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Interactions between people and the environment are complex and dynamic. Direct relationships between two specific phenomena (e.g., human fertility and deforestation) are rare, if not nonexistent. More commonly, data from a variety of sources are needed to adequately understand and explain the social and biophysical factors that are a part of population–environment interactions. One method of integrating the various phenomena affecting population–environment relationships is by creating a spatial representation to provide a spatially explicit data modeling environment. A critical aspect of these spatially linked datasets is the decision of what spatial unit of analysis to use to study a specific social-biophysical process. This chapter discusses the importance of land settlement pattern and land tenure to these spatial representations and implications for subsequent spatial data analysis. The application discussed here is the task of understanding how social and biophysical factors affect landcover change.

There is a long tradition of linking demographic and other social factors to the consumption of natural resources, from Malthus to more contemporary calls for such research (Pebley 1998). Until relatively recently, spatially explicit studies have focused on either macro-scale analyses with large spatial units of analysis (nation, region) or more local-scale analyses with a small number of observations. Macro-scale/regional-scale analyses are well suited to the examination of large spatial extents and are important tools for assessing global landcover change (Wood and Skole 1998). Micro-scale analyses, however, while limited to smaller geographic areas, are able to explore aspects of human–environment relationships that are typically not possible within macro-scale analyses because of data limitations. While coarse resolution satellite imagery enables landcover to be characterized for large spatial extents, it is often difficult to acquire data for the wide variety of factors affecting landcover change at the appropriate spatial resolutions and extents (e.g., soil characteristics, elevation, land tenure, agricultural productivity). While these data may be available in a highly aggregated form, it is the spatial variability of these datasets that often lends insight into local-level behavior.

Demographers and other social scientists are increasingly using spatially explicit representations to examine population–environment relationships at a variety of scales (Entwisle et al. 1998; Wood and Skole 1998; McCracken et al. 1999). This chapter presents methodological issues related to linking social survey data with landcover data at the household and community levels of analysis. Research methods from three sites with different land settlement patterns are presented to demonstrate the importance of land settlement to the types of spatial linkages that can be created between social survey and landcover data. These sites are: Altamira, Brazil—a site located along the Trans-Amazon highway in eastern Brazil; Monroe County, Indiana—a county in the Midwest region of the United States; and Nang Rong, Thailand—a largely rural district in northeast Thailand. The history of land use and land settlement in each of these research sites will be briefly described in the context of their implications for spatial data analysis and for linking social data characteristics to landscape outcomes.

One method of linking demographic data to land-use/landcover change is to use nonspatial data. For example, aggregated census data can be integrated with agricultural census, forest inventory, and land purchasing or urbanization/suburbanization data from secondary sources. This type of integration provides a rapid means of assessing general trends in landcover change, but analysis is usually restricted to a limited set of variables that likely only explain a small part of the interaction between social and biophysical phenomena. However, these nonspatial analyses are practical because they generally have more modest data collection requirements. In addition, nonspatial analyses are well suited to global scale extents because of the difficulty of acquiring and processing spatially explicit data for large areal extents.

Despite the considerable front-end cost of building spatially explicit datasets, a new level of analysis is possible with these data. These spatial analyses are particularly useful for representing the biophysical variables affecting landcover change, such as surface slope and soil characteristics. Rather than asking a survey respondent to characterize the proportion of his/her parcel suitable for rice production, this proportion can be modeled using geo-referenced elevation data (admitting that information from a respondent may be useful in validating assessments made from those data). Rather than asking a respondent how much of his/her parcel has been cleared for row crops at different times in the last ten years, this can be detected using remotely sensed satellite imagery. The availability of spatially explicit datasets (e.g., topography, landcover data) provides a means to make a more direct connection between landscape changes and the agents affecting those changes and the ability to measure the implications of those landscape changes in different ways. Examples of this type of analysis will be presented later in this chapter.

Social survey data are commonly collected and made available at the individual, household, community, and regional levels. Each of these levels of analysis presents different challenges when one links them to the landscape. While there are certainly individual-level mechanisms related to landcover change (e.g., migration), land management decisions are more commonly made within the context of a household unit. While households in some areas are little affected by community-level institutions (e.g., Altamira), other areas are heavily influenced by both public and private community organizations (e.g., Monroe County; Nang Rong, Thailand). The utility of community-level analysis depends on the social structure of the study area, which is in part a product of the pattern of land settlement.

It can be argued that household-level analyses are most suited to capturing the heuristics behind landcover change because it is at the household level that many land-use decisions are made (Entwisle et al. 1998). It is difficult to capture the reasons behind land management decisions at highly aggregated levels of analysis, although this method is often applied within some disciplines. While it may be possible to relate population growth to the rate of deforestation at a regional level, this level of analysis does not necessarily inform the researcher of the motivations and incentives of landholders in their decisionmaking process. It can be argued that it is these motivations and incentives that are particularly important to understand in the context of introducing policy prescriptions that affect land transformation. However, regional-level analyses remain a rapid means of observing major mechanisms behind landcover change and are critical components of global environmental change research for their ability to track large areas over time. In addition, household- and community-level analysis can be used to complement larger-scale studies to put micro-scale processes in the context of larger geographic extents (Moran, Ostrom, and Randolph, in press).

Deriving landcover characteristics from satellite imagery

Demographers have recently joined researchers from a broad range of disciplines using remotely sensed landcover data (Rindfuss, Walsh, and Entwisle 1996; Entwisle et al. 1998; Pebley 1998; Wood and Skole 1998; McCracken et al. 1999). Earth scientists have long been using satellite imagery for a variety of applications, and a broad literature exists on the topic (see Jensen 1996 for an introductory overview). A growing literature attempts to bridge social science and the use of remotely sensed imagery (see Liverman et al. 1998), but not with a focus on the implications of the choice of spatial unit of analysis.

