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RESEARCH ARTICLE

Spatiotemporal dynamics of housing growth hotspots in the North Central U.S. from 1940 to 2000

**Christopher A. Lepczyk · Roger B. Hammer ·
Susan I. Stewart · Volker C. Radeloff**

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Abstract Housing growth is a primary form of landscape change that is occurring throughout the world. Because of the ecological impacts of housing growth, understanding the patterns of growth over time is imperative in order to better inform land use planning, natural resource management, and conservation. Our primary goal was to quantify hotspots of housing growth in the North Central United States over a 60-year time frame (1940–2000) using a spatial statistical approach. Specifically, our objectives were to: (1) determine where housing growth hotspots exist; (2) determine if hotspots are changing in space and over time; and, (3) investigate if hotspots differ based upon the type of measurement and scale of analysis. Our approach was based on a spatial statistical framework (Getis-Ord G* statistic) that compared local housing growth patterns with regional growth rates. Over the 60-year period the number and mean area of hotspots, measured both as absolute and percent growth, remained largely constant. However, total area of all hotspots increased significantly over time as measured by absolute growth. Spatially, the hotspots shifted over time and exhibited different patterns based upon the measurement. Absolute growth hotspots exhibited patterns of expanding sets of rings around urban centers, whereas percent growth hotspots exhibited both expanding rings and shifting locations throughout rural locations. When increasing the neighborhood size used to discern hotspots from 5 to 50 km, the number of hotspots decreased while their size increased. Regardless of neighborhood size, ~95 and ~88% of the landscape, as measured by absolute and percent growth, respectively, never contained a hotspot. Overall our results indicate that housing growth is occurring at distinct locations on the landscape, which change in space and time, and are influenced by the scale of analysis and type of measure. In general these results provide useful information for the natural resource, planning, and policy communities.

C. A. Lepczyk (✉) · V. C. Radeloff
Department of Forest Ecology and Management,
University of Wisconsin-Madison, 1630 Linden Drive,
120 Russell Laboratories, Madison, WI 53706, USA
e-mail: clepczyk@wisc.edu

R. B. Hammer
Department of Rural Sociology, University of
Wisconsin-Madison, Madison, WI 53706, USA

Present Address:
R. B. Hammer
Department of Sociology, Oregon State University,
Corvallis, OR 97331, USA

S. I. Stewart
USDA Forest Service, North Central Research
Station, Evanston, IL 60201, USA

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Introduction

One of the primary causes of anthropogenic landscape change occurring in the United States today is housing development (Hammer et al. 2004). Housing development is occurring not just in suburban fringes, typically described as urban or suburban sprawl, but is ubiquitous in rural areas as well (Theobald 2001; Brown 2003; Radeloff et al. 2005a; Theobald 2005; Hansen et al. 2005). The 19 northernmost counties of Wisconsin, popularly referred to as the Northwoods, provide a case in point. Although the region contains only one metropolitan county, its abundant natural amenities, namely lakes and forests, have engendered substantial increases in housing density in recent decades (Radeloff et al. 2001; Gobster and Rickenbach 2004; Brown et al. 2005). The Wisconsin Northwoods exemplifies a common situation, namely that in recent decades housing growth occurred in selected rural areas, not just in urban and suburban locations. This rural sprawl (or exurbanization) results not just from the evolving spatial distribution of the population but also because the number of housing units has increased at a faster rate than the human population in the U.S., in part because of declining mean household size and the increasing number of second homes (Fig. 1). An increasingly inefficient allocation of land resources on a person-per-unit of land is a direct repercussion of these trends, demonstrating that housing may capture the ecological footprint of human influence better than human population counts (Theobald 2001; Liu et al. 2003).

Ecologically, housing growth, both in the form of suburban and rural sprawl, has been identified as one of the major threats to ecosystems, due to its effects on water quality (Wear et al. 1996), land use (Matlack 1997; Parks et al. 2000), forest management (Marcin 1993), wildlife populations (Soulé 1991; Cincotta et al. 2000), biodiversity (McKinney 2002; Hansen et al. 2005), endangered species (Czech et al. 2000), and habitat loss (Theobald 2000). Even an individual home impacts the environment as evidenced by effects on wildlife species (Odell and Knight 2001). Hence, whether at the scale of a single home or an entire housing development, housing produces a marked ecological impact.

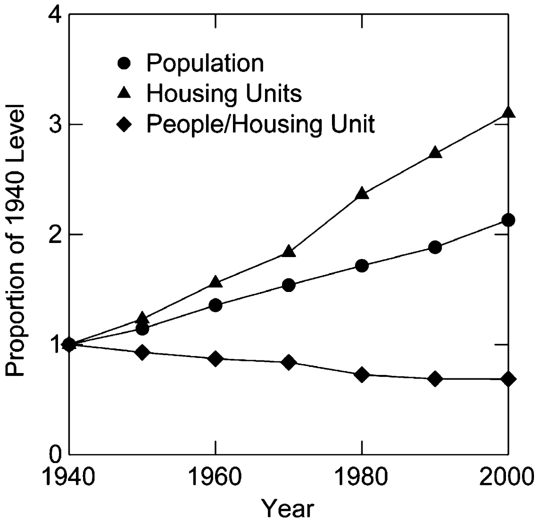


Fig. 1 Divergence of the human population and houses across the U.S. based upon U.S. Census data. Change in the population, housing units, and number of people per housing units over 60 years in proportion to the 1940 level

In considering houses in ecological systems it is important to note that housing growth is not an isolated phenomenon, but is accompanied by a suite of associated commercial, industrial, and infrastructural development, such as retail outlets, office buildings, roads, and utilities, that also impact the environment (Dwyer and Childs 2004; Forys and Allen 2005). For example, as road density increases, the amount of intact habitat, such as forest, decreases, resulting in a more fragmented ecological system (Hawbaker and Radeloff 2004). Similarly, recreational developments, such as hiking trails, increase predation rates and reduce nesting opportunities for birds (Miller et al. 1998). Thus, we suggest considering housing growth a proxy for the manifold ecological effects of both rural and suburban sprawl, which include housing, commercial, industrial, infrastructure, and other types of human development.

