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Research Note

Exploring the Spatial Relationship Between Census and Land-Cover Data

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Landscapes are shaped by complex relationships between human population, social structure, and environmental conditions. Traditionally, these factors have been studied separately within their respective disciplines. Few studies explore the relationship between indicators of social structure and ecological factors. Our objective was to examine the relationship between housing density, as recorded in the U.S. Census data, and a satellite land-cover classification in the northwest Wisconsin Pine Barrens region. We used a geographical information system (GIS) to integrate these two data sets. Our results revealed strong patterns. For example, housing densities were higher where water is more abundant, a possible case where land cover influences housing density. In other cases, housing density appears to influence land cover. These complex relationships are discussed. Our approach represents an initial methodology to integrate social and ecological data, a task needed to improve our understanding of rural societies and to facilitate broad-scale ecosystem management.

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Rural sociologists, human ecologists, geographers, and demographers have been examining social behavior, social organization, and institutional structure within a spatial context since before the turn of the century. For many students of rural life, space and time have been essential ingredients for understanding the size and composition of human populations, their distribution across the land, the means by which they organize their social life, the levels of technology accessible to them, and their cultural values and traditions. Rural demographers like Douglas Chittick in South Dakota (1955), Paul Landis in the state of Washington (1938), C. E. Lively in Minnesota (1932), and Charles Galpin in Wisconsin (1915), to name but a few, were able to discern patterns of community growth and decline associated with spatial relations of communities one to another and to metropolitan areas.

In addition, environmental features and natural resources likewise contributed to the social organization of rural communities and to their growth and decline. Rural demographers were careful in describing the association of primary production practice such as agriculture, forestry, mining, and fishing to community social organization. These studies of population, social structure, and the environment set the tone for additional inquiry into regional characteristics associated with the organization of rural life. Such work flourished from the 1920s through the 1950s. Then as scientific inquiry shifted to more inductive research, the number of demographic scholars pursuing landscape-scale research diminished.

Among the characteristics of this early work, however, was that the data employed in the studies (both primary data gathered by the sociologists and their graduate students, and secondary data available from the decennial censuses of the period) rarely came from outside the narrow disciplinary boundaries of the researchers. Measures of the importance of extractive enterprises in the communities, for example, generally were based on human variables such as the relative importance of *employment* in farming, in forestry, fishing and mining. The research was ecological in the sense that it examined relationships on the land—and indirectly, *with* the land—but the many studies based on this research paradigm can hardly be called interdisciplinary.

With the emergence of geographical information systems (GIS) during the last two decades, a resurgence of research by rural demographers and social ecologists at a regional/landscape scale is occurring—and for the first time, the promise of broadly interdisciplinary research is at hand (Voss, Field, and Kyllo 1991). Land-cover classifications derived from satellite data present a consistent data source that can capture entire regions with high spatial resolution (Lillesand and Kiefer 1994). Further, the compatibility of demographic data and biophysical data at a landscape scale allows the merger of data sets in an integrated, interdisciplinary manner. However, relatively few attempts have been made to merge census data and satellite imagery. In most cases, census data have been used to improve general land-cover classifications (Luman and Ji 1995; Vogelmann, Sohl, and Howard 1998) or mapping efforts in densely populated areas (Imhoff et al. 1997; Sutton et al. 1997; Mesev 1998). The combination of satellite classification and census data has been used to assess quality of life (Lo and Faber 1997) or to describe census and land-cover information for jurisdictional regions (Howard, Fuller, and Barr 1996; Marçal and Wright 1997). Both a satellite classification and census data were used to predict favorable wolf habitat in northern Wisconsin (Mladenoff et al. 1995). Satellite classifications have also been integrated with spatial land-ownership data (Turner, Wear, and Flamm 1996; Wear, Turner, and Flamm 1996).

However, little research has been conducted that truly integrates census data and land-cover classifications with high spatial resolution across entire landscapes. Our work in the Pine Barrens of Wisconsin represents one such effort. In this methodological note, our objective is to examine the spatial pattern of housing density in the Pine Barrens as it influences, and is influenced by, lakes and land cover in the region. We present a method to merge census data and remotely sensed land-cover data at the landscape scale.

