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LINKING SATELLITE IMAGES TO LAND USE ACTIVITIES: AN EXPLORATORY STUDY OF SOUTHERN INDIANA NON-INDUSTRIAL PRIVATE FORESTS

by

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Introduction

Global climate change ranks as one of the most significant potential threats to life as we know it on Earth. In particular, global warming is expected to raise sea levels worldwide, devastating many coastal cities and wetland environments; to disrupt oceanic thermal currents, threatening important ecosystems; and to increase the severity and frequency of storms, droughts, and other extreme weather events.

While climate change is a normal part of the Earth's history over geologic time, the recognition that such change may be accelerating due to anthropogenic causes has led to significant efforts to understand human-climate links. Natural scientists provide a wealth of knowledge about the role of atmospheric gases, soil chemistry, ocean currents, polar ice, and vegetation, while social scientists focus on human activities that alter environmental conditions. Scientists developing sophisticated global climate models attempt to explain and predict effects of various factors on climate. Millions of dollars are devoted to global environmental change research, and a plethora of books and journals are devoted to these topics.

Such research has led to a growing consensus about key factors influencing global climate change. One such factor, the focus of this study, is land cover change. Since plant biomass is a substantial carbon sink, the quantity of vegetative growth, especially forests, on land has important implications for atmospheric carbon dioxide levels and, thus, global climate change.

The ability to identify and describe land cover properties has grown. Increasingly, scientists have incorporated technological advances in their methods of analysis. Over the last two decades, the use of remotely sensed satellite images has become an important tool. The availability of satellite images at multiple points in time has allowed studies that have improved greatly our understanding of land cover changes over time. Moreover, with the development of land-cover classification maps from these images and, more recently, development of spectral mixture analysis (Smith, et al., 1994), scientists can infer land cover conditions even in remote locations.

But efforts to link remotely sensed data to human causal factors are a relatively new component of land use research. Early attempts to do so often relied on few causal variables. For example, population, an aggregate measure linked to particular geographic regions, has been emphasized. But relying on population data, where available, does not explain why some areas have land cover characteristics and trends far different from regional averages. In many locations, information about the subtle interplay of individuals as they relate to their environments has not been collected.

Examining human behavior related to land cover has been, primarily, the domain of social scientists. Anthropologists have sought to explain the role of population, technology, community norms, and culture in shaping activities that affect land use and cover. Political scientists have emphasized factors such as land tenure, political instability, governance structures, resource concessions, and regulations. While social science efforts provide useful insights into human activities that affect land cover, they typically do not include rigorous measures of geographically-linked land cover properties. Instead of measuring vegetative outcomes, these studies most often measure outputs not directly tied to geographic locations, such as budget expenditures, acres of vegetation planted, quantity of roads built, or even presence of particular laws or regulations. Clearly, better links between land cover outcomes and human activities are needed.

Integrating remote sensing tools with social science methods facilitates such links. This study represents an exploratory effort to do so in the context of the United States. Specifically, the aim is to examine southern Indiana temperate hardwood forests in non-industrial private ownership.

While much forest research has been devoted to tropical regions, the critical role of temperate forests should not be overlooked. Tropical forests account for an estimated 52 % of the world's forest cover, which means that temperate forests comprise about 48 % (WRI, 1994: 305). Therefore, the trajectory of global climate change will depend heavily on forest conditions in temperate regions such as the United States.

Non-industrial private forest (NIPF) is a key type of forest ownership in the United States. In fact, about 58 % of all U.S. timberland is NIPF (Cubbage, et al., 1993: 16). A particular challenge in understanding present, and predicting future, forest conditions in this ownership class is the presence of millions of individuals making independent decisions about relatively small land holdings. Though largely uncoordinated, the cumulative impact of these numerous individuals is substantial. In the United States alone, NIPF accounts for over 417 million acres of timberland (ibid.).

To explore what factors influence NIPF owners' land use activities and resulting land cover, this study uses archival and interview data linked to GIS maps and remotely sensed images. The paper proceeds in five sections. Following these introductory remarks, prior research related to the topic is presented. Subsequently, data and methods are described. The next section discusses findings. Finally, concluding remarks are offered to summarize the analysis and highlight plans to perform additional remote sensing analysis.

Prior Research

Analysis of land use and cover related to forests is not new. This study builds upon past efforts to describe and explain human behavior, including individuals' decisions about managing natural resources, the role of policy instruments in shaping NIPF owners' actions, and the impact of land ownership change on land use. In addition, this study builds upon past research relating remote sensing to land cover.

Explaining individuals' decisions about managing natural resources requires attention to many factors. A useful tool for organizing analysis of such factors is the Institutional Analysis and Development (IAD) framework developed by scholars associated with the Workshop in Political Theory and Policy Analysis at Indiana University. This framework focuses the analyst's attention on individual actions as affected by values, preferences, and information; the physical world; communities; rules; and interactions with others (see Figure 1). Empirical work using this framework has examined management of many different natural resources, including ocean fisheries, pastures, oil fields, water, and forests (Ostrom, et al., 1994).

[Figure 1 here]

Elements of the IAD framework have been included in numerous studies seeking to explain individual behavior towards forest resources. For example, in the developing world context, William Ascher (1995) emphasizes the importance of technical expertise, tenure security, community size, and distribution of forest resources across the landscape.

In the United States context, studies of forest resource management often emphasize rules established by legislation or agencies that create incentives and constraints affecting forest owners. Such rules are policy instruments through which governments may shape NIPF owner behavior. For example, Hardie and Parks (1996) and Royer (1987) argue that cost-sharing programs encourage reforestation efforts. In addition, to increase the time between tree cutting on a given parcel, researchers have cited the utility of timber yield taxes (Englin and Klan, 1990) and property tax adjustments (Hickman, 1982: 53). Moreover, increased attention to non-timber forest benefits may be encouraged with tax deductions for managing wildlife habitat (Wigley and Melchiors, 1987). On the other hand, rigid laws such as the Endangered Species Act may give individuals unintended incentives to remove forest habitat (Cubbage, et al., 1993: 416).

Government intervention also may affect U.S. forest owners by altering their information or values. Technological assistance to provide individuals with a different understanding of forest management benefits has been shown to change behavior (Cubbage, et al., 1993: 470-2), while education and demonstration programs can change individuals' values and preferences (Jones, et al., 1995; Harmon, et al., 1997).

Of course, factors other than government intervention affect U.S. NIPF owners' behavior. Farming conditions and topography play important roles in forest management (McKibben, 1995; Rudel and Fu, 1996), while climate and location limit the quantity and types of trees that can grow. Owner characteristics such as age, occupation, wealth, and education also matter (Hardie and Parks, 1996; Rudel and Fu, 1996), as do an individual's beliefs and values regarding what constitutes appropriate forest management practices.

Ownership change also may have important consequences for NIPF owners' behavior. In fact, most private forest land in the U.S. has been held for a relatively short period of time, and private forest lands continue to change hands fairly rapidly (Birch, 1994: 4). Ownership change may be a critical driving force in determining land use change such as deforestation of formerly forested areas or reforestation of agricultural areas. Deforestation can result from rules such as inheritance tax codes that force beneficiaries to liquidate standing timber to pay tax bills (Kahn, 1997: 47). Forest change also may result from differences in seller and purchaser values and beliefs about appropriate land management. Since a common source of ownership change is the sale of forest land to non-relatives (Lewis, 1980: ii), differing beliefs and values may lead to the clearing of formerly forested land. Even when ownership is transferred within a family, new owners may have gender and generational differences that create conflict over land management (Salamon, 1993:589).

