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Characterizing dynamic spatial and temporal residential density patterns from 1940–1990 across the North Central United States

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Abstract

The spatial deconcentration of population during the 20th century and the resulting expansion of human settlements has been a significant cause of anthropogenic landscape change in the United States and many other countries. In the seven-state North Central Region, as in other regions of the US, changing human settlement patterns are most prominent at the outlying fringe of metropolitan areas and in rural regions with attractive recreational and aesthetic amenities. This process of growth and change has profound implications for the ecology of the region that will require the reformulation of resource management policies.

We use attribute clustering of both housing density and housing growth for each decade from 1940 to 1990 to illuminate the dynamic process of housing density change in the North Central Region. While cross-sectional housing density maps display the uniformity of residential density within urban, suburban, and rural areas, historic density clustering demonstrates the spatial variability of density trajectories in urban and suburban areas, and the relative stability and homogeneity of more rural density trajectories. Clusters based on housing growth, without regard to absolute density, reveal similarities between urban cores and rural areas, where in both cases, housing growth has been very slow in recent decades. We identify density/growth clusters with high potential for future growth, which are spatially clustered on the periphery of metropolitan areas, in smaller urban centers, and in recreational areas throughout the region.

Keywords: Housing density; Housing growth; Sprawl; Amenity growth; Cluster analysis; Landscape change

1. Introduction

Housing development, along with its accompanying infrastructure, commercial, and industrial development, has been recognized as a primary cause of anthropogenic landscape change in the United States and many other countries. In the seven states of the North Central Region (Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, and Wisconsin), as in other regions of the United States, patterns of spatial deconcentration and expansion are receiving their greatest attention at the outlying fringe of metropolitan areas. But this predominant focus on "suburban sprawl" overlooks the importance of housing growth across the urban to rural spectrum, and fails to recognize the profound effects occurring in more remote rural areas with attractive recreational and aesthetic amenities where recent growth rates have been highest (Gobster et al., 2000). Rural zoning codes often

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require large-lot development in an effort to maintain their rural character, resulting in dispersed settlement patterns that have many negative ecological consequences (Heimlich and Anderson, 2001). Low-density development disproportionately increases road density on a per housing unit basis and contributes to forest fragmentation (Miller et al., 1996; Reed et al., 1996; Forman and Alexander, 1998). Because scenic natural resources attract development, rural housing growth is more likely to occur in areas of particularly high ecological value (McGranahan, 1999). Riparian zones, coastal areas, and lakeshores are particularly susceptible to environmental damage and are also preferred home sites (Bartlett et al., 2000; Schnaiberg et al., 2002).

Housing development and population growth in rural regions and the metropolitan fringe have major implications for the ecology of the region and for forest management practices (Ehrlich, 1996; Matlack, 1997). Housing growth on the edge of or within public forest lands has influenced allowable timber harvests and will, no doubt, become an even more important factor in the future (Wear et al., 1999). Likewise, housing development in the wildland urban interface has affected forest fire management efforts, especially in recent years (Cardille et al., 2001; Cleaves, 2001). Strategies for management of public lands must address not only the impact of increasing population and housing development in nearby communities but also the effects of changing characteristics of the resident population (Hull and Stewart, 2002). Newcomers to an area may have different environmental values and attitudes from other residents, and their views regarding how local forest resources are best managed are likely to differ accordingly (Green et al., 1996). In short, as land fragmentation due to housing construction continues, it will require reformulation of forest policies covering timber harvest, fire management, recreation, second home development, water quality, and biodiversity sustainability.

Data on housing development and population growth can thus be enormously useful in understanding the effects of landscape change and formulating policies to guide future growth. But our research, planning, and policymaking abilities have been severely hampered in this respect, as spatially detailed information on housing and population change in the US is virtually nonexistent for larger areas. Although the decennial census has provided population and housing data for sub-county areas for many decades, the reconstruction of historical trends at the sub-county scale is difficult. Population and housing characteristics for sub-county political entities (cities, villages, and towns/townships) are available, but this geography is too coarse for many types of analysis, and boundary changes are impossible to trace. Housing growth should be analyzed at a grain fine enough to capture its location-specific impact, but at a broad enough extent to put patterns and changes into a regional context. Extensive, fine grain analysis is required when analyzing spatial and temporal aspects of population change, as well as when integrating housing densities with ecological information such as land cover data (Radeloff et al., 2001).

Housing development, the resulting growth of human settlements, and the overall deconcentration of population are dynamic spatial and temporal processes. Nevertheless, changes in human settlement patterns are usually studied as either spatially or temporally static. Spatially detailed studies quantifying urban growth or suburban sprawl tend to select two or at most three points in time, principally due to the lack of longitudinal data. Studies that examine shifts in population over multiple time periods are most often non-spatial, examining the growth of municipalities or counties without reference to spatial dynamics occurring within boundaries. The limitations of cartographic and analytic techniques in quantifying and portraying spatially- and temporally-detailed change over large regions and long time spans also limits the scope of analysis.

However, physical phenomena are neither purely spatial nor purely temporal, but instead result from and exist within these interlinked processes (Blaut, 1961). Thus, changing human settlement patterns, like other spatial and temporal dynamics, need to be examined through the fundamental concepts of change and process (Hazelton et al., 1992; Dragicevic et al., 2001). In this paper, we describe and analyze the various spatial and temporal dimensions of housing development and human settlement in the seven-state North Central Region of the United States. To illustrate in more detail some of the patterns of change not evident in this expansive region, we also include analysis of the Minneapolis/St. Paul Metropolitan Area, along with its environs to the north and east. The fine spatial scale and broad extent, along with the temporal dimension, make the methods introduced here for estimating housing density particularly appropriate for interdisciplinary landscape change research, with practical extensions to the planning and policy arenas.

2. Methods

2.1. Study area: the North Central Region

The land cover map of the North Central Region provides an important reference for understanding the observed patterns in housing density (Fig. 1). This map is based on the National Land Cover Dataset and results from a classification of Landsat Thematic Mapper satellite imagery with 30m resolution (Vogelmann et al., 2001). Differences in climate, topography, hydrology, soil conditions, and land-use

Fig. 1. Land cover, North Central Region.

history result in a readily apparent separation of forests and agriculture in the North Central Region. Forests are most abundant in the northernmost latitudes (Northwoods), and in southern Missouri (Ozarks). Agriculture dominates Iowa, Illinois, and northern Indiana and is also prevalent in the southern portion of Michigan's Lower Peninsula, the southwest quadrant of Wisconsin, western Minnesota, and the "boot heel" of southern Missouri. In the major metropolitan areas (e.g. Detroit, Chicago, Minneapolis, and St. Louis), urban land cover is both spatially clustered and intermixed with areas classified as forest or agriculture. Much of the area within this intermix of urban, forest, and agricultural land-cover types that the satellite classification interprets as forest and agriculture is undoubtedly urban open space and parks, forested neighborhoods, and the "crabgrass frontier" of large-lot residential developments.