Study Area Description

Our research focuses on the Pine Barrens region in northwestern Wisconsin. The 1500-square-mile Wisconsin Pine Barrens is located on an outwash plain deposited by glaciers (Figure 1). The soils consist of coarse sands and have low nutrient content. At the time of European settlement, the central Pine Barrens were primarily composed of jack-pine stands separated by savannas, more open areas with variable tree density (Radeloff et al. 1998). In the southern Pine Barrens, oak (*Quercus* spp.) and red pine (*Pinus resinosa*) savannas were common, whereas the northern Pine Barrens contained forests of mixed red, white (*P. strobus*), and jack pine (*P. banksiana*). The Pine Barrens landscape is distinctly different from the typical northern Wisconsin landscapes composed in presettlement times of white and red pines, hemlock (*Tsuga canadensis*), and sugar maple (*Acer saccharum*).

In the last 150 years, logging, agriculture, and other human activities have altered the original Pine Barrens landscape (Radeloff et al. 1999). After loggers cleared the forest, an attempt at agricultural production took place. But due to the poor, sandy soils and a relatively short growing season, agriculture had limited success in the region (Murphy 1931). As a consequence, county governments reclaimed much land due to defaulted taxes.

In recent decades, a new use for this land has come into prominence. Since the 1960s, recreational use of lands in this region has increased dramatically. In association with this change in land use, there has been an increase in housing units, many of them second homes held for occasional use by residents of regional metropolitan areas—especially Minneapolis and St. Paul, and, to a lesser extent, Milwaukee and Chicago. Initially, these second homes were small, seasonal-use cabins dotting the shorelines of the region's many lakes. Today these homes may be large, expensive dwellings built for eventual year-round occupancy.

The Pine Barrens cover parts of five northwestern Wisconsin counties (Figure 1). In the remainder of this article, the term *Pine Barrens counties* is used to refer to these five counties, in their entirety, plus the two Minnesota counties that lie immediately adjacent to the Pine Barrens. We chose this larger area in order to contrast land use and land cover in the actual Pine Barrens with adjacent areas in the larger region.

Methods

Housing unit density was calculated from data available from the U.S. Census Bureau 1990 Census of Population and Housing (U.S. Bureau of the Census 1991). Total housing units and land area (i.e., both occupied and vacant) were extracted at the census block level. Census blocks are the smallest units of census geography for which data are published from the decennial census. They consist of polygons defined by relatively fixed features on the land (e.g., roads, rivers, railroad tracks, lake shores, etc.) and other features such as municipality boundaries, property lines, and short, imaginary extensions of streets and roads. While having the disadvantage of being polygons of widely varying size and shape, they represent the highest spatial resolution of any census data. For each census block, the total number of housing units was divided by land area (in square miles) to calculate housing density (housing units per square mile). Each census block was assigned to one of seven density classes based on its housing density (see Table 1).

"Water blocks" in Table 1 are census blocks that consist entirely of water. That is, the block boundaries delineate a body of water, such as lakes, ponds, or, occasionally, wide sections of rivers. These blocks do not and cannot contain population or housing units, so it is important that they are kept separate from other blocks without housing units for analytical purposes.

Land-cover data in the Pine Barrens counties were classified using multitemporal Landsat satellite imagery with a resolution of 28.5 × 28.5 m (Wolter et al. 1995). This classification distinguished about 30 different land-cover classes. Overall classification accuracy of tree-species classes was 83%. We grouped these into eight classes to be used in our analysis: pine forest, other conifer, oak, other deciduous, brush, grass, water, and artificial. *Pine* consists primarily of jack and red pine, while *other conifer* is primarily lowland conifers such as white spruce (*Picea glauca*), cedar (*Thuja occidentalis*), and tamarack (*Larix laricina*). *Oak* encompasses all oaks, with *other deciduous* covering all other major deciduous trees present—primarily aspen (*Populus* spp.), maple, and ash (*Fraxinus* spp.). *Brush* land cover is largely open areas covered primarily with low shrubs. *Grass* land cover includes grassland and agricultural lands. *Water* includes all hydrographic features. *Artificial* land cover consists of roads, parking lots, and other developed areas (see Table 2).