Thus, in the context of U.S. NIPF owner behavior, many elements of the IAD framework have been examined. Much empirical work has relied on measures such as the existence of forest management plans, levels of government program participation, and survey responses indicating individuals' attitudes (see, for example, Birch, 1994; Harmon, et al., 1997). But a problematic characteristic of such studies is the limited ability to link individual behavior to specific land cover outcomes. Therefore, better connections between individual behavior and land use outcomes are needed. Remote sensing and GIS technologies combined with interview data provide valuable means to make such connections.

The emergence of remote sensing and GIS technologies over the last two decades has equipped researchers with potentially powerful tools for studying change in land cover condition over broad geographic areas. Many of the advances in these technologies have resulted from military intelligence activities. Only recently have these technological advances (computer processing speed, storage and software) been readily available to the social science community (Drury, 1990). However, before these technologies became available to the broader civilian environmental change research community, satellite platforms such as "Landsat" began working steadfastly and, since the early 1970s, have amassed a significant time-series image inventory for most areas of the Earth.

Given that remote sensing technology is relatively new, much of the effort to date to utilize this technology has focused on technical issues related to image processing (e.g., Hall, et al., 1990; Teillet and Fedosejevs, 1995). Scholars attempting to quantify landscape characteristics based on the digital numbers these images provide generally follow one of two methods. The first, vegetation indices, involves the use of ratios of data supplied in multi-sensor satellite images (see, for example, Curran, 1980; Then Kabil, 1994; Campbell, 1996). But the application of indices to studies of land cover change can be problematic because these indices are sensitive to many external factors (e.g., leaf orientation, atmospheric noise, soil background, vegetation spacing, and instrument drift) that vary across time points.

A second method commonly used to quantify and map land cover is image classification. This technique involves the conversion of the data contained within image picture elements, or "pixels," to produce a new map of land-cover categories for a particular landscape. The categorization can be "unsupervised"—generated entirely by the computer using only the digital data and statistics~or it can be guided or "trained" through the use of land cover inventories from the field. Despite the amassed sets of temporal imagery for locations on the Earth, the majority of the classification studies during the 1970s and 1980s concentrated on static inventorying of the physical properties on the Earth with little attention to the human component of land cover change.

During the 1980s and 1990s classification became an important method for inventorying land cover. Large research programs such as "gap analysis" underway in many U.S. states have used classification maps and other GIS data to identify gaps in biodiversity management (Scott, et al., 1993). Others have applied classification techniques to the inventory of wildlife habitat (Pearce, 1991), forest resources (Hall, 1994; Chuvieco and Congalton, 1988; Franklin, 1992; Nel, et al., 1992) and even urban areas (Lee and Marsh, 1995). Much of the current GIS/remote sensing efforts today integrate classification maps based on satellite images with other GIS layers such as digital elevation models, road networks, wetland areas and political boundaries for planning or modeling purposes at regional, state, and local levels (see for example, Randolph and Lee, 1994; Millette, et al., 1997). Most questions asked in these studies require only one time point for analysis.[1]

It is true that, very early in the Landsat program, a few scholars began to focus on the use of multi-temporal satellite image data sets as an information source for understanding land cover change (see, for example, Miller, 1977). But it has only been more recently that a significant body of multi-temporal analyses has appeared (see Stringer, et al., 1988; Green and Sussman, 1990; Moran, et al., 1994; Brondizio, et al., 1994; Sader, 1995; Wolter, et al., 1995; Lee and Marsh, 1995). The slow growth in quantitative spatio-temporal analysis can be attributed to two missing components: (1) computational resources required to process images, and (2) processing techniques to remove image "noise" that hinders our ability to conduct direct comparison of a time series of imagery (Davis, et al., 1991). As researchers developed innovative methods to overcome these technical issues, more temporal land cover analyses appeared. Like their predecessors, the single time point studies, many of these newer studies also employ a classification technique to inventory land-cover. Most emphasize vegetative

' Recently, another method for analyzing land cover change, referred to as "spectral mixture analysis" has been developed (Smith, et al., 1994). This method essentially "breaks down" individual pixel information into sub-components referred to as "end-members." End-members can be percentages of soil, water, and vegetation that exist within the pixel data. These procedures are just recently being applied to temporal studies of land cover change and their application toward the questions this study addresses will be explored in future endeavors.

inventories or general categories of the landscape instead of attempting to identify the causes of change that may be detected (e.g., Wolter, et al., 1995; Lee and Marsh, 1995).

However, recent efforts by scholars such as Westman and colleagues (1989), Moran, et al. (1994), Brondizio, et al. (1994) and Sader (1995) have forged new territory in linking patterns identified in multi-temporal imagery to human activities. Brondizio, et al. (1994), for example, link patterns of land cover to various methods of agriculture production. Sader (1995) identifies differences in forest clearing and vegetation regrowth and attributes this to differences in socio-economic conditions at two different study areas. These studies make important contributions toward the study of the environmental change, for they begin to link particular changes indicated by satellite images to specific human actions.

We intend to build upon the work of these scholars by using this approach to study human responses to institutional configurations. To our knowledge, very few, if any, researchers have attempted to link policy instruments and human incentives and behavior to outcomes in land cover using satellite imagery as a measurement tool. Thus, the opportunity exists to connect prior research about individuals' decision-making over the management of natural resources, the role of policy instruments in shaping NIPF owners' actions, the impact of land ownership change on land use, and multi-temporal sets of satellite images as a measure of outcomes. In this exploratory study, we examine several research questions:

1. How important are previous land uses and physical characteristics of the land in determining subsequent activities and resulting land cover?
2. How, and to what degree, does ownership change impact land cover?
3. Under what circumstances might government intervention be more or less effective in shaping individuals' land use activities on their parcels?
4. What motivates land owners to leave forests intact rather than clear or cut them?

Data and Methods

To address these research questions, we analyze ten cases in southern Indiana. Indiana's forest cover trends are fairly representative of land cover changes that have occurred throughout the eastern U.S., where a high proportion of forests are privately owned (Cubbage, et al., 1993). Historically, native forest cover in this region declined substantially after the arrival of European settlers and the associated increase in agricultural production. But since the early part of the 20^{th} century, as farmers abandoned unproductive lands and trees were planted to restore eroded slopes, some formerly deforested areas have returned to forest cover. Thus in this study we focus on understanding land cover change on parcels of a size and location typical for agricultural use. Each case centers on a parcel of privately-owned land between 50 and 100 acres with at least one acre of forest.

The sample was drawn randomly from 87 parcels sized between 50 and 100 acres within one township of Monroe County. This township is primarily rural in land use, but a growing town within it provides stimulus for increasing population and housing development. We drew the sample using county tax assessment records indicating parcel size and ownership.

To encourage parcel owners to participate in this study, we relied on letters and followup phone calls inviting participation. Of twenty owners contacted, ten (50%) chose to participate, while ten (50%) declined. We visited owners, in most cases on the parcel itself, to conduct semi-structured interviews. To facilitate open and honest communications, we guaranteed participants anonymity.