Many research projects use social data that are spatially sampled from the landscape. For example, household-level data may have been collected in a sample of villages. Census data, while providing complete coverage of populations in the landscape, are problematic because of their coarse temporal resolution (e.g., every ten years in the United States with periodic projections) and the omission of observations in areas with small populations for reasons of confidentiality. In contrast, satellite imagery provides a complete coverage of the landscape using a raster (or gridded) surface representation through a set of pixels arranged in rows and columns. A pixel indicates the smallest spatial unit for which data are available, and the spatial resolution of an image indicates the pixel size of raw/unprocessed imagery. To search for a satellite image the researcher need only identify the study area extent using geographic coordinates in order to identify dates for which images are available and important metadata such as the amount of cloud cover in the available imagery. In a best case scenario the study area falls entirely within one image footprint and does not span two adjacent image footprints; the latter circumstance increases acquisition and processing costs.

Online tools exist to help researchers conduct these searches. An example is the United States Geological Survey Web site Earth Explorer (http://earthexplorer.usgs.gov), which has metadata about archived spatial data products including those from the Landsat satellite platforms. Similar tools exist online for searching for imagery from other satellite platforms such as the French SPOT satellite series and the Indian IRS series and from commercial satellites (e.g., the high resolution IKONOS satellite). Metadata are data that describe key characteristics of datasets; it is critical to assess metadata for imagery prior to purchasing imagery. Important metadata for satellite imagery include the spatial resolution (minimum mapping unit or smallest area observable with the imagery), spectral resolution (number of bands in the electromagnetic spectrum that the satellite senses), and the percent of the image obscured by clouds. Metadata serve as a tool for researchers to assess the appropriateness of different datasets for their analyses. While the cost of imagery was once prohibitively expensive for many research projects, this has changed somewhat, particularly for historical imagery, which is now comparatively inexpensive. A larger cost associated with satellite imagery is the labor necessary to produce landcover classifications and accuracy assessments.

Image processing and classification is a labor-intensive process that is subject to many sources of error. These types of error include both positional error and classification error. Geo-referenced field data describing landcover conditions at specific known locations are necessary to attain the highest possible accuracy of landcover classification. For contemporary imagery, field data collection of landcover data can be conducted in conjunction with social surveys. A training sample is a geo-located field site where the landcover has been characterized using some kind of field form. These training samples can be used to train clustering algorithms to produce landcover classifications for entire images and to validate classifications of satellite imagery. Collection of training samples with social survey data collection saves travel time and resources but requires interviewers/researchers to have a broad set of skills (e.g., interviewing techniques and familiarity with forest inventory data collection and with the use of Global Positioning Systems (GPS)).

Satellite imagery can be used to enhance the social survey data collection, particularly in regard to land-use practices. Raw imagery (i.e., preclassified) can be used as a means of asking landowners about the specific land-use activities conducted on different management areas within their parcels and the motivations and incentives behind those land management decisions (Koontz, Kauneckis, and Carlson 1999; McCracken et al. 1999). Once classified, a satellite image can be used to identify areas with different landcover types. A typical classification might be one that discriminates forest, agriculture, urban, and water cover types. A more detailed classification may discriminate different types of forest (coniferous vs. deciduous), different stages of forest regrowth, and different agricultural land uses (pasture vs. row crops). With classified imagery from multiple dates, areas that have experienced specific landcover changes can be identified, such as the clearing of forest or the abandonment of agricultural land and subsequent succession to forest.

By linking a landcover change dataset with a Geographical Information System (GIS) layer of land ownership (e.g., map showing parcel boundaries), the location of these landcover change events can be used to identify landowners who have performed specific land-use activities on their parcel. This allows the survey sample to be focused on collecting data for households that have performed a specific landcover change activity on their parcel—such as a sample of landowners who have cleared forest for agriculture or allowed a formerly cultivated area to turn to fallow. Alternatively, the survey can be targeted to landowners on whose landholdings there has been no observed change. What factors motivated a landowner to clear a forest area? Does the age composition of households on whose parcel clearing has occurred differ from the age composition of households on whose parcel no change has occurred? Do households who hire wage labor clear forest at a faster rate than those who do not? If the researcher relied on a random sample of landowners/parcels, then the sample may or may not include an adequate representation of the specific landcover change processes that are to be explored.

Classification of older imagery is more problematic than the classification of contemporary imagery because of the difficulty in obtaining ground truth data to validate classifications of older imagery. Aerial photography may be used to determine landcover, but it is not possible to derive information with the same level of detail as with field data collection. For example, using forest inventory techniques and field data collection, it is possible to determine several stages of forest succession and use these data with contemporary imagery (Mausel et al. 1993). However, given 1:50,000 scale aerial photography from 1970 and 1978 it may only be possible to determine forest/non-forest areas as opposed to multiple ages of forest regrowth, limiting the level of classification that can be derived. This difficulty in classifying historical imagery is particularly a problem with coarse resolution imagery in areas where the landscape is highly heterogeneous or mixed. Hierarchical classification systems are used to provide the most detailed classifications for contemporary products that can still be used with historical imagery for landcover change analysis. Another approach is to use distant forest areas or other unchanging landcover features to adjust the digital values to changes in atmospheric and other conditions (Mausel et al. 1993).