Spatial patterns of housing density and land cover changed substantially over the past 150 years as European settlers began using this region intensively. Settlement patterns changed in response to shifts in the dominant employment opportunities; agriculture, mining, and lumbering declined in importance and manufacturing grew during much of the 20th century. In the latter part of the century, manufacturing waned and service industries gained prominence (Bluestone and Harrison, 1982). These trends resulted in population decline in rural areas and strong population growth in metropolitan cities and suburbs. However, the latter part of the 20th century, and especially the 1970s, witnessed an urban-to-rural migration turnaround resulting in stronger population growth in rural counties (Fuguitt, 1985).

The spatial pattern of housing density in 1990 (at the census partial block-group scale described later) is the result of these complex processes and provides an important context for analysis of density and growth from 1940 to 1990 (Fig. 2). Housing density in 1990 across the North Central Region exhibits the classic urban/suburban/rural pattern, with density declining with greater distance from the urban core or central business district (Clark, 1951; Mills, 1972; Batty and Kim, 1992). The large high density area and the relatively narrow periphery of medium density surrounding Chicago compared to that around many of the smaller metropolitan areas conforms to the observation that larger urban areas exhibit flatter density

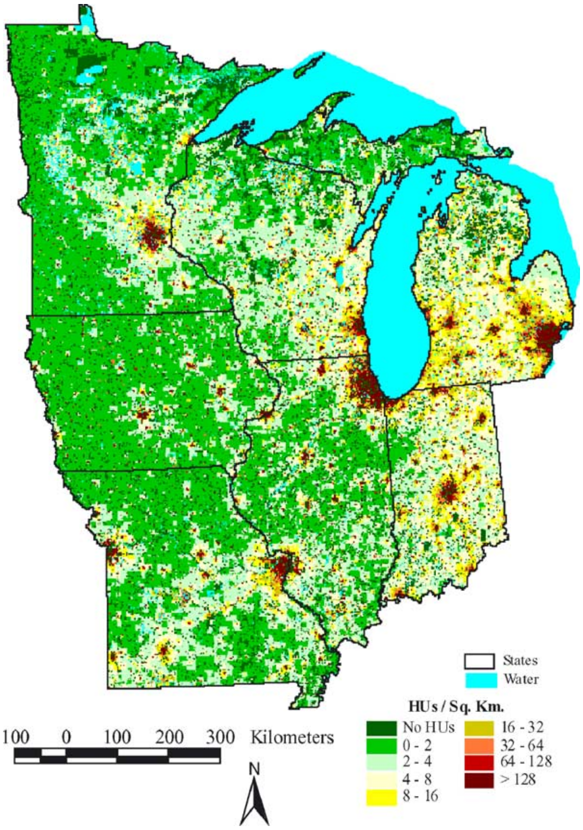

Fig. 2. Housing density, 1990, North Central Region.

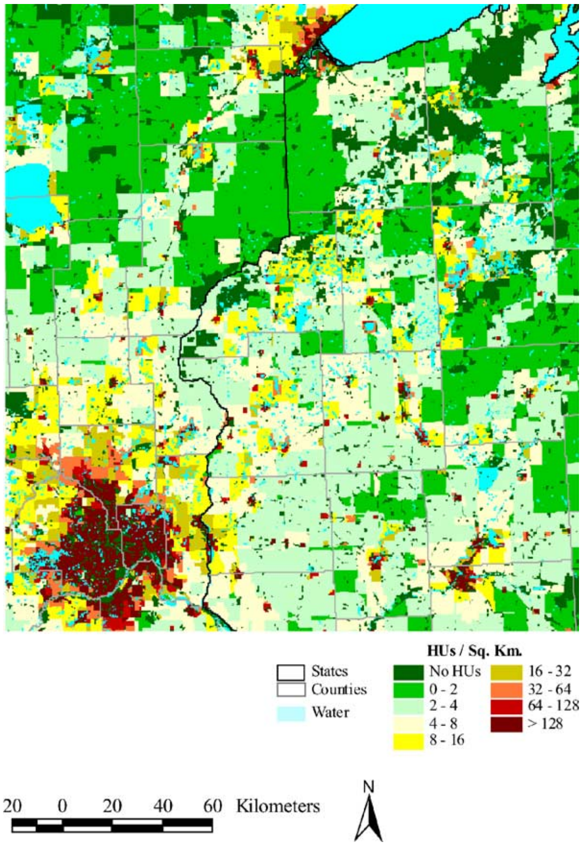

Fig. 3. Housing density, 1990, Twin Cities, MN and surrounding area.

gradients (McDonald, 1989; Wang and Guldmann, 1996). In the enlarged map of Minneapolis/St. Paul and surroundings (Fig. 3), both the radial density pattern of development following major arterial transportation routes and a multi-centric population density pattern are evident (McMillen and McDonald, 1997).

Areas with densities between 4 and 32 housing units per square kilometer encompass nearly the entire Lower Peninsula of Michigan, Indiana, the southeast quadrant of Wisconsin, the periphery of every city, as well as other parts of the region demonstrating the extent of low to medium density exurban development. The preponderance of this same low to medium density interspersed with both high and low densities is also the defining characteristic of amenity areas such as the recreational lake districts north and east of the Twin Cities (Fig. 3). The agricultural region of western Minnesota, Iowa, northern Missouri, and central Illinois, located along the eastern edge of the Great Plains, comprises a large expanse of territory with fewer than two housing units per square kilometer, with the exception of Des Moines and a few smaller urban centers. In the forested sections of the region, northern Minnesota and to a lesser extent northern Wisconsin, Michigan's Upper Peninsula, and also the Missouri Ozarks contain large tracts with fewer than two housing units per square kilometer. However, when looked at in its totality, the paucity of sizeable areas with no housing units illustrates the extent to which human settlement has affected the entire region.

The multitude of factors that contribute to settlement pattern changes make it difficult to depict complex past changes such that they can inform planning efforts aimed at influencing future development. The North Central Region is thus an ideal study area in which to develop and apply new methods to more clearly depict and understand the changing temporal and spatial patterns of human settlement.