Due to these environmental effects, housing growth has become an important concern for ecologists, conservation biologists, and natural resource managers (Alberti et al. 2003), where it had previously been studied mainly by urban planners, economists, and sociologists (Ermisch 1996; Sýkora 1999; Pacione 2004). The importance of housing to both the ecological and social sciences has focused increasing attention on the spatial patterns of housing growth. Furthermore, because housing growth is not a spatially random process, understanding its patterns requires a spatially explicit view. However, as Theobald (2005) noted, spatially explicit efforts to understand rural housing growth have been limited to a few case studies. Thus, what is currently needed is an assessment that considers growth across the entire landscape (i.e., both urban and rural locations) from a spatially explicit perspective. By taking such a landscape perspective the analysis can also provide evidence for different theories and views of how growth occurs. For instance, Burgess's urban land use model (1925) holds that cities are arranged in concentric circles of different land uses (similar to von Thünen's location theory; von Thünen 1826; Wartenberg 1966) and that over time as urban growth occurs the concentric rings expand outwards from the city center (Burgess 1925). Conceptually, this growth over time can be thought of as an onion where each layer is a new ring of growth. In contrast, recent theories of urban growth describe the process as leapfrog development, where new houses are added at some distance from a city center with intermediate areas left undeveloped (Ewing 1997; Heim 2001). In rural areas, the patterns of growth emerging over the past three decades—since the Rural Rebound of the 1970s (e.g., Johnson and Beale 1998)—appear to take a different form, one where growth centers around the amenity resources home buyers find most attractive, such as lakes and forests (Walsh et al. 2003; Gonzalez-Abraham et al. In Press). Rural growth patterns do not follow typical suburban growth patterns; this rural sprawl appears to take a different pattern. For instance, attribute clustering of housing data in the North Central U.S. showed that, while rural amenity areas had housing density in the same range as those of suburban communities by the end of the 1990s, their growth trajectories were clearly different, a finding with even greater significance when one considers the reliance on past trajectories to inform future housing growth projections (Hammer et al. 2004).

While other theories and views exist that describe housing growth, it is important to note two considerations pertaining to growth patterns. First, the type of growth pattern observed is ultimately dependent upon how and at what scale growth is measured. Specifically, growth measured as an absolute change in the number or density of houses may have a very different pattern than growth measured as a percent change. Similarly, growth patterns that appear at the scale of a county or group of counties may disappear at the scale of the state or region. Second, it is important to keep in mind that "There is no point in the continuum from large agglomerations to small clusters of scattered dwellings where urbanity disappears and rurality begins; the division between urban and rural populations is necessarily arbitrary" (United Nations 1955). In other words, when trying to discern patterns of housing growth it is necessary to look across the entire landscape as no consistent definition of urban and rural exists throughout the world and the distinction between these two ends of a continuum are often arbitrary.

One approach that can be used to discern different patterns of housing growth and address different theories is hotspot analysis. Hotspots analysis is a spatial approach most often used to develop conservation priorities (Reid 1998; Myers et al. 2000; Rutledge et al. 2001). The term "hotspots" has several connotations in ecology and conservation that can be categorized into three general groups. First, in conservation biology the term hotspots generally refers to locations with a high concentration of species diversity, endemic species, rare and endangered species, or other biological attribute (Dobson et al. 1997; Reid 1998; Myers et al. 2000; Rutledge et al. 2001; Fox and Beckley 2005). Conservation biologists typically identify hotspots using complementarity analysis, which calculates the minimum area or number of locations needed to conserve/preserve the particular item of interest (Pressey et al. 1993; Csuti et al. 1997; Reid 1998). Second, geographers consider hotspots to be a neighborhood of values that are significantly higher/greater/different from surrounding areas (Getis and Ord 1996; Ord and Getis 2001). When the hotspots are identified, they are analyzed against other a priori considerations or data. Third, there is a similar but more loosely conceived view of hotspots that designates locations as hotspots based on arbitrary cut-off levels, predetermined values, or visual inspection of landscapes or maps (e.g., Wilson et al. 2005). For example, in thinking about housing data, we could consider all counties that have growth in the top 10% to be hotspots. While commonly used in initial stages of inquiry or informal assessments, this method is not suitable for empirical research. Although these three perspectives are not necessarily mutually exclusive, the one which offers the greatest potential for understanding patterns of housing growth is the geostatistical or spatial approach developed by geographers, because it can be applied to any question of spatial concentration, using any spatially explicit data.

Conceptually, the spatial approach is important for understanding housing growth patterns because it can identify if hotspots are large or small, if they are clustered or spread out on the landscape, and if they exhibit different patterns at different scales of analyses. Furthermore, the spatial approach is not forced to differentiate between urban and rural housing growth, thus allowing it greater utility and more relevance in addressing spatial patterns of housing growth over time. As a result, the spatial approach can help to support or refute different theories of housing growth as well as be used to identify if the growth patterns have changed over time. Thus, a spatial statistical approach can provide an important tool for developing a more robust understanding of housing growth patterns over time across a broad region. This understanding of housing growth is a requisite foundation for integrated, landscape ecological research to determine the full range of impacts associated with residential development.