Spatial and temporal scales of analysis

Key components to conducting spatially explicit research are the spatial and temporal scales of analysis. High resolution spatial data (e.g., 1–30 m) are capable of detecting the spatial patterns that exist in areas where the landscape is spatially complex or heterogeneous. Coarse resolution spatial data use larger pixels that are more likely to span multiple landcover types, complicating the task of coding a pixel or cell with a single landcover type. Classification techniques such as spectral mixture analysis can represent mixed pixels better than standard classifications.

The temporal resolution of data is of as much importance to population–environment research and especially landcover change research as spatial resolution. With multi-temporal data analysis, the objective is to detect changes in the landscape that have been caused by different human actions. But the temporal resolution necessary to capture these landcover changes depends on the environment. Some landscapes are highly dynamic compared to other landscapes. For example, parts of the Brazilian Amazon along the Trans-Amazon highway are undergoing dramatic landcover changes in short periods of time as colonists clear land for cultivation and allow former agricultural lands to go fallow and regrow into forest. In such an environment more frequent satellite imagery (e.g., at 2- or 3-year intervals) would be necessary to capture the true nature of these landcover changes. If the multi-temporal imagery is of too coarse a temporal resolution (e.g., ten-year intervals), then the imagery may misrepresent areas where multiple landcover change transitions have occurred, such as areas that have gone from forest to annuals production to pasture and back to a young forest regrowth over the course of ten years. For research trying to complete an accounting of the landscape a coarse temporal resolution may be suitable, but a high temporal resolution may be necessary to adequately understand the link between human actions and landscape outcomes. In many cases the availability of data at different spatial and temporal scales determines what research questions can be adequately explored and what analytical methods can be used to explore those questions. Suitable imagery often are not available at the desired spatial or temporal resolutions to address a particular research question.

Landscape partitioning and landscape characterization

The spatial operations described in this chapter involve partitioning the landscape in order to make a linkage between the social unit of study (e.g., household, community, region) and a particular landscape zone. The objective is to link people to an area of the landscape in order to understand how landholder characteristics and decisionmaking affect landcover change. In the case of a household-level analysis, the landscape partition may be the area within a parcel or set of parcels owned by that household. For a community a distance or travel time buffer may be used to identify the area most likely affected by residents of a particular village or community. Social data for districts, departments, or other areal administrative units can be linked to the landscape within a particular administrative boundary. However, the impact of exogenous factors outside these boundaries is important to consider (e.g., circular migration, access to markets).

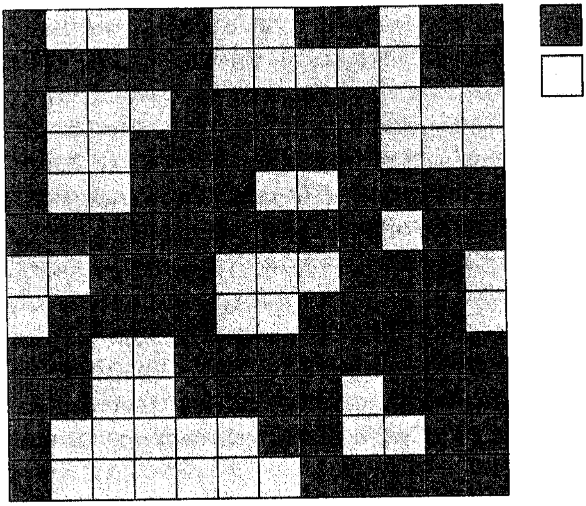
Once a partition is defined, the spatial pattern and composition of landcover can be quantified within that partition and related to specific social characteristics and land-use practices collected from social survey data. For example, what is the relationship between household composition and rate of deforestation? What is the relationship between rural-to-urban migration and the rate of forest succession? How is the availability of wage labor related to the fragmentation of forest cover? These questions require a link between the social unit of analysis and the landscape area related to those social units.

Spatial metrics are one set of tools that can be used to characterize landcover (McGarigal and Marks 1994), and are measurements of the composition and pattern of the landcover features. Examples of spatial metrics include the percent of forest cover, the amount of forest edge in a landscape, and the degree of forest fragmentation. Spatial metrics are important because they are indicators of the ecological and social function of a landscape (Forman and Godron 1986; McGarigal and Marks 1994; Forman 1995). For example, highly fragmented landscapes are a poorer habitat for some species compared to non-fragmented landscapes. A very patchy and dispersed urban landscape can be an indicator of urban sprawl. These landcover characteristics can be used as inputs for models with various applications such as species habitat/biodiversity assessment and carbon cycling/carbon sequestration. Collectively, these spatial metrics describe the spatial pattern and composition of landscape areas and sub-areas. Landcover composition refers to the proportions of different landcover types within an area and is particularly useful for questions of carbon sequestration models that rely on the carbon cycling rates of different landcover types. Landcover pattern measures are measures of the spatial distribution of a particular landcover type and are particularly useful for assessing the ecological function of a landscape.

Spatial metrics can be used to describe the characteristics of individual patches, classes of patches, or entire landscapes. A patch is a single contiguous area, such as a forest stand in the midst of an agricultural area. An example of a pattern metric is the amount of edge in a landscape. Class metrics describe the characteristics of all patches of the same type, such as all forest patches in a landscape. For example, the connectivity of forest patches can be characterized by measuring the mean distance to the closest forest patch for all patches in the landscape (mean nearest neighbor distance measure). Landscape metrics describe the aggregate patterns observed in an entire zone. Examples include measures of landscape diversity (variety of landcover types present) and homogeneity (number of distinct patches in the landscape). These metrics have long been used by ecologists to characterize natural landscapes (Turner 1990). More recently, social scientists have used these metrics to describe the impact of people on modified/managed landscapes (Fox 1994; Rindfuss, Walsh, and Entwisle 1996; Walsh et al. 1999).