2.2. Estimating historic housing density

The decennial census is virtually the only source of information on historic population distribution and human settlement patterns across broad (i.e. multiple-county) regions of the US. However, spatial and temporal analysis of historic settlement patterns using decennial census data is greatly hindered by the ever-changing political (i.e. municipal) and tabulation area (i.e. blocks, blocks groups, and tracts) boundaries and the lack of GIS-compatible, digitized boundary information prior to 1990 (Theobald, 2001). To overcome these problems, we developed techniques to (1) subdivide census tabulation areas into smaller sub-county units that are more appropriate for landscape change analysis, and (2) estimate housing density change within these sub-county units for each decade back to 1940.

Although the block group is the smallest tabulation area for which detailed social and economic census data are readily available, block groups are often divided, or transected, by a variety of political boundaries. In 1990, these boundaries included congressional districts, places, minor civil divisions (MCDs), 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. Housing unit density can differ significantly across the parts of a block group divided by such a boundary, particularly when the municipalities that comprise the block group differ in type. For example, one part of the block group might be a rural town (or township) while the other might be a more urbanized village or city. Using the complete block group level of geography creates an illusion of housing density homogeneity within block groups that are split by municipal or other boundaries. The use of partial block groups partially corrects this problem and distributes a higher proportion of the variance in housing density among, rather than within, the geographic units. The Summary Tape File (STF) 3A (US 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. At the time this research was conducted, Summary File 3 for 2000 had not yet been released for all states in the region.

In 1990, the "year housing unit built" question was coded in census tabulations with the following response options: 1989 or 1990, 1985–1988, 1980–1984, 1970–1979, 1960–1969, 1950–1959, 1940–1949, and 1939 or earlier. For consistency in our comparisons, 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 retrospective estimate of the number of housing units at the beginning of each decade. Our housing estimates for the decades before 1990 are made within the 1990 partial block group geographies.

Retrospective estimates include only housing units that were present in April 1990 and were correctly enumerated in the 1990 census. Over time, houses have been demolished, destroyed by accidental or natural events, or fallen into disuse and become uninhabitable. These housing units, not present in the housing stock of 1990, are missing from the retrospective estimates. In addition, the substantial renovation of older housing units, conversion of nonresidential properties to residential use and vice versa, misreporting the age of a housing unit, and the upgrading of seasonal units for year-round occupancy also can result in the 1990 census reported age being more recent than the actual age. 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 the number of housing units present in earlier decades.

For each decade prior to 1990, we aggregated the partial block groups to obtain the estimated (i.e. retrospectively reported) number of housing units in each county. These county-level retrospective estimates were then compared to the number of housing units enumerated in the county by the actual census for each respective decade, providing a means to assess and correct for underestimation.

To correct for underestimation, we adjusted the partial block group estimates to equal, in the aggregate, the actual county-level census counts. As detailed in Appendix A, we used a three-step procedure to correct the retrospective 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. 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.

In the North Central Region, partial block groups are, on average, about one tenth the size of block groups and three to five times larger than blocks. Their mean size varies across the seven states, with the largest in Minnesota (393 ha) and the smallest in Illinois (180 ha). Overall, they offer a substantial improvement in spatial resolution, when compared to block groups, while providing the full array of census population and housing attribute information normally available only at the block-group level.

2.3. Cluster analysis

We employed attribute cluster analysis to identify partial block groups with similar housing density characteristics over time within the seven-state North Central region. Given the vast number of partial block groups in the North Central region (480,762 total and 73,659 containing housing units in 1990), clustering observations into groups greatly facilitates the synthesis, interpretation, and comparison of housing density and housing growth characteristics across space and time. Cluster analysis procedures separate observations into distinct, relatively homogenous groups based on specified characteristics. Partial block groups were the units of analysis, and two clustering analyses were performed, one using housing density as the attribute, the other using housing growth, as described in detail in the appendix. The two clustering procedures identify meaningful similarities in decadal housing densities and growth patterns, and provide a means of identifying partial block groups with characteristics that suggest a high potential for housing growth in the future.

2.4. Future growth

The examination of past housing growth and density patterns provides insight into potential future growth. The results of the two clustering analyses were used jointly to identify partial block groups likely to experience future growth and landscape change. We selected features of the housing density trajectories and the housing growth dynamics that suggest a partial block group has both the capacity and the likelihood to grow in the future. We used a two-step process, first selecting partial block groups with the key density trajectory characteristics, then selecting those partial block groups that also have the key growth dynamics. Essentially we intersect promising density and growth clusters to identify those partial block groups with both the density and growth characteristics that indicate the highest potential for future growth resulting in significant potential for landscape change.

The key density characteristic that indicates high potential for future growth is a density trajectory that distinguishes the cluster from the more stable, lower density partial block groups to which it was previously similar. The slope of its density trajectory should be fairly uniform, especially in the most recent decades, indicating potential for sustained growth. A recent significant upward inflection in the density trajectory might indicate an unsustainable period of growth, while a downward inflection might indicate that densities are approaching a maximum density or ceiling. A relatively high final density in the urban to suburban range might also limit future growth.

Growth clusters can be used to further distinguish partial block groups with high potential for future growth from other partial block groups within the selected density clusters. Neighborhoods with high growth rates in recent years should be more likely to continue growing into the future, assuming that they also meet the density trajectory criteria discussed above. Ideally, this would involve selecting clusters that experienced their highest growth in the most recent decade, the 1980s in this case. However, because of the widespread downturn in housing growth in the 1980s, this mode of selection is not possible as there are no clusters dominated by 1980s growth. Instead, clusters with high and/or sustained growth in 1960s and 1970s are selected. Partial block groups that fall into both the density and growth clusters chosen using these criteria are identified as those with the greatest potential for future growth.

3. Results and discussion

3.1. Housing density clusters

The housing density clusters capture the history of residential development in each partial block group, rather than portraying density for a single point in time, such as 1990. Because our focus is change over time, we will not discuss the very high density urban clusters that experienced little change or the lowest density rural clusters in which housing density on average remained below two housing units per square kilometer. This leaves 10 density clusters of interest. In the following description of findings, housing densities are given as housing units per square kilometer, and clusters are denoted by their mean 1940 and 1990 densities (e.g. 4 units/km^2 in 1940 and 14 units/km^2 in 1990 would be denoted as D4-14). The density clusters are presented in three groups of low, medium, and high density to facilitate graphic display and to organize discussion of results.

