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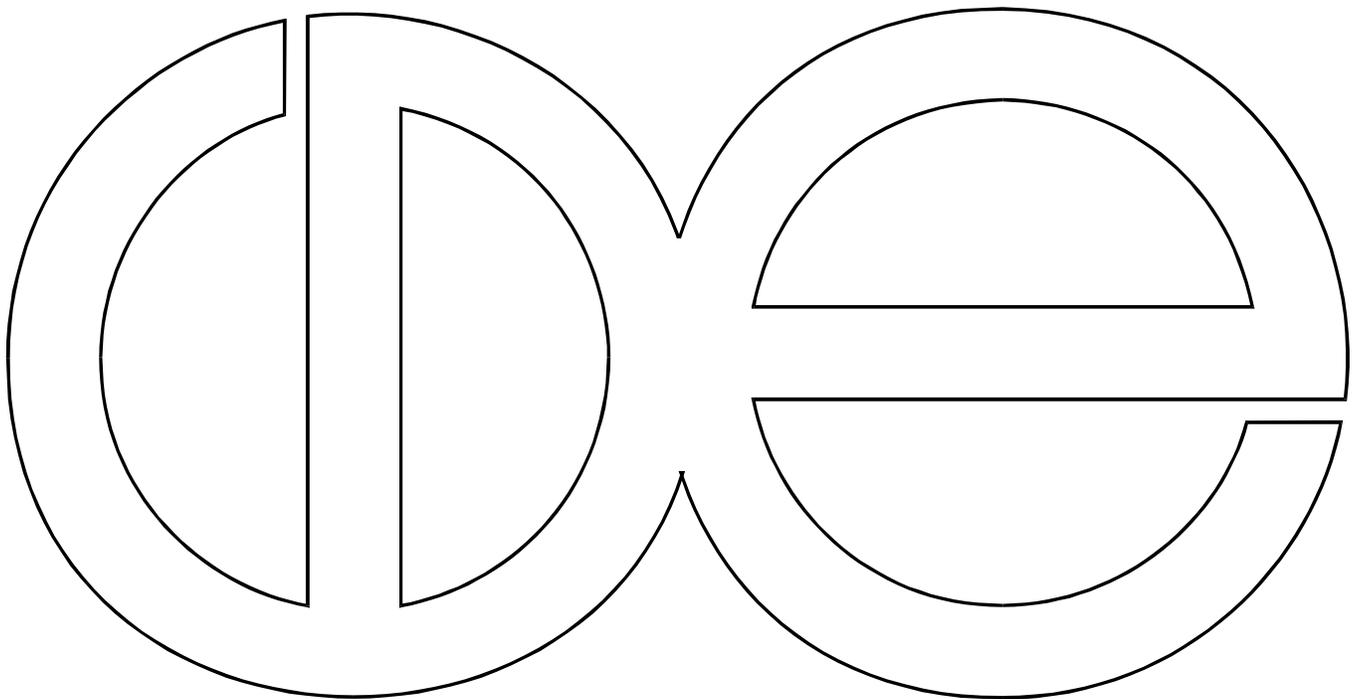
**Sub-county Spatial Patterns of Residential Development  
from 1940-1990 in Wisconsin's North Woods**

**Roger B. Hammer**

**Paul R. Voss**

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Roger B. Hammer,\* Paul R. Voss,\* and Volker C. Radeloff\*\*

\*Applied Population Laboratory  
Department of Rural Sociology  
University of Wisconsin-Madison  
[rhammer@facstaff.wisc.edu](mailto:rhammer@facstaff.wisc.edu)

\*\*Department of Forest Ecology and Management  
University of Wisconsin-Madison

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# **Sub-county Spatial Patterns of Residential Development from 1940 to 1990 in Wisconsin's North Woods**

## **ABSTRACT**

While ample data on demographic change in local communities spanning numerous decades are available from the decennial censuses and other sources, information on change in the geographic distribution of population within local communities is virtually nonexistent. Municipal boundary changes, which reflect political change rather than geographic change in the distribution of a community's population, confound analyses of population change. Our main objective is to analyze housing change from 1940 to 1990 across the Wisconsin North Woods region at a fine spatial resolution. Our second objective is to introduce a new methodology to estimate this housing change using the "year housing unit built" question from the 1990 census, combined with county-level housing unit counts from previous censuses.

Our estimates of housing density over the 50-year period demonstrate considerable change in Wisconsin's North Woods. The percentage of land with fewer than five housing units per square mile has declined while higher density areas have expanded, especially in the counties near the Minneapolis - St. Paul and Green Bay Metropolitan Areas, as well as a recreational area with abundant lakes. Due to the availability of census data and the limited processing involved, the method can be cost-effectively generalized to virtually any area of the U.S., including multi-state regions. This technique of estimating the growth in housing units in very small areas has practical policy implications for land use planning, forestry management, recreation management,

water quality monitoring, reintroduction of native species, and various other land use, natural resources, and environmental issues.

## **INTRODUCTION**

From its inception, rural sociology has focused on the growth and decline of rural communities. Galpin's studies of rural communities and social organization first in New York and then in Wisconsin, concerned settlement patterns and began with the mapping of towns and on rural farmsteads (Galpin 1914, 1915, 1918, and 1938). The "rural social centers" with varying levels of social and economic institutions and services that emerged from Galpin's maps of towns, roads, and homes described a hierarchically organized urban/rural complex that predated Christaller's central place theory (1933, 1966) by nearly 20 years. The methods and research focus developed by Galpin were replicated in numerous areas across the U.S. (Baumgartel 1923, Nelson 1952, Sanderson and Thompson 1923, Zimmerman and Taylor 1922). Galpin's study areas, as well as those of other researchers, were also revisited over the course of several decades (Kolb 1933, 1955; Kolb and Day 1950; Kolb and Marshall 1944; Kolb and Polson 1933; and Selz and McD 1951) in order to observe population, social, and spatial changes in these rural communities. Population deconcentration, migration, and the growth and decline of rural areas have remained a focus of rural sociology (Johnson and Fuguitt 2000, Frey and Johnson 1998, Long and Nucci 1997, Lichter et al. 1985), especially since the rural renaissance of the 1970s (Beale 1975, Wardwell 1989).

The underlying processes of population and housing growth in rural areas have changed over time. In the second half of the 20<sup>th</sup> century, recreational amenities have become an increasingly important determinant of population growth and housing development (McGranahan 1999, Galston and Baehler 1995), whereas the importance of natural resources declined due to decreasing employment opportunities in extractive

industries. While preferences for living in small towns or rural settings underlying rural growth were not new, the directional shift of migration and population growth patterns to rural areas was a new development in the late 1960s and early 1970s. Public opinion polls dating back to the 1940s have demonstrated the desire on the part of large portions of adults living in urban and suburban areas to live in more rural settings (Fuguitt and Zuiches 1975, Fuguitt and Brown 1990, Brown et al. 1997). These changes have substantially altered rural areas in terms of population size, housing density and extent of settlement, and the socio-economic composition of inhabitants.

The Wisconsin North Woods exemplifies these historic shifts in rural population change and settlement patterns. The region was cleared of timber and settled in the late 19<sup>th</sup> century. Following the logging era, farming was promoted in the region but then was largely abandoned in the first half of the 20<sup>th</sup> century. Mining activities have also resulted in cyclical population growth patterns in some parts of the region. In recent decades, the region experienced substantial recreation- and retirement-driven population growth and, to an even greater degree, housing growth. These population and settlement changes affect both forest (Radeloff et al. 2001) and lake ecosystems (Schnaiberg et al. 2002), but previous studies have only examined housing growth in small parts of the region, such as single counties or lake districts.

Residential development, particularly in rural areas and in suburbanizing areas, has had and is expected to have significant effects on land use, agricultural productivity, timber resources, wildlife populations, ecological services, and biodiversity (Turner et al. 1996; Douglas 1994; Parks et al. 2000; Marcin 1993; Matlack 1997; Theobald et al. 1997; Befort et al. 1988). More than a decade ago, Luloff and Befort (1989) urged the

integration of aerial photography with other spatial data to analyze land-use change and other development issues in rural areas. However, obtaining residential development information through aerial photography, satellite imagery, land records, or other sources is difficult for large areas. Satellite imagery of land cover is now widely available for the entire U.S. but change analysis is limited because no imagery is available before the mid-1970s and even 30 meter resolution Landsat data (Vogelmann et al. 2001) fails to adequately capture the low-density settlement patterns in rural areas, especially those under a forest canopy. Thus, studies of the location of rural growth at the sub-county level have been very limited (Schultz and Luloff, 1989; Schultz and MacArthur, 1994; Bradshaw and Muller, 1998), and the studies that do exist have focused on limited geographic areas such as Portage County, Ohio (Lee et al. 1998); Central Massachusetts (Levia 1998); California's Central Valley (Bradshaw and Muller 1998); and Chicago (Greene 1997). Therefore, cost-effective methods of estimating historical patterns of residential development for small areas, a fine scale, yet encompassing large regions, a broad extent, are necessary for understanding land-use and ecological change.