The interviews, which typically lasted about two hours each, provided extensive information about past and current land use on the parcels. Using products provided by the researchers, participants described and geospatially located land use activities and explained reasons for undertaking them. These products included color composite satellite image maps of each parcel from 1972, 1979, 1985, and 1992, as well as topographic maps, all printed at the same geographic scale. Participants identified locations of specific activities on the maps, providing a crucial link between individual behavior and land cover change detectable using remotely sensed images.

Several considerations and processing steps were required in order to utilize satellite images for this study. These include image: (1) platform considerations; (2) sampling issues; (3) preprocessing; and (4) restoration.

Several satellite image platforms have captured images of the southern Indiana region, including the U.S. Landsat Thematic Mapper (TM) and Multispectral Scanner (MSS) and the French SPOT system (Campbell, 1996). For this study we used Landsat Multispectral Scanner (MSS) images, primarily because they cover a wider temporal extent (dating back to 1972). The Landsat satellite's MSS sensors take snapshots of the Earth at four regions along the electromagnetic or light spectrum. Each sensor is referred to as a "band." Band 1 of MSS captures visible green light (.5-.6 µm) reflectance from the Earth's surface (as well as from the atmosphere). Band 2 collects visible red light (.6-.7 (am) reflectance information. Bands 3 and 4 are sensitive to near infrared light in the .7-.8 urn and .8-1.1 um range, respectively. Each band represents one "image layer" of reflectance information. The utility of multispectral images in general is that the multiple bands together provide spectral reflectance information that can be used to distinguish various land cover types.

However, these spectral qualities are sensitive to seasonal effects on land cover, particularly in temperate, deciduous forests, such as those in Indiana. The second consideration, then, is appropriate temporal image sampling. Attempts to minimize seasonal effects for this study involved selecting images from the month of September for each year. Furthermore, since reflectance in multispectral images is greatly influenced by water abundance, we selected images from years with relatively normal precipitation and temperature patterns for the month of September, based on a thirty-year average. Finally, only images with little or no cloud cover were chosen. Four images were therefore selected: 9/30/1972, 9/12/1979, 9/01/1985 and 9/28/1992. Since a six to seven year sampling frame is considered adequate to capture the effects of forest harvesting without losing change information to forest regrowth, these images effectively capture the temporal extent of the phenomena we are studying.

Following image acquisition, several steps were required for image preprocessing. First, we verified the images to ensure there were no problems related to "line drop outs" or "striping" — two common problems that result from MSS sensor defects. The 9/12/1979 image had visual striping artifacts that were removed using Fourier analysis and the ERDAS Imagine™ image processing software package. Second, we made sure that each image was correct in geometric rectification. Several images were acquired from the USGS North American Landscape Characterization (NALC) program and were already georeferenced. The 9/12/1979 image was purchased from EROS data center and had to be geometrically rectified to the other NALC images. Image resampling produced satisfactory results by producing image registration root mean square (RMS) error below .5 pixel. Subsequently, visual verification for each image using a GIS roads coverage of the area supported the conclusion that the images were adequately georeferenced and compatible with one another.

Finally, we completed image restoration procedures for each image (Jensen, 1996; Green, Schweik, and Hanson, 1998). Restoration involves removal of the effects of atmosphere, conversion of satellite digital numbers to measures of at-Earth reflectance, and image to image normalization (Hall, et al., 1991).

Development of a geographic information system (GIS) allows linking information collected in the field to satellite image data. We obtained topographic information from scanned 1:24,000 topographic maps of the area. Using Arc-Info™ and Arc-View™, we printed topographic maps for field use. In addition, we digitized parcel boundary information from georeferenced property maps acquired from the county auditor's GIS database. Another GIS layer will be created which outlines management units identified by respondents in the field. We will then be able to analyze the satellite image data located within these management units over time and across parcels. Figure 2 presents an example of one NIPF parcel boundary delineated from county property record documents, with forested area boundaries identified by the respondent, overlaid on the georeferenced image.

[Figure 2 here]

Findings

In our initial analysis across our exploratory ten cases, we identify several patterns relating to individual land use behavior. These patterns are discussed below in terms of key factors affecting individual decisions about land use activities, generally, and about forest management, in particular. Analysis also provides insight into the potential for policy interventions to affect forest activities.

Key Factors Affecting Individual Decisions About Land Use Activities

Land owners undertake a wide range of activities that impact vegetative cover on their parcels, including crop production, livestock grazing, home building, road construction, mowing, earth moving, pond construction, timber harvest, and tree planting. Extensive interview data provide a rich source of information about factors influencing decisions about these land use activities. Across a number of individuals and activities, the most important factors thus far have been physical characteristics of the land, previous land uses, and owners' values and beliefs.

Physical Characteristics of the Land

To a large degree, physical characteristics of the land are important in determining previous and future land use. Specifically, soil types and topographic features are critical. Soil characteristics greatly affect crop success. One respondent cited the importance of soil types in his father's decision to use land for extensive Christmas tree production. Knowledge of soil types and topography, gained partly from consultation with a soil professional, led him to the conclusion that Christmas tree fanning would be a productive use of the land. Another respondent explained that, in an area with poor drainage, grazing was the primary activity because the soil was too wet to grow crops; otherwise the area would have been farmed.

A second key physical characteristic, topography, has played a crucial role in determining patterns of land use in the United States, and southern Indiana is no exception. Flatter areas are more conducive to soil retention and farming implement treatments than are steeper areas. Moreover, well-drained soil is better than poorly-drained soil for cultivating most crops. Consequently, flatter and well-drained areas are more likely to be farmed, while steeper and wetter areas are more likely to remain forested. For example, Figure 3 shows land use patterns on one of the study parcels, with crop activities centered on flat, well-drained areas. As in the other study parcels, most of the forest on this parcel is located on hilly or poorly-drained areas. Across the sample, all ten respondents cited physical characteristics such as topographic features and soil as a key factor determining land use activities.

[Figure 3 here]

Previous Land Uses

In addition to physical characteristics of the land, individual behavior towards natural resources depends on previous land use. This is especially true in agricultural production. Since crop success depends on physical factors such as microclimate and soil qualities, farmers are interested in matching crop types (e.g., corn, soy, and alfalfa) to specific locations. Previous land use can be a helpful indicator of the likely success of planting a given crop in a particular place. Moreover, planting on previously cultivated areas can reduce effort in clearing and soil preparation, since unplanted areas often foster growth of woody plants that require substantial work to remove before a commercial crop can be established.

For example, one respondent described his ongoing, multi-year battle to clear a brushy field that had been allowed to revert to woody vegetation during a time of absentee ownership which preceded his arrival. Despite the respondent's yearly attempts, which required substantial amounts of his time and the use of a friend's labor and equipment, the field has yet to be planted since he began clearing efforts ten years ago. By contrast, other fields on the same property had been maintained by regular grazing and haying undertaken by renters and other authorized users during the same period of absentee ownership. Because of this previous use, the respondent has been able to cash rent these fields to a farmer.

Another respondent described an area which previously had been untillable because of the presence of a railroad grade installed at the beginning of the century. After the removal of the tracks, the right-of-way had reverted back to the titled landowners. However, this previous use as a railroad grade made mechanical crop cultivation untenable, since the cost to clear the trees and level the built-up land exceeded the probable profit, so the area naturally regenerated to woody vegetation. Had this area not been used for a railroad grade, it would have been farmed with the adjacent land and the trees would not have remained. Across the cases, all ten respondents indicated previous land use as a key determinant of agricultural production activities.