We integrated the census data and land-cover classification in two ways. First, we used GIS to superimpose the boundaries of census blocks over the land-cover classification, and highlighted blocks with high housing density to qualitatively examine spatial patterns. Second, we quantitatively assessed the correlation between housing density and land-cover classes. In order to do so, we needed to transform the housing unit density data (defined by census blocks) so that its resolution matched the land cover data (defined by pixels) from the land-cover classification. We did this by converting the block housing density coverage to a raster format (cell-based maps) with cells 28.5 m on a side to coincide with the Landsat pixels. Each cell within a block was assigned the housing unit density for that block. We assumed homogeneous housing density within each block in the absence of information with higher spatial resolution. Cells that included a census block boundary

TABLE 1 Housing Unit Density Classes, Their Respective Numbers of Census Blocks, and the Area Represented by Each Class

Housing density class	Housing units per square mile	Number of census blocks	Total area in square miles
0	0	5413	1065
1	0.01–4.99	1496	3129
2	5.00–9.99	1644	1607
3	10.00–19.99	1396	860
4	20.00–39.99	859	300
5	≥ 40.00	4856	233
99	0 (water blocks)	3205	209

TABLE 2 Land-Cover Classes Provided by the Satellite Classification, and the Area Represented by Each Class

Land-cover class	Description	Total area in square miles
Pine	Jack and red pine	409
Other conifer	Lowland conifers (e.g., spruce, cedar, tamarack)	587
Oak	Oak	545
Other deciduous	Hardwoods (e.g., aspen, ash, maple)	2498
Brush	Low shrubs	1073
Grass	Grassland and agricultural land	1732
Water	Water	372
Artificial	Roads and developed areas	96

were assigned the density of the block with the majority area in the cell. After the transformation of the housing-density map, we compiled a table containing both housing-density class and land-cover class for each grid cell of the Pine Barrens counties. From this table, we calculated the relative area of land-cover classes within each housing density class and, similarly, the relative area of the housing-density classes within each land-cover class.

Results and Discussion

Our qualitative approach of superimposing the boundaries of census blocks with high housing density onto the land-cover class is presented in Figure 2. Since many census blocks adjacent to lakes are very small, the high-density census blocks are outlined in white to aid in their visual identification. The quantitative relationships between land cover and housing density are summarized as both the proportion of each housing-density class in each land-cover class (Table 3) and the proportion of each land-cover class in each of the housing-density classes (Table 4).

The objective of our analysis was to identify associations between housing density, an indicator of social structure, and land cover. This approach does not

TABLE 3 Relative Abundance of Each Land-Cover Class Within a Given Housing-Density Class

	Housing unit density (HUs per square mile)							
Land-cover class	Water blocks	Number of HUs	0.0–4.9	5.0–9.9	10.0–19.9	20.0–39.9	≥ 40.0	Mean
Pine	0.8	14.0	4.7	2.7	3.8	7.3	5.5	5.5
Other conifers	1.4	10.0	9.6	5.5	5.7	7.5	6.8	7.9
Oak	1.2	9.1	7.5	6.8	7.0	7.4	7.3	7.4
Other deciduous	4.3	31.3	43.1	28.9	25.1	24.0	24.0	33.7
Brush	2.8	19.2	17.1	13.6	13.2	17.0	15.3	15.7
Grass	2.6	11.9	15.3	38.6	40.3	29.2	28.2	23.4
Artificial	0.6	1.5	0.6	1.5	2.1	2.4	4.5	1.3
Water	86.3	2.9	2.0	2.3	2.9	5.2	8.5	5.0
Sum	100	100	100	100	100	100	100	100

Note. HU, housing unit.

TABLE 4 Relative Abundance of Each Housing Unit Density Class Within a Given Land-Cover Class

	Housing Unit Density (HUs per square mile)							
Land-cover classification	Water blocks	Number of HUs	0.0–4.9	5.0–9.9	10.0–19.9	20.0–39.9	≥ 40.0	Sum
Pine	0.4	36.6	36.0	10.7	7.9	5.3	3.1	100.0
Other conifers	0.5	18.2	51.2	15.2	8.3	3.8	2.7	100.0
Oak	0.4	17.9	43.3	20.2	11.1	4.1	3.1	100.0
Other deciduous	0.4	13.8	54.7	17.9	8.2	2.8	2.2	100.0
Brush	0.4	24.1	38.9	18.7	10.2	4.8	2.9	100.0
Grass	0.3	7.3	27.7	35.9	20.0	5.1	3.8	100.0
Artificial	1.2	17.1	19.5	25.2	18.5	7.5	11.0	100.0
Water	48.5	8.2	17.1	9.9	6.7	4.2	5.3	100.0
Mean	2.8	14.4	42.3	21.7	11.6	4.0	3.2	100.0

Note. HU, housing unit.

permit identifying causal relationships, but it helps in revealing correlations. These correlations can assist in formulating hypotheses about the underlying causal relationships. For example, one can hypothesize that housing density is higher where water is abundant because of the recreational potential of lakes. The test of this hypothesis will require further analysis and data collection, such as conducting surveys. In the following, we present examples of hypotheses on the causal relationships between housing density and land cover in the Pine Barrens that were generated by our approach.