The U.S. Census of Population and Housing provides an alternative source of information concerning residential development in rural areas. Although the decennial census has provided data for sub-county areas for many decades, the reconstruction of historical trends for small areas is difficult. Population characteristics for sub-county political geography (cities, villages, and towns/townships) are available historically, but extensive annexations and other boundary changes sometimes preclude a reasonable assessment of demographic change over time. Moreover, towns or townships, nominally

36-square mile geographic units, are too large to examine truly fine-scale demographic change over time.

The U.S. Census Bureau, in cooperation with local government entities, delineates blocks, block groups, and census tracts, although prior to 1990 block groups and tracts were not defined for many rural areas.<sup>2</sup> Since 1990, the Topologically Integrated Geographic Encoding and Referencing (TIGER) system has provided a digital representation of these boundaries that can be analyzed in a geographical information system. Data from the 1980 and earlier censuses is available in tabular form, but cannot be mapped using the 1990 geographic areas because boundaries have undergone substantial change each decade. Examining demographic change even between 1980 and 1990 for small areas remains difficult and changes in the 2000 census again make small-area comparisons with earlier censuses difficult or impossible.

In this paper we analyze housing change from 1940 to 1990 across the Wisconsin North Woods region at fine spatial resolution. Given the lack of spatially-referenced historical population and housing data, this paper also presents a new methodology to estimate (“backcast”) sub-county and sub-municipal level housing unit counts over a multiple-decade period by using the “year housing unit built” question from the 1990 census.

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<sup>2</sup>Census blocks are the smallest unit of geography for which basic census data are collected and tabulated. Census block groups, aggregations of census blocks, are generally the smallest unit of statistical geography for which sample, or “long form,” data are tabulated. Census tracts are aggregates of block groups.

## **THE WISCONSIN NORTH WOODS**

For purposes of this research, we define the area as the 19 northernmost counties in Wisconsin.<sup>3</sup> This area has been termed the “cut-over” region due to the extent of clear-cut logging that occurred there at the end of the 19<sup>th</sup> century (Welch and Marshall 1968). The counties comprising the region were noted in the early part of this century for the extent of underdeveloped land (Whitson et al. 1922) and for being the first rural counties in the U.S. to adopt county zoning ordinances in an effort to limit agricultural development and restore forest lands (Kirkpatrick and Boynton 1936). A recent survey of Wisconsin residents’ concepts of and experiences of “Northern Wisconsin” consistently identified these 19 counties as comprising the region (Stedman 1997).

The timber industry’s exploitation of the vast white and red pine and hemlock-hardwood forests in the northern Great Lakes frontier of Michigan, Wisconsin, and Minnesota stimulated rapid population expansion in Northern Wisconsin in the post-Civil War era of the 19th century. The demand for Wisconsin lumber was fueled by the emergence of industrial cities, especially those along the western shore of Lake Michigan extending from Chicago to Green Bay, and the settlement of the vast, fertile, but largely treeless Great Plains. Between 1830 and 1930, about 320 billion board feet of softwood lumber was harvested in those three states, almost exclusively from the northern tier of counties; nearly a quarter of that total was harvested during the five-year period from 1878 to 1883 (Williams 1989). Wisconsin’s contribution to timber production increased

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<sup>3</sup>The terms northern tier of counties, northern counties, the North, and the North Woods will be used interchangeably in this paper to indicate the following 19 counties: Ashland, Barron, Bayfield, Burnett, Douglas, Florence, Forest, Iron, Langlade, Lincoln, Marinette, Menominee, Oconto, Oneida, Polk, Price, Rusk, Sawyer, Taylor, Vilas, and Washburn.

from 1.1 billion board feet in 1869 to 3.2 billion board feet in 1889, representing one-ninth of the total lumber production in the U.S. (Steer 1948 as cited in Williams 1989). This explosive expansion was made possible by changing technology in the timber industry, particularly the construction of railroads, including the completion of the Wisconsin Central Railroad running from Milwaukee to Ashland in 1877 (Bawden 1997). Throughout the 1890's, Wisconsin was consistently among the leading timber-producing states in the U.S., holding the top position for a number of years (Bawden 1997).

However, the relentless level of timber harvesting could not be sustained. By 1900, the merchantable pine forests of Wisconsin had been exhausted and only inaccessible, low-yield, scattered tracts remained (Williams 1989). Although loggers turned to other timber species in order to sustain harvests, especially hemlock and hardwoods, the timber industry experienced economic decline. The stagnation of the region's major industry triggered a concomitant demographic decline. Decennial censuses (Williams 1989) measured a population decline between 1890 and 1910. This regional depression contrasts with the mill towns to the south, like Eau Claire, La Crosse, and Oshkosh, that were able to diversify their economies through manufacturing and thus sustain growth. Concerned with the economic decline of the North Woods, the Wisconsin State College of Agriculture (University of Wisconsin), the state legislature, lumber companies, railroads, local newspapers, and land speculators encouraged farmers to settle in the cut-over area and begin farming among the stumps (Clark 1956a). However, this experiment largely failed due to the short growing season, sandy and infertile soils, difficulty of stump extraction and the hardship of enduring northern

Wisconsin winters in frame-construction, un-insulated, tar paper-covered shacks (Carstensen 1958, Gough 1997).

During World War I, agriculture promoters, abetted by high commodity prices created by wartime demand, surpassed the zeal and organization of their predecessors by planning farming communities, screening potential residents, and providing educational programs. By 1920, 20,000 new farms comprising two million acres had been established in the cut-over region, half of them after the turn of the century (Clark 1956b). However, with the post-war slackening in the market for agricultural products, North Woods agriculture declined rapidly. By 1921, property tax delinquencies encompassed one million acres in 17 counties of northern Wisconsin; six years later, tax delinquencies had increased to 2.25 million acres (Clark 1956b).

In an attempt to reverse forest depletion and eventually revive the timber industry, a reforestation movement began at the turn of the century and, although it generated a significant backlash on the part of North Woods agricultural interests, by 1912 the state forest reserve had grown to 400,000 acres (Solberg 1961). In the 1930s, the Federal Government purchased 1.5 million acres in Northern Wisconsin and established the Chequamegon and Nicolet National Forests (Bawden 1997). In 1933, adopting the guidelines of reforestation, Oneida County became the first rural county in the U.S. to adopt a comprehensive zoning ordinance. The ordinance allowed the county to abandon maintenance of any road to inhabitants of areas that were zoned for forestry, encouraging these residents to resettle in more densely populated areas (Bawden 1997). Ironically, reforestation, like deforestation, precipitated a period of population decline in the North Woods region. In addition to the natural regeneration of forest that occurred on

abandoned lands, the reforestation movement proved remarkably successful. By the 1960s, over two-thirds of Northern Wisconsin was again forested and 80% of Vilas and Oneida Counties had reverted to forest (Kouba 1973).

In the mid-1960s, the demographic fate of northern Wisconsin began to reverse (Durant and Marshall 1968). Population growth returned to the North Woods in the form of retirees from metropolitan areas to the south (predominantly from Minneapolis and St. Paul, Milwaukee, and Chicago), and the subsequent growth in the service and retail industries as local economies expanded to accommodate the new arrivals. Tourism also played a substantial role in the growth of the service and retail industries. However, the impact of new economic and population growth was not uniform across the North Woods, rather, it was focused in those subregions rich in environmental amenities, such as freshwater lakes and mature secondary forests (Voss and Fuguitt 1979). Growth in these counties continued at a relatively rapid pace throughout the “turnaround” or “rural renaissance” decade of the 1970s, a decade marked by faster growth in nonmetropolitan counties than in their metropolitan counterparts across the U.S. (Fuguitt 1985). Although growth in Wisconsin’s northern tier of counties has subsided since the 1970s, selected “recreational counties” with extensive lakes and forests continue to grow at annual rates exceeding the state average.

We chose to study residential development in Wisconsin’s North Woods for several reasons. The oscillating social and economic conditions that have characterized the area have resulted in significant demographic changes, including the geographic expansion of human settlement, which are not well understood, especially compared to the similar emergence of housing and population expansion in the suburban fringe in

metropolitan areas. Environmental change in the North Woods has been a major research focus for an extended time period, including the Northern Temperate Lakes Long-Term Ecological Research. Dramatic changes in the region have clarified the need to incorporate sociological and demographic research into those efforts (Riera et al. 2001).