Given the importance of housing growth, coupled with the need to better understand its patterns and processes at the landscape scale, we sought to address the issue of housing growth using a spatial hotspots analysis based on spatially consistent long-term housing data for the entire North Central U.S. Specifically, our goal was to measure hotspots of housing growth over time using a spatial analytic approach and address the following objectives: first, determine where hotspots occur on the landscape; second, determine if hotspots are changing in space and over time; and third, investigate how different measures and scales of analyses affect the hotspot analysis. The yield from these objectives will help to elucidate the spatiotemporal nature of housing growth as well as aid the natural resource management and urban planning communities.

Methods

Study area

We investigated the North Central region of the U.S., which encompasses the seven states of Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, and Wisconsin (Fig. 2). This region has experienced marked housing growth during the latter half of the 20th century (Hammer et al. 2004) and has significant ecological and natural resources. Within this region we used a data set of fine resolution housing density in vector format. Specifically, the housing data are U.S. decennial census data at the partial block group level (see Hammer et al. 2004 for details) that are spatially consistent by decade from 1940 to 2000. Partial block groups fall between blocks and block groups in the hierarchy of U.S. Census Bureau geographies (see http://www.census.gov/geo/www/reference.html), and are roughly equivalent, in social terms, to subdivision-sized neighborhoods. A total of 531,291 partial block groups (excluding water blocks) comprise the North Central region, with a mean area of 198.3 ha. The advantage of the partial block group data for measuring housing growth is twofold. First, the data are at a finer spatial scale than many human influence databases collected over time, allowing for more detailed analyses of houses and housing growth. Second, the spatial stability of this unit of analysis facilitates temporal analyses, not previously possible with U.S. Census data given the problem of

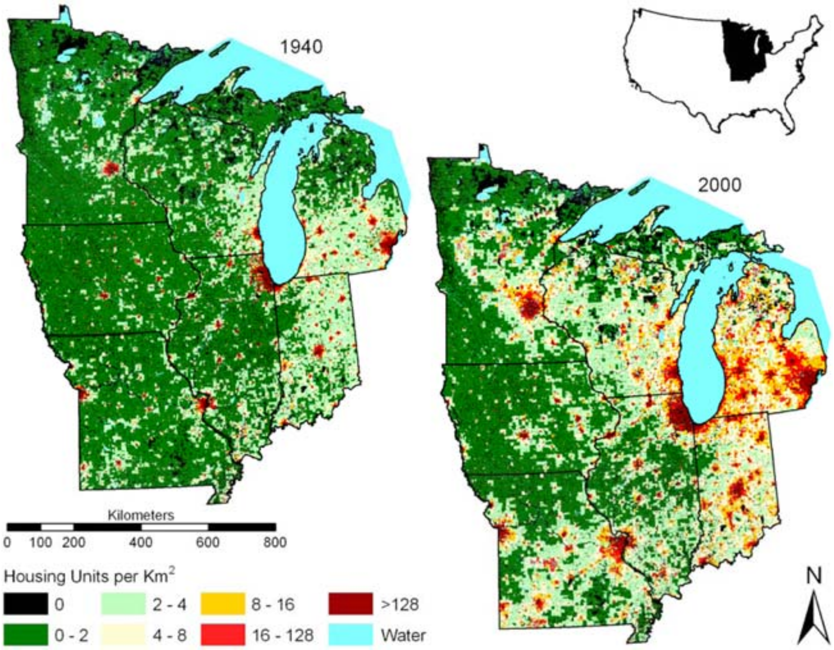


Fig. 2 Housing density in 1940 and 2000 in the North Central U.S. study area

boundary changes over time (Hammer et al. 2004).

Data processing

Housing density change was analyzed using ArcGIS, R, and Systat 10 software. We calculated two measures of change in housing density between each decade at the partial block group level; an absolute measure which yields the total number of housing units added to or subtracted from each partial block group, and a percent measure which yields the percent change in housing units added or subtracted from the previous time step. Each partial block group change measure (i.e., absolute or percent) was then adjusted by a decade-specific growth factor (Table 1). This growth factor was used to weight each decade over the six decade period in order to normalize the data and allow for temporal comparisons within the spatial statistical approach (see below). The growth factor was calculated separately for each of the six decades for the absolute measure as

$$\mathrm{DGF}_t = \frac{6\sum_{i=1}^{n}(\mathrm{HU}_i)_{t+1} - (\mathrm{HU}_i)_t}{\sum_{t=1}^{6}\sum_{i=1}^{n}(\mathrm{HU}_i)_{t+1} - (\mathrm{HU}_i)_t}$$

Where DGF_t is the decadal growth factor for decade t and HU is the density of housing units in polygon i. Using these same parameters, we modified the growth factor calculation slightly for the percent measure as follows:

$$\mathrm{DGF}_t = \frac{6\sum_{i=1}^{n}\frac{(\mathrm{HU}_i)_{t+1} - (\mathrm{HU}_i)_t}{(\mathrm{HU}_i)_t} \times 100}{\sum_{t=1}^{6}\sum_{i=1}^{n}\frac{(\mathrm{HU}_i)_{t+1} - (\mathrm{HU}_i)_t}{(\mathrm{HU}_i)_t} \times 100}$$

Table 1 Decadal growth factors used to normalize the six decades for absolute and percent change in housing unit density

Time period	Absolute change growth factor	Percent change growth factor
1940–1950	1.142	1.132
1950–1960	1.569	1.312
1960–1970	0.998	0.893
1970–1980	1.216	1.531
1980–1990	0.452	0.445
1990–2000	0.623	0.687

Following the adjustment the vector data for each partial block group in the region were converted to 100 m grid cells for each decade and each measure (i.e., 6 decades × 2 measures = 12 output grids). Because of file size and computing limitations, this initial set of twelve grids were each averaged into grids of 5 km cells, which was the minimum size grid cell that allowed for spatial statistical analysis over the entire region. All water cells in the initial 100 m grids were converted to 'nodata,' which allows for cells to remain in the database, but with no attribute information. Following aggregation the attribute information for each grid was exported into the statistical software package R (Ihaka and Gentleman 1996).