Owners' Values and Beliefs

The role of physical characteristics of the land and previous land uses suggests a substantial degree of path dependence in determining current land uses. That is, current uses are highly correlated with pre-determined factors. However, other variables can be influential. In particular, land owners' values and beliefs are an important determinant of their activities. Most respondents expressed a belief in the value of maintaining the land's rural character. Several respondents listed an important reason for owning the land as wanting to keep it in the family, or simply to live in the area where they grew up. Several indicated a desire to carry on the legacy of their parents by managing a working farm that could generate some amount of revenue. While none of the respondents made a living entirely off of the land, each used it in some way to gain income.[2]

[2] Many of them did not farm their own lands, but instead engaged in share- or rent-farming.

In one case, an owner explicitly said that non-economic values and beliefs overrode economic factors in land management: "If I was interested in maximizing my economic returns, I'd probably sell off this land. But I keep it because of the family history and memories attached to it." Another respondent commented, "The way we use the land, it doesn't pay its own way — but there are more important things." Two other respondents indicated that decisions to keep and tend cattle were based on an affinity for the animals rather than economic gain. Although cattle upkeep required a substantial amount of effort and inputs, these owners chose to graze animals on their land for aesthetic enjoyment, and some chose to do so in order to prevent forest colonization of open areas.

In these examples and other cases, owners' values and beliefs play an important role in land use activities and change over time. Thus vegetative cover is a function not only of pre-determined factors such as physical characteristics of the land and previous land uses, but also of individual behavior.

Institutional and Economic Factors

A striking finding in these data is the seemingly inconsequential impact of institutional factors and economic incentives on individual land use decision making. The set of institutions related to land use in this region is best described as permissive; landowners in this study listed few, if any, rules restricting their freedom to use the land as they wished. For example, owners of land in Indiana do not face private forest regulations, such as those found in some states' Forest Practices Acts, which might limit forest management activities. Nor do extensive regulations restrict agricultural production, livestock grazing, or home building on particular types of land.

This permissive institutional setting does not mean individuals are wholly without rules related to land use. Though minor in impact, respondents did discuss county zoning ordinances, which may impact potential future benefits and parcel boundaries. One respondent indicated that, should she wish to build another house, zoning laws required her to create a small parcel (five acres) to meet permissible housing density requirements. Another respondent recently had completed such a parcel boundary change to comply with these zoning laws. He explained that the boundary change would not alter his land use; it was only a "paper change."

In addition, county legal requirements may keep parcels intact. For example, one owner holding a parcel for investment purposes desired to divide it into lots to increase the resale value. However, planned unit development requirements led him to sell his parcel in whole rather than invest the time and money necessary to meet the requirements.

Another institutional constraint that land owners can potentially face is tax on property or land use activities. For parcels in this study, property tax obligations for land classified as agricultural are based on a combination of parcel size, soil productivity, and land type (e.g., woodland, undeveloped, commercial, agricultural support, other farmland, tillable, non-tillable, homesite, or classified) (Indiana Continuing Legal Education Forum, 1987: II-28). Since county officials define both soil productivity and land type based on the underlying soil (ibid, at II-64), individuals cannot change their tax burden within land classified as agricultural. However, there is a potential tax incentive to shift activities into agricultural uses from commercial, residential, or industrial uses, since tax obligations for the latter three classifications are based on market values (ibid. at II-37), which typically exceed assessed values for agricultural lands.

In practice, however, this potential tax-driven land use change has not occurred. No respondents indicated that property taxes were an important factor in land use decisions. While a few complained that their tax bill had risen substantially over time, others said that their increases were not unreasonable. Thus, as with other institutional factors, tax codes did not substantially affect these ten land owners' decisions.[3]

Nor do economic incentives weigh heavily in determining individuals' land use activities. In this township, local and external markets are readily accessible. Thus individuals take advantage of opportunities to use their land for production of commercial crops such as corn, soy, alfalfa, and even Christmas trees. Livestock, especially cattle, have been raised on some of these parcels as well. But such activities do not maximize owners' revenue. For example, as discussed above, livestock owners attributed this activity more to an affinity for the animals than a means to generate substantial profits. When discussing goals for their land, most respondents stressed a strong preference for activities that would retain the rural and farm character of the land over activities that would increase economic profits. These goals are fostered by the participation of all respondents in wage-earning jobs outside their parcels, so that land uses are not relied upon as a primary source of income.

[3]One owner did note a tax code change at the national level that reinforced his decision to sell the parcel - capital gains tax reduction from 28% to 20% that allowed him to keep a greater share of the increase in value of his parcel that came largely from growth in commercially valuable trees.

Key Factors Affecting Individual Decisions About Forest Management

Of particular interest in this study are variables affecting individuals' forest management decision. Like other land use activities, forest management activities are linked to numerous factors. Forest use on the study parcels depends largely on previous land use and physical characteristics of the land. In addition, owners' values related to appropriate forest use and beliefs about potential benefits from different forest activities are important. Of less impact are institutions and ownership change.

Aesthetics, Topography, and Perceived Benefits

Six of the ten study parcels include substantial forests, with trees covering more than a third of the parcel. Owners of these six parcels exhibited significant knowledge about, and concern for, careful and conservative forest management. In four of the six cases (67%), owners cited aesthetic enjoyment of the woods and conscious efforts to protect it, and they were very knowledgeable and concerned about the visual impacts of timber management. For example, in explaining his rationale for not selling potentially valuable timber, one respondent shared his concern that a timber harvest might leave his land looking like "a bomb had gone off." Another respondent explained her reluctance to cut timber from her forested area due, in part, to a prior logging operation that had "made a mess of the area."

Owners of four of these six parcels had undertaken timber sales in order to generate a profit and/or to improve the health of the forest by promoting regeneration. Each had invested personal time and effort in managing the timber sale, to protect the scenic and aesthetic characteristics of the woods while generating a substantial amount of timber sale income. Information was critical in allowing these owners to reach their goals. One of the owners had extensive knowledge of forest management issues, including the benefits of hiring a professional forester to oversee timber sale tree selection, bidding and contract compliance. Another owner relied on his knowledge of timber markets, which enabled him to take advantage of an unusual, temporarily high demand — and price — for maple wood by selling maple timber at that time. The other two owners had previously worked in timber-related businesses, so they felt knowledgeable in selecting and selling trees.

In the four study parcels that have smaller patches of forest, the owners described somewhat different reasons for the continued existence of forest cover. Most cited the topography of the land, especially characteristics related to drainage and slope, for the trees still being there. All four of those with smaller, unmanaged woodlots stated that they considered their trees to be void of commercial timber value; one had attempted to sell timber but discovered no buyer interest. One respondent managed to keep pigs, cattle, chickens and corn in the fields while at the same time maintaining at least one, and often two, wage jobs. Yet he made no attempt to actively manage his woods because he considered it too much work. Instead, he allowed cattle and pigs to graze among the trees. Two of the other three small woodlot owners also permitted grazing on forested areas. The remaining owner did not graze animals among his trees, but he did graze them in a non-cultivated field in order to prevent forest growth in that area.