## **METHOD**

The ever-changing boundaries of tabulation areas (i.e., blocks, blocks groups, and tracts) and the lack of GIS-compatible, digitized boundary information preclude any analysis of changes in historic settlement patterns, especially in more rural regions like the Wisconsin North Woods. Counties, the finest scale geography with virtually stable boundaries, are too coarse to completely address these types of research questions. To overcome this problem, we developed a technique to estimate housing density change within counties. To approximate the geographic pattern of demographic change during a 50-year period, we use the “About when was this building first built?” question (H17) from the census “long form” questionnaire. The “long form” sample included approximately 17% of the households in the U.S., but in minor civil divisions (i.e., municipalities) with fewer than 2,500 persons, approximately 50% of households were sampled. For the 19 North Woods counties of Wisconsin, the aggregate “long-form” sample was 41.4% of households.

The block group is the smallest level for which “long-form” census data are readily available in the 1990 census. However, block groups are divided, or transected, by a variety of political boundaries. These boundaries include congressional districts, places, minor civil divisions (MCD), American Indian/Alaska Native Areas, American

Indian Reservation/Trust Lands, and urbanized areas. A block group transected by one or more of these boundaries is composed of multiple “partial” block groups. That is, block group and municipal or MCD boundaries are not always coextensive, especially in rural areas. A single block group may be located within more than one MCD, especially on the fringe of urban areas in more rural counties. Housing density can differ significantly across the parts of a block group divided by such a boundary, particularly when the municipalities involved differ in type. A village might differ significantly from an adjacent rural town or township. Using the complete block group creates an illusion of housing density homogeneity within block groups that are split by a municipal or other boundary. The use of partial block groups distributes a higher proportion of the variance in housing density among, rather than within, the geographic units. The Summary Tape File (STF) 3A (U.S. Bureau of the Census 1992) includes tabulations for these partial block groups that can be used to improve the geographical and statistical precision relative to using data for complete block groups.

In 1990, the “year housing unit built” question was coded in census tabulations with the following response options: 1989 or 1990, 1985 to 1988, 1980 to 1984, 1970 to 1979, 1960 to 1969, 1950 to 1959, 1940 to 1949, and 1939 or earlier. We aggregated the initial three categories of the question into a complete decade. By adding the number of housing units built during each successive decade to the housing units constructed during the previous decades and prior to 1940, we created a preliminary estimate of the number of housing units at the end of each decade.

Given that the estimates include only housing units that were present in April 1990 and were correctly enumerated in the 1990 census, these preliminary estimates

underestimate the number of housing units in previous decades due to a variety of underlying causes. Over time, houses have been removed by human volition (i.e., demolition), been destroyed by accidental or natural events, most commonly by fire, or fallen into disuse and become uninhabitable. These housing units, not present in the housing stock of 1990, would cause a retrospective accounting of housing units, working back from 1990, to underestimate the earlier housing stock. A resident or a census employee enumerating a vacant unit can misreport the age of a housing unit. The substantial renovation of older housing units, conversion of nonresidential properties to residential use and vice versa, and the upgrading of seasonal units for year-round occupancy (common in Northern Wisconsin) also can result in the 1990 census reported age being more recent than the actual age of the original unit. The extent to which each of these factors contributes to the underestimation of housing units is unknown, but their overall effect is an underestimation of historic housing unit counts.

We aggregated the partial block groups to obtain the estimated (i.e., retrospectively reported) number of housing units in each county at the end of each decade to assess the degree to which these underestimations occur. These county-level estimates of the number of housing units based on 1990 census data were then compared to the county-level number of housing units enumerated in the actual census for the respective decade.

To correct the underestimation of the number of housing units by partial block group in earlier census years, we adjusted the partial block group estimates to equal, in the aggregate, the actual county enumerations. As shown in detail in the methodological appendix, we used a three-step procedure to correct the estimates. First, our estimate of

the number of housing units in each partial block group was adjusted upward in proportion to the implied housing unit increase that occurred during the succeeding decade according to the estimate from the 1990 Census. Second, any residual missing housing units were allocated based on the number of housing units in each partial block group. Finally, blocks with zero housing units in 1990 were subtracted from the respective partial block groups. Three elements were used in the procedure: the increase in the number of housing units in each partial block group, the sum of the increased number of housing units by county, and the number of missing housing units for each county. The adjustment procedure ensures that the 1990-based partial block group housing unit estimates match the county-level historic census enumerations. In summary, this adjustment method corrects the sample-based 1990 census data with the 100% count data from the previous censuses for each county.

Data was summarized and mapped in five housing density classes based on the number of housing units per square mile: less than 5, at least 5 but less than 10, at least 10 but less than 20, at least 20 but less than 40, and 40 or more. These class breaks were selected to illustrate change in housing density, especially in rural areas.

## **RESULTS**

*Underestimation in Preliminary Estimates* – As expected, the problem of underestimation of historic housing unit counts in the initial estimates based solely on 1990 census data increases as the decades recede (Figure 1). In 1990, there was zero underestimation by definition. In 1980 and 1970, the underestimation was less than 20% for all counties and in 1980 was less than 10% for half the counties (Figure 1). By 1960,

the underestimation was between 20% and 30% for 11 of the counties and 30% to 40% in four counties. For 1940, there are two counties, Sawyer and Rusk, where more than 50% of the housing units enumerated in the 1940 census are absent in the estimates based on the 1990 census. In another eight counties, the underestimation was between 40% and 50% and between 30% and 40% in the remaining nine counties. As outlined in the methods section and the appendix, the final estimates incorporating historical census housing unit counts eliminates this county-level underestimation problem.

*Spatial Aggregation* - The spatial accuracy of the estimation methodology is affected by the scale of spatial aggregation inherent in partial block group level data. Census data can be analyzed at different levels of geography, and generally speaking, finer spatial resolution (e.g., blocks) will exhibit higher variability and a larger range of housing density values than coarse spatial resolution (e.g., counties), where fine-scale heterogeneity is averaged. To assess the potential impact of spatial aggregation on our results, we compared the block group, partial block group-, and block-level housing density for 1990. Partial block group-level geography results in a lower proportion of the land area being classified as having fewer than five housing units per square mile than the block group-level analysis, but a higher proportion than the block-level analysis (Figure 2). Partial block group also slightly overestimates the proportion of land in the three intermediate categories, but very closely approximates the proportion of land in the highest density category compared to the block-level densities. However, the shape of the partial block group distribution is closer to the block distribution than is the block group distribution.

The partial block group distribution appears even closer to the block distribution when compared to housing density aggregated at the county level. The county distribution (not shown) is a log-normal inverted “U” skewed to the right, which is very different from the downward parabolic shape of the block distribution. With an  $N$  of 19, corresponding to the number of counties, and using an  $F$  test, the differences between the block and partial block group means are not significant for the 5 to 10 housing units per square mile category and the 40 or more housing units per square mile category at the  $p \# 0.05$  level but the differences are significant for the other three categories (Table 1). The differences between the block and block group means are significant for all but the 40 or more housing units per square mile category.

Housing density maps for 1990 at the partial block group and block levels illustrate the same general pattern (Figure 3). Although the residential settlement patterns in the block-level map are slightly less dispersed, the sizeable regions of very low-density residential settlement are nearly identical to the partial block group-level map. As expected, there are more block size patches of very low-density settlement scattered throughout the generally higher density areas in the southeast, southwest, and the lake district of Vilas and Oneida Counties. The higher density areas are correspondingly smaller and less consolidated, indicating that in the partial block group-level analysis they have a disproportionate effect on the area composition of housing densities. Focusing on the lake district reveals that the very high density blocks are largely located on the shores of large lakes or chains of lakes. In the Eastern and the Southwestern portions of the region, there are substantial areas in the 10 to 20 housing units per square mile category at the partial block group level, whereas the block level exhibits more

spatial heterogeneity among small high- and low- density areas in close vicinity. Overall, partial block groups replicate spatial patterns of housing density observed at the block level well and represent a significant improvement compared to block groups and counties as units of analysis.