Our results suggest that the underlying causal relationships between housing density and land cover probably work in both directions. That is, we find in these data examples where land cover may determine housing density. In other examples, the data suggest that housing density may determine land cover. In other words, this relationship between housing density and land cover presents a situation where one variable is not necessarily the dependent variable, or outcome, and the other variable strictly the independent variable, or predictor. We discuss these differences for three land-cover classes to present examples of different types of interactions between housing density and water (Figure 3A), grass (Figure 3B), and pine (Figure 3C).

Aside from those census blocks coded as water blocks, the relative abundance of water increases with increasing housing density (Figure 3A). We suggest that this may be an example of a relationship where the land-cover type influences the housing density: People prefer to site their homes along the shorelines of lakes and rivers. One could assume that there should be no water contained in a census block that is not a water block. However, the land-cover classification has a higher spatial resolution, and can depict smaller water bodies than the housing-density map. Furthermore, boundaries of water bodies may vary between the two data layers, and this can cause additional pixels of streams and lakes in the satellite classification to fall into housing-density units. These cases result in the positive correlation between water and housing density.

Herbaceous or grassy land cover shows a different but equally strong pattern when compared among different housing-density classes (Figure 3B). This may be an example of a relationship where the type of land-use (and thereby of housing) influences the land cover. The herbaceous land-cover class encompasses an array of agricultural lands, both grasslands and row crops, as well as some wetlands such as