The three clusters with low densities in 1990 (D2-3, D3-6, and D4-14) all exhibit consistent decadal changes in density prior to 1970 with greater density change thereafter, represented by the slight upward inflections of the trend lines (Fig. 4). The 1970s marked the first decade in the history of the United States in which nonmetropolitan counties registered a net gain in population through migration (Fuguitt, 1985). The density trajectories among formerly homogeneous, very low density rural areas diverge over time, particularly after 1970. The medium-density clusters (D9-32, D26-72, and D64-159) exhibit the same upward inflection in the 1970s and divergence over time (Fig. 5). However, unlike the low-density clusters, the 1970s upward inflection is followed by more of an offsetting downward inflection in the 1980s that essentially returned the partial block groups to their pre-1970s density trajectories. The high-density clusters (D146-277, D9-290, D48-524, and D244-561) generally exhibit the same inflections in the 1970s and 1980s as the medium-density clusters (Fig. 6). The high-density cluster that experienced the greatest proportional change in density during the five decades (D9-290) did not return to its pre-1970s trajectory during the 1980s. In this regard it is similar to the faster-growth low-density clusters, but at considerably higher density levels. Interestingly though, this cluster

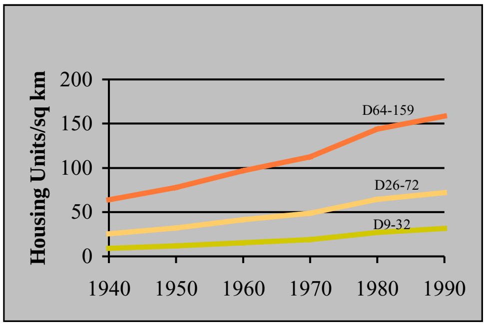

Fig. 5. Medium density clusters.

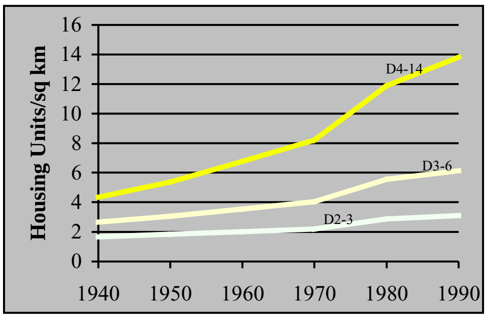

Fig. 4. Low density clusters.

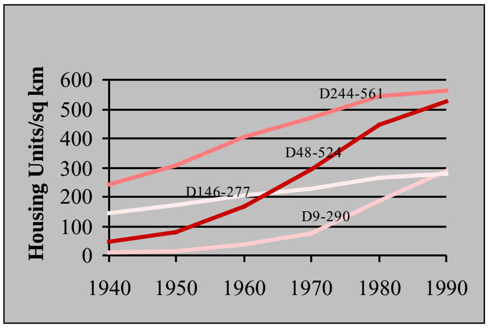

Fig. 6. High density clusters.

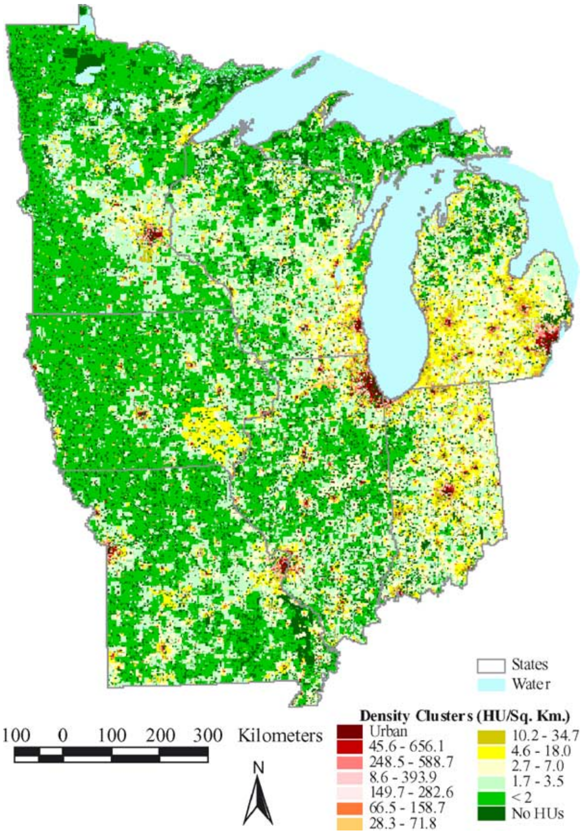

Fig. 7. Housing density clusters, 1940–1990, North Central Region.

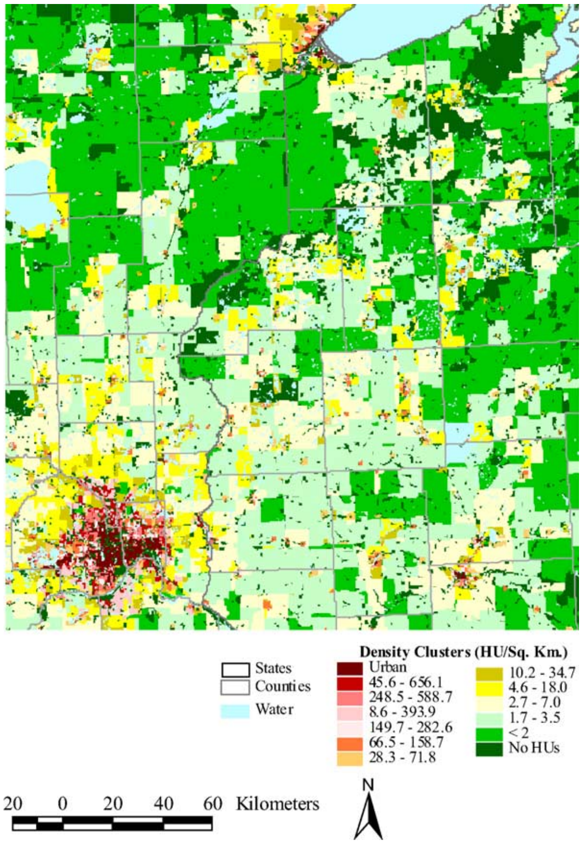

Fig. 8. Housing density clusters, 1940–1990, Twin Cities, MN and surrounding area.

had a very low housing density in 1940 but grew rapidly and surpassed one of the other high-density clusters (D146-277) that had an initial density nearly 20 times as high. The high-density cluster (D48-524) with the greatest absolute change in density began at an intermediate density of 48 units/km^2, but its development trajectory propelled it beyond one of the two clusters with higher density in 1940 and nearly beyond the other. This outstripping of the two clusters with relatively high initial densities by a cluster with much lower initial density demonstrates the heterogeneous character of residential development.