*Housing Density Change in Wisconsin's North Woods* – The final estimates, which are corrected using historic census county-level housing unit tabulations, depict the change in the geographic distribution of housing units between 1940 and 1990 (Figure 4). Housing density in 1940 was very sparse and scattered, most of the land area had a density of fewer than five housing units per square mile. In 1940, housing densities were higher in three areas: in the southwest near Minneapolis - St. Paul, in the southeast near Green Bay and in the northwest near Duluth - Superior. Areas of higher housing density, over 10 units per square mile, tended to be unconsolidated, isolated clusters, even in the counties near the three metropolitan areas just mentioned. By 1950, the scattered areas of residential development had moderately expanded, with mainly low densities (5-10 housing units per square mile), especially near Minneapolis-St. Paul and Green Bay. The development of the lake district in Vilas and Oneida counties had begun in the 1940s, but with barely perceptible results. The areas of very low housing density, with five or fewer units per square mile, essentially remained unchanged in the lake district during the 1940s, however densities increased in numerous previously settled areas, mainly in Vilas County. The expansion of low density housing, with between 5 and 10 housing units per square mile, in the exurban areas bordering Minneapolis - St. Paul, Green Bay, and Duluth - Superior, evident on the 1950 map continued to 1960. By 1960, the very low

density areas in the lake district of Vilas and Oneida Counties began disappearing as the development of the region slowly intensified.

In 1970, there were still significant pockets of low and very low density areas within the three most heavily settled exurban regions. In the 1970s and 1980s, the pattern of development changed. The regions of very low density were increasingly filled in and the high density categories, which remained virtually static for the previous 30 years, expanded significantly. The largest consolidated high density cluster in 1970 was the lake district along the boundary of Vilas and Oneida Counties. The most dramatic change in these decadal maps occurs between 1970 and 1980. Housing density change in northern Wisconsin reflected the national trend of the nonmetropolitan turnaround decade of the 1970s, especially in Vilas and Oneida Counties. Finally, the 1990 map indicates a slowing of housing development in the North Woods of Wisconsin during the 1980s. The housing densities include seasonal housing units as well as those occupied year-round. In several subregions of the North Woods, seasonal housing units exceed 50% of the housing stock.

The patterns evident in the maps of housing density are corroborated by a graph of the percent of land area within each density category (Figure 5). In 1940, over 70% of the land area in the North Woods had fewer than five housing units per square mile. This category declined steadily during the period and, by 1990, occupied just over 40% of the land in the North Woods. The rate of decline of the lowest density category considerably accelerated during the 1970s but, in the 1980s, reverted to a lower level of change more closely approximating its historical pattern. The second density category (5 to 10 housing units per square mile), while being the second largest in 1940 was a very distant

second, representing only 20% of the land area. This category increased considerably during the first decade of the period, but its proportion of the total land area remained virtually unchanged thereafter at approximately 25%. The land area in the 10 to 20 housing units density category was nearly 4.5 times greater in 1990 than it had been in 1940, representing about 20% of the North Woods. This category experienced a steady increase from 1940 to 1970, and a near 100% increase in the 1970s, finally slowing considerably in the 1980s. The final two categories, representing the highest densities, each represented slightly more than 1% of the land area in 1940. Both high density categories increased significantly; the 20 to 40 housing unit category experienced the greatest proportional growth, encompassing nearly eight times more land area in 1990 than in 1940. However, the total land area developed at these higher densities remained fairly small, representing a combined area of approximately 12% of the northern counties.

Although the overall trends in housing density change in the two lake district counties, Oneida and Vilas, are generally similar to the North Woods, they experienced more extreme changes (Figures 6 and 7). In many respects these two counties are archetypal “turnaround” counties (Voss and Fuguitt, 1979). The lowest density category declined further and the high density categories represented a significantly higher portion of the total land area by 1990. In the lake district of Oneida and Vilas counties, the lowest density category declined from nearly 70% of the land area in 1940 to just over 30% by 1990, over 25% less than its representation in the entire North Woods region. However, the decline of the very low density area was not equivalent in Oneida and Vilas counties. In Vilas County, the lowest density category declined most sharply during the

first two decades of the period, until 1960, and thereafter its rate of decline diminished. In Oneida County, however, the very lowest density areas declined at an ever-increasing rate until 1980, and then remained unchanged during the 1980s. In Oneida County, the proportion of the land area encompassed by the second lowest density category (between five and 10 units per square mile) remained nearly static, dipping from about 18% in 1940 to 16% in 1960, and then rebounding to just over 17% in 1990. A very different pattern for this category was evident in Vilas County, where the proportion rose from 16% in 1940 to peak at nearly 25% in 1970, before declining precipitously to below six percent in 1990. By 1990, the two highest density categories comprised 31% of the land area in Oneida County and nearly 40% in Vilas County, as compared to 12% of the entire North Woods. In Vilas County, the second highest density category (20 to 40 housing units per square mile) increased 10-fold during the 50 year period, while the highest density category increased 15-fold.

## **DISCUSSION AND CONCLUSIONS**

This is the first study to analyze subcounty (partial block group) spatial patterns of housing density across an extensive area over a long time period. The method, employed to analyze temporal housing density change at a very fine spatial scale, uses 1990 census data corrected with historic censal housing unit counts. Several components of the methodology must be considered when interpreting the results and applying the approach elsewhere. First, the initial estimates of housing unit counts do not include all historic housing units because only units present and correctly enumerated in 1990 are included. Second, these initial estimates are corrected at the county level using historic census

tabulations. While the accuracy of decennial census enumerations has improved during the period of the study, the absence of alternative, comprehensive historical population and housing data prevents an assessment of the error at the county level of the historical census enumerations, although it would be extremely small, especially compared to sample-derived counts. Finally, the allocation of missing housing units to partial block groups within a county assumes that the location of missing housing units is correlated with subsequent growth and to a lesser extent density. Although this assumption may not hold for every time period across a large region, it is the most parsimonious assumption, given the lack of other housing unit location data.

The combined error resulting from these factors cannot be estimated using traditional statistical approaches due to the lack of other independent historic data. It would be possible to calculate confidence intervals around the historic points estimates of housing density using the Census Bureau's published error estimates for 1990 sample data, such as the "year housing unit built" question. However, these confidence intervals would be of limited value for an assessment of the overall error in the estimates. The major source of error in the initial estimates of housing unit counts is the "missing" housing unit problem, historic units that were not enumerated in 1990. The Census Bureau's error estimates for 1990 only account for sampling error and do not capture the missing housing unit problem. Confidence intervals for preceding decades based on the published 1990 census error estimates would suggest an unjustifiably high level of accuracy, because they would only capture one minor source of error. In each decade, partial block groups with similar estimated housing density levels tend to cluster geographically, which indicates that the methodology accurately replicates actual historic

spatial patterns. Although the historic housing density estimates are not free of error, the proportion of “missing” housing units (Figure 1) must be considered in conjunction with the historic housing density patterns (Figure 4) in analyzing and interpreting housing density change. We suggest that the model can provide valuable insights into the dynamics of housing growth and that the method developed in this paper fills a need for spatially-explicit, time-series estimates of housing counts and densities.

Housing densities across the northern tier of Wisconsin counties changed dramatically over the 50-year period from 1940 to 1990. Three areas experienced particularly sharp increases in housing density and the virtual disappearance of very low housing densities most closely associated with the North Woods. Two of those areas are suburban or more appropriately exurban emanating from the Green Bay and Minneapolis - St. Paul Metropolitan Areas. The third of these areas, rural in nature and far distant from any metropolitan agglomeration, is the lake district of Oneida and Vilas counties, principally stretching along the common boundary of the two counties. However, the growth trajectory of these two counties was not identical, although they are very similar in other respects (Figures 6 and 7). In other areas of the North Woods, although the density levels do not match these more developed areas, the compact pattern of development prevalent in 1940 and remaining evident as late as 1970 no longer persists.

These results have important implications both for sociological research in rural areas as well as for resource management and regional planning. The results highlight the importance of recreational amenities for housing growth in recent decades. County level analysis is insufficient to reveal such patterns as they can vary significantly within a single county (Figure 4). Strategies for the management of national, state, and county

forests are partially dependent upon the demographic characteristics of the surrounding landscape. Areas of higher and growing housing density are less amenable to the establishment of large expanses of consolidated forest, while those same areas may exert greater pressure on forest-based recreational resources. Changes in housing density also change the extent of land cover types, affecting both plant and animal communities. These historic changes in housing densities can be used directly to identify critical areas for preservation for such purposes as wildlife corridors and sustainable resource management more generally.

Looking ahead one decade from 1990 and repeating this analysis using data from the 2000 Census will not be straightforward. Translating 2000 block geography into 1990 partial block group geography and then adding 2000 housing unit counts (from the 2000 Census SF1 file) to the historical estimates, thus extending the time series, would facilitate analysis of residential development during the 1990s in a historical context. However, extensive changes in block boundaries between the 1990 and 2000 censuses give rise to spatial interpolation problems that cannot be solved with complete accuracy. In addition, the 2000 Summary File 3 (U.S. Census Bureau, 2002) could be used to replicate the entire historical series. However, although partial block group-level data will again be available, it will not be equivalent to 1990 and, most importantly, the geographic scale will not be as fine. Consequently, analysis of the “year housing unit built” question from the 2000 Census can be carried out only on a coarser spatial scale than that presented here.