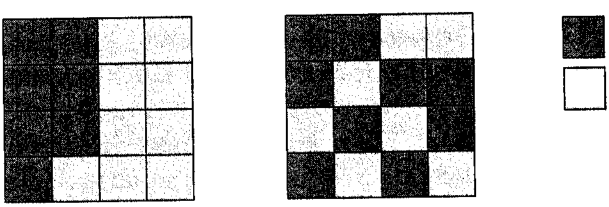
Figure 1 shows a set of spatial metrics describing the pattern and composition of a single landscape area. Figure 2 shows a possible subset of a landscape representing the area of two distinct parcels. The image on the left is highly homogenous with only two patches (one agriculture, one forest) and a high mean patch size. The image on the right is highly heterogeneous and is characterized by many patches. Different rules can be used to determine adjacency. In the figures presented here, a rooks-case rule is used to identify patch contiguity. That is, two cells can only form a single patch if they share a north/south or east/west edge. Alternative rules can be used, such as a queens-case rule that allows for diagonal adjacencies. The amount of edge in a landscape is an important indicator of ecosystem

FIGURE 1 Spatial metrics: Landcover pattern and composition



function. The amount of edge within each parcel differs because of the different degrees of patchiness in the two parcels. The two parcels are of similar landcover compositions, yet have very different landscape patterns. The patterns exhibited on these two parcels may be a function of a variety of factors such as previous land use, soil fertility, topographic land suitability, timber harvesting practices, and land use/landcover on proximal parcels. Spatially explicit landcover data at the parcel level allow these factors

FIGURE 2 Landcover pattern and composition: Parcel-level metrics



	Parcel A	Parcel B
Forest (percent)	43.75	56.25
Agriculture (percent)	56.25	43.75
Mean patch size (all landcover class types)	800m^2	145m^2
Mean agricultural patch size	900m^2	117m^2

to be evaluated in the context of the characteristics of the household managing the parcel.

This type of social–spatial link is particularly suitable for land-use/landcover change analysis because of the availability of satellite imagery that provides a relatively inexpensive method of attaining complete data coverage for a large spatial area. As an example, one image from the Landsat Thematic Mapper (TM) satellite scene covers approximately 183 x 170 km. Global scale analyses use mosaics or groups of scenes, while images are often subset to a portion of the scene for local scale studies in order to speed processing. In addition, archived imagery exists dating to 1972 (Landsat Multi-Spectral Scanner [MSS] data) providing the ability to determine historic landcover changes over nearly three decades. Aerial photography, including declassified military images, can extend the temporal scale of study further (although these types of products are more difficult to acquire for less developed areas and require more processing time to produce landcover classifications).

Characterizing social–spatial relationships

The spatial integration of social and environmental data provides a mechanism to explore the relationship between human activity and landscape changes, an important step in understanding the impact of people on species habitat and global bio-geochemical cycles. A variety of spatial operations allow data of different types to be integrated. Collectively these methods are called data transformations and refer to the spatial transformation of data between representations. For example, climate data collected at point locations can be transformed to an interpolated surface, transforming the data from a point representation to a surface (or raster) representation. Likewise, population data collected at the community level (point data) can be interpolated to provide a continuous surface of population density.

Such a population density (or distribution) surface can be overlaid with a landcover change map to find the correlation between high population densities and zones of deforestation. However, interpolated surfaces do not always adequately represent the true distribution of phenomena. In particular, the density of point samples determines the adequacy of interpolated surfaces generated with those data. Additionally, some variables do not lend themselves to interpolation. Examples include nominal data such as ethnicity or occupation.

Alternatively, a one-to-one or one-to-many linkage can be made between the social unit of observation (household, community) and the landscape associated with that spatial unit. A one-to-one linkage associates the social unit to a single partition of the landscape, such as a household, which resides on a single parcel of land. A one-to-many linkage associates the social unit of observation to multiple partitions of the landscape, as with a household that has several distributed landholdings in separate locations.

Making a distinct linkage between a social unit and a spatial unit is often complicated by the varying definitions of households and communities. For example, in Nang Rong, Thailand, researchers found that the administrative definition of a village often differed from the spatial or social definition of village. The definition of a household can be ambiguous, ranging from a nuclear family definition to an extended family definition. Extended household definitions are important to micro-scale analysis of population–environment interactions because of factors such as remittances, labor sharing between family members, and land inheritance and fragmentation. Once a social unit of observation is defined, spatial analytic techniques can be used to link that social unit to the landscape.

All studies compromise between spatial coverage, data collection costs, and data representation. Demographers typically collect data at the individual, household, or community level. These data collection efforts may be samples or complete censuses of geographically defined areas. For example, in the Nang Rong study described below, researchers conducted a community-level survey of all villages in the study area. A household survey was conducted in all households in a subset of the villages in the study area because the cost to collect household-level data for the entire population was prohibitive. The study design employed in the Nang Rong study area provided for complete spatial coverage for some data (at the community level) and also a household-level survey that allowed for better exploration of household behavior and decisionmaking for individual villages. Landcover data are readily available as spatially continuous data from satellite imagery. Partitions around the communities can be used to relate community-level characteristics to landcover changes within the entire study area. The decision to use sampling strategies as opposed to a complete census in the collection of social survey data has important implications for how social and biophysical data are linked to landcover change data using GIS tools. Had the study consisted of community-level data that represented a sample of those communities, then there would be important spatial interactions between proximal villages that would obfuscate the relationship between communities and landcover change in the data.