Institutions

The role of institutions is less prominent than other factors in determining individual forest management activities. As described in the discussion of land use more generally, forest use activities are not restricted by a state Forest Practices Act. Instead, owners and timber operators are encouraged to abide by voluntary "best management practices" when cutting trees. In fact, a state statute forbids local governments from passing ordinances that would restrict removal of minerals or timber by private rural land owners (Indiana Code 36-7-4-1103).

Incentives created by timber yield taxes, as described by Englin and Klan (1990), are not applicable in this study, as no yield tax is levied on timber sales in this township. In fact, one respondent described contacting various state and local officials in an attempt to understand taxes he owed on a timber sale. Receiving no clear answer, he decided to treat the revenue as a capital gain on his federal income tax return.

State and federal laws have created a set of institutional incentives, including technical assistance, cost-sharing, and tax subsidies. State law created the Indiana Classified Forest Program, which includes provisions for paying individuals who abide by program requirements. But the impact of this program has been limited to a small percentage of land owners who choose to participate. (See "Policy Interventions" section below for data regarding participation rates and further discussion.)

Ownership Change

The relatively low impact of institutional variables parallels the minimal role of ownership change in affecting individual forest management activities. Data from this exploratory study do not support expectations about ownership change leading to forest cover change. While it has been argued that ownership change causes deforestation due to financial implications of land transfer and/or differences between previous and new owners' values (see, for example, Kahn, 1997), data from this research do not clearly support such a pattern. Instead, ownership change in these cases has not been closely associated with deforestation. For the most part, owners have avoided negative financial impacts of transfers that might cause them to generate revenue through timber sales, and new owners have not exhibited values substantially different from previous owners.

Land transfers can be divided into two types: within family and outside of family. One form of within family change is inheritance. As discussed above, some scholars argue that inheritance taxes often lead individuals to liquidate assets such as standing timber to pay tax obligations. Inheritance taxes are a matter of both federal and state jurisdiction. At the federal level, the definition of a taxable estate changed from one that is valued at over $175,600, prior to 1981, to one that is valued at over $600,000, since 1987 (Kahn, 1997: 46). At the state level, Indiana inheritance tax prior to 1997 was levied on amounts over $10,000 (to surviving minor children), $5,000 (to surviving children over age 21 and parents), or $2,000 (to surviving grandchildren and great-grandchildren). Since 1997 state inheritance tax has been levied on amounts over $100,000 (Beaven, 1997). None of the study participants, however, indicated that such taxes were a substantial factor in determining their land use activities. Four respondents acquired their parcels from older family members (see Table 1), but, in at least three of these cases, inheritance taxes were avoided through either parcel transfer before death, incorporation, or delay in legal recording of the transfer.

Table 1: Ownership Change and Forest Cover

Case	Year of most recent Ownership change	Previous Owner	Associated Forest Clearing or Cutting?
1	1967	non-family	no
2	1989	family	no
3	1995	family	no
4	1967	non-family	no
5	1948	non-family	no
6	1985	family	yes: cleared for house building
7	1993	family	no
8	1971	non-family	no
9	1997	non-family	yes: substantial timber harvest
10	1990	non-family	yes: cleared for agricultural production

While inheritance taxes relate to within-family acquisition, land acquisition by non-family members might encourage deforestation if the purchaser needs cash to finance the purchase. In our sample, only one of the six cases in which the current owner acquired land from non-family members involved timber cutting (Case 9 in Table 1). In this case, the owner's decision to sell timber was motivated by a need for money to make the loan payment. In another non-family transfer (Case 10), forest was cleared for agricultural production. The remaining four cases of non-family transfer do not exhibit associated forest clearing or cutting.

A second mechanism by which ownership change might impact land cover is through differences in values and beliefs about appropriate land uses. In this study, reliable data about previous owners' values and beliefs are available for those four parcels in which land was transferred within a family, where respondents were able to speak knowledgeably about relatives. The current owners of these four parcels described adherence to the values and beliefs of the previous owners. Specifically, they indicated the importance of managing a working farm and enjoying a rural lifestyle. One of these respondents had purchased the parcel in whole from his father, while three had purchased a relative's share of the land. Thus the current owners do not face land use disagreements from relatives with shared parcel ownership.

Consequently, they are able to follow their values and beliefs about forest management and land use, which do not differ greatly from those of the previous owners.

Overall, then, ownership change is not strongly associated with deforestation in our sample. As Table 1 indicates, only three of the ten cases exhibit forest clearing or cutting associated with ownership change. Data for this table come from discussions with parcel owners. In the future, we will incorporate remotely sensed images into the analysis, as another source of information regarding changes in forest conditions over time. At present, for illustrative purposes, Case 6 is displayed in Figure 4 as an example of ownership change that lead to forest cover change. The current owner purchased the parcel in 1985 from his father, and in 1987 he cleared a small area in the northwest corner of the parcel to build his residence (this land cover change is reflected in a subtle change in reflectance in bands 2, 4, and 1, represented by red, green, and blue, between the 1985 and 1992 images). As he explained, his home building was contingent upon acquiring the land. It is important to note, however, that this case is more the exception than the rule, as most ownership changes in our sample did not result in forest clearing or cutting.

[Figure 4 here]

Policy Interventions

Given the impact of vegetation on global climate change (as well as on more local phenomena such as watershed conditions), forest cover is an important target for policy interventions. The control of vast acres of forest by numerous, uncoordinated, individual owners presents enormous challenges in shaping forest conditions on a global or even regional scale. Understanding individuals' land use decisions and activities related to forests allows more informed policy choices. If a policy goal is to alter NIPF owner activities, then the effectiveness of various policy instruments depends on which factors affect owner behavior.

Existing forest policy instruments on NIPF land can be categorized into three general types: land use restrictions, economic incentives, and information dissemination to promote change in owners' values and beliefs. Data in this study suggest that, within the Indiana context, in the absence of significant land use restrictions, economic incentives are less likely to alter forest owner behavior than is information dissemination. These differences in effectiveness reflect key factors affecting forest owner behavior.

An existing state program targeting NIPF owners, the Classified Forest Program (CFP), emphasizes economic incentives and information dissemination. The Indiana Department of Natural Resources, Division of Forestry, manages this voluntary program. Enrollment of land into the program requires land owners to agree to minor restrictions on forest use (for example, Classified Forest Land may not be pastured or burned, and open areas of more than one acre must be planted with an acceptable species of trees). In exchange, the assessed value of the land for tax purposes is set at $1 per acre, which can provide the owner with property tax savings. Once enrolled, the land stays in the program until withdrawn, regardless of ownership change. If withdrawn from the program, the land is subject to back taxes plus a penalty of 10 % of the tax obligation saved over the previous ten years.

The fundamental objective of the CFP is to "encourage better private woodland management and protection" (Indiana Division of Forestry, year unknown). However, the CFA's effectiveness is limited by the small number of land owners who choose to participate. Only one of the ten study parcels had enrolled acreage, and just two of the 87 parcels in the study population contained land designated as Classified Forest.

A common reason cited by respondents who were aware of the CFP for not participating was an unwillingness to accept a decrease in autonomy about decision making on their land. After all, the CFP requires participants to agree to certain activities specified by state forest officials in a forest plan. Interestingly, though, many of these same respondents allowed their land to be farmed at the total discretion of a rent or share farmer, taking a very passive role in decision-making about land use on those areas. They seemed to have greater trust in their neighbors who farmed than in state land-use professionals.