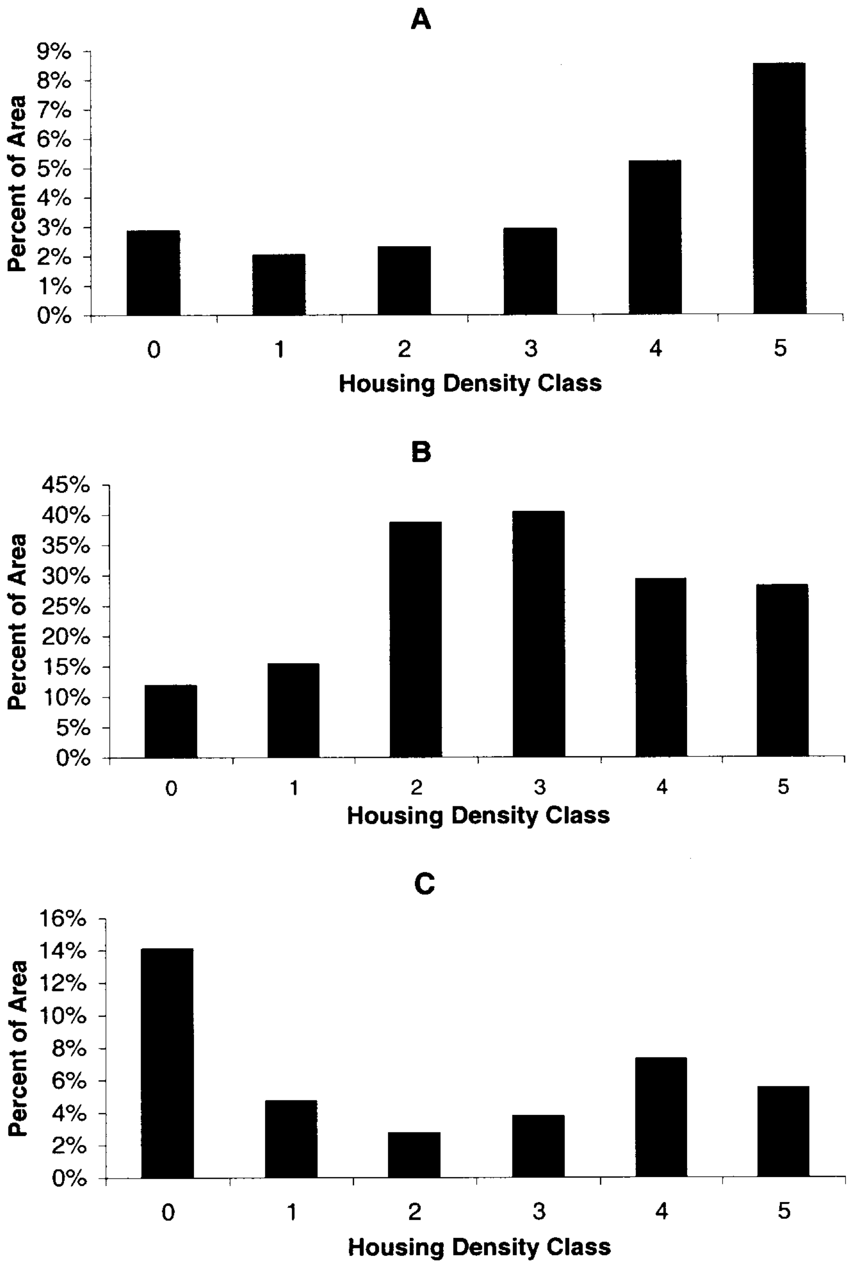

FIGURE 3 Relative areas of (A) water, (B) grass, and (C) pine compared to all land-cover classes within the area of each of the five housing-density classes.

sedge meadows. Herbaceous cover is a small percentage of the low-housing-density classes, but represents approximately two-fifths of the medium-housing-density classes. These are mostly areas in the south and west of our study area, where farming prevails. We suggest that agricultural land use results in a landscape dominated by grasslands and row crops, where scattered farmhouses form a medium-level housing density.

The relative abundance of pine reveals yet another pattern, showing two levels of housing density where pine abundance peaks (Figure 3C). This pattern may present a case of multiple interactions between land cover and housing density. Pine plantations, many of them part of private industrial forest holdings, county forests, or the Chequamegon National Forest, result in a relatively high abundance of pine in the lowest housing-density classes. Medium-level housing, which appears to be more typical for farmland, shows a relatively low abundance of pine, but pine increases again with higher housing densities. This relationship is an example of multiple feedbacks. Pine was historically most abundant on the poorest soils, areas that were unsuitable for farming. Once management of these areas for pine began, an increase in housing density was unlikely because housing would interfere with forest management, for example, by increasing the risk of forest fires. On better soils, pine was less abundant and occurred in mixtures with oak. These soils permitted farming, and existing pine was cut to clear the land, thus magnifying the difference in pine abundance between poor and better soils. The higher abundance of pine in the higher housing density classes is probably related to the higher abundance of lakes on the sandy outwash plain. This is an area where pine is naturally more abundant and an area people are drawn to because of the accessibility of lakes.

These three examples highlight the complex interactions between housing density and land cover that result in the varying occurrence of all land-cover classes within each housing-density class (Figure 4A). Other strong patterns are, for example, the distribution of "other conifers," which exhibit their strongest presence in the lowest housing-density classes. The conifer species depicted in this class, such as tamarack and black spruce, are typically found in lowlands and swamps. Such sites are not well suited for housing units. "Other deciduous" species comprise the most common land-cover type in the lowest housing-density classes. Parts of these areas are aspen stands managed on short rotations for pulp wood, often part of industrial forest holdings, county forest, or national forests. The land-cover class "brush" shows a pattern that is almost opposite to the land-cover class "grass." Brush is relatively common in the lowest and the highest housing-density classes, but less common in the medium housing densities. One reason for this pattern may be that agricultural land is commonly cleared of brush. On the contrary, forest management is most active in areas with low housing density. These areas contain a relatively high proportion of young forest regeneration, and this is classified as brush in the satellite map.

However, we mentioned before that the relationship between land cover and housing density is interactive; each part affects the other. This becomes apparent when examining the relative area of different housing-density classes within each land-cover class (Figure 4B). For instance, the highest housing-density classes are most common in the land-cover class "artificial," which is not surprising, but corroborates our method. Housing-density classes 0 and 1 are particularly common in the land-cover classes "pine" and "other deciduous," and housing density class 2 is most common in the land-cover class "grass." Such patterns may reflect effects of certain types of settlement, and thereby housing densities, on the land cover depicted in the satellite classification.