Spatial statistical approach

To identify housing growth hotspots we used a local indicator of spatial association (LISA; Anselin 1995), the Getis-Ord G-Star statistic (hereafter termed G*; Getis and Ord 1992). The G* statistic compares a local neighborhood average (including the cell of interest) of a given attribute against the global average and calculates a *z*-score for each 5 km cell. For each of the twelve grids we calculated G* for five different neighborhood sizes (5, 10, 15, 25, and 50 km), resulting in a total of 60 output matrices/analyses (6 time steps × 5 neighborhood sizes × 2 measures). We calculated G* using the statistical software package R and then imported the output matrices back into ArcGIS as grids.

For each time series (i.e. six time steps) at each specific neighborhood size and each change measure, we calculated the global mean and standard deviations of the *z*-scores in order to make comparisons between time steps. The *z*-scores for each 5 km cell within a grid were then classified into a binary system, with *z*-scores ≥ 2 standard deviations above the global mean being classified as 1 and all other values being classified as 0. We chose the 2 standard deviation cut-off because Getis and Ord (1996) indicate that the critical value of G* (i.e. *z*-score in the 95th percentile) increases with larger sample sizes, but they do not provide G* values above sample sizes of 1,000 and our sample size was 44,362. All reclassified cells of 1 were considered to be hotspots, i.e. locations of significant housing unit growth. Hotspot cells that were contiguous with one another were combined into a single hotspot. Thus, the size of a hotspot was determined by how many contiguous cells were merged together. To measure changes in the location of hotspots over time we combined grids from all time periods for each change measure and neighborhood scale (e.g., absolute growth and 5 km neighborhood) and summed all individual cells of the hotspots at one, two, three, four, five, and six time periods as well as those cells which were never hotspots.

Statistical analyses

From each grid we determined the following basic summary statistics: total number of hotspots, mean size of hotspots, and the total area of all hotspots summed over the landscape (i.e., the full extent of the grid). We analyzed these summary statistics for temporal changes at each neighborhood scale using ordinary least squares regression analysis with both linear and quadratic models. We selected both linear and quadratic models to test whether there were temporal trends and then whether the trends were linear or exhibited temporal peaks or valleys. Because quadratic results were not significant in most instances (see Results) we report only linear model results, except where noted. After finding no significant trends over time in most analyses (see Results), we pooled data across all decades to test for differences among neighborhood sizes, using ANOVA with a Tukey post hoc test. All statistical analyses were conducted in Systat 10 with $P \leq 0.05$ considered significant.

Results

The number of housing growth hotspots, measured either as absolute or percent growth, increased from 1940 to 2000 (Fig. 3). Despite this trend, significant increases in the number of hotspots were found in only two of ten regression models (Fig. 3). Similarly, while the number of hotspots peaked during the 1970–1980 period for most time series (Fig. 3), a quadratic relationship was only found for hotspots calculated at the 25 km neighborhood (P = 0.011 and 0.028 for

