforces the important fact that land use and land cover are not identical. Non-forest land uses all have some forest land cover. Some of this pattern may be attributable to spatial error in the hand-drawn maps of land use or the difference in the number of land-use and land-cover categories used, but in general, this pattern points to the fact that land use is defined by human actions. Respondents were asked to define management areas by activities that were undertaken on those areas, and patches of forest were included in all management unit types. Land-use types such as lawn, pasture, and homesite all had more than 25% forest land cover. As exurban land uses continue to increase in this and similar areas, forest land will likely move from land managed as forest to land managed for some other purpose that has some forested area.

The relatively high percentage of forest land cover in land-use types that are not necessarily forest-related suggests one reason why treating land use separate from land cover is important for understanding pattern-process linkages. For example, land mapped as homesite is on average comprised of more than 40% forest land cover (Table 3.1). The forest land cover of this increasingly prominent land use will be of greater ecological importance in the future landscape. Given the results above, the conversion of farm land to residential use would mean a change from perennial crops, about 20% forested on average (Table 3.1), to homesite use, about 40% forested on average. Thus a potential increase of forested land cover without an increase in land classified as forest land use.

By comparing the land use by type and portfolio statistics, it is also clear that there is substantial variance in the amount of forest land cover on homesites that comprise the entire portfolio and those that are grouped with other land uses in a portfolio. Homesites that are not grouped with other land uses on average have a higher percentage of forest land cover than homesites that are grouped with other land uses.

3.4.3 **Notable portfolio relationships**

Given that the homesite land-use type on average contains a substantial amount of forest, it is perhaps surprising that the *Forest* and *Forest/Homesite* portfolios are at all statistically distinguishable. More unexpected, however, is that these are the only two portfolios that significantly differ in all metrics. In a forested region where exurbanization is occurring, the construction of a home on a forested parcel is a common path from a *Forest* to *Forest/Homesite* portfolio. The process behind this change can be more fully understood by looking at the portfolio descriptive statistics. First, a parcel with a *Forest* portfolio is on average almost twice as large as one with the *Forest/Homesite* portfolio, so this transition would generally require a subdivision of the parcel. The parcel shape indexes for the two portfolios are almost identical, indicating a continuation of the general trend of rectangular parcels. The shape indices of the land-cover patches and management units, however, are both higher for the *Forest/Homesite* portfolio as are the number of land-use and land-cover patches. The fact that this change leads to significant differences in both land-use patterns and land-cover patterns is an important finding of this research.

Along with the differences between the *Forest* and *Forest/Homesite* portfolios, the *Forest/Pasture* portfolio differs from both of these in terms of the land-cover metrics. The *Forest/Pasture* portfolio is especially fragmented in terms of both land use and land cover. With few examples of commercially productive livestock herds in the study area, the majority of pasture is likely used for animals whose primary value is for home use, be it subsistence agriculture or more likely recreation. In any case, the presence of pasture land use makes a clear difference in the landscape.

The role of topography has been critical in understanding historical patterns of land use and land cover in the study area. While most of the area was cleared of forest for agriculture over the past two centuries, land with higher slope began to return to forest largely due to abandonment in the first half of the twentieth century. This afforestation process resulted in the high correlation between forest and higher slopes that is apparent today. The increased prevalence of residential land is now weakening this correlation as can be seen in the mean and standard deviation of slope values for homesite management units. These patterns are also reflected in the portfolios with forest generally having less flat land (< 10°) and portfolios with pasture and crops having more flat land (Table 3.3). The *Homesite* portfolio has a relatively low mean value and the highest variability of flat land. With a relatively high mean percent forest, the fact that the *Homesite* portfolio can occur across a greater range of topographic conditions could mean either more flat land will become forested or more hilly land could become non-forest. The finding that the *Pasture/Homesite* portfolio has a relative lack of steep slopes goes against this generalization, however, and again suggests that some land uses might be better understood in combination.

An example of the challenge in understanding land-cover dynamics associated with residential land use can be seen in the fact that the *Homesite* portfolio differed from *Forest/Homesite, Forest/Pasture/Homesite, Forest/Perennial Crop,* and *Forest/Annual Crop* portfolios in land-use metrics but not land-cover metrics (Table 3.4). This means that even though these portfolios are significantly different in management strategy, this difference does not have a clear connection to land-cover outcomes as measured here. While this finding again underscores the need to treat land use and land cover separately, it also suggests that the formulation of a land-use portfolio presented here does not simply solve how to accomplish this separation.

Future applications of the land-use portfolios approach might take into account that several pairs of portfolios were not significantly different in any metrics and that the shape metrics did not add much information. A lack of difference between the *Forest/Lawn* and *Forest/Homesite* portfolios is not surprising and likely reflects land-use classes that could be merged without the loss of important management information. The lack of difference between portfolios such as *Perennial Crop* and *Forest/Annual crop* and almost all other portfolios probably reflects the fact that agriculture is not an important land use in this landscape. It is reasonable to think that in areas where agriculture is a more important land use and carries more weight in decision making, these land uses would be more prevalent and potentially more separable based on the land-use and land-cover metrics.

3.4.4 **Context of exurbanization**

The relationships observed in this small study area should be considered in the broader context of urbanization. Exurban development is a dominant form of urban expansion in this study area and many other regions in the United States. Brown et al. (2005) show that between 1950 and 2000, the amount of land in the United States classified as exurban rose from 5% to 25% of total land area. At the scale of the household and parcel, exurbanization is characterized by the subdivision of parcels but the continued dominance of the one household to one parcel relationship. In terms of this research, the increasing role of residential land use in the process of exurbanization might best be addressed by looking at portfolios that contain the homesite land use. As discussed above, the relationship between land use and land cover in portfolios containing the homesite land use is noticeably weak. The only portfolio pairs that are significantly different in land-use metrics but are not significantly different in land-cover outcomes are three pairs involving the *Homesite* portfolio. An important exception to this generalization comes in the fact that at almost 85% forested, the *Forest/Homesite* portfolio has a significantly higher percent forest than many of the other portfolios.

Given the drastic increase in the amount of exurban land in the United States, the ecological implications are of great and increasing importance. The above findings suggest several things. First, the weak link between land use and land cover on parcels that include the homesite land use point to increased heterogeneity that is inherent in the exurban landscape is also present at the parcel scale. Second, the findings suggest that on an increasing number of small parcels, the configuration of land use and land cover will change but not necessarily the composition of land cover. That is, the configuration of forest patches may change but not necessarily the amount. Landscape ecology has focused on the effects of such changes in spatial structure of the landscape and has shown that these changes in configuration even when composition is relatively stable can have significant effects on ecosystem processes involving habitat edge and core (Turner et al. 2001).

While this research further explores the link between land use and land cover on individual parcels, understanding how these individual management decisions aggregate to the landscape scale is clearly of importance. Further research, then, should move to that broader scale to assess if there is a spatial pattern in the distribution of portfolio types. In this question lie the historical processes of the shift from predominantly agricultural land uses to the current exurban mix of agriculture, forest, and residential land uses. The particular spatial organization of this transition is shaped by the path-dependent nature of parcelization (Donnelly and Evans 2008). A spatially explicit modeling approach that describes the parcel-scale land-use and land-cover patterns could be used to test different spatial arrangements of those same parcels to address this question.

3.5 Conclusions

In order to address the relationship between land-management complexity and land-cover fragmentation in Monroe County, Indiana, this research employed land-cover metrics taken from landscape ecology to compare spatial patterns in land-use maps derived from household interviews and land cover derived from aerial photography. Land management was described in terms of land-use portfolios, or parcels with distinct combinations of land uses. Properties are in most cases diversified entities with about two-thirds of landowners managing their parcels as multiple land-use units. In general, increased land-management complexity is positively related to more fragmented patterns of land cover in the study area. Of ecological importance in this naturally forested region, the land cover of portfolios made up of only forest land use is predominantly but not completely forest land cover. Furthermore, all land-use types have some forest land cover included in them. The heterogeneity that defines exurbanization is present at the parcel scale as a mix of management unit types that are observed in combination with homesites. One example of the importance of the broad trend of exurbanization is the significant difference between parcels with only forest land use and parcels with forest and homesite land uses. These two portfolio types exhibited the statistically significant positive relationship between land-management complexity and land-cover fragmentation across all spatial metrics. The portfolio-based approach provides some specific insights and greater descriptive power than the constraints of an approach based on land cover or simply assigning a single land-use type to each parcel. The methods developed here facilitate separating land use and land cover and will thereby aid in understanding the connection between increasingly diverse household characteristics and the land-cover outcomes of their management decisions.

4 Land Ownership and Land Cover in Intentional Communities of the Eastern United States

4.1 Introduction

Land-use and land-cover change is an important contributor to global environmental change. Understanding these broad-scale outcomes entails connecting institutions at a variety of scales to decision making and ecological processes at very local scales. At the intersection of land use and land cover is the set of ownership or property-rights rules that enable and constrain the decisions of land managers. The successes and failures of collective property-rights arrangements have received substantial attention in the search for effective strategies to address environmental degradation (Gibson et al. 2000, Campbell et al. 2001), but this attention has focused much more on non-industrialized nations and the history of industrialized nations than on current strategies in industrialized countries. In this context, the dichotomous formulation of private versus public ownership is often the only differentiation made in developed nations. A higher level of awareness and concern over global environmental change in the context of urbanization has led to an increase in the occurrence and recognition of alternative property-rights arrangements that can be matched to the sustainable use of a particular resource.

This paper examines intentional communities in the eastern half of the United States as examples of property-rights arrangements that do not easily fit into the private versus public dichotomy and may have value in addressing issues of land-use and land-cover change in an urbanizing context. The notion of intentional community, a term now widely adopted by a variety of groups (Schaub 2005), encompasses much of the spectrum between the two endpoints of private and public ownership. The definition and history of intentional communities will be further discussed below, but generally the term will be used here to refer to a group of people who have come together with a goal of residing on land somehow owned in common. The scholarly attention that intentional communities have received has been almost exclusively focused on the shared goals of the members of the communities (Fairfield 1972, Halfacree 2006, Meijering et al. 2007a) and has not addressed the relationship of the community to the physical landscape. Land ownership provides a useful way to bridge from the ideological characterization of communities to these increasingly important social-ecological relationships. This chapter will address whether the legal type of land ownership in intentional communities is related to the fragmentation of land cover within community boundaries. The necessary first step in addressing this question is to identify the legal types of land ownership used by intentional communities. Then, the relationship of the legal type of land ownership with community characteristics will be tested. The expectations are that more communal forms of land ownership will be associated with communities with higher population density, more overall forest area, and less land-cover fragmentation.