As would be expected, the maps of the housing density clusters (Figs. 7 and 8) look similar to the maps of 1990 housing density (Figs. 2 and 3), especially over the broad extent of the entire region. However, there are interesting deviations evident when one examines the detailed maps of the Twin Cities area (Figs. 3 and 8). First, the consistently very high-density urban clusters are much more confined than the highest density category (>128 units/km^2) in the 1990 density maps. This is most prominent in the Minneapolis-St. Paul metropolitan areas, but is also evident in the smaller urban center of Duluth at the top-center of Figs. 3 and 8. This demonstrates that the density clusters capture the highly variable spatial and temporal process of development that occurred in previous decades. Although these urban/suburban-core areas were homogeneous by 1990, very different development trajectories led to that condition. These heterogeneous density trajectories that converge toward uniform densities also underscore the observation that urban density gradients flatten over time (McDonald, 1989). A second major difference between density and density cluster maps can be seen around the edge of the Twin Cities (Figs. 3 and 8). While the very high density urban area constitutes a fairly homogeneous core and the suburban clusters are arrayed in a ring or radiating outward along transportation corridors (see Fig. 3), the four high-density clusters, along with scattered very high-density clusters, are completely interspersed in Fig. 8. This mix of clusters indicates the highly varied density histories of metropolitan edges, reflecting both checkerboard or leapfrog development, and the incorporation of pre-existing small urban centers (Morgridge, 1985). In rural areas, 1990 housing density and 1940–1990 density clusters (Figs. 2 and 7) are more similar, due to the flatter density trajectories of rural areas. As will be seen in the next section, growth clusters are more useful for differentiating rural areas from one another.

It is somewhat surprising that the only clusters with limited or no density change during more recent decades were those at the very highest density levels, rather than at intermediate or low densities. It might be expected that partial block groups would asymptotically approach some local "density ceiling" imposed by land markets in response to consumer preferences, government regulation, and other factors. The slight downward inflection in the 1980s in the trajectories of clusters in the medium- and high-density groups might indicate the presence of local growth ceilings, or could merely indicate a momentary pause in density change following the rapid growth of the 1970s. The recession of the early 1980s may have played a role in density changes. It impacted nonmetropolitan areas heavily, but recovery from the recession differed with agricultural and mining-dependent counties lagging behind (Johnson and Beale, 1998). Incorporation of 2000 census data measuring density changes during the 1990s, a decade similar to the 1970s in terms of growth (Beale and Fuguitt, 1990; Johnson and Beale, 1994; Long and Nucci, 1998), may provide greater insight into this question.

3.2. Housing growth clusters

Although the density clusters portray each partial block group's trajectory across the decades, they do not adequately capture the decadal variability in growth rates. Growth clusters expose the temporal and spatial variability of residential development more clearly. Urban cores and rural areas with similarly slow growth rates could be expected to appear in the same cluster or clusters. Temporal effects become more apparent; for example, across all the clusters, the 1980s represented the slowest or nearly the slowest decadal growth during the 50-year-period. Growth clusters are labeled by the decade in which they grew fastest, and their maximum growth rate, for example, G40s-5 for the cluster experiencing its fastest growth in the 1940s at a maximum growth rate of 5%. Among the low growth clusters (Fig. 9), three clusters (G40s-47, G40s-19, and G40s-5) experienced their highest growth rates during the 1940s and then declined steadily to reach a negligible or even negative level of growth by the 1980s. One of those clusters, G40s-5 grew by only 5% during the 1940s and then did not experience any appreciable growth after 1950. Among the high growth clusters (Fig. 10), two clusters, G50s-184 and G50s-62, experienced their most rapid growth during the 1950s, although they both sustained relatively high growth rates during the succeeding decades as well. None of the clusters in either group experienced its highest growth rate in the 1980s.

A majority of the clusters in both groups experienced faster growth during the 1970s than during other decades. Cluster G70s-453 sustained a growth rate of over 350% during both the 1960s and 1970s, and then slowed considerably in the 1980s, though it still had the highest growth rate for that decade. This "hyper-growth cluster" was also unique in that its growth rate increased during each decade up to the 1980s (Fig. 10). For the other clusters that experienced their fastest growth during the 1970s, their growth rates prior to that decade were either stable or declining. One of these clusters, G70s-8, experienced a minimal growth rate in the 1940s that declined during the 1950s, 1960s, rose slightly in the 1970s, and declined again in the 1980s (Fig. 9).

The growth clusters are represented on the maps in Figs. 11 and 12 first by the decade of most rapid growth (color) and then by the rate of growth during that decade (hue). In urban/suburban areas, these growth clusters are almost like a photographic negative of the housing density clusters: whereas the high-density clusters seen in Figs. 7 and 8 dominate the urban cores and more moderate density clusters dominate the suburban periphery, in Figs. 11 and 12 the high growth clusters dominate suburban areas while the urban cores are comprised almost exclusively of low growth

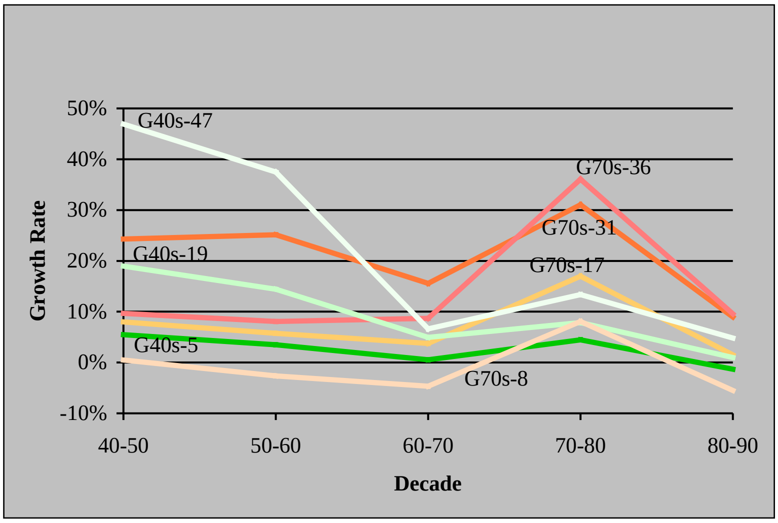

Fig. 9. Low growth clusters.