Land settlement patterns and social–spatial linkages in three study areas

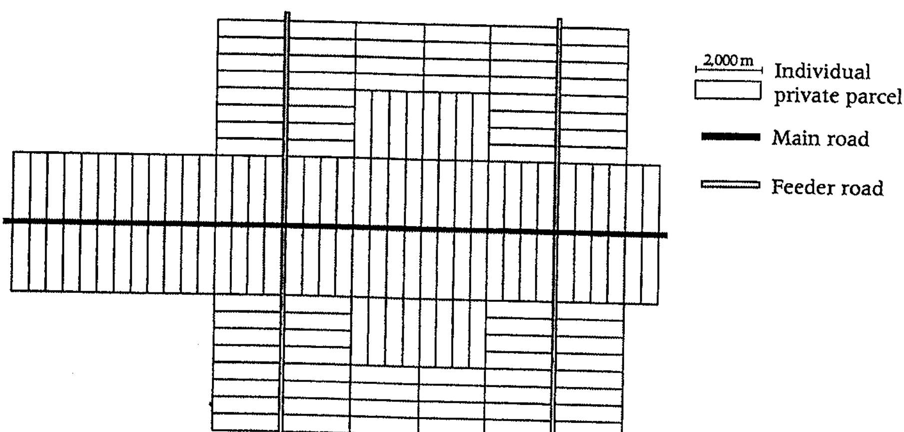
Land ownership provides one means to link land-use decisions to outcomes on the landscape. However, the pattern of settlement and the types of land tenure determine the types of linkages that may be reasonably made and the amount of effort required to make those linkages. The following sections describe the cases of three research projects linking social survey data to landcover change. Each of the three study areas has distinct settlement patterns and land-tenure situations. These research projects demonstrate the difficulties involved in creating a distinct linkage between landcover change and individual social characteristics but also the analytical potential. The unique social and spatial organization of each site determines which methods are appropriate for linking social decisions to landscape outcomes.

Altamira: Brazilian Amazon

Altamira, located in the Xingu Basin of the Brazilian Amazon, is an old riverine town that experienced government-directed, large-scale colonization starting in 1971 (Moran and Brondizio 1998). Land was parcelled into individual properties and distributed to immigrants. Parcels are rectangular lots of 500m x 2000m, with the 500m boundary adjacent to the road to maximize the collective access for all parcels (Figure 3). This land settlement pattern has resulted in the well-documented "fishbone" pattern of settlement and deforestation found in many parts of the Brazilian Amazon (Moran et al. 1994).

During the initial wave of colonization (ca. 1971), each household was given a single parcel in exchange for little, if any, capital. Subsequent waves of colonization also have seen households allocated a single parcel, although as time passed land acquisition required more capital as a land market emerged, reflecting the area's development and farm improvements (e.g., buildings, pastures, plantations). More recently there is evidence of land consolidation particularly in areas close to Altamira, the nearest mar-

FIGURE 3 Model land settlement pattern: Altamira, Brazil



ket town, as cattle ranchers purchase adjacent parcels to create large areas in which to graze their cattle. There is no evidence to date of land fragmentation in Altamira, despite the apparent absence of rules prohibiting the splitting of parcels. While no formal rules prohibiting parcelization of land have been found by researchers working in the study area, many landholders believe such laws do exist. This belief in part explains the lack of land fragmentation. Since land settlement in the Altamira region is relatively recent, it is possible that such land fragmentation will occur in the future as household heirs prefer to stay close to other family members rather than migrate to distant frontier areas.

This situation provides a nearly ideal scenario for determining what social, institutional, and biophysical conditions result in particular land-use decisions and what landscape outcomes result from those land-use decisions. Because most landholders cultivate one parcel, there is almost a one-to-one linkage between the social unit of study and a partitioned space of the landscape. Therefore, household characteristics and decisions can be reliably linked to specific landscape outcomes. Landholders commonly reside on the parcel they cultivate, which simplifies fieldwork because no additional time is needed to travel to remote sites to collect data about the parcel. However, properties are large (~100 ha), roads are often in poor condition, and, for any single property, distance from the front to the back of the property is 2 km. It is rare for a pair of interviewers to be able to carry out more than two household surveys per day.

Despite the presence of survey planimetric maps (maps showing property boundaries), the construction of the digital property grid proved to be an intensive process, requiring substantial fieldwork over multiple field seasons to properly geo-reference the grid to a common coordinate system and map projection and to correct errors in the existing base maps (McCracken et al. 1999). However, once this process is completed, new satellite imagery can be routinely geo-referenced and overlaid with the parcel boundaries.

Researchers conducted surveys of 402 landholders using two protocols focusing on land-use practices and on demographic characteristics (McCracken et al. 1999). These surveys are capable of linking social and demographic characteristics to land-use practices by identifying specific cultivation practices, land-use activities, economic constraints (e.g., supply of labor/capital) and soil quality. The surveys when integrated to remotely sensed data can link landcover outcomes to land-use activities identified by the social survey. The social and demographic data provide insight into what led the landholder to pursue those land-use activities, whereas the satellite data provides an independent data source on landcover change over a 25-year period.

While the initial wave of colonists needed very little capital to purchase rights to a parcel, the market today does require capital. Households must save in order to make the substantial investment needed to acquire land for their children. This has a tremendous impact on second-generation dynamics. Land prices and the resistance to land fragmentation encourage second-generation colonists to seek land in frontier areas far from their relatives. Urban merchants and professionals, or newcomers with capital, commonly purchase available properties from earlier settlers.