4.2 Background

Initially postulated as a relatively simple relationship between driving forces and environmental impacts, an understanding of the underlying and proximate causes of land-use and land-cover change has resisted simple generalization (Lambin et al. 2001). One primary factor that structures how management decisions translate into land-cover outcomes is the existing property-rights arrangement, in terms of what decisions managers can make and the spatial organization of those decisions, but no single type of land ownership has proven effective in preventing ecological degradation in all cases (Ostrom and Nagendra 2006). In the United States, private ownership is most often described as an individual, household, or corporation having nearly unbounded rights to use the land that they own as they see fit. Such simplifications about the nature of property rights and how those rights are spatially distributed need to be examined to better understand how property-rights institutions affect land-cover outcomes, as research has shown that a combination of local and state actors may be the best hope for long-term conservation (Vogt et al. 2006). Recent scholarship on the increasing prevalence of community-based forest management in the United States provides an exception to the public-versus-private simplification (see Baker and Kusel 2003). While most of the groups examined in terms of community-based forestry do not fit in the definition of intentional community used here, Nelson et al. (2008) report on changing forest conditions in an intentional community in the state of Michigan. These authors point out that forest extent is often the measure used to ascribe success or failure to communally managed forest but that the lack of management in communities where forest is valued for spiritual reasons may lead to degradation of biodiversity.

4.2.1 **Property rights as institutions**

The concept of intentional community helps to fill in the remaining gap between the oversimplification of public and private land ownership. McKean (2000) explains that inappropriate property-rights institutions may be rooted in the failure to separate the goods derived from a resource, the type of rights being defined, and the entities in which the rights are vested. While each of these issues is important in understanding the relationship between the spatial patterns of land ownership and land-cover outcomes on private property, understanding the special case of intentional communities begins by delineating the agents in whom property rights are vested. Various *positions* that exist in intentional communities must first be identified and understood as the institutional building blocks. These positions are filled by specific *participants*, who may be either individuals or groups treated as individuals (Table 4.1) (Schlager and Ostrom 1992). While private-property laws generally describe what rights are vested in the positions, the added institutional layer provided by intentional communities allows the organization of the building blocks in a myriad of ways. This diversity may complicate the dynamics occurring in land-use and land-cover decisions, but may be important in the resilience of the landscape system. This research uses these notions of positions and participants to describe the institutional composition of intentional communities so their effects on land-cover patterns at the community and landscape levels can be addressed.

Table 4.1 Positions within intentional communities defined by combinations of rights.

Positions	Operational-level rights		Collective-choice rights		
	Access	Withdrawal	Management	Exclusion	Alienation
Squatter					
Authorized entrant	X				
Authorized appropriator	X	X			
Claimant	X	X	X		
Proprietor	X	X	X	X	
Owner	X	X	X	X	X

Source: Adapted from Schlager and Ostrom (1992).

Two dimensions of property rights will be used here to elucidate intentional communities in terms of legal ownership. First, land ownership must be understood as a separable bundle of rights that can be distributed among several individuals or groups rather than one all-encompassing right. Within the bundle of rights that constitute land ownership are the right to alienation, the right of occupation, and the rights of use. Therefore, one person may own the land in the sense that he or she has the right to sell the land, another may rent the land such that he or she holds the right to occupy it, and yet another may hold use rights so he or she may legally be allowed to alter resources or harvest them from the land. The second dimension of property rights important for this research is that one community is not necessarily a single or homogeneous entity to which rights are assigned. That is, as a self-defined entity, an intentional community can be composed of any combination of individuals and corporations with any combination of rights given to those entities. The resilience of intentional communities as social-ecological systems is, at least in some part, related to the strategies devised to distribute the facets of ownership among the different positions created.

Several examples of the separation of the bundle of ownership rights are already quite common in the United States. From the 1960s, the growth of common-interest developments and the use of homeowners' associations have skyrocketed. Some estimates suggest that one in three Americans now lives in some form of common-interest development (Klein 1995). While there is some variation in the distribution of property rights in these communities, usually some use rights are given up on the resident's land while some use rights are granted to commonly held land. The use of a condominium legal structure is also common and closely related in its division of the bundle of ownership rights and responsibilities. The increasing prevalence of land trusts as a means of environmental conservation is a different division of rights that has a stronger emphasis on restricting the actions of future landowners. From 2000 to 2005, the amount of land held in state and federal land trusts doubled to more than 37 million acres (Aldrich and Wyerman 2006). Common-property approaches such as grass banks (Sayer 2005, Robbins 2006) and community-based forestry (Baker and Kussel 2003) are still not common legal ownership structures but their occurrence is on the rise.

4.2.2 Intentional community

Reviewing the history of intentional communities in the United States, Zablocki (1980) points out that although communal organization has never played a dominant role in American society, not a single year has passed in which no new intentional communities were initiated. The rate of incidence and the reasons for community formation, however, have been far from constant. Kanter (1972) divided the history of intentional communities in the United States at the time of her writing into three periods based on the set of community core values that was most dominant during the period.

Communities formed during the earliest period, from the early 17th century to the early 19th century, had at their core some set of religious or spiritual values while the second wave of intentional communities held at its core the want of an alternative to capitalist economics (Zablocki 1980). The third and largest wave of new intentional communities in the history of the United States began with the counter-culture movement in the 1960s (Oved 1999). While the overall number of communities initiated during this period dwarfs that of any other period, the ratio of communities to overall population is similar from period to period (Zablocki 1980). The majority of the communities beginning during this period did not survive for more than a few years due to their lack of a theoretical or practical base (Oved 1999), but enough did survive the maturation process to continue on through the present day.

The dominant ideological core of the most recent wave of intentional communities is one of environmental or ecological concern. This wave of intentional communities has moved toward balancing individual and collective needs and has resulted in less comprehensive institutions, where some parts of life are lived collectively but others are controlled by the individual. New community types, such as ecovillages and cohousing, focus on relatively specific applications of communal structure while leaving the governance of other facets of life to the individual. The move away from a strict communal form of intentional community has been described as both a degradation of the utopian ideal (Kanter 1972) and a more realistic approach resulting in increased community stability (Oved 1999).

A related and concurrent social trend has been described as the back-to-the-land movement, which began in the 1960s but had largely disappeared by the 1980s (Garkovich 1989, Jacob 1997). This movement consists of relatively well-educated people choosing to move to rural areas and pursue a simpler life with an emphasis on environmentally sensitive subsistence and semisubsistence living. Part of a larger overall counterurban demographic trend (Garkovich 1989, Jacob 1997), many people were seeking better access to recreational amenities, greater natural resources, ecosystem services (Midmore and Whittaker 2000), and cheaper land (Daniels 1999) in these fringe areas. In many cases, these individuals have played fundamental roles in the formation of the most recent wave of ecologically oriented communities.

Although substantive work on intentional communities has been produced in fields such as anthropology (Fairfield 1972), history (Zablocki 1980), and political science, there has been little attention given to the geographic dimensions of intentional communities. One of the few current studies of intentional communities focuses on the "life-course" of communities and their relationship to the rural context in which they may exist (Meijering et al. 2007a, Meijering et al. 2007b). This project has employed both detailed case studies and widely distributed questionnaires to assess the degree of withdrawal of the community from mainstream society. The typology that resulted included four types of communities (religious, ecological, communal, and practical) that occurred in roughly equal proportions (Meijering et al. 2007a). Intentional communities have garnered some attention in the broader examination of urban-to-rural migration and especially the back-to-the-land movement that has seen some resurgence in the last decade (Halfacree 2006, 2007). This approach focuses on the role of counter culture in the change from a productivist to a post-productivist rural space. Gibson and Koontz (1998) provide a rare example of drawing connections between the social and ecological characteristics in intentional communities by describe the relationship between forest management and the institutional mechanisms used to homogenize and mitigate conflicting values of community members.

Inherent in any examination of intentional community is the definition that is used, and no single definition has been widely adopted. In his book on communes, Fairfield (1972) defines a commune as a group of three or more people whose primary bond is some form of sharing and treats an intentional community as something even more general than that. In an attempt to more clearly describe what makes an intentional community, Questenberry (1996) gathered responses "on the nature and description of intentional community" (p. 1) from those living in such communities in the United States. Providing a useful working definition, one longtime community member and organizer stated that "an 'intentional community' is a group of people who have chosen to live together with a common purpose, working cooperatively to create a lifestyle that reflects their shared core values" (p. 2).

The definition from Questenberry (1996) highlights several important facets of intentional communities. First, an intentional community must consist of a group of people. While this aspect may seem trivial, various property-rights arrangements as well as the location of those considered members of the community may complicate this idea. Next, the group of people must in some way reside together. The intentional part of such a community comes from the fact that the people have consciously chosen to be part of the group and live together. This stands in contrast to a "circumstantial community," such as a neighborhood or nation in which the participants may or may not have chosen to be part of the group (Questenberry 1996, p. 3). A corollary to having chosen to be part of an intentional community is that the group accepts the individual as a member of the community. The definitions collected by Questenberry (1996) also highlight the importance of a set of shared values, goals, or ideals. The set of ideals provides the core around which cooperation is organized and has been the basis of most work on understanding and categorizing communities. From these definitions, it is clear that the idea of intentional community describes a wider range of existing scenarios than has been previously considered.