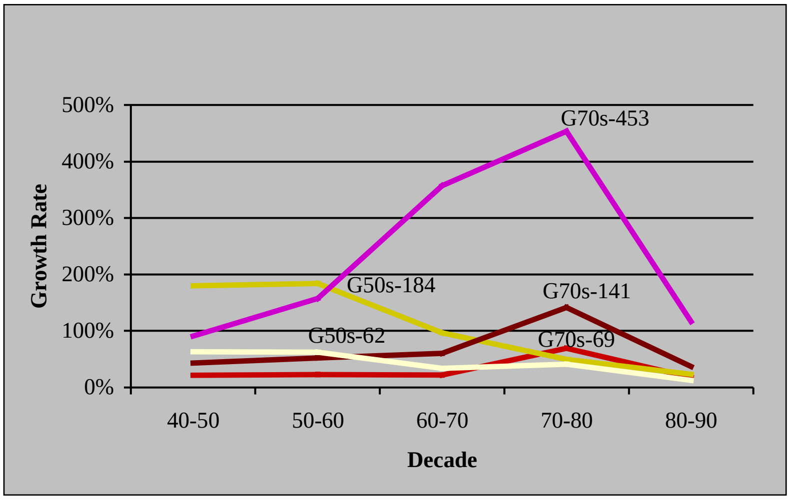

Fig. 10. High growth clusters.

clusters. Up to a certain point this same reversal in pattern also holds true when comparing the growth cluster maps with the 1990 housing density maps (Figs. 2 and 3) except that, due to the flattening of the urban to suburban density gradient over time (McDonald, 1989), only the older, previously-established high density areas experience low rates of growth, while the newer, more peripheral high density areas were experiencing high growth rates during preceding decades. Although some of the very high 1970s growth clusters lie on the periphery of metropolitan centers, this suburban ring is not the most prominent location of these high growth clusters. Instead, the high 1970s growth clusters are predominantly located in rural areas, especially areas with many scenic and recreational amenities (Johnson, 1999). Although clearly important in the North Central Region, forms of rural growth and the resulting density patterns have received much less research attention than suburban growth and urban density patterns (Fonseca and Wong, 2000).

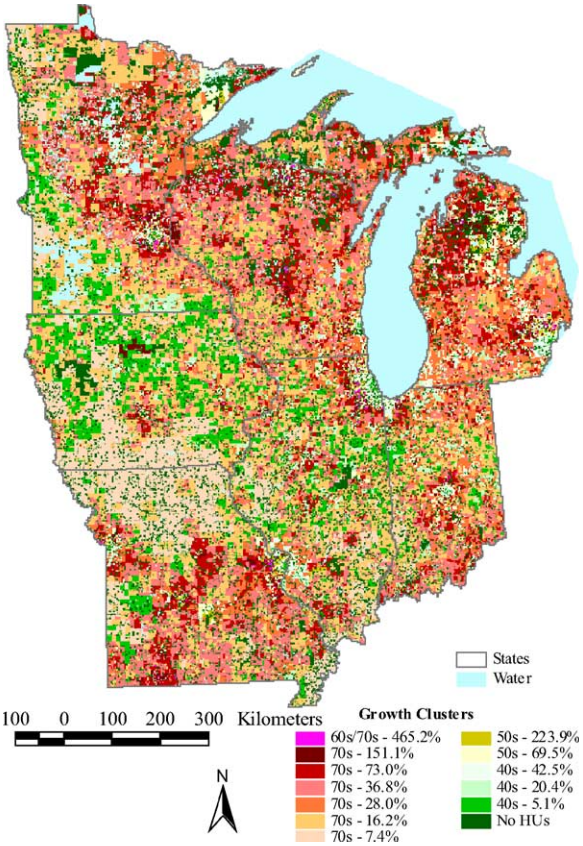

Fig. 11. Housing growth clusters, 1940–1990, North Central Region.

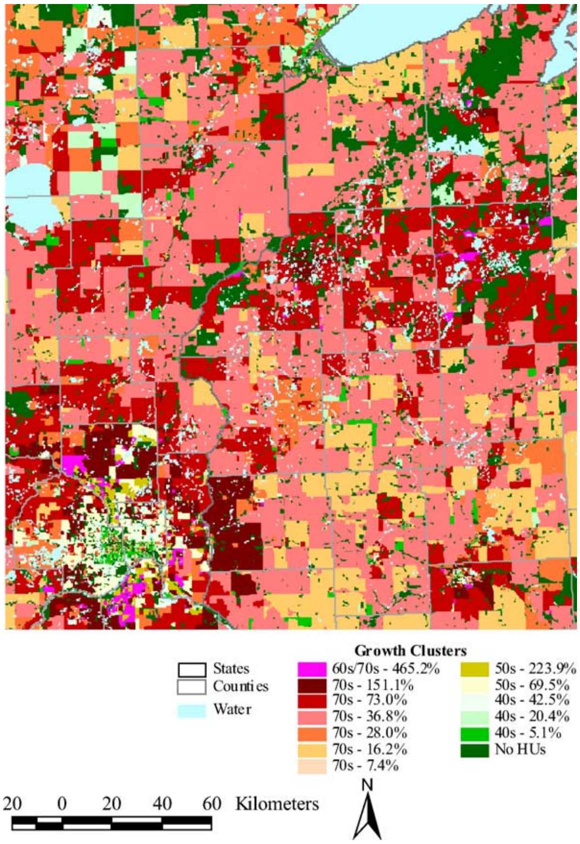

Fig. 12. Housing growth clusters, 1940–1990, Twin Cities, MN and surrounding area.

High growth rural clusters are extensive in the forested Missouri Ozarks, southern Indiana, the western portion of Michigan's Lower Peninsula (especially the far northwestern portion along Lake Michigan), and in the central portion of Michigan's Upper Peninsula. They are also arrayed along the Mississippi River and the Wisconsin River Valley in the central portion of Wisconsin. Finally, the lake districts of northern Minnesota and Wisconsin were very high growth areas during the 1970s (Fig. 12). Thus, the growth patterns in all of these ecologically sensitive forest, river, and lakeshore sub-regions equal those of metropolitan suburbs. Although the 1960s and 1970s sustained, very high growth cluster (G70s-453, bright pink) is not readily apparent on the map of the entire region, it does stand out on the enlarged map in the suburban periphery and along northern lakeshores (Fig. 12).

In contrast to the high growth characteristics of the areas just mentioned, the largely agricultural area of the North Central region that intersects the eastern portion of the Great Plains exhibits a low or very modest growth trajectory as shown by the growth cluster map. This is most evident in the nearly solid concentration of the G70s-8 (salmon) cluster in southern Iowa and northern Missouri, reflecting a steady decline in housing density except for limited growth in the 1970s. Just above this, a larger diagonal swath, extending from southern Minnesota through Iowa and central Illinois and into Indiana, is characterized by moderate 1970s growth clusters (G70s-17, orange) interspersed with very limited growth clusters (G40s-5, medium green). Together, these patterns of growth clusters make the eastern Great Plains even more obvious than it is on the 1990 density and 1940–1990 density cluster maps. Regardless of their density (some areas are rural, some exurban, and some small urban areas), they share a common growth trajectory—one of very modest growth.