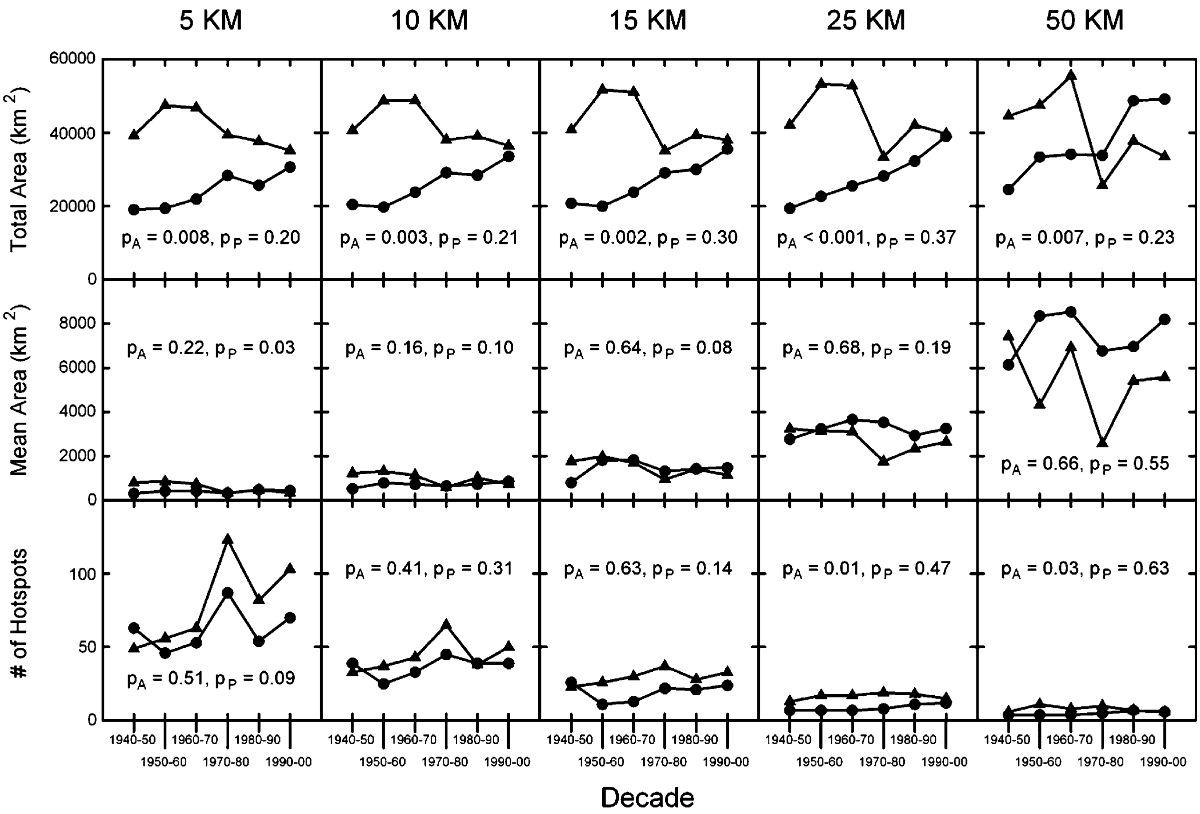
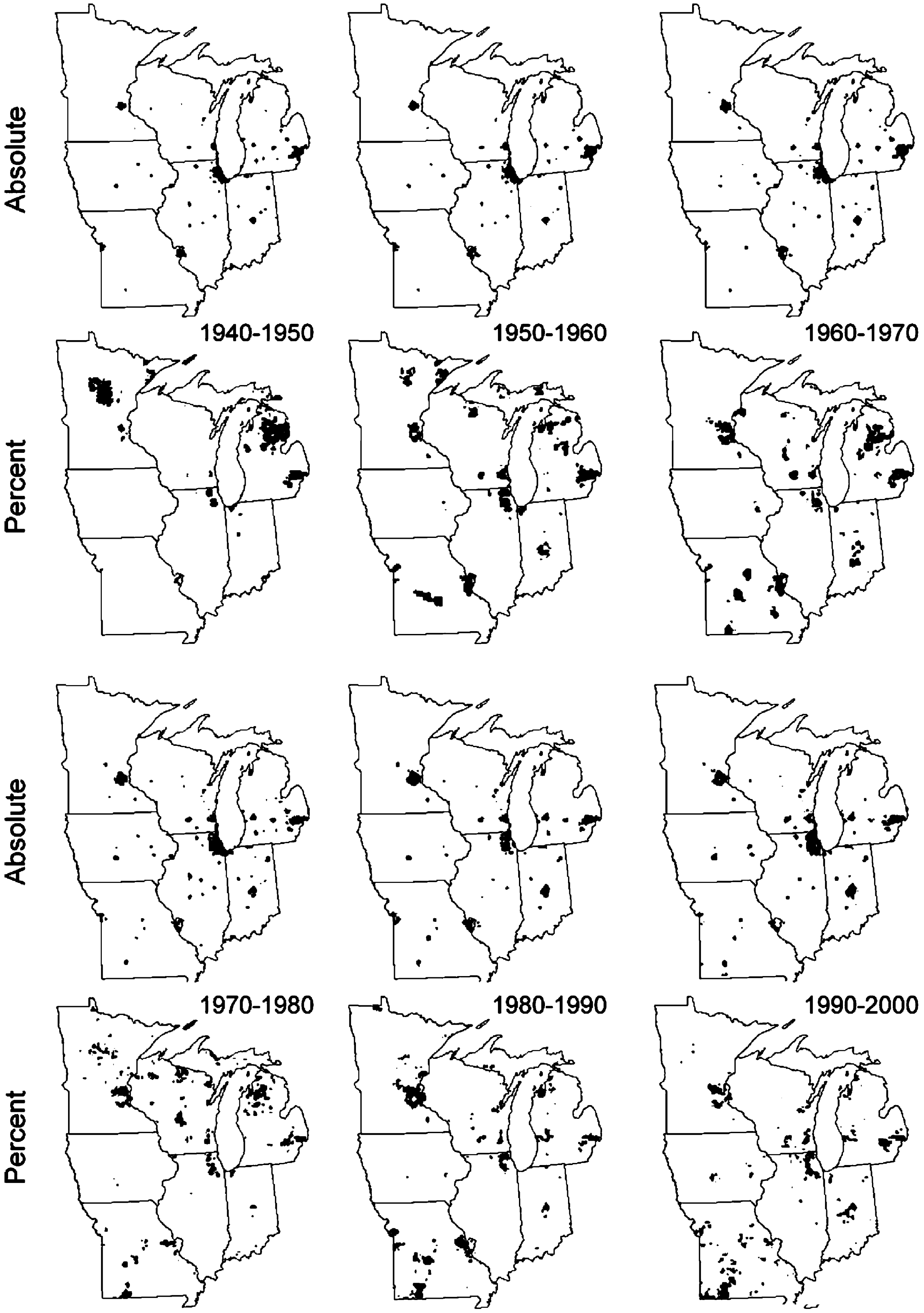


Fig. 3 Temporal trends of housing growth hotspots over six decades in the North Central U.S. for both absolute (•) and percent (▲) measures at five neighborhood sizes. Results of linear regression models for temporal trends of each landscape metric are presented as *P*-values, with absolute and percent measures denoted as P_A and P_P, respectively

absolute and percent growth, respectively). Thus, the number of hotspots remained essentially constant over time. Over the six decades, the mean area of the hotspots tended to increase as measured by absolute growth and to decrease as measured by percent growth (Fig. 3), but was only statistically significant for a decrease in area at the 5 km neighborhood scale (Fig. 3). Total area of all hotspots combined increased significantly over time for all neighborhoods investigated as measured by absolute growth, but did not change significantly over time as measured by percent growth (Fig. 3). Notably, while both the number and area of hotspots tended to increase over the six decades, and though not statistically significant alone, the cumulative effect of these changes was an overall significant increase in the total amount of the landscape that was part of a hotspot (Fig. 3). This suggests that over time, there was an increase in the amount of the landscape that experienced significantly greater than average housing growth, consistent with a trend toward population decentralization over time.