Of particular interest here is the legal form used by communities to own land. Several useful articles, handbooks, and websites exist with the aim of better informing those seeking to establish intentional communities on the possible ways of legally structuring land ownership. Hensen et al. (2000) give the following list of legal mechanisms used in communities that will serve as a starting point in this research for identifying the relevant institutional building blocks:

- Simple partnerships
- For-profit corporations
- Subchapter S corporations
- Limited liability companies
- Limited Partnerships
- Non-profit corporations
- Cooperatives or mutual benefit corporations
- 501(c)&(d) non-profits
- Private land trust
- Community land trust
- Homeowners/condominium association

In the context of using legal ownership structure as an organizing principle, it is also useful to describe what will not be considered an intentional community for this research. The current research is concerned with the relationship of intentional communities to land-cover change. As such, the focus is necessarily on more rural rather urban intentional communities because they own land. The bounds of this study have on one side a group of individually owned parcels where the participants consider themselves a community but have no formalized legal relationship. Also on this end of the spectrum is the increasingly prevalent common-interest development (CID) where some land is owned collectively by residents incorporated as a homeowners' association. This form of community is not included in the study because it is nearly always initiated by a land developer who forms the homeowners' association and at some point leaves it for the residents to run. Increasingly, however, this boundary is becoming blurred as groups of people wish to form a community and hire a development firm to do so. Bounding the notion of intentional communities on the other end is public land held by the government. While there are often many restrictions on the use of this land, they apply equally to all citizens of the state.

4.3 Data and Methods

At the present time, the number and visibility of intentional communities is on the rise. According to Questenberry (1996), nearly 200 communities provided detailed information to the 1990 *Directory of Intentional Communities*. By 2007, this number had increased by nearly tenfold (www.ic.org). In 1990, the communities in the Fellowship for Intentional Community (FIC) directory consisted of more than 10,000 people holding more than 35,000 acres of land. Along with the fact that these numbers only represent communities which chose to include themselves in the directory, these numbers also reflect only a certain, more modern definition of intentional community. Excluded from these statistics are some of the largest religious communities such as the Hutterite (40,000 members in various U.S. and Canadian colonies) and Bruderhof (2,500 members in North America, Europe, and Australia) communities (Oved 1999). Given the definition developed above, many more communities could be included that would drastically increase these numbers.

As argued above, viewing land ownership as a bundle of rights that can be organized in a myriad of ways allows the public-private dichotomy to be better described as a spectrum. The notion of *intentional community* is useful in elucidating part of this spectrum but requires a more specific definition, as no standard has yet arisen. The criteria for communities to be included in the current study are:

- the community is located in a forested ecosystem of the eastern United States,
- the community owns more than 10 acres of land,

- some rights to the land are legally held in common,
- the community must have at least three non-family members, and
- the community was initiated by past or present members.

A sequential exploratory strategy (Cresswell 2003) is used in this research where the initial research goal is to identify existing categories, types of land ownership in this case, followed by quantitatively testing those categories to see if they are related to differences in population, area, and land-cover patterns. The overall population of communities was compiled from a combination of existing databases and snowball sampling. The FIC maintains a directory of intentional communities around the world that is currently comprised of more than 1,700 groups that self-identify as intentional communities. While the majority of these groups do not fit the criteria for this study, the database is still the largest source of information on communities and often provides a means to contact the community. The International Forestry Resources and Institutions (IFRI) research program has collected highly detailed information on communities worldwide that own forested land collectively. Several communities have been identified and visited by IFRI researchers in Indiana and Michigan and a subset of the communities meet the criteria for inclusion in this study. Any community in either of these databases that was contacted was asked to list other communities that might be willing to participate in the study. The specific data and methods for each research questions are described separately to highlight the fact that different subsamples were necessarily used for each question because of data limitations.

4.3.1 Legal type of land ownership

From the data sources listed above, 128 communities were identified as meeting the criteria to be included in this study. A subsample of these communities (n = 46) was contacted for details on the legal type of their land ownership. Information on the types of ownership employed by the communities was gathered from personal correspondence in the form of email, phone conversations, community websites, and other literature provided by the communities. The minimum information collected was enough to verify that the community met the criteria for being included in the study and how the community owned land. In most cases, much more information on the goals, strengths and weaknesses, and history of the community was also made available. As mentioned above, each community was asked to recommend any other communities that they thought would be important to this study because they represented a different ownership type and would likely participate. Collection of this qualitative data ceased when all of the known types of ownership identified by the respondents had been encountered.

4.3.2 Land-cover patterns

One goal of this paper is to test the relationship of ownership structure to patterns in land cover. As a broad means of controlling for ecological variation, the states of the United States east of the Mississippi River have been included. The natural vegetation of this ecosystem domain is almost entirely composed of broadleaf, coniferous, and mixed broadleaf-coniferous forest ecosystem divisions.

The availability of cadastral and land-cover data allowed for an intensive spatial analysis of 18 of the 46 communities that were used in developing the categorization of land ownership. Existing digital spatial databases of cadastral and land-cover data were the preferred format when available. As there is yet no standard method of disseminating digital cadastral data in the United States, sources varied from one community to another. Where the town, county, or state made digital cadastral data available, the entire dataset was obtained. More often, the data are served via an online GIS where only snapshots of the data are available, requiring that the images be registered and the parcels digitized. When digital data were unavailable altogether, hard-copy plat maps were obtained from either local government or libraries. These paper maps were then scanned, registered, and digitized for integration in the GIS.

Land cover was derived from digital aerial photography. As with the cadastral data, data from local governments were preferred because they were often more recently acquired and of higher spatial resolution. When necessary, photos from the United States Geological Survey were downloaded in digital format and used. While no specific cutoff date was used for the age of the photos, the acquisition date had to be after the community had reached its current level of development so the land cover reflected the current institutional situation. Land cover was digitized in ArcGIS to the level of forest/non-forest using a minimum mapping unit of 20 m by 20 m and 50% crown cover to define forest.

From the above data, several spatial metrics developed in the field of landscape ecology for comparing spatial patterns in areal data were calculated to test the relationship between ownership structure in intentional communities and land-cover outcomes. All spatial metrics are calculated for the spatial extent of all ownership parcels comprising the community. The boundaries of the community were treated as the boundaries of the land-cover patches even when the land cover might continue across the boundary. One of the communities owned parcels that were not all adjacent.

The shape metric used is a ratio of the perimeter of the polygon to the perimeter of the circle with the same area (McGarigal and Marks 1995). This metric has a range of one, in the case of a perfect circle, to infinity where a higher value results from a more complex or less compact shape. The shape metric for a square, a more likely parcel shape in the context of the Public Land Survey System, is 1.128. While the polygon areas in this study do not cover a very large range, this shape metric is robust across scales. The shape metric was calculated for each forest patch and an average (MShp) and standard deviation are reported in Table 4.2 in section 4.4.2.

For each community, counts of the number of forest patches (NFP) and non-forest patches (NNFP), percent forest (%For), and mean area of forest patches (MFA) were used to describe the fragmentation of the land cover. Because the land-cover categorization was dichotomous, only the percent of the parcel in forest cover was necessary to describe the land-cover composition.

Results of the qualitative category building provide the groupings for the communities based on their ownership structure. Because of the non-normal distribution of the metrics, statistical comparisons are made using the Mann-Whitney U (MWU) to compare the mean rank of metrics between groups. To provide further information on the relationship between variables, Spearman's rho non-parametric correlations were also calculated.

4.4 Results

4.4.1 **Legal types of land ownership**

The process of grouping communities based on legal structure of land ownership began from the direct examination of 46 communities and was informed by existing lists of possible legal structures. These considerations along with the need for quantitatively testable categories led to a hierarchical categorization of legal structures used by the communities (Figure 4.1). Short descriptions of the three categories with maps of representative communities (Figures 4.2, 4.3, and 4.4) are provided in the next three subsections, with further treatment included in the discussion and tables in section 4.4.2.

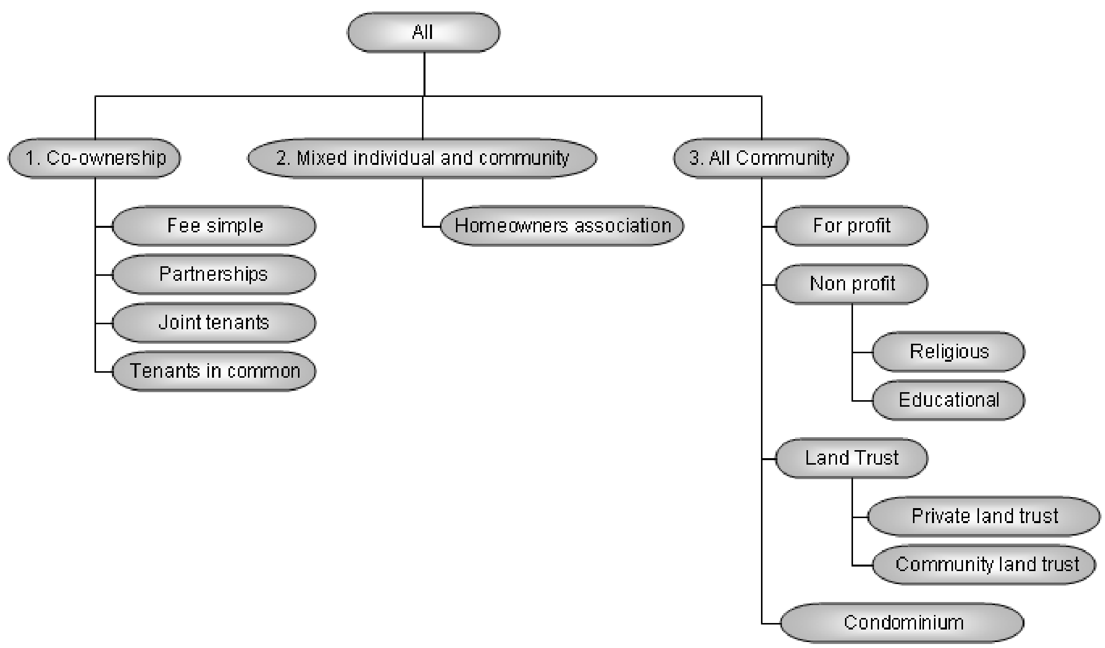


Figure 4.1 Classification tree of types of land ownership used by intentional communities in the eastern United States.