3.3. Future growth

We identified four density clusters with high growth rates, one with very low densities in 1940 and three with medium densities, as having high potential for future growth. The one low-density cluster grew from 4 to 14 housing units per square kilometer during 1940–1990, while the three medium-density clusters grew from 9 to 32, 26 to 72, and 64 to 159 housing units per square kilometer. All four exhibit ever-increasing density, distinguishing them from the other rural and exurban clusters. Another density cluster with an extremely high growth rate grew from 9 to 290 units per square kilometer, surpassing all the medium-density clusters and all but two of the high-density clusters. This cluster emerges in groupings of nearly contiguous partial block groups predominantly on the periphery of metropolitan centers. However, by 1990 the cluster had reached such a high level of density that its growth would not be likely to continue at a similar pace into the future, without a significant change in overall urban density gradients. Thus, we do not include it among our density clusters with high probability of future growth and landscape change. The other four clusters are more likely candidates for experiencing sustained future growth, and tend to be located on the far periphery of metropolitan areas, within the vicinity of smaller urban centers, and in rural areas with recreational and scenic amenities.

From all the partial block groups in our selected density clusters, we reselected only those that were also in one of the five high growth clusters (Fig. 10). Three of these high growth clusters experienced their most rapid growth during the 1970s (G70s-453, G70s-141, and G70s-69) including the extremely high growth cluster that grew by 453% that decade and by 357% the previous decade. Although the sharp fall in growth in that cluster during the 1980s might indicate that future growth is unlikely, we select it because even with its sharp decline relative to the previous two decades, it remained the fastest growing cluster in the 1980s. Moreover, we have already excluded those partial block groups that have reached very high density levels that might preclude future growth. The other two high growth clusters experienced their most rapid growth in the 1950s (G50s-184 and G50s-62), which would not seem to be an indicator of high potential for growth in the 1990s and beyond. However, the cluster with the lower 1950s growth rate of 62% declined much less than other clusters, even over the three decades subsequent to its growth nadir, and continued to grow at a rate of 13% in the 1980s. Although the higher 1950s growth cluster did slow more significantly, its final 23% growth rate made it the third fastest growing cluster during the 1980s.

From the intersection of density and growth clusters conforming to these selected characteristics, we were able to construct a map identifying the 1990 housing density of those partial block groups with high potential for future growth (Fig. 13). As expected, they are spatially clustered on the periphery of metropolitan areas and smaller urban centers, as well as in recreational

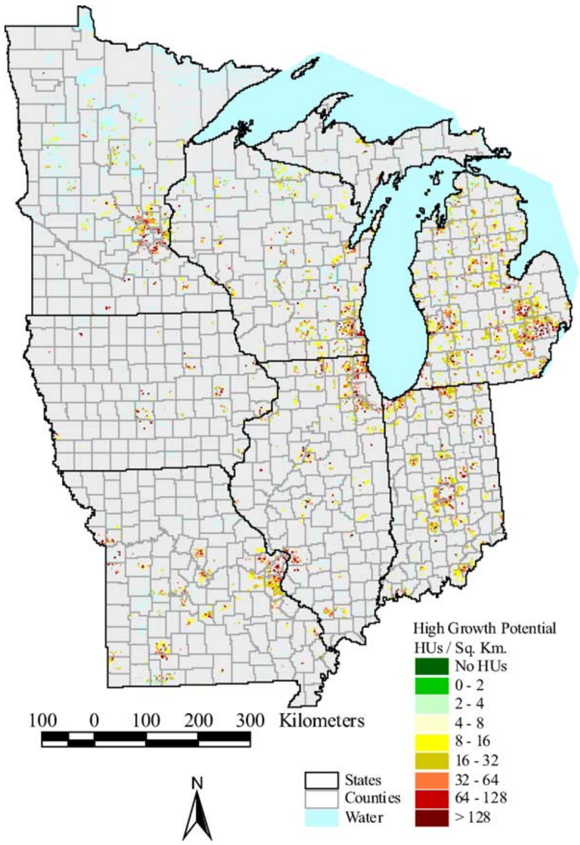

Fig. 13. High housing growth potential, North Central Region.

areas. The most prominent of these future growth areas is the northern suburbs of the Detroit-Ann Arbor metropolitan area. Recreational areas throughout the region emerge as future growth areas, especially in northern Wisconsin, along the northeast Lake Michigan coast in the Lower Peninsula of Michigan, and peppered across central Minnesota.

4. Conclusions

While fine-scale information about housing density over five decades provides an unprecedented wealth of information for the seven-state North Central Region, the sheer abundance of detail and extent of coverage makes comprehension difficult without the aid of tools to simplify and help visualize the patterns of difference that exist. Attribute clustering illuminates features of settlement patterns and their change over five decades that are not otherwise apparent. The clustering of density and growth data retains both temporal and spatial detail but generates a simpler outcome. When the data are reduced through clustering, the resulting maps highlight features of housing growth and density that cannot be seen on simple maps of current or historic housing density.

The prominence of the 1970s in the outcome of both clustering analyses reaffirms the demographic significance of that decade. Early indications from the 2000 US Census that migration and growth patterns of the 1990s resembled those of the 1970s give added importance to this finding, and argue against the claim that the 1970s were a one-time exception to long-term urban growth and rural decline in the United States. Density clustering demonstrates the variability of density trajectories in urban and suburban areas, and the relative stability of rural densities over time. Clusters based on growth rates without regard to absolute density reveal the similarities between urban cores and rural areas, where in both cases, housing growth has been very slow in recent decades. This is an important insight because the attention to growth, the factors to which it is attributed, and the policies designed to address growth—or in this case, the absence of growth—are traditionally separated into urban and rural constituencies, policy making groups, oversight agencies, and economic development programs. While there are no doubt more differences than commonalities between urban and rural growth dynamics, the similarity of outcomes illustrated here should prompt a renewed interest in problems and potential solutions these two types of areas might share. Where density maps display the uniformly high density of urban areas, growth rate maps highlight the differences across the urban area in rates of change. Similarly, the rural areas in the North Central Region clearly belong in different growth categories and are likely to have different growth patterns in the future. This finding is further impetus for re-thinking the way in which we approach growth management as an urban, suburban, or rural issue. Growth dynamics vary greatly within those categories and share characteristics across them. Furthermore, broad areas that share land cover characteristics also share growth characteristics, making the growth clusters map a rough analogue of the land cover map and highlighting the importance of resource management as a component of growth planning, and resource managers and specialists as experts whose involvement is essential to wise growth management.