This paper presents a method of estimating change in housing unit counts and density estimates, an important demographic phenomenon, at a sub-county and sub-

municipal level over a multiple-decade period by using the “year housing unit built” question from the 1990 census. The method estimates historical patterns of residential development for sub-county areas as delineated by the 1990 census, thus eliminating the problem of unstable boundaries across decades. The method provides information at a more detailed spatial scale than previous census-based methods, yet can be applied to larger regions than previous studies using aerial photography, satellite imagery, or land records information. Due to the availability of census data and the limited processing involved, the method can be cost-effectively generalized to virtually any region of the U.S.

## METHODOLOGICAL APPENDIX

As noted above, actual county tabulations of housing units from the respective census years demonstrate that the initial historical estimates of the number of housing units by partial block group suffer from serious underestimation problems. The number of housing units in county  $j$  at time  $t$  enumerated by the census taken at time  $t$  is  $C_j^t$ . The number of housing units estimated to be in the county at time  $t$ , based on the “year housing unit built” question in the 1990 census is,  $H_j^t$ . Thus, the number of housing units in county  $j$  at time  $t$  missing from the estimate based on the 1990 Census is equal to:

$$A_j^t = C_j^t - H_j^t \quad [\text{eq. 1}]$$

$A_j^t$  is the number of housing units missing from the estimate of housing units for county  $j$  at time  $t$  that must be allocated to partial block groups within the county, in order to compensate for the known county-level error. To correct this problem, we used the following three step adjustment process.

### STEP 1:

The first step adjusts the estimated number of housing units in each partial block group according to the growth that occurred in that partial block group during the next decade relative to the growth that occurred in the county. We first assume that the number of housing units allocated in the adjustment procedure at time  $t$  to partial block group  $i$  of county  $j$  cannot exceed the estimated change in the number of housing units occurring between time  $t$  and time  $t+10$  ( $\Delta_{ij}^{t+10}$ ), with 10 representing the 10-year

period between censuses. The maximum adjustment for partial block group  $i$  in county  $j$  at time  $t$  is given by:

$$\Delta_{ij}^{t+10} = \hat{H}_{ij}^{t+10} - H_{ij}^t, \quad [\text{eq. 2}]$$

where  $\Delta_{ij}^{t+10}$  is the estimated change in housing units,  $\hat{H}_{ij}^{t+10}$  is the adjusted number of housing units one decade after time  $t$ , and  $H_{ij}^t$  is the estimated number of housing units at time  $t$ . Thus, the adjusted number of housing units at time  $t$  cannot exceed the adjusted number of housing units at time  $t+10$ . Partial block groups that did not experience an increase in the number of housing units between time  $t$  and time  $t+10$  are not adjusted in this step. The estimated change in the number of housing units during the decade from time  $t$  to  $t+10$  in partial block groups can then be aggregated for the county ( $j$ ) to provide the estimated increase in the number of housing units for growing partial block groups:

$$\Delta_j^{t+10} = \sum_{i=1}^I \Delta_{ij}^{t+10}, \text{ for } \Delta_{ij}^{t+10} > 0 \quad [\text{eq. 3}]$$

The first adjustment step with  $\hat{H}_{ij}^t$  representing the adjusted number of housing units in partial block group  $i$  of county  $j$  at time  $t$  is given by:

If  $\Delta_{ij}^{t+10} > 0$ , then

$$\hat{H}_{ij}^t = H_{ij}^t + \left( \frac{A_j^{t+10}}{\Delta_j^{t+10}} \Delta_{ij}^{t+10} \right) 0, \quad [\text{eq. 4}]$$

otherwise

$$\hat{H}_{ij}^t = H_{ij}^t 0 \quad [\text{eq. 5}]$$

The adjusted estimate,  $\hat{H}_{ij}^t 0$ , is equal to the initial estimate,  $H_{ij}^t 0$ , plus the ratio of the number of missing housing units in the county,  $A_j^{t+10} 0$ , to the change in housing units in the county,  $\Delta_j^{t+10} 0$ , multiplied by the change in housing units in the partial block group,  $\Delta_{ij}^{t+10} 0$ . To ensure that the adjusted number of housing units at time  $t$  does not exceed the adjusted number of housing units at time  $t+10$  following the first step of the adjustment procedure the following limit is placed on the ratio:

If  $\frac{A_j^{t+10}}{\Delta_j^{t+10}} > 10$ , then

$$\frac{A_j^{t+10}}{\Delta_j^{t+10}} = 1 \quad 0[\text{eq. 6}]$$

For counties in which the ratio of the number of missing housing units,  $A_j^{t+10} 0$ , to the change in housing units,  $\Delta_j^{t+10} 0$ , is greater than one (1), residual missing housing units  $A_j^{t+10} 0$  will remain after the first adjustment procedure. That is, the number of housing units in county  $j$  at time  $t$  enumerated by the census taken at time  $t$ ,  $C_j^t 0$ , will exceed the estimated number of housing units after adjustment:

$$\hat{H}_j^t = \sum_{i=1}^I \hat{H}_{ij}^t < C_j^t \quad [\text{eq. 7}]$$

This necessitates a second adjustment.

STEP 2:

The second step in our procedure allocates the remaining missing units,  $A_j^{t+10} - \Delta_j^{t+10}$ , based on the number of housing units at time  $t$ , rather than on the increase in housing units that occurred between time  $t$  and  $t+10$ , as in the first step.

If  $A_j^{t+10} - \Delta_j^{t+10} > 0$ , then

$$H_{ij}^n = H_{ij}^t + \left[ (A_j^{t+10} - \Delta_j^{t+10}) \frac{\hat{H}_{ij}^t}{\hat{H}_j^t} \right] \quad [\text{eq. 8}]$$

otherwise

$$H_{ij}^n = \hat{H}_{ij}^t \quad [\text{eq. 9}]$$

The second adjusted estimate,  $H_{ij}^n$ , is equal to the first adjusted estimate,  $\hat{H}_{ij}^t$ , plus the number of residual missing housing units in the county,  $A_j^{t+10} - \Delta_j^{t+10}$ , multiplied by the ratio of the adjusted number of housing units in the partial block group,  $\hat{H}_{ij}^t$ , to the adjusted number of housing units in the county,  $\hat{H}_j^t$ . This revised estimate is the final estimated number of housing units for each partial block group.

STEP 3:

A third step in our method removes census *blocks* with zero housing units in 1990 from the respective partial block group. This step assumes that if a block did not contain housing units in 1990 then it did not contain housing units in any of the previous decades. This removes blocks that do not contain housing units from the partial block group that they are located in, thus further improving the geographic scale of the analysis by moving from the partial block group to the block level in certain cases.