The farm property grid was overlaid on the satellite images using a Geographical Information System (GIS). This permits extraction of transition classes (i.e., change from one landcover class to another in a time interval) for each property in the study area (3,718 farm properties). These data were then imported into a spreadsheet package, cleaned, and prepared for statistical analysis. Data representing deforestation and land-use trajectories were tabulated into summary statistics. Farm properties were stratified into cohorts based on when a property had at least 5 percent of the total area deforested. This resulted in eight cohorts (Brondizio et al., in press).

After 25 years of settlement, 61 percent of the total area examined remains in primary forest. About half of the area deforested during the period 1970–96 remains in production in 1996 and the other half has been taken over by secondary forests and fallows. Of the area in production, 50–80 percent of the landcover is in pasture. There seems to be a clear association between the percentage of a property in pasture and the absence of above-average soils. As the amount of nutrient-rich alfisols increases, the percent of the property in pasture declines and the area in cocoa and sugar cane increases.

The data show consistent deforestation trajectories across cohorts with marked pulses reflecting changes in the larger political economy. Farmers deforest exponentially in the beginning stages of settlement to establish cultivatable land. This is followed by a period of consolidation and investment due to increases in commodity prices and credit availability.

The use of satellite remote sensing, GIS, and demographic household surveys in an integrated methodology able to scale from the property of households to the region permits long-term monitoring of change in landcover and its demographic correlates. Additional details of this effort may be found elsewhere (McCracken et al. 1999; Brondizio et al., in press; McCracken et al., in press; Moran, Brondizio, and McCracken, in press).

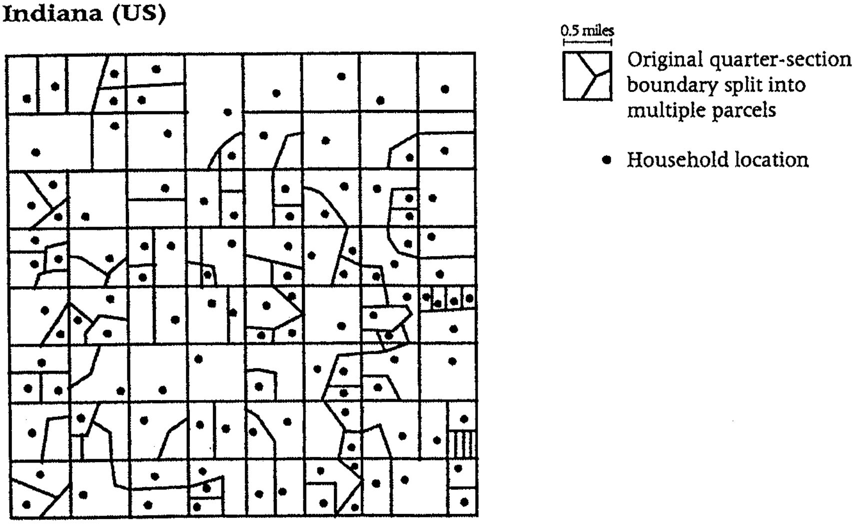
Monroe County, Indiana: American Midwest

Monroe County, Indiana, located in the Midwestern United States, presents both similarities and contrasts to Altamira. Pre-colonial inhabitants had relatively little impact on the landscape, and large-scale land clearing did not occur until the first major wave of settlers arrived in the early 1800s. Land was surveyed according to the Township and Range system, which partitioned the landscape into square parcels that were allocated to individual settler households.

This situation is analogous to the Altamira case in that parcels were of common size and dimension and there was one household per parcel of land at the time of initial settlement. In contrast to Altamira, perhaps because 180 years have transpired since the initial major waves of settlement, there is considerable parcelization and none of the parcels have retained the boundaries originally demarcated in the county (more heavily agrarian parts of Indiana have experienced considerably less parcelization). Figure 4 shows a depiction of this land settlement pattern where smaller parcels have been created within the original parcels that had mostly regular dimensions.

Monroe County and the state of Indiana experienced massive and steady deforestation from the time of initial settlement around 1810 to about 1920. Landholders reduced forest cover from the nearly 100 percent cover in the pre-colonization period to approximately 5 percent by 1910—a rate not unlike what has been seen in the Brazilian Amazon for the past 25 years (Nelson 1998; Brondizio et al., in press). Since approximately 1910, forest cover has been gradually increasing because of the state and federal acquisition of territory for managed forest land. While some of the management units within these acquisitions are currently under timber production, the acquired areas were often not under forest cover at the time of acquisition. Areas marginal for agricultural production that were previously under cultivation are now changing into either forests or residential developments, many of which are characterized by greater forest cover than when they were under agricultural production (Evans, Green, and Carlson 2001).

FIGURE 4 Model land settlement pattern: Monroe County, Indiana (US)



Community-level institutions have been found to play an important role in land-use management (Burby and May 1997; Sanford and Stroud 1997). However, an examination of community-level data does not provide insight into how different landowners react to different institutional contexts. In particular, landowners are sometimes motivated by factors such as aesthetics rather than maximizing profit (Koontz 2001). Macro-level approaches are not well equipped to observe variation in these micro-level processes. Macro-level approaches are well suited to identify the economic motivations driving land management in cases in which a homogenous pattern of land use exists (e.g., forest to agricultural land use in Altamira). However, Monroe County presents a more heterogeneous land-use pattern (e.g., vacation homes, forest management areas, residential and suburban areas, commercial zones). A large number of Monroe County residents are professionals with non-farm employment, and the management of their land is motivated as much by aesthetics as by economics (Evans, Green, and Carlson 2001).