The hotspots shifted location over the six decades and showed markedly different patterns depending upon whether measured by absolute or percent growth, as exemplified by the 5 km neighborhood analysis (Fig. 4). Hotspots determined by absolute growth were generally located in or around cities and urban centers, whereas hotspots determined by percent growth were located throughout many rural locations. As time progressed the absolute growth hotspots tended to expand in a ring pattern away from urban cores, whereas the percent growth hotspots exhibited both suburban growth rings and drastically shifting patches in the non-urban matrix (Fig. 4). In terms of spatial overlap among hotspots over time, relatively few locations had hotspots present in all time periods, and those that did tended to be in


Absolute
Percent
1940-1950
1950-1960
1960-1970
Absolute
Percent
1970-1980
1980-1990
1990-2000

◀**Fig. 4** Locations of housing growth hotspots across the North Central region during each decade for both absolute and percent measures based on a 5 km neighborhood

urban areas (Table 2, Figure 5G). Specifically, under the absolute growth measure, only 0.67–1.39% of the North Central region had hotspots in all six decades (Fig. 5G), whereas under the percent growth measure the range was reduced to 0–0.28%. On the other hand, ~88 to ~95% of the landscape never contained hotspots (Table 2, Fig. 5G), indicating that significant levels of growth are occurring on a relatively small portion of the landscape.

The number of hotspots was sensitive to neighborhood size. As the neighborhood size was increased from 5 km to 50 km there was a significant decrease in the number of hotspots averaged over all time periods for both measures of growth ($F = 53.5$; df = 4,25; $P < 0.0001$, and $F = 23.4$; df = 4,25; $P < 0.0001$ for absolute and percent, respectively). Under the absolute measure, the number of hotspots calculated at different size neighborhoods differed significantly from one another in eight of the ten post-hoc comparisons, whereas under the percent measure, six of ten post-hoc comparisons showed significant differences (Table 3). The mean area of the hotspots increased significantly as the neighborhoods became larger ($F = 201.4$; df = 4,25; $P < 0.0001$, and F = 29.6; df = 4,25; $P < 0.0001$ for absolute and percent, respectively; Fig. 3). This significant increase occurred at every neighborhood size in the case of absolute growth hotspots, as evident by post-hoc comparison (Table 3). Total area encompassed by all hotspots was similar across all neighborhood sizes for the percent measure ($F = 0.18$; df = 4,25; $P = 0.95$), but showed a significant increase with larger neighborhoods for the absolute measure ($F = 3.45$; df = 4,25; $P = 0.022$). However, this significant increase was likely due to the 50 km neighborhood being larger than the total area calculated at the 5, 10, and 15 km neighborhoods.

We found more hotspots at each size neighborhood for percent growth than for absolute growth. This difference was significant for the 15, 25, and 50 km neighborhoods. On the other hand, mean area did not show any consistent differences between the percent and absolute measures. Specifically, at the 5, 10, and 15 km neighborhoods the mean area was greater under the percent measure, but only significantly so at the 10 km neighborhood, whereas at the 25 and 50 km neighborhood the mean area was greater under the absolute measure, with a significant difference at the 50 km neighborhood. The total area of all hotspots was always greater under the percent measure than the absolute, with only the 50 km neighborhood not exhibiting a significant difference.

Discussion

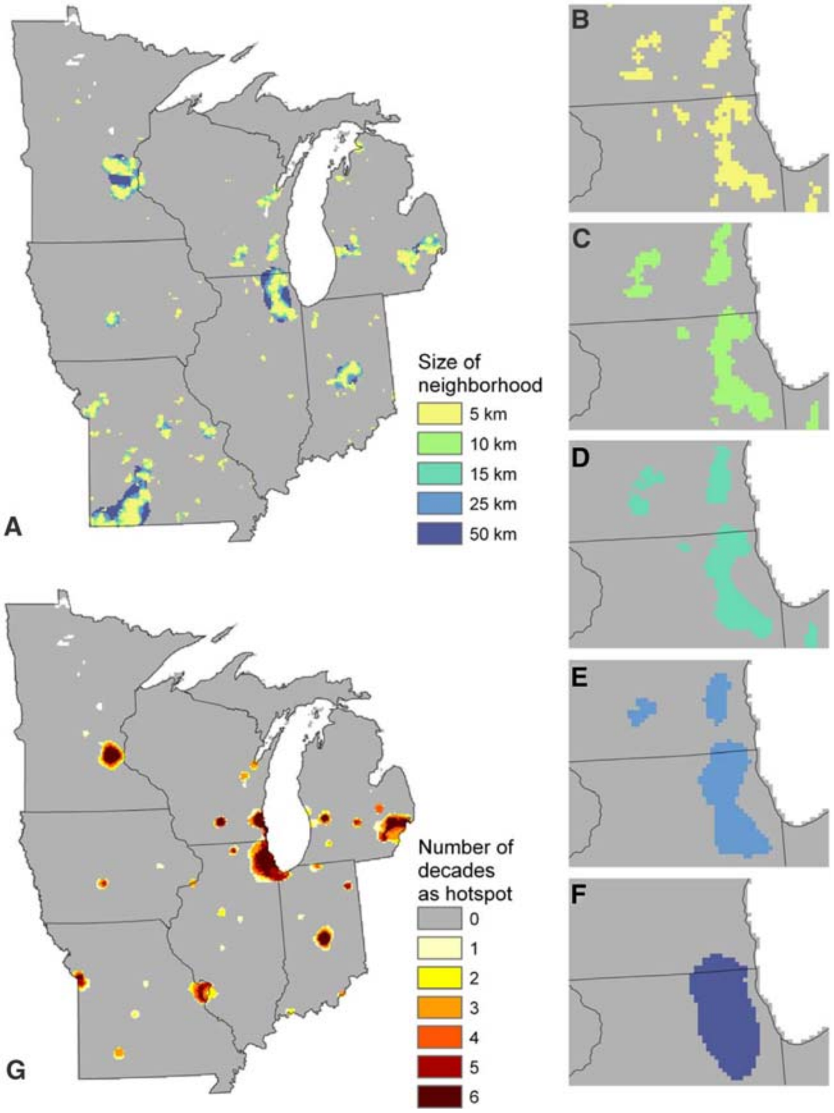
Housing growth in the North Central U.S. is concentrated in distinct locations (i.e. hotspots) demarcated by significantly faster growth rates than the rest of the region. These hotspots of growth highlight the fact that while housing development has been occurring throughout the region (Fig. 2), it is concentrated in only ~5 to ~12% of the landscape, depending upon method of measurement. We suggest that these hotspot