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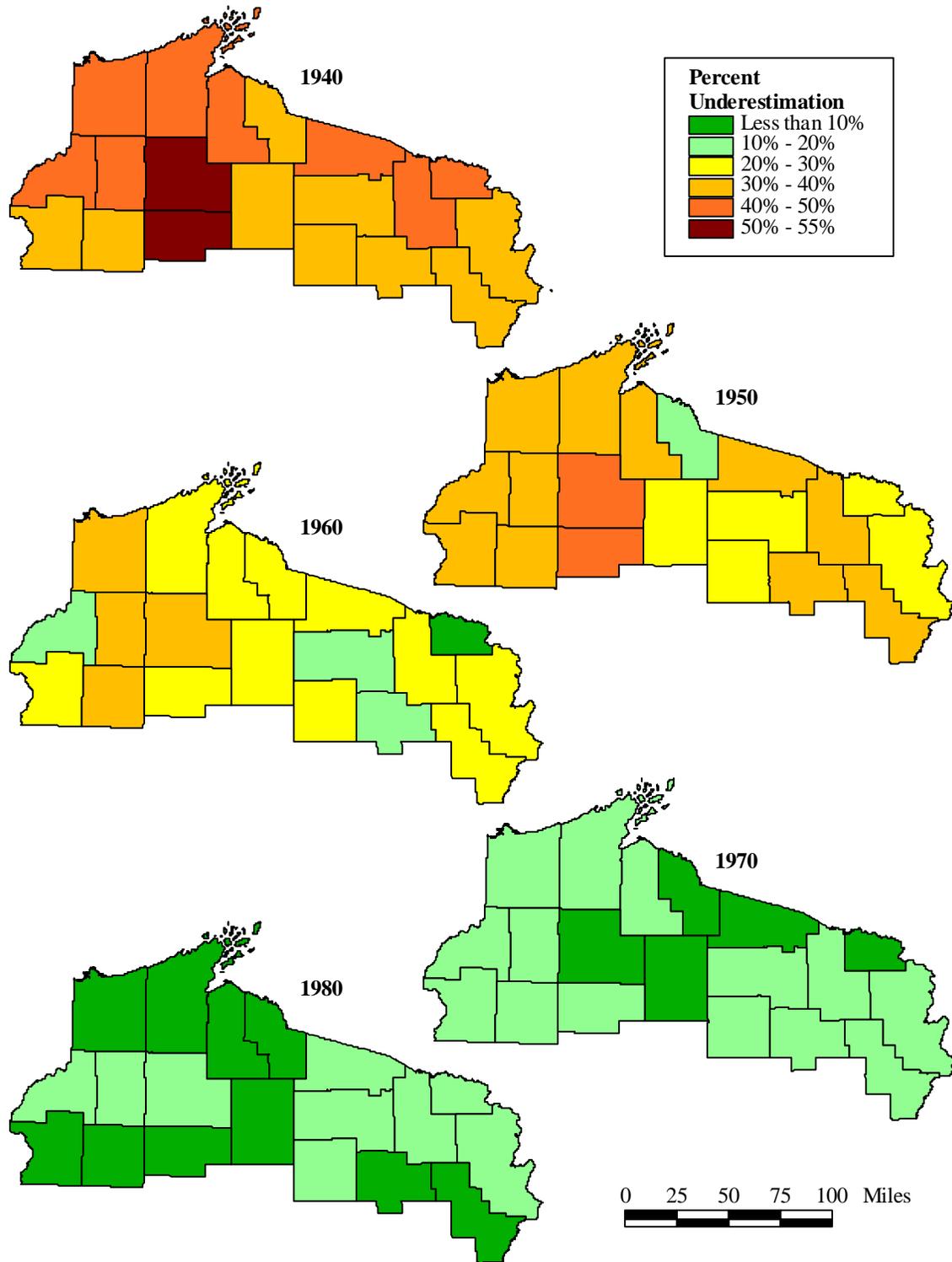
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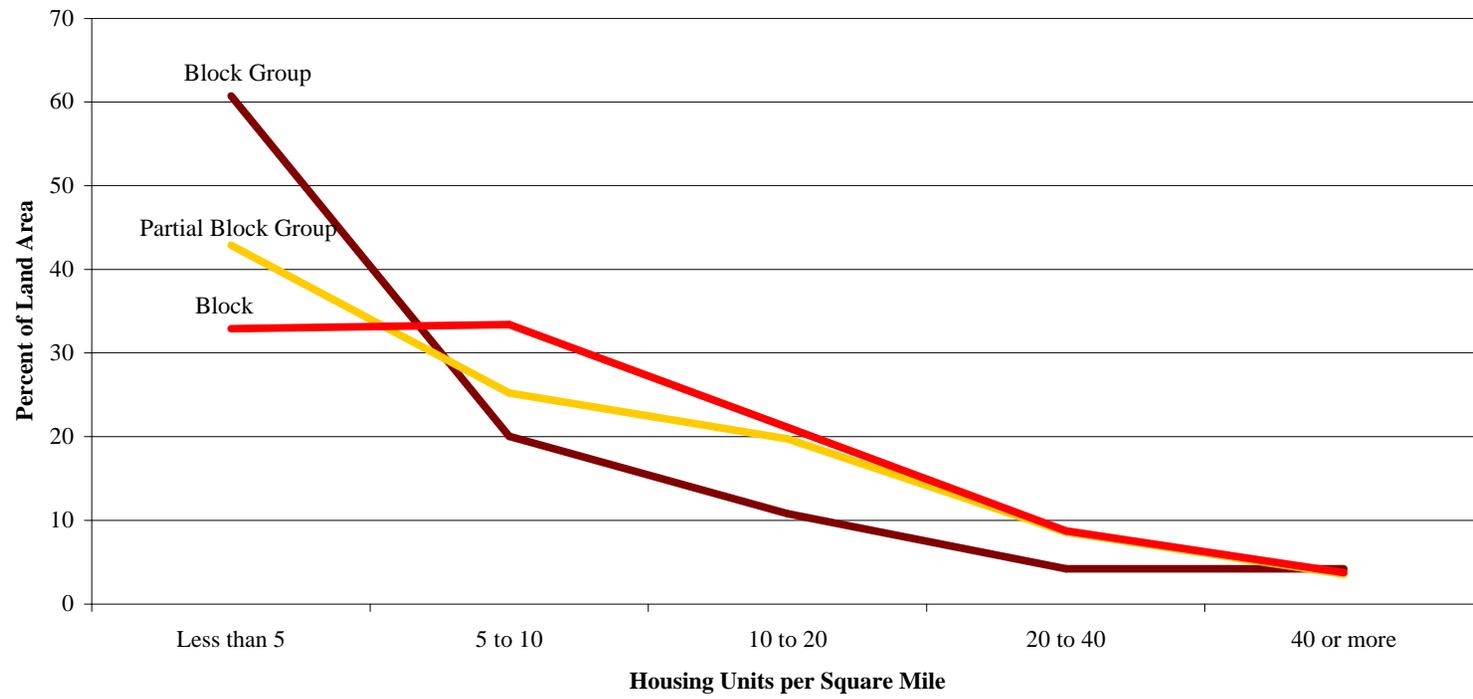
**Table 1: Mean Housing Density Category Land Area by Block, Partial Block Group, and Block Group North Woods Counties, Wisconsin**

	Block	Partial Block Group	Block/Partial BG Comparison		Block Group	Block/BG Comparison	
			F	<i>p</i>		F	<i>p</i>
<b>Less Than 5</b>	609.5 (250.1 )	434.5 (262.1 )	4.433	0.042	369.5 (242.7 )	8.496	0.006
<b>5 to 10</b>	201.3 (100.4 )	255.4 (115.8 )	2.366	0.133	335.6 (146.2 )	10.891	0.002
<b>10 to 20</b>	108.5 (61.4 )	200.1 (96.1 )	12.270	0.001	223.8 (123.4 )	13.168	0.001
<b>20 to 40</b>	42.2 (25.7 )	87.1 (78.8 )	5.573	0.024	104.3 (80.9 )	10.025	0.003
<b>40 or more</b>	42.4 (27.0 )	36.2 (34.5 )	0.382	0.540	37.9 (30.8 )	0.228	0.636