Besides a distaste for government programs, respondents cited other reasons for not participating in the CFP. Some felt that their advanced age precluded realization of possible long-term benefits from program participation, which involves short-term investments of effort and money. Others cited the relatively low economic benefit from the decreased tax assessment associated with CFP land as opposed to non-CFP land, as well as the expenses involved in obtaining the required forest survey. Finally, one respondent reported he did not participate in the program because he planned to divide his parcel for development, which would incur substantial monetary penalties if the land was in the CFP.

Since values and beliefs are among the most important determinants of land use activities in this study, the most effective policy interventions would likely be those that emphasize information dissemination. The first step might involve emphasizing basic information about opportunities to participate in programs such as the CFP. For example, one respondent indicated a belief that his forest acreage was too small to qualify for the state CFP, even though it appears that his forest would, in fact, qualify. Another owner said she knew very little about the CFP. For land owners who are aware of their opportunities for participation in such programs, outreach programs emphasizing aesthetic, wildlife, and other non-timber benefits hold promise for encouraging owner involvement.

Given differences between factors motivating owners of larger and smaller forest acreage, a useful policy intervention might focus on land owners with smaller forests. As described above, these owners tend to use their woods to graze animals, which can be detrimental to forest health. Opportunities to explain conflicts between grazing and forest benefits may lead to changes in land owner behavior.

Of course, policy interventions may be limited by underlying beliefs about government programs generally. Several respondents indicated a reluctance to allow any government officials or rules to prohibit or require certain land use activities, even as part of a program to which the land owner voluntarily agrees.

Conclusion

Understanding factors affecting individual land use activities becomes increasingly important as humans grapple with the potentially significant effects of global climate change. Forest cover issues, while often the focus of research in tropical regions, must also be examined in temperate regions such as the United States. In the context of temperate hardwood forests in southern Indiana, our exploratory study suggests that a number of factors affect owner behavior relating to land use. Most important among them are previous land use and physical characteristics of the land. Economic considerations have less of an effect on land use patterns overall, though they are somewhat more important in determining forest uses. In this permissive institutional setting, rules do not substantially alter individual behavior. Nor is ownership change strongly associated with forest cover reduction.

Ongoing efforts to alter human use of forest resources in the U.S. rely on policy interventions as a means to affect forest owners' behavior through use restrictions, economic incentives, or information dissemination aimed at changing values and beliefs. The effectiveness of these different approaches depends on what factors are significant in land owner decisions about activities on their land. This exploratory study emphasizes the role of information dissemination as a policy tool to affect NIPF owner behavior through beliefs and values.

Further Analysis with Remote Sensing

This research provides only the initial linkages between factors affecting non-industrial private forest owner land uses and land cover information provided by multispectral satellite images. There are several additional GIS/remote sensing related analytic techniques we intend to undertake in future research activities.

First, this study utilizes only side-by-side color composites to analyze forest and land cover change as sensed remotely. To better support our findings as our sample size grows, we intend to develop unsupervised and, possibly, supervised classification maps (Campbell, 1996; Jensen, 1996) or spectral mixture maps (Adams, et al., 1993) based on the reflectance data that can be combined to produce "change maps" of the region. These change maps will provide a clearer picture of where land cover has changed or remained the same, increasing our ability to generate and test related hypotheses.

One such hypotheses links land use activities to physical characteristics of the land. We expect that hilly and poorly drained locations will more likely remain forested than flat and well-drained locations. This relationship can be tested using classification change maps and overlaying them with surface data generated with the GIS. Using the USGS 1:24,000 scale digital elevation models of the region, we can generate "drainage" layers using flow-related commands supplied by the Arc-Info™ GIS software. We also can create classification maps representing high, medium, and low water availability that are directly comparable to the satellite image change maps. Combining these maps would allow analysis of correlations between forest cover and these different areas of water availability, slope, and aspect.

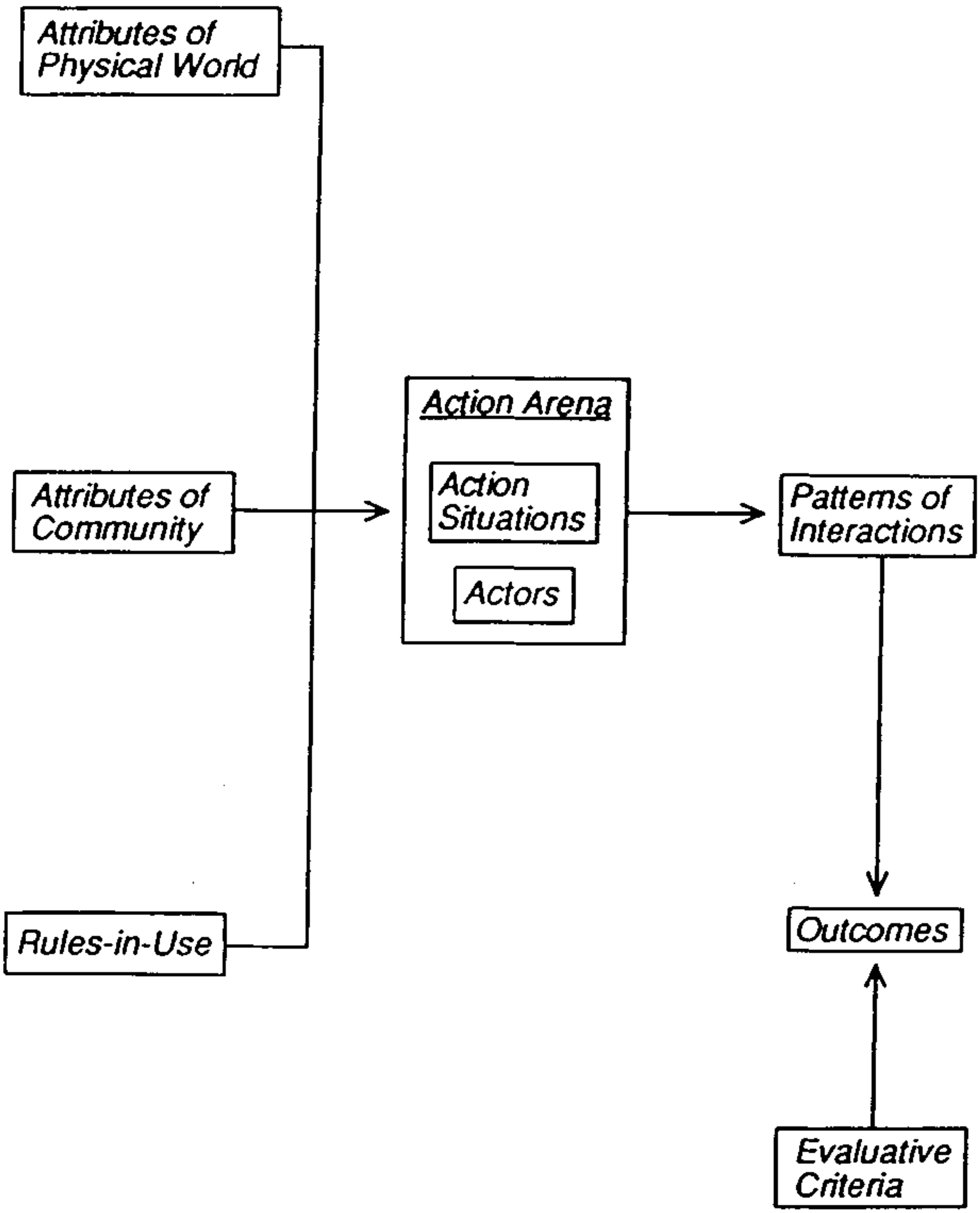
A second hypothesis expands upon our exploratory finding that, more often than not, ownership change is not a determining factor of land cover change. As described above, interviews provide owners' descriptions of land cover change. Digital change maps tied to remotely sensed images would provide a useful complement to these owners' descriptions.