Landscape change throughout the North Central Region has strongly affected commodity production, ecosystem integrity, rural communities, and recreation potential (Gobster et al., 2000). Housing growth is commonly recognized as a significant driver of landscape change. However, knowledge of its many reputed effects and the circumstances under which they do and do not occur is sorely lacking. This gap in understanding makes formulation of effective growth management policies a difficult undertaking. The methods introduced here to estimate housing density capture the pattern and history of housing at a scale fine enough to be useable in multi-disciplinary applications. For example, by examining the relationship between housing density and harvesting patterns over time, we are gaining insights into effects on forest productivity; and by adding overlays of vegetation data to current and historic housing density maps, we can map and trace changes in the wildland-urban interface. This research lays the groundwork for more extensive analysis of human/forest environment interactions in the North Central Region at a landscape scale, work that can be extended nationally and may have implications for those working in other countries as well. The spatially explicit information about landscape change that such research generates will be crucial for scientists and resource managers alike in their efforts to identify critical areas for further research and for the implementation of resource plans and policies.

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Appendix A. Estimating historic housing density

As noted in the main text, 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^t_j. 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^t_j. Thus, the number of housing units in county j at time t missing from the estimate based on the 1990 Census is equal to:

$$A^t_j = C^t_j - H^t_j \tag{A.1}$$

A^t_j 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 $t+10$ (Δ^{t+10}_{ij}), 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:

$$\Delta^{t+10}_{ij} = \hat{H}^{t+10}_{ij} - H^t_{ij}, \tag{A.2}$$

where Δ^{t+10}_{ij} is the estimated change in housing units, $\hat{H}^{t+10}_{ij}$ is the adjusted number of housing units one decade after time t, and H^t_{ij} 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:

$$\Delta^{t+10}_j = \sum_{i=1}^{I} \Delta^{t+10}_{ij} 0, \quad \text{for} \quad \Delta^{t+10}_j > 0 \tag{A.3}$$

The first adjustment step with $\hat{H}^t_{ij}$ representing the adjusted number of housing units in partial block group i of county j at time t is given by:if $\Delta^{t+10}_{ij} > 0$, then

$$\hat{H}^t_{ij} = H^t_{ij} + \left(\frac{A^{t+10}_j}{\Delta^{t+10}_j} \Delta^{t+10}_{ij} \right), \tag{A.4}$$

otherwise

$$\hat{H}^t_{ij} = H^t_{ij} \tag{A.5}$$

The adjusted estimate, $\hat{H}^t_{ij}$, is equal to the initial estimate, H^t_{ij}, plus the ratio of the number of missing housing units in the county, A^t_j, to the change in housing units in the county, Δ^{t+10}_j, multiplied by the change in housing units in the partial block group, Δ^{t+10}_{ij}. 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 $A^{t+10}_j / \Delta^{t+10}_j > 1$, then

$$\frac{A^{t+10}_j}{\Delta^{t+10}_j} > 1 \tag{A.6}$$

For counties in which the ratio of the number of missing housing units, A_j^t, to the change in housing units, Δ_j^{t+10}, is greater than one (1), residual missing housing units A_j^{t+10} 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, will exceed the estimated number of housing units after adjustment:

$$\hat{H}_j^t = \sum_{i=1}^{I} \hat{H}_{ij}^t < C_j^t \tag{A.7}$$

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

$$H'^t_{ij} = H_{ij}^t \left[(A_j^{t+10} - \Delta_j^{t+10}) \frac{\hat{H}_{ij}^t}{\hat{H}_j^t} \right] \tag{A.8}$$

otherwise

$$H'^t_{ij} = \hat{H}_{ij}^t \tag{A.9}$$

The second adjusted estimate, H'^t_{ij}, 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, $\hat{H}_{ij}^t$. 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. Other unpopulated areas such as public and industrial lands could also have been removed, if comprehensive, current, accurate data regarding the location of such lands was available.

Appendix B. Cluster analysis

To produce reliable, valid clusters, we used a two-stage procedure that combines hierarchical agglomerative and partitioning methods (Milligan and Sokol, 1980; Cheng and Milligan, 1996; Milligan, 1996). In the first stage we performed an initial hierarchical agglomerative clustering on a simple random sample (with replacement) of 3000 observations to identify seeds (i.e. mean housing density and housing growth rate values for each of the clusters) for the second-stage partitioning clustering, which assigned the full set of partial block group observations from across the region to these cluster seeds. We performed this two-stage clustering procedure separately for housing density (i.e. houses per square kilometer for each census year from 1940 to 1990) and for housing growth (the rate of growth for each decade from the 1940s to the 1980s).

The hierarchical agglomerative method employed in the first stage created clusters using similarity distance measures in which each observation is grouped with the most similar observations and placed furthest from the most dissimilar observations. We used the average-linkage method to avoid both the extreme single-linkage "chaining," which can create clusters that are distinct from one another but not internally consistent, and the extreme complete-linkage "clumping," where clusters are internally consistent but are not isolated from one another (Aldenderfer and Blashfield, 1984; Kaufman and Rousseeuw, 1990; StataCorp, 2001). Due to the skewed distribution of housing density, we used a natural-log transformation with the Euclidean distance measure, which is otherwise allows outlier values to disproportionately affect cluster designation (Aldenderfer and Blashfield, 1984). Housing growth rates were also skewed, but a logarithmic transformation was not practical due to negative values, precluding use of the Euclidean distance measure. As an alternative, we used a Canberra distance measure, which is especially sensitive to small changes and is not affected by disproportionately large values (Gordon, 1999; StataCorp, 2001).

Hierarchical agglomerative methods create a complete range of clusters, from placing all observations in one cluster to placing each observation in its own cluster, which necessitates the selection of a set of clusters that adequately distinguish similar and dissimilar observations. The number of resulting clusters thus depends on the distance threshold below which neighboring clusters are combined or eliminated. After each of the initial sample-based hierarchical clustering procedures, we examined the resulting 25-cluster dendrogram. To reduce the effects of outliers, we combined relatively similar clusters and dropped dissimilar clusters with limited numbers of observations (5 or fewer in the density clustering and 10 or fewer in the growth clustering). For housing density, 15 clusters remained, while 12 remained for housing growth.

In the second stage of the clustering using the partitioning method, the observations from across the region are assigned to the clusters that were predetermined by the first-stage hierarchical agglomerative sample-based clustering. Partitioning methods are useful for large data sets because they require fewer comparisons than hierarchical methods and thus are less computationally intensive. However, the selection of appropriate seeds is critical to avoid inconsistent and/or poorly differentiated results (Milligan, 1980; Aldenderfer and Blashfield, 1984). K-medians partitioning procedures, which limit the effect of outliers in determining clusters compared to k-means portioning, were applied to both housing density and growth. For both the density and growth cluster analyses, partial block groups without any housing units were excluded from the procedure and were assigned to two additional clusters, water and land.

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