Table 2 Overlap of hotspot locations over time

Neighborhood size (km)	Absolute change					Percent change				
	5	10	15	25	50	5	10	15	25	50
Landscape without hotspots	96.09	95.91	95.82	95.85	94.32	88.07	88.09	88.02	87.88	88.57
Hotspots present during 6 time steps	0.67	0.80	0.92	1.14	1.39	0.20	0.23	0.28	0.27	0.00
Hotspots present during 5 time steps	0.53	0.53	0.49	0.44	0.78	0.40	0.50	0.50	0.57	0.52
Hotspots present during 4 time steps	0.58	0.64	0.55	0.59	0.82	0.72	0.76	0.76	0.74	0.54
Hotspots present during 3 time steps	0.67	0.61	0.66	0.53	0.43	1.26	1.19	1.19	1.43	1.80
Hotspots present during 2 time steps	0.65	0.67	0.65	0.65	1.10	2.91	2.99	3.04	2.94	3.32
Hotspots present during 1 time step	0.80	0.84	0.90	0.81	1.15	6.42	6.24	6.21	6.17	5.25

Values represent the percent of the landscape in a given category

Fig. 5 (**A**) Housing growth hotspots identified during 1990–2000 at different sized neighborhoods based on percent growth; (**B–F**) Housing growth hotspots around Southern Wisconsin and Northern Illinois for neighborhoods ranging from 5 to 50 km; (**G**) Spatial overlap of hotspots across the six decades using the 15 km absolute results. The number of times a cell was determined to be a hotspot is denoted by the number of decades



locations should be targeted for research, management, conservation planning, and policy efforts.

Overall, the temporal patterns of the hotspots were fairly stable as indicated by the landscape metrics (Fig. 3). While the number of hotspots exhibited a slight increase over time with a peak in the 1970–1980 decade, there was no significant quadratic relationship. Interestingly, this peak in the 1970–1980 time period (Fig. 3) corresponds well with the decade during which many people left urban areas and built houses in the suburbs and rural areas (Vining and Strauss 1977). This population deconcentration was fueled in part by natural amenity and recreational opportunities available in the countryside (Fuguitt 1985).

Spatiotemporal patterns of hotspots, on the other hand, displayed a number of interesting and significant relationships. One of the most notable relationships was that hotspots discerned by absolute growth tended to exhibit a pattern of expanding rings around large metropolitan and urban centers (Fig. 4). This ring-like pattern makes inherent sense under the absolute measure given the fact that the greatest number of new houses added to the landscape tend to be located near city centers or major transportation corridors. Furthermore, the ring pattern is similar to

Table 3 Differences between neighborhood sizes

Measure	Statistic	Neighborhood size (km)	Neighborhood size (km)			
			5	10	15	25
Absolute	# of Hotspots	10	<0.0001			
		15	<0.0001	0.007		
		25	<0.0001	<0.0001	0.152	
		50	<0.0001	<0.0001	0.028	0.926
Percent		10	0.002			
		15	<0.0001	0.393		
		25	<0.0001	0.018	0.521	
		50	<0.0001	0.001	0.097	0.837
Absolute	Mean area	10	0.812			
		15	0.010	0.117		
		25	<0.0001	<0.0001	<0.0001	
		50	<0.0001	<0.0001	<0.0001	<0.0001
Percent		10	0.916			
		15	0.387	0.862		
		25	0.002	0.018	0.144	
		50	<0.0001	<0.0001	<0.0001	<0.001

Results are *P*-values from a Tukey HSD multiple comparison test based upon pooled data for all decades

the conceptual idea of different land use rings around a settlement as theorized by von Thünen (von Thünen 1826; Wartenberg 1966) and expanded upon by Burgess (1925). Thus, while our rings represent the same land use, expanding around a city over time, the concepts of transportation costs and proximity to the city center remain the same as considered by von Thünen. Such patterns are particularly evident over the six decades for the large absolute growth hotspots located around Minneapolis-St. Paul, Chicago, and Detroit, which show a gradual movement away from the core area (Fig. 3). Notably, however, the scale of our analyses was too coarse for the hotspots to be used to discern the difference between such spatiotemporal patterns of housing growth as ''leapfrogging'' (*sensu* Heim 2001; Gillham 2002) and rings.