Limitations of the Data Sources

The approach presented here is based on census data and a satellite image classification. Both data sets have limitations that potential users should be aware of. The

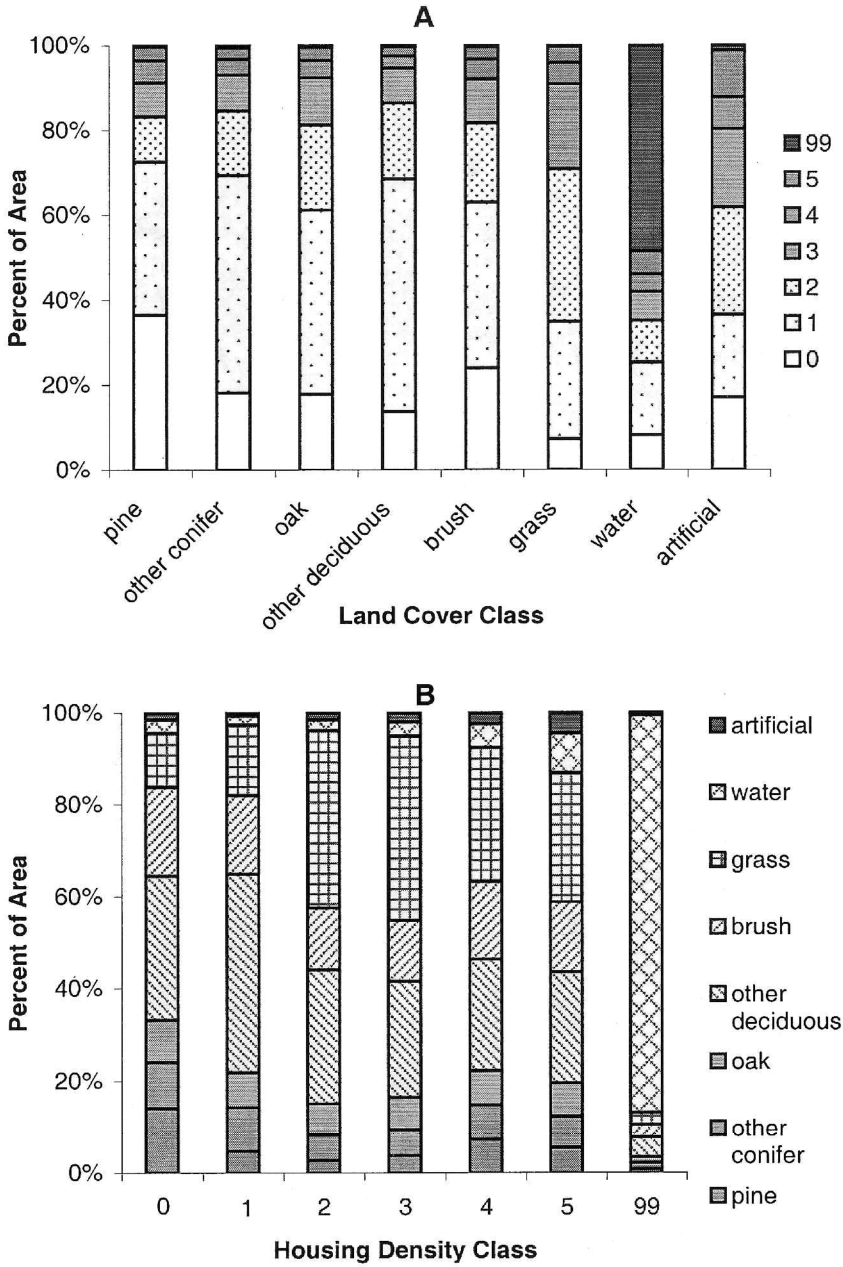

FIGURE 4 (A) Relative areas of the different land-cover classes within each housing-density class (Graph A) and (B) relative areas of the different housing density classes within each land-cover class.

resolution of the census data is limited to the size of the census blocks. The size of census blocks varies, and they are largest in areas with low housing density. We assumed homogeneous housing density within a census block. This is most likely not realistic, but a necessary assumption given the lack of higher resolution spatial information on housing units.

The satellite data have a higher spatial resolution (28.5 × 28.5 m). This poses a problem because the scale of the two data sets does not match. The calculation of the relative abundance of different land-cover types within a given housing-density class is not affected by this problem. Such values could be computed for even larger spatial units, such as entire counties. However, the calculation of the relative abundance of different housing-density classes within the area of a given land-cover class may be inaccurate. The amount of error depends on the average patch size of the land-cover class and to what extent housing units are concentrated within a census block. These errors may have added noise to our results, thus clouding potential further associations. We focused in this study on the associations between housing density and land cover. Other factors, such as land ownership and land-use history, are also important in determining housing density and land cover and warrant further study. The goal of this study was to provide a methodological approach to such research.

Conclusions

The apparent patterns that were revealed by merging housing-density and land-cover data are most likely the result of both the ecology of the Pine Barrens counties and the legacy of about 150 years of land use by immigrants (Radeloff et al. 1999). Caution is required when interpreting these patterns because correlation does not imply causal relationships. However, our results suggest numerous hypotheses for varying interactions between housing density and land cover, highlighting that much can be learned about a landscape when these two data sources are merged.