4.4.1.1 Co-ownership

Communities composed of land owned by individuals as joint tenants, tenants in common, or in partnerships constitute the category most similar to standard fee-simple ownership in terms of the distribution of rights. In this category, each of the individuals involved may retain the full spectrum of property rights associated with the position of owner. Differences in legal structures such as joint tenancy and tenancy in common become important to communities when one member's share, because of death or choice to alienate the land, is sold to another individual. Differences in joint tenancy and tenancy in common include the option to have unequal shares among tenants in common and to whom the ownership passes upon death. Restrictions on resale of the land are common such that members of the community are first given the chance to buy the land before it is offered to non-members. In general, these forms of ownership do not differentiate use rights such that any member can make decisions about how to use the land and does not need, legally speaking, authorization from the other partners. Legal arrangements such as covenants, conditions, and restrictions might also be used to structure the rights of owners.

Generally, communities employing this form of ownership hold areas where their houses are located in individual, private ownership while areas such as forest, lakes, ponds, and shared infrastructure are held in common (Figure 4.2). Agreements on how to manage the common areas are informal, as they are not dictated by the legal structure of land ownership, and sometimes the source of conflict. Instances were observed where this right of first refusal was both a formal rule and an informal rule.

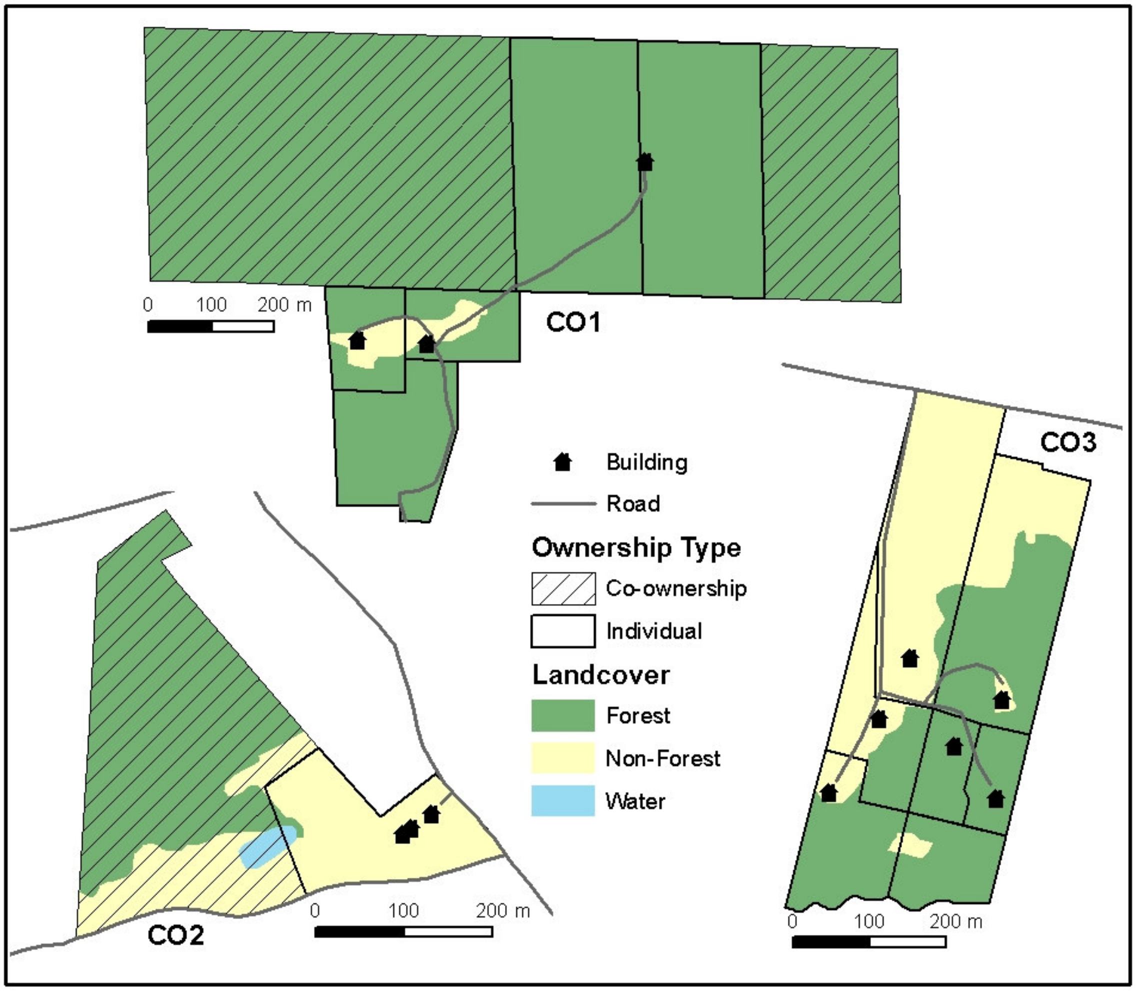


Figure 4.2 Examples of communities that use co-ownership.

4.4.1.2 All land owned by community

Several different types of corporate structures have been used by communities to own land ranging from for-profit corporations to several types of non-profit corporations to private and community land trusts (Figure 4.3). While this category of legal structures is generally the most communal of the three categories used here, substantial variation exists in how and why communities use these forms. One important variation in this category of ownership is whether the board in charge of the corporation is filled by residents or non-residents of the community. In terms of filling the positions defined by the legal structure, this is potentially a radical deviation from how land ownership is often conceived. Community land trusts, as opposed to private land trusts, are used for this purpose and require that a majority of the board of trustees be non-residents. Communities encountered in this research include boards composed entirely of residents, entirely of non-residents, and a mix of residents and non-residents.

In general, communities in this category structure ownership such that the corporation owns the land and individuals lease land and buildings from the corporation. The corporation then dictates what rights the lessee has to the land. Other considerations that were mentioned by respondents in choosing between the corporate forms employed are liability concerns, tax considerations, controlling who can join the community, the maximum allowable size of the community, the ability to apply for government and foundation grants, restrictions on political activity, and how assets of the corporation are distributed upon dissolution. While each of these considerations was mentioned by at least one community, none was frequently cited as important. The condominium legal structure falls in this category, as all land and buildings belong to the corporation. The living space in the building may change ownership and the right of first refusal may or may not be required by the community.

The somewhat paradoxically named "private land trust," used by communities AC1 and AC3 in Figure 4.3, is where the board of the corporation is filled by members of the community. This structure gives the community the most control over the allocation of rights and responsibilities and is most frequently used when economic activities take place on the community land. Depending on the particular activity, it is likely that the use of community land for economic activities other than residential uses tends to result in a greater total amount of non-forest land cover that occurs in a more spatially dispersed pattern. Common in communities in this category is an explicit goal of education or outreach, most often focused on sustainability. Community AC3 is engaged in activities ranging from hosting workshops to publishing literature about intentional communities as well as commercially harvesting timber and running a commercial nursery on the land. Some communities, such as AC2, grant others temporary use of the land for activities such as music festivals and camping, which generate income for the community and generally require that additional area be maintained in non-forest land cover. In only one of the surveyed communities was a for-profit form of corporation used to own land and, according to the community members, that was not for economic reasons. In many cases, economic activities are organized as separate corporations from the non-profits that legally own the land, so some communities are associated with numerous corporations that serve different functions.

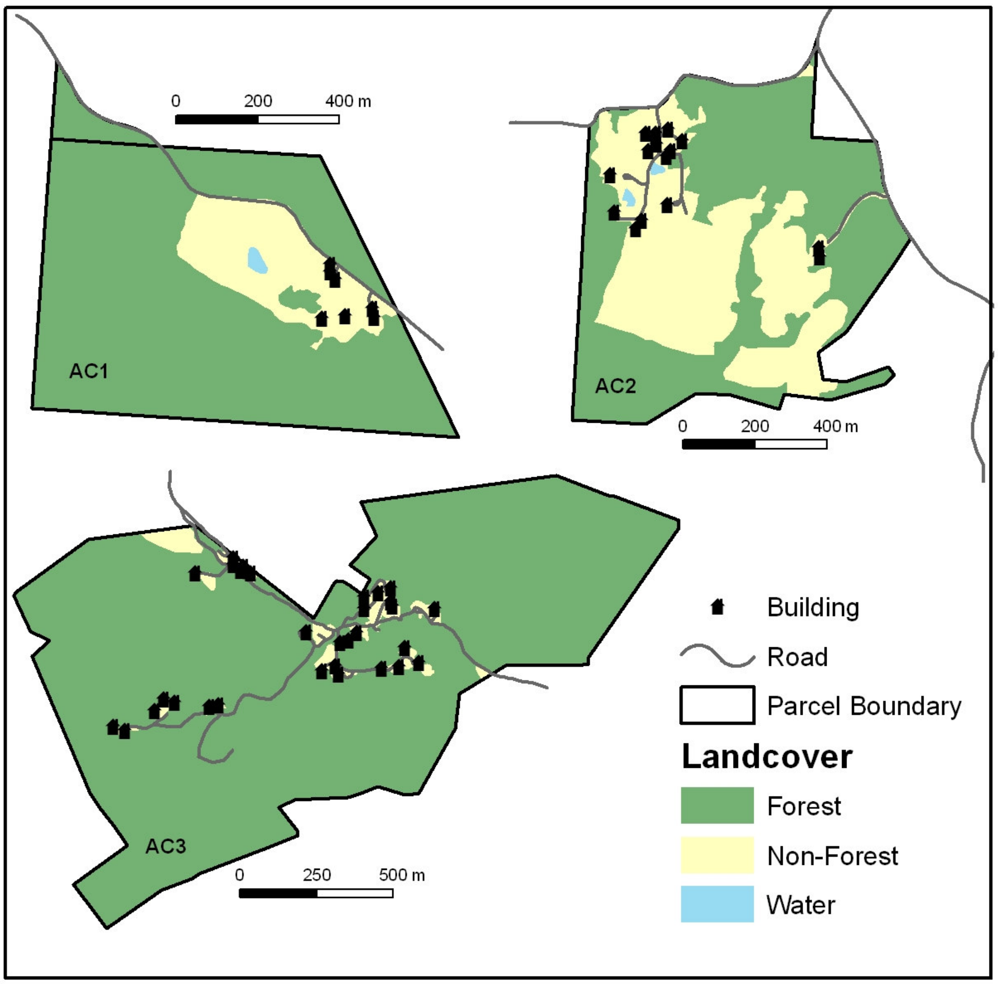


Figure 4.3 Examples of communities where all land is owned collectively.