Hotspots based on percent growth exhibited even stronger ring-like patterns around urban centers as well as many large patches that shifted location in the non-urban matrix. Thus, the percent growth measure captured not just areas of rapid growth in the suburbs, but the increasing growth of housing in rural areas rich in amenity value, such as the northern hardwood region of the Great Lake States (Fig. 4). In fact, the percent growth measure corroborates the findings of other analyses that illustrate the marked expansion of houses in the North Central U.S. (e.g., Radeloff et al. 2005b; Brown et al. 2005).

The difference in spatiotemporal patterns of absolute and percent growth hotspots highlights but one important aspect of the two growth measures. In fact the two measures also differed in many of their landscape statistics. For example, the percent growth measure always resulted in more hotspots and more of the landscape being comprised by hotspots than the absolute measure. One reason for this may be due to the situation where numerous locations have similarly high percentage growth, but quite different absolute growth. Take as an example the situation in which two locations (A and B) have identical growth (e.g., 200%) during a decade. This identical growth can occur even if there is more than an order of magnitude difference in actual housing unit change as evident by a change in housing numbers from 5 to 15 homes at A and from 100 to 300 homes at B. These differences in percent and absolute growth may also translate to differences in ecological impact, depending upon the location. Namely, a large number of additional homes may always have a greater ecological impact, due to the physical alteration and removal of part of the landscape than a large percent gain. But, a large percent gain in houses could indicate where the biggest changes in growth are occurring. Moreover, percent gain could be an early warning signal in locations that are ecologically sensitive, such as lakeshores, river corridors, wilderness areas, etc.

As in many landscape ecological studies that investigate changes or impacts at different scales (e.g., Turner et al. 1989), neighborhood size had a marked influence on the results. The greatest number of hotspots were found at the smallest neighborhood size (i.e. 5 km; Figs. 3, 4 and 5B). Moreover, as neighborhood size increased, small individual hotspots began to amalgamate into fewer and fewer large hotspots and tended to occupy only the largest metropolitan locations of the North Central U.S. (Fig. 5A–F). With this amalgamation a significantly larger portion of the landscape was represented by hotspots, as measured by absolute growth. Because hotspots decreased in number but increased in size as the neighborhood of consideration increased, there ultimately exists a trade-off for conservation and planning. Specifically, the smallest possible neighborhoods can identify numerous locations of importance, but they may be so distant from one another or so numerous that further analysis is needed to make decisions about conservation planning. On the other hand, large neighborhood sizes may miss many of the rural locations that are most important for conservation planning. Consequently, several neighborhood sizes should be used in any hotspot analysis in order to capture a representative view.

While the hotspots analysis presented here used the G* approach, it is important to note that all hotspots analyses have caveats. In the case of the G* statistic, one caveat is deciding the cut-off values used to determine if a given location is significantly different from the rest of the landscape. For our analysis this cut-off value was any z-score ≥ 2 standard deviations above the global mean. As a result, if the cut-off value in our analysis were increased (e.g., 2.5 standard deviations above the mean) we would have fewer hotspots on the landscape. Thus, it bears pointing out that our results would change if the cut-off value of the hotspots analysis were changed.

The patterns and relationships of housing growth illustrated by our research have a number of implications for conservation, management, planning, and policy initiatives. First, while housing growth is not an isolated event and does in fact occur throughout the region, it is exceptionally concentrated in and around city centers and in rural areas high in amenity value (Fig. 4). While such patterns have been revealed by other approaches (e.g., Radeloff et al. 2005b; Brown et al. 2005), the strength of our analyses is that it demonstrates the spatiotemporal nature of the relationships and demonstrates how a number of perspectives on growth can all emerge from one database. For example, using the two different measures of growth (absolute and percent) yields markedly different locations for the hotspots, particularly in how they highlight growth in rural areas (Fig. 4). Moreover, growth is not confined by any definitional tie to rural and urban locations. Second, our results demonstrate that housing growth has been a continuous process moving across the landscape and as such is likely to continue well into the future, which has implications for future conservation planning. While the areas identified here as hotspots in previous decades may be past the stage where careful growth planning could protect sensitive resources, the study illustrates the potential for new hotspots to arise in areas with or without a history of rapid housing growth. More importantly, the results suggest that conservation planners cannot rely on growth projections based only on past housing growth trends, but rather, should recognize the potential for amenity natural resources and rural landscapes to attract growth. Plans for rural, amenity rich locations should address the possibility of future development pressures in ecologically sensitive areas. Third, in the case of absolute housing growth, the process has been following a consistent pattern of expanding rings that has been fairly constant over time and is likely to continue. Fourth, by using a hotspots approach we have identified locations that have experienced the most intense housing growth, and hence landscape change, which can provide details regarding where to target conservation efforts. For instance, looking at locations that have never contained a hotspot (e.g., Fig. 5G) in conjunction with land use/land cover information could provide an initial set of criteria to select land for purchase, preservation, or management. Similarly, locations that consistently contained hotspots could be targeted for additional growth management efforts, open space planning, or restoration strategies, as the persistent nature of the hotspots may be a source of ecosystem stress (*sensu* Rapport et al. 1985). Fifth, although beyond the scope of the research presented here, the results of hotspot analysis could be combined with other data (e.g., ecological, sociological, economical) to investigate potential causes and consequences of housing growth. Finally, our results demonstrate the importance of taking a landscape perspective of housing growth that moves beyond case studies or urban centers to look across the time and space continuum.

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