There are two concurrent trends in natural resource management. First, natural resource managers increasingly cooperate with the public in decision making and implementation of management practices. Second, resource managers strive to manage at broader spatial scales that focus on landscapes instead of single stands or properties. The Wisconsin Department of Natural Resources is attempting to encourage such a management perspective in the northwest Wisconsin Pine Barrens (Borgerding, Bartellt, and Cowen 1995). However, our knowledge of landscapes is in most cases limited, and seldom comprises data on both the human and ecological aspects of a landscape. We suggest that the attempts to manage entire landscapes while involving the public can only be successful if these two realities are studied and their interaction is understood. This article presents the beginning of a methodology to do so, and a case study to highlight the understanding that can be gathered from an interdisciplinary approach.

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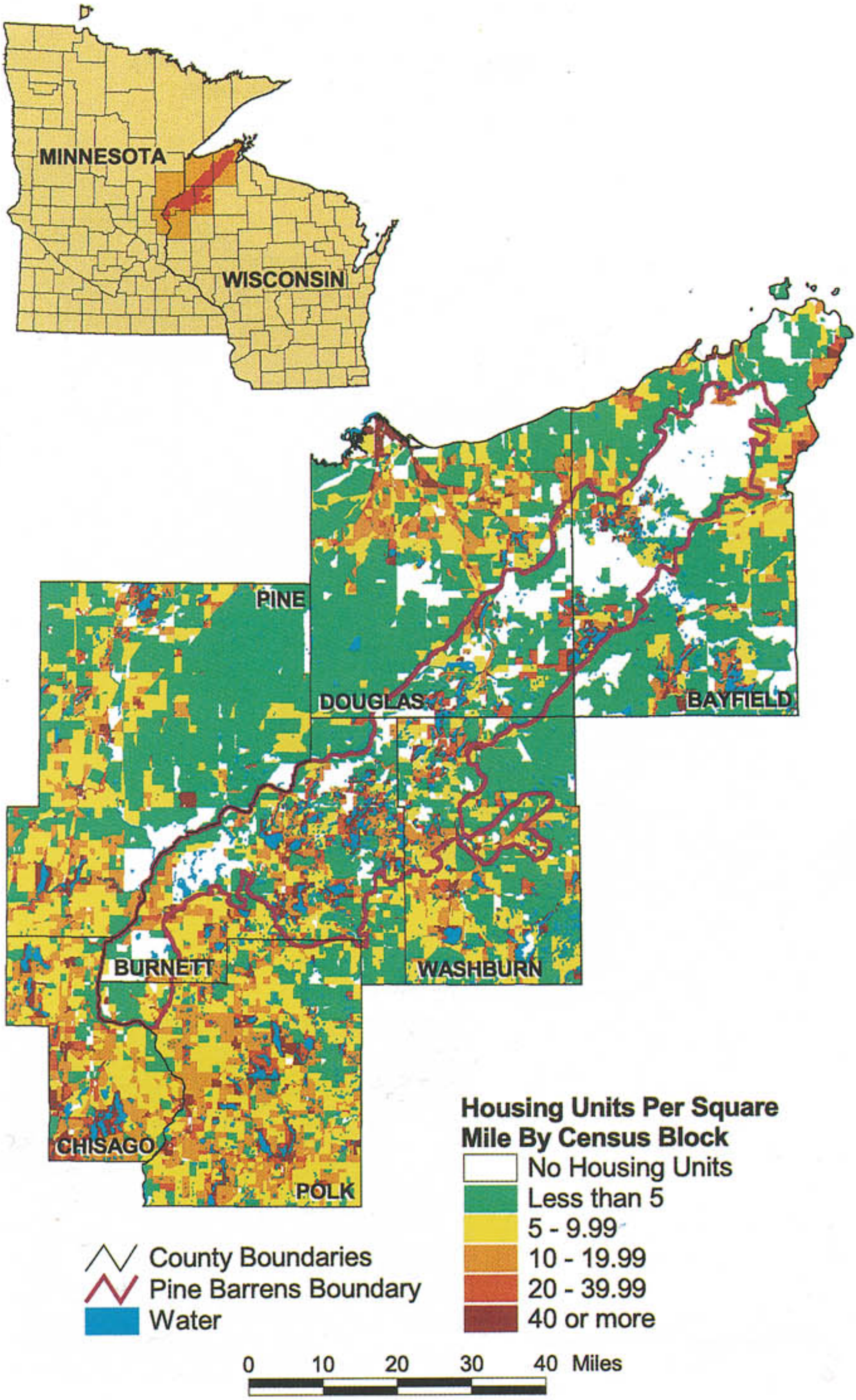

FIGURE 1 Location of the Pine Barrens and boundaries of the counties included in the analysis.