4.4.1.3 Mixed individual and community

Communities composed of some combination of land owned by individuals and by corporate entities comprise the third category used in this research (Figure 4.4). This form of ownership draws on both the desire for private lands and the recognition of the advantages of common ownership. Reflecting broader residential patterns in the country as a whole, the most common corporate form used in this category is the homeowners' association. Covenants, conditions, and restrictions on the individually held lands are the most common way of legally structuring the relationship between the land held by individuals and the land held by the community. Restrictions on land use in some communities include the clearing of forest, location of structures, and construction styles. As above, the right of first refusal when a landowner wishes to sell individually held land is used frequently.

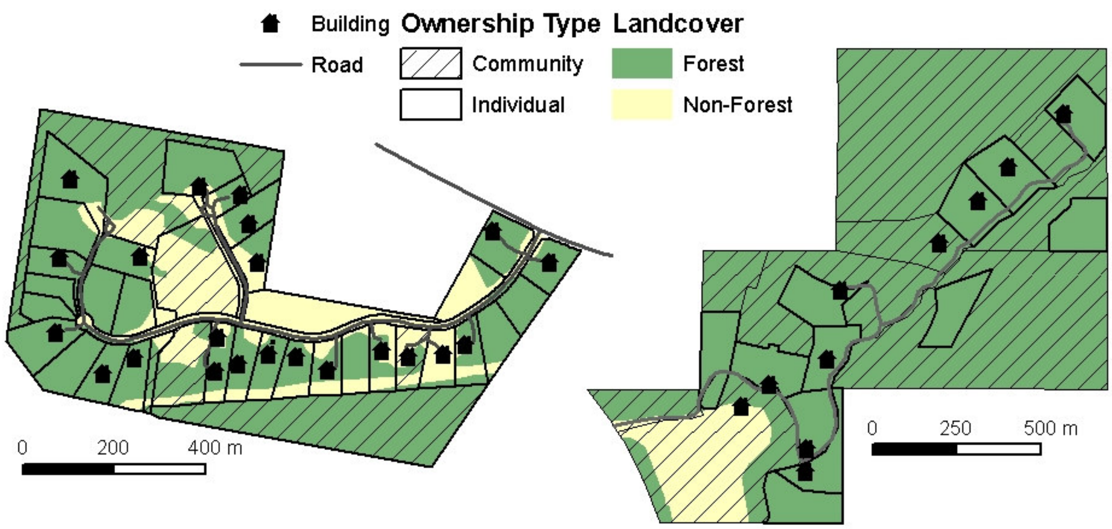


Figure 4.4 Examples of communities that use a mix of individual and collective ownership.

An important variation in this category is whether the boundaries of the individually owned parcels are chosen by the community or by the individual. In Figure 4.4, the community on the left laid out the parcel boundaries as a collective decision prior to the occupation of those parcels, whereas the individual owners in the other community chose the boundaries of their own parcels. An extreme example, not pictured here, is where the individual landowners were allowed to choose a location anywhere on community land, which became the center point of a circular parcel. This type of variation is related to whether a community knows from its inception how many parcels there will be or whether they will allow new parcels to be created as the community evolves.

4.4.2 Land-cover patterns by land-ownership type in representative communities

Sufficient data from 18 communities enabled us to proceed with a quantitative spatial analysis of the land-cover outcomes and a comparison between ownership types. Because more detail was available for these communities, we used three groups, defined by complete individual ownership, complete community ownership, and mix of both individual and community ownership. Descriptive and inferential statistics are provided in Tables 4.2, 4.3, and 4.4.

Table 4.2 Descriptive statistics for three community types and all communities. Means with standard deviations in parentheses.

	All communities	1. All individual ownership	2. Mix of individual and community ownership	3. All community ownership
N	18	4	6	8
Adult population	26.11 (27.35)	6.75 (3.59)	25.50 (16.02)	36.25 (36.00)
Area (ha)	55.21 (51.17)	24.97 (21.29)	72.76 (66.06)	57.17 (47.51)
Population density (p/ha)	1.02 (1.80)	0.42 (0.30)	0.84 (1.12)	1.46 (2.54)
% Forest	75.27 (21.78)	74.41 (22.16)	81.43 (14.26)	71.08 (27.26)
MNFP	2.28 (1.74)	1.00 (0.00)	2.83 (1.84)	2.50 (1.93)
MNNFP	3.39 (2.93)	1.75 (0.96)	2.83 (1.94)	4.63 (3.77)
MFA (ha)	27.05 (36.11)	20.99 (22.72)	24.32 (20.78)	32.14 (50.80)
MShp	1.906 (0.328)	1.723 (0.122)	1.816 (0.342)	2.065 (0.342)

Notes: MNFP, mean number of forest patches; MNNFP, mean number of non-forest patches; MFA, mean area of forest patches; MShp, mean shape of forest patches.

There is considerable variation in the size of the communities with the largest average population occurring in communities where all land is owned communally and the largest amount of area occurring in communities with a mix of individual and community ownership. Population densities are highest in communities with all communally owned land. All of the communities are substantially forested with an overall mean of more than 75% forest with a mean average forest patch size of about 27 ha (66.7 acres). The mean number of forest patches in all communities is 2.28 and the mean number of non-forest patches is 3.39.

Table 4.3 Spearman's rho non-parametric correlations (n = 18) between land-use metrics, land-cover metrics, and parcel characteristics in intentional communities. Correlation coefficients are given and shaded cells have a significance value of p < 0.05.

NNFP	-0.027					
NFP	0.056	0.098				
% Forest	-0.571	-0.030	-0.427			
MFA	-0.697	0.061	-0.392	0.884		
MShp	-0.164	0.384	-0.348	0.158	0.302	
Area	-0.579	0.128	0.411	0.344	0.542	0.071
	Pop density	NNFP	NFP	% Forest	MFA	MShp

Notes: NNFP, number of non-forest patches; NFP, number of forest patches; MFA, mean area of forest patches; MShp, mean shape of forest patches.

Population density is inversely related to the area of the community, the percentage of the community in forest, and mean size of forest patches. The area of the community is positively related to the number and size of forest patches. The percent of land in forest is positively related to the mean forest patch size and negatively related to the number of forest patches.

Table 4.4 Comparison of group means using Mann-Whitney U. Shaded cells have p < 0.05 for the 2-tailed asymptotic significance not corrected for ties.

Comparisons	Pop density	Area (ha)	NNFP	NFP	% Forest	MFA	MShp
1 to 2	0.914	0.201	0.376	0.021	0.670	0.670	0.831
1 to 3	0.683	0.174	0.140	0.056	0.734	0.865	0.234
2 to 3	0.950	0.796	0.393	0.540	0.519	0.699	0.197

Notes: NNFP, number of non-forest patches; NFP, number of forest patches; MFA, mean area of forest patches; MShp, mean shape of forest patches.

While the significance value for the difference between the mean number of forest patches between two of the community types is slightly above the cutoff, there is a strong pattern that communities composed of individual ownership have fewer forest patches. In fact, the forest in all of these communities occurs in one contiguous patch. While not significantly different in the current sample, communities of individual ownership are, on average, smaller in area and simpler in terms of forest fragmentation.

4.5 Discussion

Previous treatments of intentional communities in geography have generally focused on the social and cultural, and especially the counter-culture, characteristics of the communities. The focus on land ownership used in this research intentionally casts a wider net in an attempt to employ the idea of intentional community as a means to describe the spectrum of land ownership strategies that exist between household fee-simple ownership and government ownership. This is not to minimize the importance of a shared core value that might precipitate a group to own land collectively, but to emphasize that the variety in members' values may be difficult to categorize and may or may not connect to the physical landscape.

From the findings above, it is clear that land ownership does provide a more discrete means of categorizing communities. Beginning with the legal forms of land ownership for 46 communities, communities were aggregated into three categories. A mix of individually owned land and collectively owned land is probably the most familiar legal form of land ownership by groups because of its common use by developers in recent decades. It is not, however, the most similar to fee-simple ownership by a single household. The use of a corporation to own all land is the most communal of the three categories and is increasingly dominated by the use of a community land trust. The community land trust is also the most radical departure from dominant notions of "private property," where all rights are vested in an individual, as it distributes rights to the broader community by filling positions with individuals who are not residents of the intentional community. The focus on formal ownership structure does provide a useful link between the social and ecological systems that has been missing from previous research on intentional communities. The lack of accounting for informal institutions or non-member participants misses several potentially important sources of variation that are discussed below.

The primary goal of this research is to assess whether the type of ownership used by a community is related to the fragmentation of land cover in that community. As discussed above, the expectation is that more communal forms of land ownership will be associated with communities with higher population densities, higher percentage of land in forest, and less land-cover fragmentation. The descriptive statistics (Table 4.2) suggest that some, but not all, of these hypotheses hold for the 18 communities examined in detail here. More communal forms of land ownership are associated with higher population density as communities in the co-ownership category have less than one-third the population density than communities where all land is owned by the community. The hypothesis that more communal ownership is related to more land in forest is not true for these communities as all of the categories are similarly and substantially forested. Communities with a mix of individual and community ownership have the highest average with just more than 81% land in forest, and communities where all land is owned by the community have the lowest average with just more than 71% land in forest. The hypothesis that more communal forms of land ownership are related to less forest fragmentation is not supported as communities in the co-ownership category have the lowest average number of forest and non-forest patches and the lowest shape index for forest patches. This relationship is more complicated and further interpretation of the spatial metrics is provided below on a category-by-category basis.

Inferential statistics do not show significant differences in the mean population density and spatial metrics grouped by ownership type (Table 4.4). The only statistically significant difference is in the number of forest patches in communities using co-ownership and communities where land is owned by a mix of individuals and the community. Communities where land is owned by a mix of individuals and the community have a higher number of forest patches, which on its own could be translated as more land-cover fragmentation.

Examination of the measures for the entire sample, rather than grouped by ownership category, does show some statistically significant patterns. Population density is inversely related to the total area of a community, the percent of the community in forest, and the mean forest patch size. As forest is the "natural" land cover in the study region rather than an intentionally cultivated land use, it is expected that an increase in population density is associated with a decrease in forest. Communities with more land have significantly more forest patches that are on average larger in area. The percentage of land in forest is positively related to the mean size of forest patches and negatively related to the number of forest patches. None of these findings go against standard expectations in landscape ecology.