Figure 1: Percent Underestimation of Housing Units by County, 1940-1980



**Figure 2: Housing Density by Block Group, Partial Block Group, and Block, 1990**  
North Woods Counties, Wisconsin



**Figure 3: Housing Density by Partial Block Group and Block, 1990**

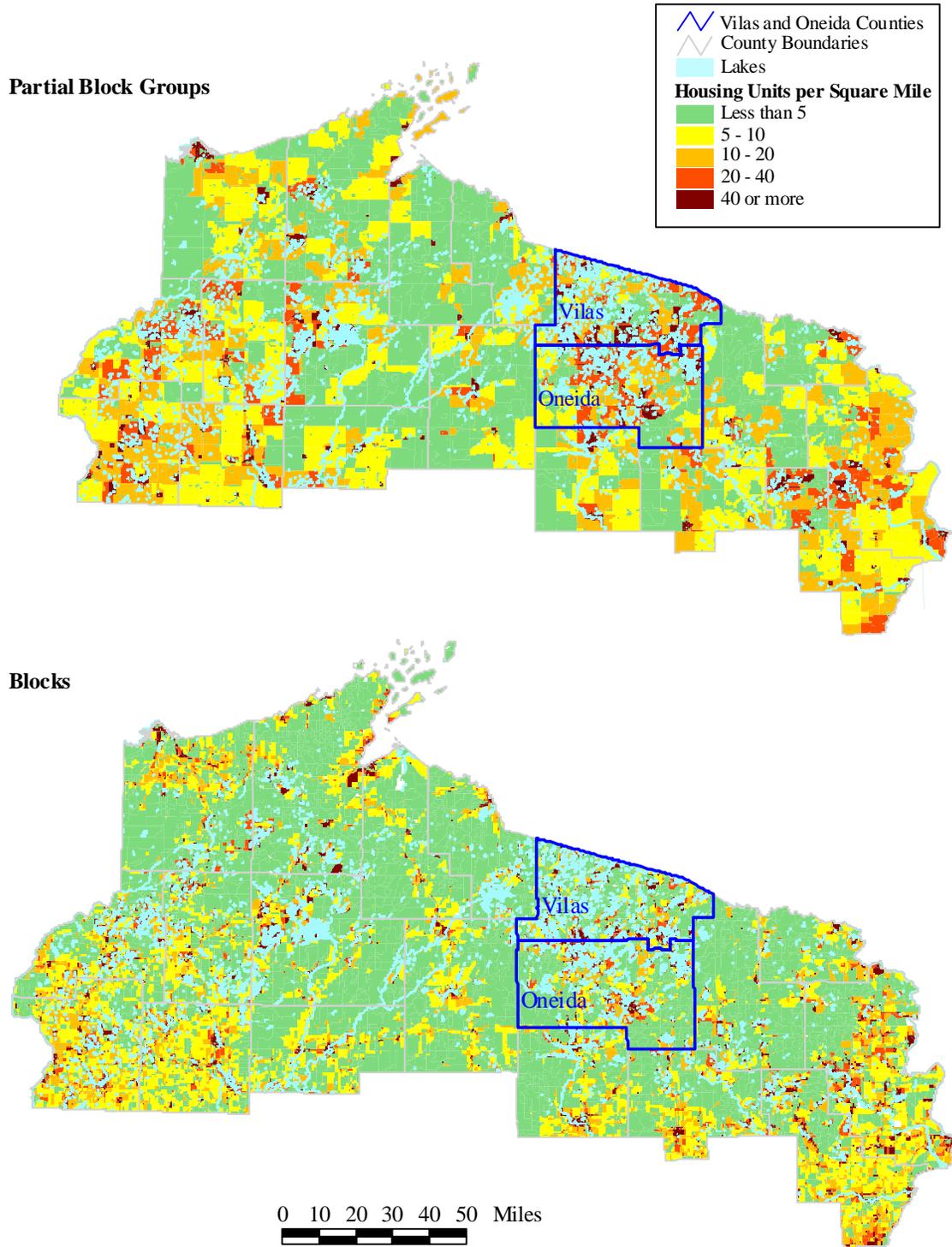
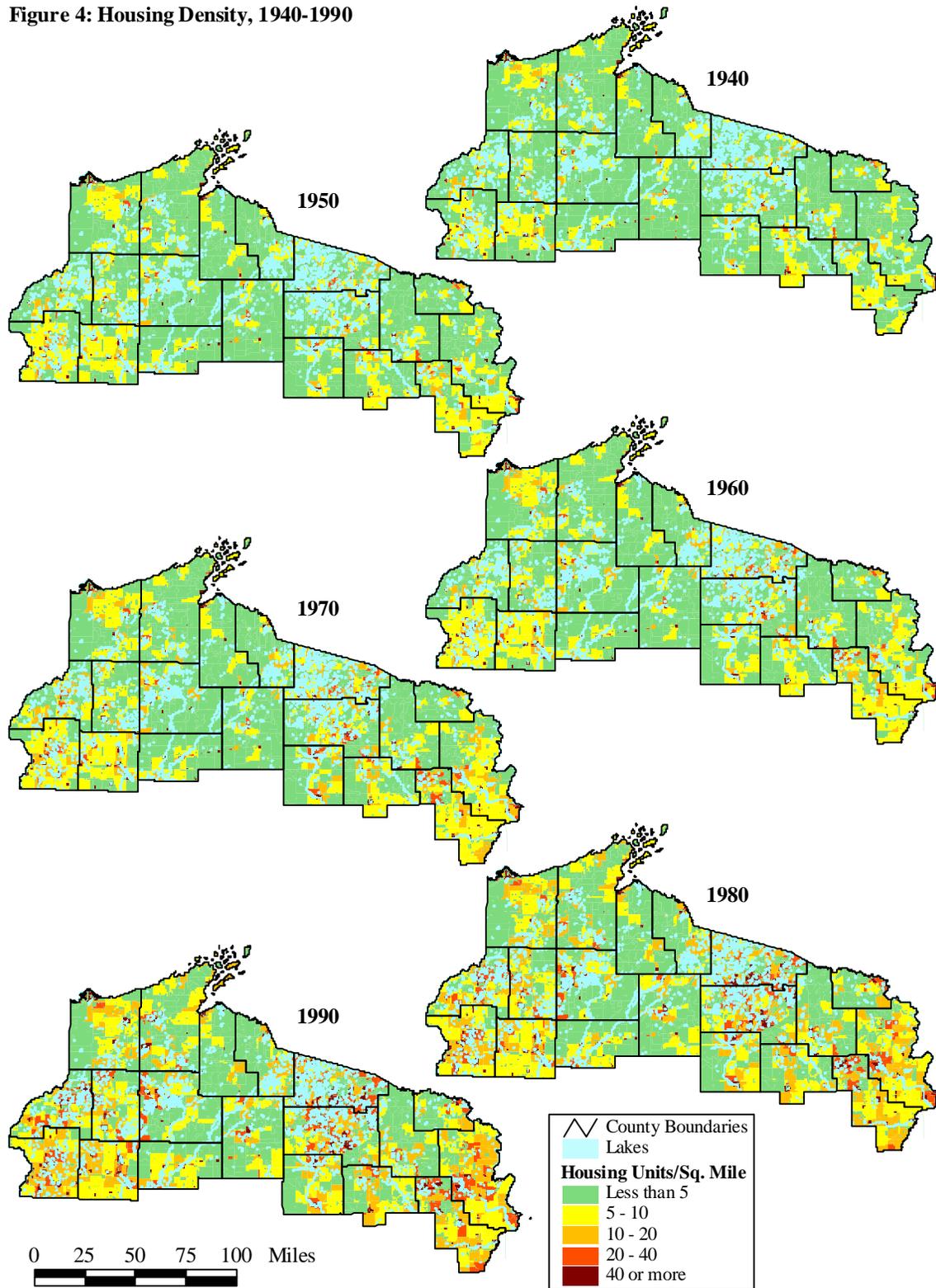
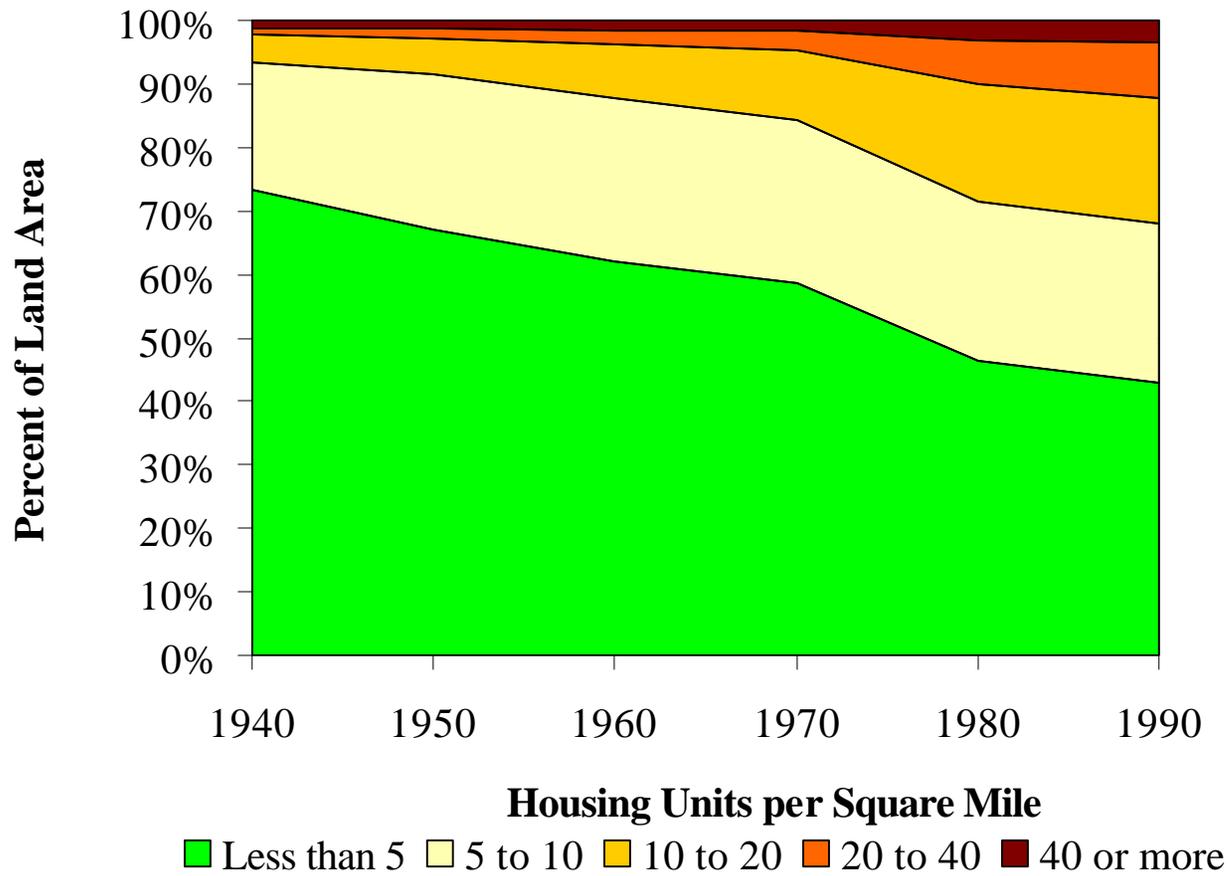