A third hypothesis would allow investigation of our exploratory finding that current land use is closely tied to previous land use. Analysis of land cover classification changes over time, ranging from the earliest Landsat images (1972) to the most recent, would allow quantitative measures of the extent to which land cover outcomes are linked to land cover at previous time points.

In addition to hypotheses testing, images can help address the question of sampling bias. That is, are there any patterns in who agrees to participate versus who declines to participate in the interviews? Perhaps owners who decline have used their land differently than those who volunteer. Remote sensing provides opportunities to examine land use over time on parcels of owners who declined to participate in the study.

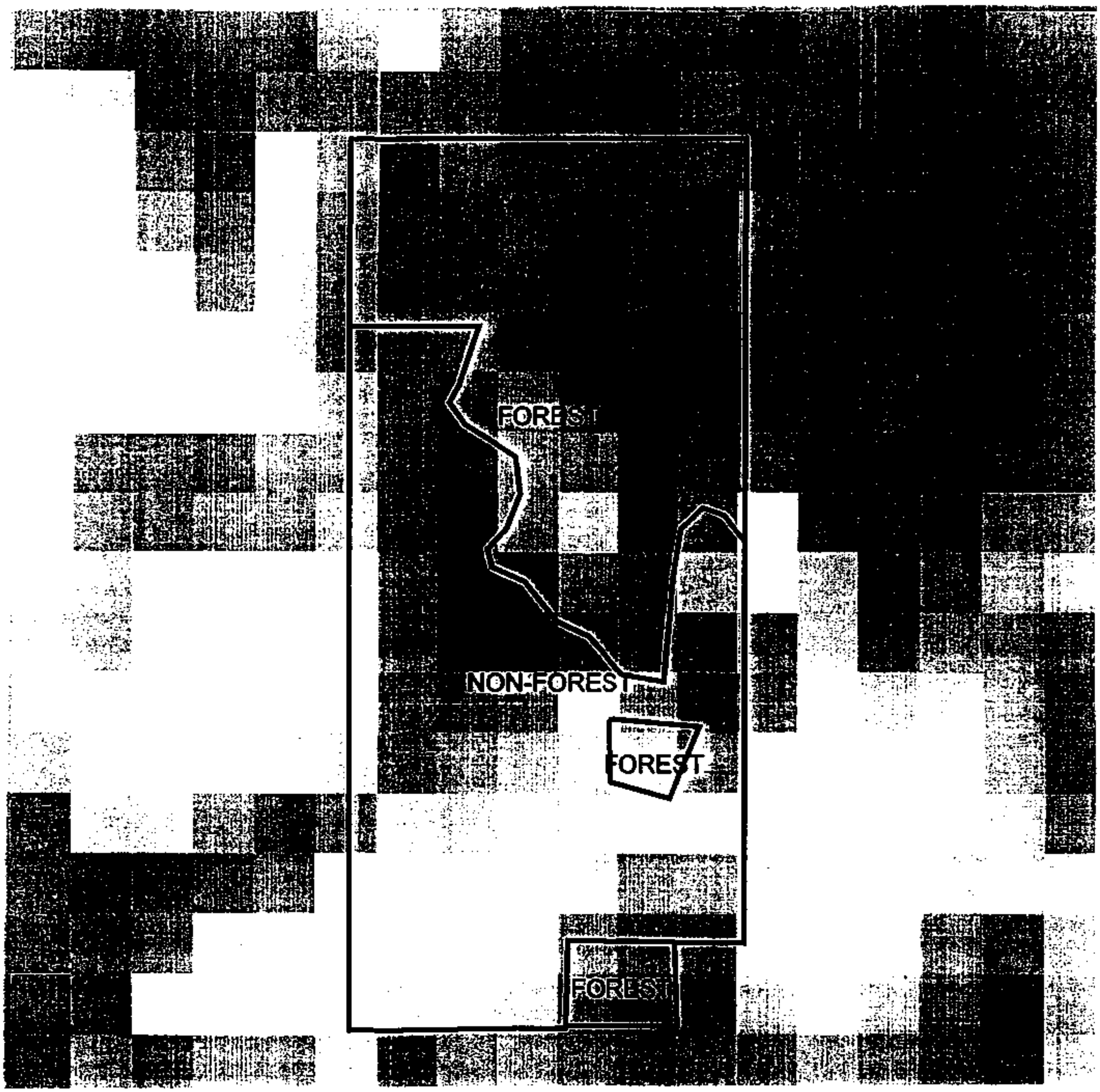
Such image analyses, coupled with the information we are collecting about human behavior in the field, will help us better determine what factors—topographic, institutional, or both—influence the stability or instability of forest cover in the Indiana setting.