According to the sample used here, the communities do not simply conform to the hypotheses that more communal land ownership results in these particular land-cover characteristics. To address why stronger relationships were not observed between ownership type and land-cover outcomes is partly to ask why so much variation exists within ownership categories. Assuming that the theoretical formulation of the relationship between legal ownership structure and land-cover outcomes is feasible, the greatest weakness of the current study is the sample size for the analysis of land-cover outcomes. The primary reason preventing a more robust sample is the availability of recent cadastral data. The availability of digital cadastral data is increasing rapidly but is very expensive to produce. Often, communities preferentially move to areas where land is inexpensive and these are the same areas that do not have enough resources to produce expensive products such as digital parcel data. Even when the local government has invested in the creation of such data, they are often looking to recoup some of the cost by charging for use of the data. In some cases, local governments are charging thousands of dollars for such data, making access unfeasible in this research context. To better understand where these hypotheses do and do not work, example communities will be discussed for each of the three ownership categories.

4.5.1 Sources of variation within ownership categories

Communities in the co-ownership category are generally small in size, population, and population density. According to data collected in this research, this small size is sometimes a result of the desire to maintain only a small group of people and sometimes the characteristic of a community that intends to grow in the future. Two of the three communities shown in Figure 4.2 (CO1 and CO2) are composed of a combination of land held by individuals and land held as tenants in common while the third (CO3) is composed entirely of land held by individuals. The CO3 community organized the ownership to include restrictions on the rights of the individual to only develop a particular percentage of their land. This restriction would "run with the land" such that future owners would also be legally bound to it ensuring the continuation of the community even though the land is held by individuals.

While the communities appear similar in terms of their legal structure of land ownership, CO1 and CO3 are small groups that intend to stay small while CO2 is actively trying to increase its population. The residents of CO1 expressed expectations that none of them will move from the community and that they are happy with their current arrangement. Residents of CO3 do not intend to grow, but did expect that there could be some change in the membership of the community. Residents of CO2 intend to evolve a more communal lifestyle, including changing the land ownership to a more communal form. Several communities in this category reported similar intentions to create a corporation, most often a community land trust, at a later date. These differences are most obviously expressed in the landscape by the organization of the houses. In CO1 and CO3, each household occurs on land owned by that household. In CO2, all households are located on land held by one individual. The level of communality clearly varies within this category, which may result in the variability in land-cover patterns. This within-group variance likely contributes to the lack of statistical differences between the co-ownership and other groups.

Communities in which all land is held collectively were the most frequently occurring type encountered in this study and have, on average, the highest population density and most fragmented forests. The degree to which the land is used for residential versus other economic endeavors in three of these communities (Figure 4.3) appears to be an important factor influencing how much land is maintained as non-forest. An explicit goal of community AC2 is to give people who could not otherwise afford ownership rights the opportunity to do so. Having non-residents control the corporation is one way in which communities can separate those that make collective-level management decisions about the land from those that might benefit from an increased market value of the land if it were to be sold. This ownership structure has come to be called a "community land trust" in the sense that members of the wider community populate the board of trustees. The centralized arrangement of houses and non-forest land can be interpreted as an outcome of the goal of providing affordable residential opportunities. Community AC3 is organized into several neighborhoods such that multiple residential nodes exist. This additional level of institutional organization creates a more distributed pattern of non-forest land in this community.

Generally, the institutional flexibility made possible through complete community ownership allows increased possibilities in spatial arrangement and resulting land-cover outcomes. Examples of the distribution of various use rights encountered during this research include the right to build structures, the right to harvest timber, and the right to exclude others users from a designated area of land. The formality of leases varied greatly from renters who paid to stay in a house month-by-month to formal long-term contracts leasing houses and land. In some cases, this institutional flexibility allows the community to circumvent subdivision requirements that would restrict particular residential patterns. A community may want to cluster its houses and buildings in order to minimize the disturbance on the land or they may want to disperse across the land for maximum privacy. Both of these motivations were encountered in this research. In several cases observed in this research, a condominium legal structure was used to own the residences and surrounding land but was then combined with another corporate structure, such as a land trust, to own undeveloped land. The grouping of ownership types into the three categories used here is not sufficient to capture this variation. The inclusion of non-land-holding corporations and informal rules in the categorization of communities might capture this variation but would require a larger sample size.

While the seemingly ubiquitous American subdivision that incorporates some shared land held by a homeowners' association is not legally different from intentional communities categorized as having land owned by a mixture of individuals and the community, the stipulation for this research that a community must be initiated by its residents precludes their inclusion here. Nevertheless, the familiarity of this legal form with its known benefits and drawbacks potentially makes it appear less exotic than the other community types. As with the standard subdivision, the land use in the communities in this category is dominated by residential concerns where the community members work outside of the community. In most cases, some sort of community building is located on the commonly held land.

As observed at least once in this study, a community can move from the second ownership category (completely community ownership) to the third (mix of community and individual) by having members buy land outside of the original land held entirely by the community. The community on the right in Figure 4.4 began with all of the land held collectively, but in order to more easily secure financing for home construction chose to subdivide parcels. The role of bank financing for building houses or insurance on those houses was mentioned by several communities as a motivating factor for choosing this land ownership structure. Even in the case where communities wanted to have everything owned by the community, securing a mortgage or house insurance was perceived as only possible through fee-simple ownership.

4.5.2 **Future directions**

The legal type of land ownership used by a community does help to understand the land-cover patterns in that community, but the relationship is clearly more complicated. The next steps to better understand this relationship should include adding informal rules and the ideological foundations of a community to get at a deeper understanding of how land is used. The research presented here takes into account only the formalized legal structure of land ownership but it is entirely possible that informal rules are more important in some contexts. Especially in communities where the population changes quickly or there is a predisposition against social structures imposed through legal mechanisms, local customs and personal relationships may dominate decision-making processes. Other legal institutions, such as rental agreements and non-land-holding corporations, may also be important to understanding the decisions of land managers. Renting or leasing land is an important component of the communities with land owned by the community. Communities with land owned by individuals did sometimes have other participants who were not owners but rented houses on the land owned by individuals. These participants may or may not have been considered members of the community. Non-resident members likely have little direct effect on land cover, but may well affect the direction and viability of the community as a whole. Often non-resident membership requires a monetary or labor contribution thereby providing a resource for the community. In more extreme cases, up to five different types of membership had been defined by different rights and responsibilities.

The existing literature on intentional communities has focused more heavily on the ideological core of intentional communities, and incorporating that more culturally sophisticated approach with the current institutional findings will certainly strengthen the overall understanding of land-cover outcomes. Community characteristics such as shared infrastructure, food production for consumption and markets, agroforestry, and group dietary practices would give a more nuanced understanding of the proximate causes of the observed forest and non-forest patterns. The understanding of the ideological core has a particularly tight relationship to economic activities in intentional communities. Including the types of extractive and non-extractive activities that occur in the community will also provide a better understanding of the links between land use and land cover.

While availability of recent cadastral data remains the most prominent data challenge to spatial analysis of land use and land cover in intentional communities, the incorporation of multispectral remote sensing has the potential to enhance the analysis presented here.

The length of the histories of many of the communities, their sizes, and their geographic proximities to one another increase the efficiency of using land-use and land-cover data derived from mid-resolution multispectral sensors such as Landsat. These sorts of data would facilitate comparison of land-cover change both within the community over time and comparison of change inside and outside the community. Most important, classification beyond the forest/non-forest level could be used to address land-use dynamics identified in this research as potentially important.

Taken together, these suggestions for further study of intentional communities as geographic entities point to a more longitudinal or life-course oriented approach. Although small intentional communities such as those studied here were not included in their studies, Wagner (1985) and Kitts (2000) suggest that a life-course approach to understanding communal societies would be more appropriate than thinking about successful and unsuccessful communities judged by the length of their existence. Recent developments in resilience theory provide a theoretical foundation for incorporating the growth, collapse, and re-organization of social-ecological systems (Holling and Gunderson 2002) that is potentially very applicable to intentional communities.

4.6 Conclusion

The increasing frequency of more complex property-rights arrangements in the rural residential areas of the United States highlights the need for better understanding of these social-ecological systems. Land-ownership strategies such as common-interest developments and conservation-design subdivisions have garnered some attention, but the broader concept of intentional community has been largely left on the periphery. Describing intentional communities in terms of formal ownership structure is useful in filling the spectrum of property-rights arrangements between private and public that currently exist in the United States.

Three categories of legal ownership used by intentional communities were identified in this research: land owned by some combination of individuals and partnerships, land owned solely by corporations, and land owned by a combination of individuals and corporations. Spatial metrics were used to quantify patterns in land cover derived from aerial photography to test the relationship between legal ownership type and patterns in land cover. While some relationships between the structure of land ownership and land-cover outcomes were observed, in general, the relationship was not strong. The finding that the average percent forest for all of the communities was above 75% is noteworthy, but little variation in overall percent forest was observed between the communities in each ownership category. The criteria for inclusion in the study only required that the communities be in a forested ecosystem domain such that the undisturbed vegetation would be forest. Using only formal ownership rights is useful but has several shortcomings.

The flexibility of legal structures in the United States allows for multiple paths to the same endpoint. That is, understanding land ownership as a bundle of rights and responsibilities that is separable allows multiple legal structures to achieve the same distribution of rights. The type of legal ownership does not, on its own, explain variation in land-cover patterns. Incorporating this institutional approach with existing approaches to intentional community that have focused on shared values of community members will further the understanding of intentional communities as examples of social-ecological systems.

5 Conclusions

Specific conclusions have been presented in each of the three preceding chapters, but combining those findings provides both a reminder of how the chapters are connected and insights beyond those available from any single chapter. To reflect the background presented in Chapter 1, these more generalized conclusions are grouped in terms of land ownership parcelization, land ownership institutions, and land change science. A few thoughts on future directions will then be discussed.