In order to understand the mechanisms behind landcover change in Monroe County, a multi-level and multi-focus approach was adopted. The primary social unit of study is a household and the primary spatial unit of study is the parcel. However, meso-scale (or sub-regional scale) landcover assessments are integrated with U.S. Census Bureau census block-group and tract-level data to examine larger-scale landcover change.

This multi-scale approach is particularly important for research questions related to forest fragmentation, forest structure, and biodiversity. Landcover on private parcels in Monroe County is characterized by a mosaic of forest and agriculture. Contiguous forest patches sometimes span over 100 individual parcels. Focusing solely on the parcel level does not adequately explain the impact of landowner decisions and landcover change on the spatial pattern and composition of forest as it relates to questions of species habitat.

The research design consisted of a household-level survey of 250 landholders in the county (of a total of approximately 10,000) conducted in 1998 that focused on land-use activities and the motivations for those activities. Basic demographic data such as occupation, household composition, and educational attainment were collected as well. This social survey was complemented with a rich spatial dataset including land parcel boundaries acquired in digital form from the county tax assessor's office. The data were in a format incompatible with the GIS software used by our research group and required significant processing in order to integrate them with our other datasets. Acquiring these data in digital form was critical, however, as manual digitizing of these boundaries would have been a labor-intensive and error-prone pursuit.

The acquisition of this parcel boundary dataset was critical because it allowed us to make a reliable link between the social survey data and landcover change in a particular location. In contrast to Altamira, parcel boundaries have become heavily fragmented compared to the boundaries initially established. Fragmentation occurs when landholders with multiple children split the parcel among their heirs and as farms are transformed into higher-density residential and commercial settlements.

A multi-temporal landcover time series was acquired from Landsat MSS and TM data (1972, 1974, 1978, 1984, 1988, 1992, 1997). This rich time series provides good temporal resolution so that major landcover transitions can be observed. However, the parcel boundary data were acquired in 1997 and no historical land parcel data exist in digital form (the research team is in the process of digitizing hard-copy parcel boundary maps dating back to 1860). Therefore, we cannot assume that the parcel boundaries present in 1997 existed previously unless an individual parcel was part of the household survey data collection and the respondents indicated any parcelization events over time.

The parcel-level analysis has allowed a social–spatial linkage at the level where most land management decisions are made for private parcels. A Landsat TM satellite image was acquired for 1997, within one year of the 1998 household-level social survey. This image was pre-processed and classified into landcover classes. A digital elevation model (DEM) was acquired from the United States Geological Survey (1:24,000 scale, 30 m spatial resolution) and processed to produce layers representing surface slope. The landcover data, DEM, and household-level survey were spatially referenced and integrated in a GIS to relate household characteristics to the landcover composition of parcels in the context of the site-specific slope conditions.

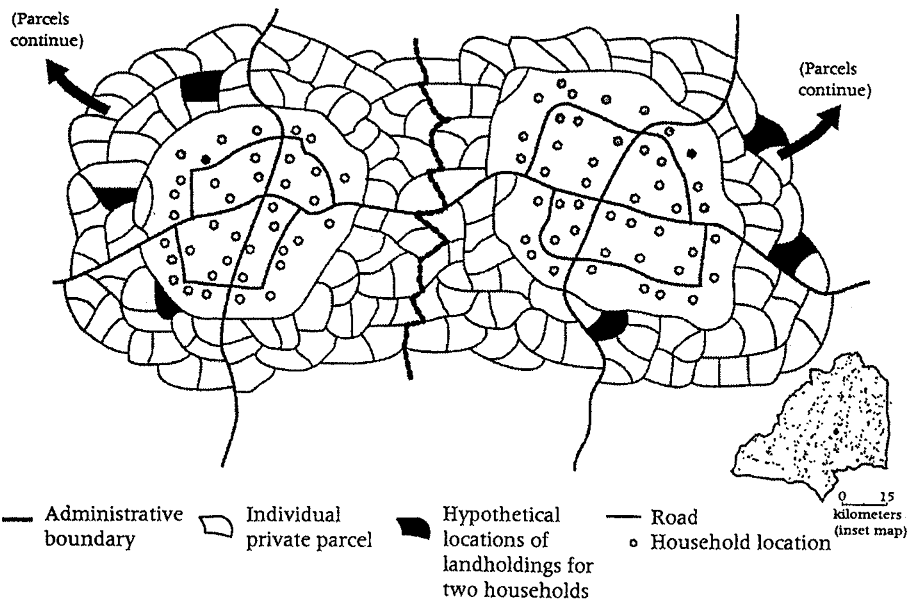
Initial results showed a strong relationship between the landcover distribution and topography (Evans, Green, and Carlson 2001). Forested lands are located in areas with steep slopes, while agriculture and pasture lands are located in relatively flat areas. This conclusion seems natural, yet 100 years ago nearly the entire state was in agricultural production of some type, including steep slope areas. Thus the presence of forested land in areas of steep topography today can be attributed to changes in the social, economic, and institutional structures through time. In particular, the decreasing viability of agricultural production, a transforming labor economy, and the establishment of state and federally managed lands have contributed to the increase in forest cover over the last 100 years.