Figure 1
Institutional Analysis and Development Framework



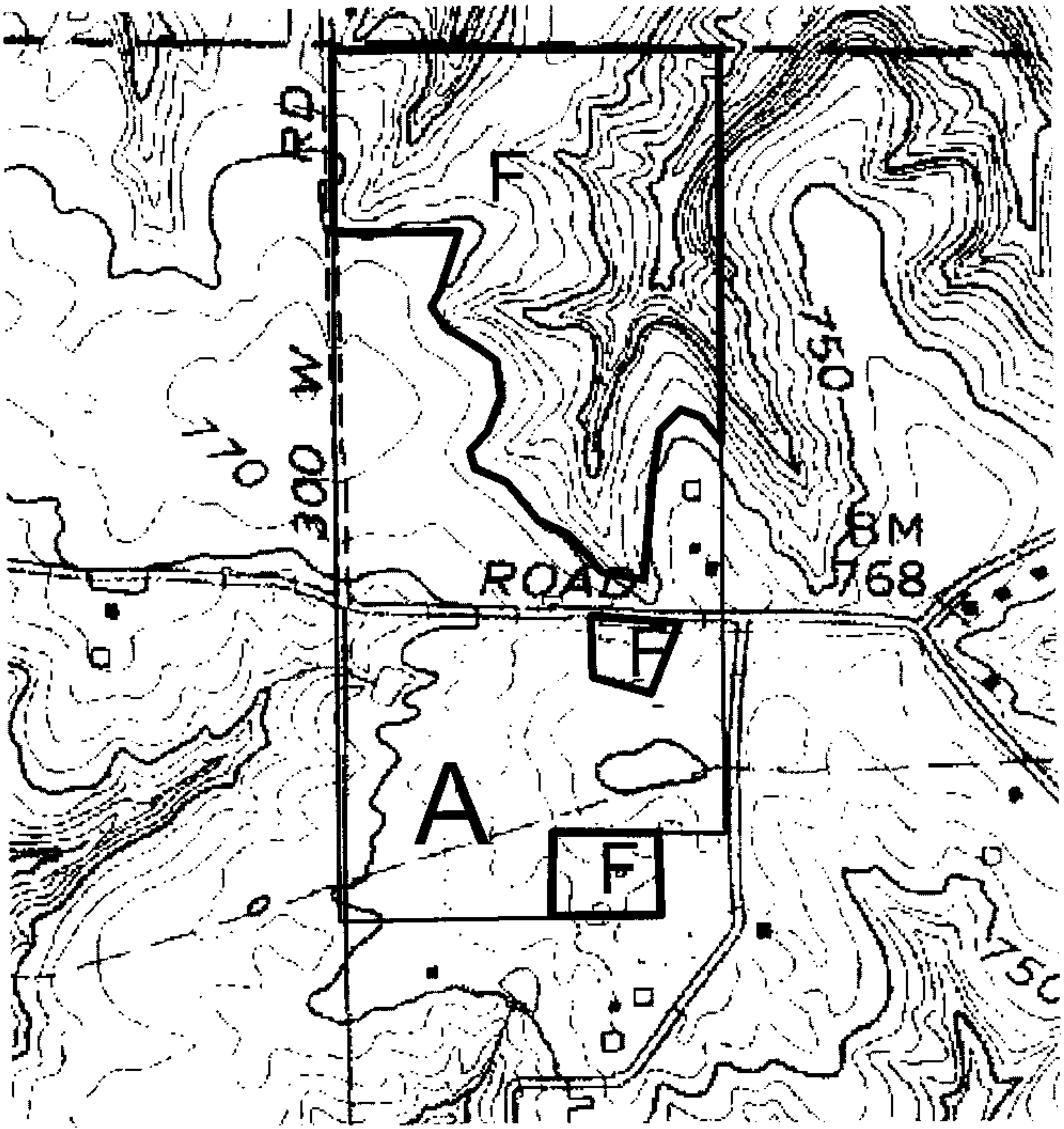
Source: Ostrom, et al., 1994: 37

Figure 2
Case 4 Map: Satellite Imagery Pixels, Digitized Parcel Boundary, and Forested Areas
(MSS Color Composite 9/28/92, Red-B2, Green-B4, Blue-Bl)



Scale: This parcel is approximately 81 acres.

Figure 3
Case 4 Map Showing Land Cover as A Function of Topography

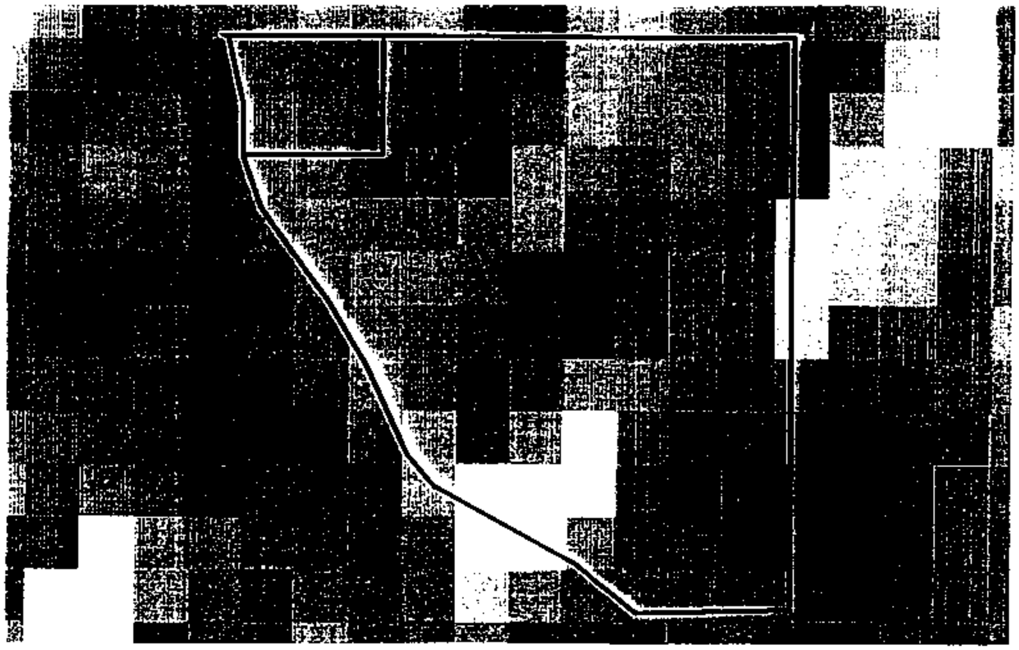


F = Forest
A = Non-forest, primarily agricultural uses

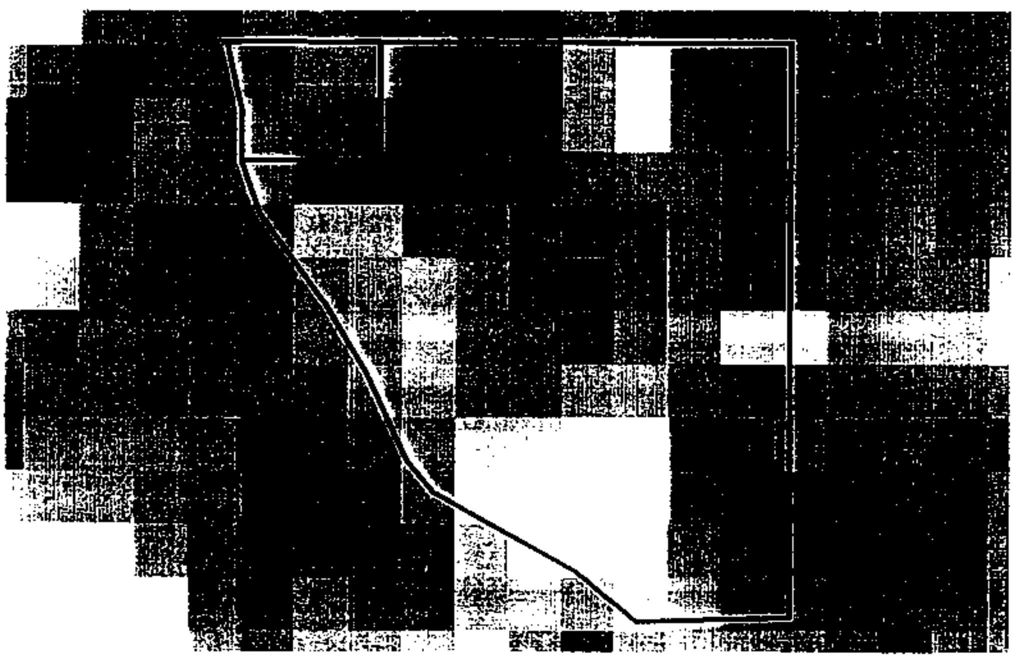
Scale: This parcel is approximately 81 acres.

Figure 4
Case 6 Maps: Satellite Images Before and After Forest Clearing Activity
(MSS Color Composites 9/1/85 and 9/28/92, Red-B2, Green-B4, Blue-Bl)

9-01-85



9-28-92



Scale: This parcel is approximately 68 acres.

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