5.1 Land-Ownership Parcelization

Land ownership is an essential component of connecting the management decisions of landholders to land-cover outcomes at both parcel and aggregate landscape scales. Taken together, the three preceding chapters provide a more in-depth understanding of both temporal and spatial dynamics relevant at the scale of ownership parcels. Chapter 2 focuses on how, and to a limited degree why, parcel boundaries change over time. The results from this chapter describe how the current set of parcels has come to exist and how those parcels might change in the future. By understanding parcels as the spatial units of decision making in the landscape, these findings can be combined with the findings from the other two chapters in a synergistic way. For example, the spatial extent of any land-management portfolio is defined by parcel boundaries. While there are some cases of parcels being split and distributed among family members for multiple generations, it is increasingly common in an exurbanizing context that parcels pass between owners that have no existing social ties. In any case, the parcelization decisions made by one person or family affect the land-management options of subsequent owners.

The possibility of collective ownership, examined here in the form of intentional communities, can potentially change this intergenerational dynamic by creating both informal and formal ties from one owner to the next. In fact, it is an explicit goal of many communities that employ a community land trust to remove the profit motive that drives parcelization in areas of increasing land values. Specifically, property values are held down on the idea that one person should not benefit from a good created by the community. On the other end of the collective ownership spectrum (and outside the definition of intentional community used here) is the case of standard, planned unit developments that use covenants, conditions, and restrictions to provide a formalized means of controlling some land uses from one owner to the next. These rules are often used to achieve the opposite goal of the community land trust—to keep property values as high as possible by homogenizing the community through strict control of land use.

In addition to over-time changes, the combination of the three chapters provides a multiscale approach to the spatial definition of ownership parcels. Chapter 2 focuses on the parcel as a whole and how that whole can change over time. Chapter 3 defines the parcel as a portfolio of management units and examines what combinations of those land-use building blocks commonly occur. Moving up in scale, Chapter 4 treats the community as a whole, which may be composed of one, or more frequently, several ownership parcels. The results from these three chapters provide context for one another in terms of the process of parcelization. In the study of human-environment questions in general and land-use and land-cover questions in particular, it has long been realized that no single scale of analysis is sufficient to understand both decision makers and the impacts of the decisions. These three chapters provide a unique focus on the scale of the individual parcel by examining its component pieces as well as the combination of multiple parcels.

While the particular study area varies between the three chapters, the geographic context can in each case be described as exurbanizing areas. The multiscale approach is particularly relevant in such a context as the defining characteristic of exurbanization is the heterogeneity of decision makers in the landscape. This heterogeneity must be understood in terms of both time and space as exurban landscapes are in the process of changing from predominantly rural to predominantly suburban/residential landscapes. Understanding which parcels make the transition from rural to residential uses is very much related to the parcelization process in both cause and effect. That is, a change in land use can result in parcelization but parcelization can also affect a change in land use. Patterns in this path dependency are the primary finding of Chapter 2. The possibility that these parcelization/land-use transitions will likely have land-cover effects depending on the portfolio type follows from the findings in Chapter 3.

The finding in Chapter 2 that aggregation of parcels is generally followed by some type of parcelization is particularly interesting in the context of collective ownership and intentional communities. With a broad definition of intentional community, as used here, it would be helpful to be able to identify scenarios that might fit the definition even if the participants do not identify with the term "intentional community." This would be advantageous both to circumvent the sampling issues associated with self-selection and to find communities that more completely fill out the property-rights spectrum, including those that fall just outside of the definition used here.

5.2 Land-Ownership Institutions

Following from the initial focus on parcels as the institutional footprint of land ownership, a common theme across the results of the three preceding chapters is the flexibility of ownership institutions in the geographic context of the Midwest United States. In terms of parcelization, there are very few limitations beyond a minimum allowable size on how parcels may be split. It has been noted by many authors that the rectangular grid of township and range boundaries that initially defined ownership parcels in much of the United States both reflects important cultural characteristics of the nation and has ecological consequences in its complete disregard for physical characteristics of the land. In linking pattern to process, it is notable that the continuation of essentially rectangular ownership parcels generation after generation cannot be attributed to any institutional barriers and therefore is driven more by cultural reproduction. An important point is that this rectangular spatial pattern is not strongly reflected in the management units used to define land-use portfolios in Chapter 3. The boundaries of management units that coincide with the boundaries of the parcel are obviously influenced by the persistent history of the rectangular survey, but the boundaries on the interior of the parcel are driven much more by biophysical influences such as slope and soil type.

Along with flexibility in how parcels are split, the flexibility of ownership laws is important in that parcels can readily be aggregated and can be owned by many combinations of individuals or corporations. While the history of the parcels owned by intentional communities was not explicitly collected as part of the dataset, it is clear that in at least some cases, multiple parcels were joined and then split in a different pattern. In most cases, the communities are composed of multiple parcels. This flexibility in ownership institutions is certainly a boon to communities but does complicate any simple connection between ownership type and land-cover patterns. Because communities can structure their land ownership in a number of ways, types of ownership that fall into the different categories derived in Chapter 4 could have the same land-cover outcomes. To better address this flexibility, informal rules need to be included in the institutional analysis of intentional communities. One step toward achieving this goal will be to implement an approach similar to the one used in Chapter 3 where management units and land-use portfolios are delineated by the residents. These management units form the spatial footprint of both formal and informal land-use rules.

5.3 Land Change Science

The fact that land use and land cover are related but not identical is a primary finding of Chapter 3. While this is not a new finding, few studies have tested this important relationship in a systematic, spatially explicit way. Any attempt to connect land manages to landscape outcome must work from some understanding of how land use and land cover are related. In contexts where there is relatively little heterogeneity among land managers and/or among land uses, the conflation of land use and land cover may be appropriate. In south-central Indiana and more generally in exurban landscapes, heterogeneity is high in terms of both land managers and land uses. Land ownership does mediate possible land-use choices and how they translate to land-cover outcomes, but as shown for the case of intentional communities, the type of ownership alone may not be a sufficient link between the two.

The research presented here was all developed in the context of understanding how spatial patterns of land ownership affect patterns of forest. While covering some range of scales in an institutional sense, the three chapters focus on geographical scales that range from tens of meters to hundreds of meters. Moving to the landscape scale where these individual decisions of land managers will aggregate into potentially different land-cover patterns should be the next step. The methods for describing parcelization trajectories can be directly implemented at a broader scale as a means to describe trends in how the spatial characteristics of parcels are changing over time. Connecting these spatial characteristics with land cover, both of which can be derived in a relatively automated way, with the relationships between land use, land cover, and land ownership derived from Chapters 3 and 4 could lead to less labor-intensive methods for deciphering land-management decisions at the household scale.

5.4 Extant Linkages and Future Directions

Each of the three chapters presented above was designed to be a stand-alone product as well as contribute to the larger project of addressing the spatial relationships between land use, land cover, and land ownership at the parcel scale in the Midwest United States. With the goal of "starting with the land," each chapter has at its core the spatial unit of analysis delineated by the parcels owned by one household or community. Chapter 2 addresses the temporal dynamics and path-dependent nature of changes in this ownership institution by describing the changes in parcels using a combination of spatial metrics. This more robust spatial description of how parcels split over time very directly leads to the question of why parcels split where they do.

Chapter 3 quantifies the spatial units of decision making on a single parcel that are the foundation for an understanding of where parcels split. This is achieved by clearly separating land use and land cover to assess the assumption that they are spatially coincident. The approach developed in this chapter is that of a land-management portfolio where the portfolio is defined by the types of extant land uses identified by the landowner. The results of this chapter confirm that there is a significant relationship between land-management complexity and land-cover fragmentation in the study area. Additionally, however, the results show that there is some important divergence between land use and land cover. Forest land cover, particularly important in the context of global environmental change, occurs in substantial amounts on many of the non-forest land uses. Forest land-management units also have some non-forest land cover, further complicating the land use–to–land cover relationship.

The goal of Chapter 4 is then to address this same relationship between land cover and land ownership for scenarios where a group of people has chosen to own land together. This research continues the approach of tying the land managers to the land via the ownership parcel or parcels but expands the scope of the existing approaches by moving from the single household to ownership by a community. Categorizing communities in terms of how they have chosen to own land is a departure from existing research in geography where the focus has been on the cultural characteristics of the community and its members. Using ownership parcels to define the boundaries of the community again provides the spatial unit for measuring land-cover patterns in the community. In Chapter 4, connecting spatial pattern to underlying social processes takes the form of comparing land-cover patterns to type of ownership and land use is not treated separately.

Each chapter provides a different perspective on the core question of how land use, land cover, and land ownership are related at the parcel level. The combination of these findings also generates further testable hypotheses. For instance, the most common type of parcelization is splitting one parent parcel into two equally sized child parcels. It is also the case that the most common types of land-use portfolios are most frequently composed of two management-unit types. Synthesizing these findings, it would be a reasonable and important hypothesis to test whether the boundaries of child parcels coincide more closely with the boundaries of land use, land cover, or neither on the parent parcels.

Another example of potential further research arises from the finding that aggregation of parcels is a relatively common process but is often followed by some type of parcelization event. This spatial-temporal pattern could help identify particular types of ownership scenarios that lie outside the one household–to–one parcel scenario. While all planned unit developments do not fall inside the definition of intentional community as developed in Chapter 4, this aggregation-subdivision process might well be related to and help identify these types of collective ownership scenarios. This sort of methodology would help circumvent the problem of self-selection encountered when trying to sample intentional communities. That is, there are certainly existing property-rights arrangements that would fall inside the definition of intentional community used in Chapter 4 that have been overlooked simply because they do not choose to use this particular label.

The focus on the spatial characteristics of land ownership in the context of the Midwest United States inherently relies on maps of parcel data. One of the biggest impediments to increasing the sample size or streamlining the methods developed here is the availability of digital parcel data. This limitation is changing as local governments are recognizing the advantages of digital spatial databases, but the process is slow due to the high initial cost of data production. Understandably, areas with lower density population (the particular areas of interest in this research) are the last to invest in the production of digital cadastral data. Recognizing this fact, a federal initiative to establish a national parcel database has focused on rural areas. Along with increased ownership data, the methods developed here will benefit from more detailed land-cover data. Adding categorical detail to the non-forest class used above may provide a tighter connection between land use and land cover. Established multispectral remote sensing methodologies along with emerging data sources such as LiDAR provide the tools to generate more detailed land-cover classifications.