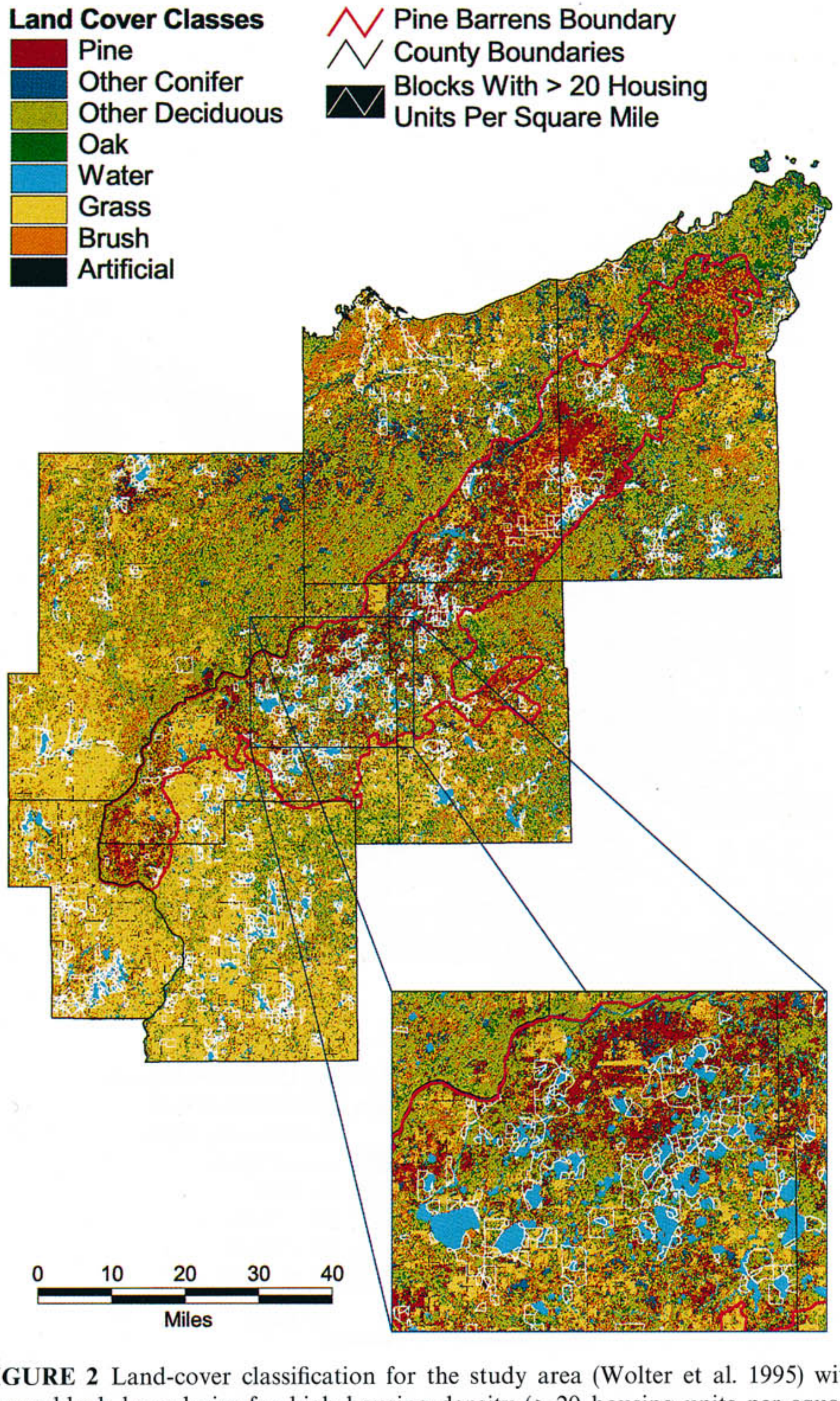

FIGURE 2 Land-cover classification for the study area (Wolter et al. 1995) with census block boundaries for high housing density (>20 housing units per square mile) superimposed in white.