Nang Rong District, Buriram Province: Northeast Thailand

Nang Rong, located in Buriram Province in northeast Thailand, presents a land settlement pattern in stark contrast to those of Altamira and Monroe County. While a one-to-one linkage between landholder and parcel can be made in most cases in the previous two study areas, the village settlement pattern typical in Nang Rong presents a much more complicated scenario. Settlement in Nang Rong is characterized by nuclear villages, where households are concentrated in a central area and agricultural fields are distributed around the village center. Households often cultivate multiple parcels, which may be located in different parts of the surrounding area. Figure 5 shows a model of two villages with concentrated household locations surrounded by individual parcels and the hypothetical locations of landholdings for two households. Landholdings for individual households are often distributed around different parts of the village area. Dispersing landholdings to areas of different biophysical conditions (e.g., soil wetness) decreases risk in years of climatic extremes. A model of these dispersed landholdings is indicated in Figure 5 by the dark highlighted household locations and associated parcels. The small inset on the lower right shows the entire Nang Rong District and approximate distribution of villages.

Fieldwork conducted in Nang Rong by one of the authors indicated that landholders owned parcels up to 12 km from the village in which they lived. The majority of landholdings by residents of a particular village are usually within 2–3 km of the village center (Evans 1998). This is a striking contrast to the case in Monroe County, but perhaps analogous to the situation in Altamira where the distance landholders travel to the back of their parcels is around 2 km. In Monroe County and Altamira the landholder's

FIGURE 5 Model land settlement pattern: Nang Rong, northeast Thailand



residence is on the parcel, but in Nang Rong the households live in the village center and their landholdings are distributed around the village in different locations. Travel time to and from fields in Nang Rong becomes a significant burden, and villagers often choose to establish temporary dwellings in the fields during harvest when the labor demands are highest. Because landholders own multiple parcels in different locations, the task of spatially linking households to the landscape is quite different from the cases of Altamira and Monroe County. Landholders in Monroe County do sometimes own multiple parcels, but the existence of digital spatial and attribute data for Monroe County simplifies reconciling these cases. Altamira historically has had single-parcel ownership; however, more recently there has been an increase in land consolidation (acquisition of multiple parcels) by some landholders, particularly those associated with cattle production.

In contrast to Altamira, Nang Rong is characterized by very strong community-level structures, in part a function of the centralized and hierarchical system of governance in Thailand. These social structures are manifested in the pattern of land settlement. While linear communities exist in Nang Rong (households located along major roads as in Altamira), the majority of settlements are concentrated clusters. It is unclear whether the land settlement pattern is a result of the strong community structures or vice versa.

Researchers in Nang Rong have adopted a multi-level modeling approach including household- and community-level variables in models of landcover change (Rindfuss, Walsh, and Entwisle 1996). Longitudinal survey data have been collected for the complete set of 310 villages in the study area and for each household in a sample of 52 of those 310 villages. Multi-temporal satellite imagery has been collected for a time series from 1972 to 1998. Because the community level dataset provides complete coverage of the district, no interactive effects of villages outside the sample need be accounted for except on the edges of the district.

Unfortunately, at the time of the last major data collection, digital parcel boundary data did not exist for the entire area within Nang Rong District. Hardcopy planimetric map products have been acquired for some areas and are currently being processed and validated through fieldwork. Previous research in the study area has focused on linking community-level variables to the landscape using data transformations to identify the landscape associated with individual villages. Examples of these methods include the generation of radial buffers around village centroid locations (Rindfuss, Walsh, and Entwisle 1996; Entwisle et al. 1998). Alternative boundary models have been created that model community boundaries based on village competition and physiographic features affecting the spatial pattern of land ownership (Evans 1998). Landcover pattern and competition have been characterized within these boundaries and linked to the community-level social data. In addition, multi-level modeling has been performed on the subset of 52 villages for which household-level data are available (Rindfuss, Walsh, and Entwisle 1996). In order to account for the influence of villages outside the set of 52 villages, measures of village density were used to model the competition for land as a function of village location.

Each of the three study areas discussed here poses unique challenges for linking human actions to landscape outcomes. While the pattern of land settlement provides one mechanism for establishing these links, issues of data availability, data quality, and scale dependence of social-biophysical phenomena complicate the identification of simple causal relationships. The integration of social survey data and remotely sensed satellite imagery through the use of Geographic Information Systems is a powerful analytical tool. However, spatial analysis must be conducted in the context of well-informed qualitative data for micro-level analyses in order to understand the complex relationship between human decisionmaking and landcover change. Despite these limitations, the use of land ownership information as a means of partitioning landscape outcomes to landscape actors, such as those discussed in this chapter, provides an effective analytical context for exploring these types of population–environment relationships.

Conclusion

This chapter has presented methods for linking social survey data to data on changes in land use and landcover using different spatial partitions. These landscape partitions represent discrete polygonal areas that can be linked to specific household or community units. Macro-level analyses offer researchers the ability to rapidly assess major population–environment relationships. In addition, macro-level analyses address the limitations of case studies by expanding the geographic extent being examined. However, land management decisions are commonly made at the household level and are not observable at higher levels of aggregation because of data limitations. Thus the ability to link a particular agent in the landscape to specific landscape changes is a powerful tool for researchers exploring the human impact on the environment.

Land settlement pattern determines the nature of the spatial linkages that can be created between social survey data and remotely sensed landcover data. Private land parcel boundary data provide a unique opportunity to create discrete partitions in the landscape that can be linked to individual households. In the absence of such data, or in the face of prohibitive data-collection costs, spatial data transformations can be used to model the community-level pattern of land ownership. Ideally, spatially referenced data can be used at the household, community, and regional levels to explore the multi-level factors contributing to land management decisions and place them in the context of broader geographic regions.

Note

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