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Vitae Page

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Employment

2007—Visiting Assistant Professor, Department of Geography and Planning, University of Akron

Education

Ph.D. Geography, Indiana University, June 2009
Advisor: Professor Tom Evans
Dissertation Title: Linking Land Use, Land Cover, and Land Ownership at the Parcel Scale in the Midwest United States
Minor: Human Dimensions of Global Environmental Change

M.S. Geography, Indiana University; May 2003.
Spatial Analysis and Geographic Information Systems.
Advisor: Professor Tom Evans
Thesis*: Linking Landscape Pattern and Social Process: A Multi-Scale Examination of Farm Woodlots in Northern Indiana*

B.A. Geography, Indiana University, Bloomington, IN; August 2000

B.A. Philosophy, Indiana University, Bloomington, IN; May 1998

Major Research Areas

- Application of GIS and remote sensing in the study of social-ecological systems
- Spatial organization of sustainable landscapes
- Land-use and land-cover change in forested ecosystems
- Collective property-rights arrangements

Teaching Areas of Expertise

- Geographic Information Systems
- Environmental Remote Sensing
- Landscape Ecology
- Cultural Landscape

Research Appointments

2005 to 2006	Research Assistant, *Biocomplexity in linked bioecological-human systems: agent-based models of land-use decisions and emergent land use patterns in forested regions of the American Midwest and the Brazilian Amazon* Center for the Study of Institutions, Population and Environmental Change (CIPEC)
2000 to 2004	Research Assistant, Biocomplexity in linked bioecological-human systems: agent-based models of land-use decisions and emergent land use patterns in forested regions of the American Midwest and the Brazilian Amazon Center for the Study of Institutions, Population and Environmental Change (CIPEC)

Teaching Appointments

2009	Instructor, G405/505, Introduction to Geographic Information Systems Instructor, G447/547, Introduction to Remote Sensing
2008	Instructor, G405/505, Introduction to Geographic Information Systems Instructor, G447/547, Introduction to Remote Sensing Instructor, G801, Seminar: Geography and Planning
2007	Instructor, G405/505, Introduction to Geographic Information Systems Instructor, G375, Geography of Cultural Diversity Associate Instructor, Geog G110: Introduction to Human Geography
2006	Associate Instructor, Geog G110: Introduction to Human Geography Associate Instructor, Geog G120: World Regional Geography
2004 to 2005	Associate Instructor, Geog G237: Cartography and Geographic Information
2001 to 2006	Instructor, Geog 326: Geography of North America. School of Continuing Studies Online Education
2004	Grader, Geog 326: Regional Geography of North America Grader, Geog 315: Environmental Conservation
2003	Grader, Geog 341: Environmental Values and Attitudes Grader, EALC 302: Geographic Patterns in China
2002	Grader and Lab Assistant, Geog 336: Introduction to Remote Sensing Grader and Lab Assistant, Geog 436: Advanced Remote Sensing
2001	Associate Instructor, Geog 338/538: Introduction to Geographic Information Systems

	Associate Instructor, Geog 438/539: Advanced Geographic Information Systems
2000	Associate Instructor, Geog 338/538: Introduction to Geographic Information Systems Grader and Lab Assistant, Geog 237: Introduction to Computer Cartography

Publications

Greer, C., S. Donnelly, J. Hayes, and J. Rickly. (in review) Landscape as Embodied Energy: Ecosystem Perspectives on the Human-Environment Relationship. Special Edition of *Landscape and Urban Planning* based on the European Science Foundation's exploratory meeting entitled "Emerging Energies, Emerging Landscapes: Revisioning the Past, Constructing the Future".

Evans, T., S. Donnelly, and S. Sweeney. (in press) Threats to the Forest Transition in the Midwest United States. In *Reforesting Landscapes: Linking Pattern and Process,* eds. H. Nagendra and J. Southworth. New York: Springer.

Donnelly, S. and T. Evans. (2008) Characterizing Spatial Patterns of Land Ownership at the Parcel Level in South-Central Indiana, 1928-1997. *Landscape and Urban Planning*.

Greer, C. S. Donnelly, and J. Rickly. (2008). Landscape Perspective in Tourism. In *Landscape, Tourism and Meaning*, eds. D.C. Knudsen, C.E. Greer, M. Metro-Roland and A.K. Soper, 9-18. Aldershot, Hampshire, UK: Ashgate.

Conway, D. and S. Donnelly. (2007) Remote Sensing, GIS and Ground Truthing. In *Doing Development Research,* eds. Vandana Desai and Rob Potter, 251-261. London: SAGE Publications.

Grants

Funded

2009-2010	Hopkins, J., N. Maaki, C. Miller, and S. Donnelly "Drinking Water Issues as a Context for Problem-Based Science Instruction" Ohio Board of Regents Improving Teacher Quality Grants. $129,981
2008-2009	Donnelly, S., J. Hopkins, and C. Miller. "Drinking water source characterization and disinfection byproduct formation modeling using land use and stream reach ecological properties." University of Akron Integrated Bioscience Faculty Research Grant. August $10,000.

Unfunded

2009-2012	Miller, C., J. Hopkins, and S. Donnelly "Development of Integrated Drinking Water Disinfection Byproduct Precursor Management Tools" National Science Foundation. $273,180

Awards

Full scholarship to attend the Byron Fellowship. Turkey Run State Park, Parke County, Indiana. May 13-18, 2007

Stephen S. Visher Award for Outstanding Paper on Indiana, Indiana University Department of Geography. April 15, 2003.

University Consortium for Geographic Information Science presentation and travel grant. May 15, 2003.

Invited Presentations and Guest Lectures

Donnelly, S. 2006. Concepts of Land Ownership in the United States. Presented in Geog G315: Environmental Conservation. Department of Geography, Indiana University, Bloomington, IN

Donnelly, S. 2006. Teaching an introductory level course as a graduate student. Presented at Graduate Student Teaching Workshop, Department of Geography, Indiana University, Bloomington, Indiana.

Donnelly, S. 2006. Incorporating maps and spatial data into pilot decision making. Presented at the Montgolfier Society of Indiana annual safety seminar.

Donnelly, S. 2006. What is GIS? Presented in Geog G235: Introduction to Geographical Methods. Department of Geography, Indiana University, Bloomington, Indiana.

Donnelly, S. 2006. GIS applications to land use and land cover change research at the Center for the Study of Institutions, Population, and Environmental Change (CIPEC). Presented in Geog G438/G539: Advanced Geographic Information Systems. Department of Geography, Indiana University, Bloomington, Indiana.

Donnelly, S., E. Ostrom, L. Persha, A. Poteete and D. Welch. 2005. Intentional Communities in Southern Indiana. Presented at Forest Land Conservation: An Indiana Portfolio. Nashville, IN.

Paper and Poster Presentations

Donnelly, S. 2008. The role of aggregate complexity in an energy-based framework for comprehensive landscape study. Paper presented at the Association of American Geographers West Lakes Division annual meeting, Bloomington, IN.

Donnelly, S. 2008. The relationship between land use portfolios and land-cover outcomes on privately owned parcels in Monroe County, Indiana. Paper presented at the Association of American Geographers annual meeting, Boston, MA.

Greer, C., S. Donnelly, J. Hayes, and J. Rickley. 2007. Landscape as Embodied Energy: Ecosystem Perspectives on the Human-Environment Relationship. European Science Foundation's exploratory meeting entitled "Emerging Energies, Emerging Landscapes: Revisioning the Past, Constructing the Future. Paris June 6th to 8th, 2007.

Donnelly, S. 2007. Land Ownership in Intentional Communities as a Form of Institutional Complexity. Paper presented at the Association of American Geographers annual meeting. San Francisco, CA.

Greer, C., S. Donnelly, J. Hayes, and J. Rickly. 2007. An Ecosystem Energy Model of Landscape Form and Function. Paper presented at the Association of American Geographers annual meeting. San Francisco, CA.

Donnelly, S., C. Greer, J. Hayes, and J. Rickly. 2007. An Ecosystem Energy Framework for Landscape Form and Process. Paper presented at Landscape, Space, and Place: 1st Annual Graduate Student Conference in Landscape Studies. Indiana University.

Greer, C, S. Donnelly, J. Hayes, J. Rickly. 2006 Sustainable landscapes: An energy-based ecosystem model of landscape form and function. Paper presented at Departmental Colloquium Series, Department of Geography, Indiana University.

Donnelly, S. 2006. Legal Structure and Land Cover in Intentional Communities in the Eastern United States. Paper presented at the Association of American Geographers annual meeting. Chicago, IL.

Donnelly, S. 2005. The role of Spatial Organization in the Persistence of Woodlots in Northern Indiana Paper presented at Association of American Geographers annual meeting. Denver, CO.

Greer, C. and S. Donnelly. 2005. Toward Integrated Landscape Study: Energy characteristics of landscape features in Monroe County, Indiana. Paper presented at Association of American Geographers annual meeting. Denver, CO

Donnelly, S. and C. Mathenge. 2004. Examining the effect of land tenure and patterns in land-use and land-cover change in Southwest Uganda and the Midwest United States. Poster presented at Geography Departmental Colloquium. November 1, 2004, Bloomington, IN.

Donnelly, S. 2004. Ownership parcelization and landscape fragmentation. Paper presented at School of Public and Environmental Affairs Ph.D. Conference. Bloomington, IN.

Donnelly, S. 2004. Land Ownership and Land-Cover Fragmentation in the Midwest United States: A Landscape Perspective. Association of American Geographers annual meeting, Philadelphia, PA.

Donnelly, S. 2003. Linking landscape pattern and social process: A multi-scale analysis of farm woodlots in northern Indiana. Paper presented at University Consortium for Geographic Information Science Summer Assembly, Monterey, CA.

Donnelly, S. 2003. Using GIS and Remote Sensing to examine land use and land cover change in Northern Indiana. Poster Presentation at Indiana University GIS Day. Bloomington, IN.

Donnelly, S. 2002. Land ownership fragmentation as a reflection of ecological awareness: Consequences and responses in the Midwest United States. Paper presented at Association of American Geographers Annual Meeting, Los Angeles, CA.

Donnelly, S. 2002. Multi-scale analysis of forest related land use decisions in DeKalb County, Indiana. Poster Presentation at Indiana University GIS Day. Bloomington, IN.