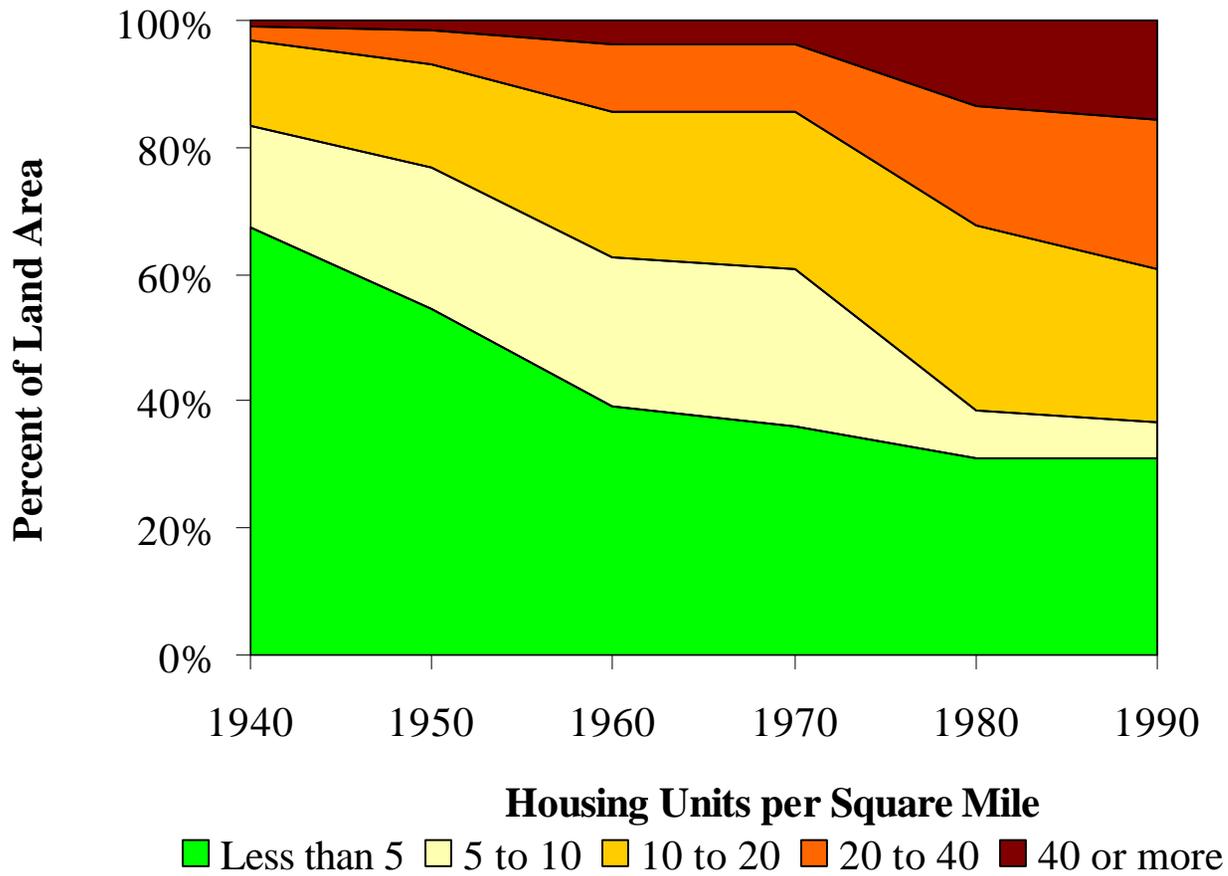
Figure 4: Housing Density, 1940-1990



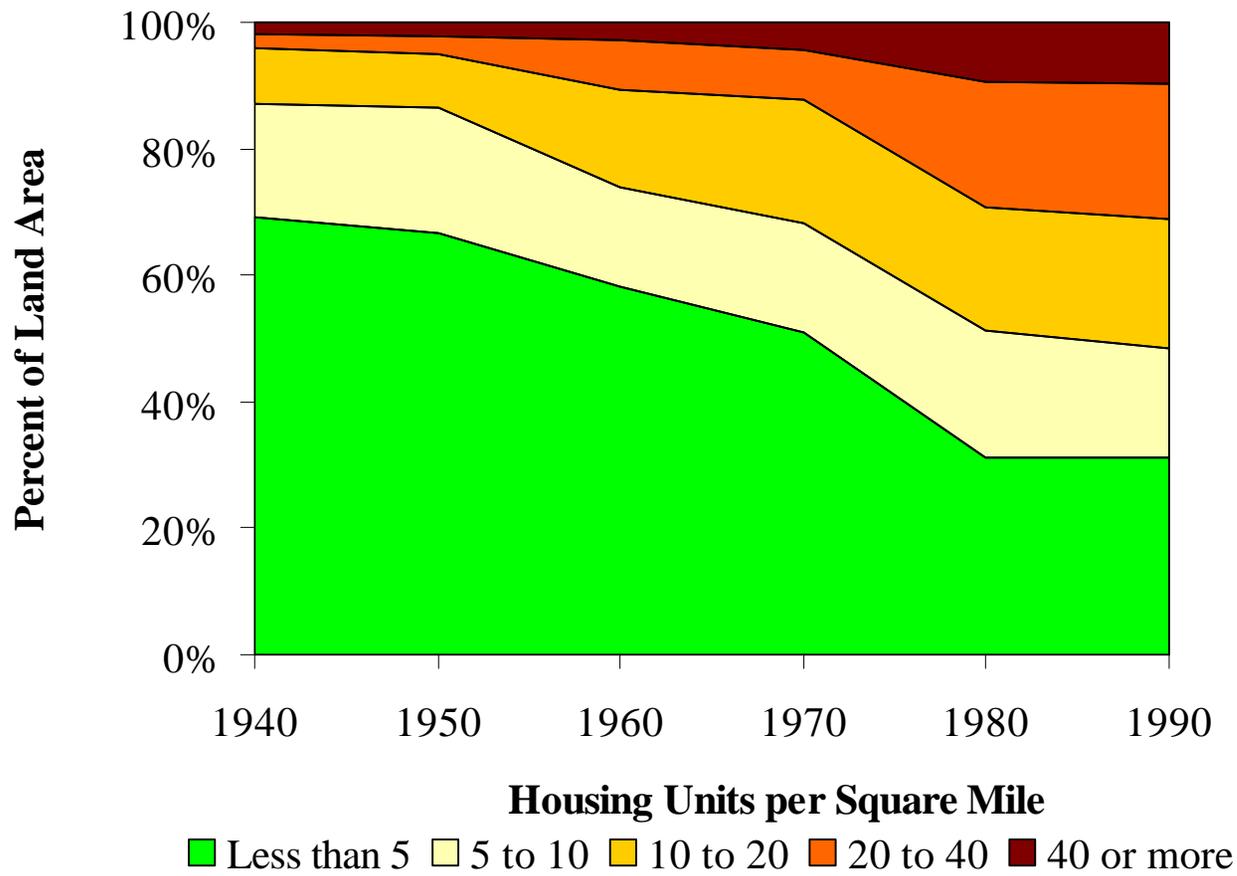
**Figure 5: Percent of Land Area by Housing Density Category, 1940-1990  
North Woods Counties, Wisconsin**



**Figure 6: Percent of Land Area by Housing Density Category, 1940-1990**  
**Vilas County, Wisconsin**



**Figure 7: Percent of Land Area by Housing Density Category, 1940-1990**  
**Oneida County, Wisconsin**



Center for Demography and Ecology  
University of Wisconsin  
1180 Observatory Drive Rm. 4412  
Madison, WI 53706-1393  
U.S.A.  
608/262-2182  
FAX 608/262-8400  
comments to: [rhammer@ssc.wisc.edu](mailto:rhammer@ssc.wisc.edu)  
requests to: [cdepubs@ssc.wisc.edu](mailto:cdepubs@ssc.wisc.edu)