Rural and Suburban Sprawl in the U.S. Midwest from 1940 to 2000 and Its Relation to Forest Fragmentation

VOLKER C. RADELOFF,* ROGER B. HAMMER,† AND SUSAN I. STEWART‡

*Department of Forest Ecology and Management, University of Wisconsin–Madison, 1630 Linden Drive, Madison, WI 53706, U.S.A., email radeloff@facstaff.wisc.edu
†Department of Rural Sociology, University of Wisconsin–Madison, 1450 Linden Drive, Madison, WI 53706, U.S.A.
‡U.S. Department of Agriculture Forest Service, North Central Research Station, 1033 University Place, Suite 360, Evanston, IL 60201, U.S.A.

Abstract: *Housing growth and its environmental effects pose major conservation challenges. We sought to (1) quantify spatial and temporal patterns of housing growth across the U.S. Midwest from 1940–2000, (2) identify ecoregions strongly affected by housing growth, (3) assess the extent to which forests occur near housing, and (4) relate housing to forest fragmentation. We used data from the 2000 U.S. Census to derive fine-scale backcasts of decadal housing density. Housing data were integrated with a 30-m resolution U.S. Geological Survey land cover classification. The number of housing units in the Midwest grew by 146% between 1940 and 2000. Spatially, housing growth was particularly strong at the fringe of metropolitan areas (suburban sprawl) and in nonmetropolitan areas (rural sprawl) that are rich in natural amenities such as lakes and forests. The medium-density housing (4–32 housing units/km^2) category increased most in area. Temporally, suburban housing growth was especially high in the post-World War II decades. Rural sprawl was highest in the 1970s and 1990s. The majority of midwestern forests either contained or were near housing. Only 14.8% of the region's forests were in partial block groups with no housing. Housing density was negatively correlated with the amount of interior forest. The widespread and pervasive nature of sprawl shown by our data is cause for conservation concern. Suburban sprawl has major environmental impacts on comparatively small areas because of the high number of housing units involved. In contrast, rural sprawl affects larger areas but with less intensity because associated housing densities are lower. The environmental effects per house, however, are likely higher in the case of rural sprawl because it occurs in less-altered areas. Conservation efforts will need to address both types of sprawl to be successful.*

Key Words: demography, development, forest fragmentation, housing growth, sprawl, U.S. census

Expansión Urbana y Suburbana en el Medio Oeste de E.U.A. de 1940 a 2000 y su Relación con la Fragmentación de Bosques

Resumen: *El crecimiento inmobiliario y sus efectos ambientales son retos mayores para la conservación. Tratamos de (1) cuantificar patrones espaciales y temporales del crecimiento inmobiliario en el medio oeste de E.U.A. de 1940–2000, (2) identificar ecoregiones fuertemente influenciadas por el crecimiento inmobiliario, (3) evaluar la extensión en que los bosques ocurren cerca de viviendas, y (4) relacionar el crecimiento inmobiliario con la fragmentación de bosques. Utilizamos datos de los Censos de E.U.A. de 2000 para derivar retrospectivas a escala fina de la densidad inmobiliaria por década. Los datos inmobiliarios fueron integrados en una clasificación de cobertura de suelos de la Prospección Geológica de E.U.A. con resolución de 30 m. El número de unidades de vivienda en el medio oeste creció 146% entre 1940 y 2000. Espacialmente, el crecimiento inmobiliario fue particularmente fuerte en el borde áreas metropolitanas (expansión suburbana) y en áreas*

Paper submitted September 2, 2003; revised manuscript accepted August 1, 2004.

no metropolitanas (expansión rural) ricas en amenidades naturales, como lagos y bosques. Las viviendas de la categoría de densidad media (4-32 unidades de vivienda/km^2) incrementaron en casi toda el área. Temporalmente, el crecimiento inmobiliario fue especialmente elevado en las décadas posteriores a la Segunda Guerra Mundial. La expansión rural fue mayor en los 1970s y 1990s. La mayoría de los bosques del medio oeste contenían o estaban cerca de viviendas. Solo 14.8% de los bosques de la región estaban en grupos de bloques sin viviendas. La densidad de viviendas estuvo negativamente correlacionada con la cantidad de bosque interior. La amplitud y la naturaleza penetrante de la expansión que muestran nuestros datos es motivo de preocupación para la conservación. La expansión suburbana tiene impactos ambientales mayores sobre áreas comparativamente pequeñas por el gran número de unidades de vivienda involucradas. En contraste, la expansión rural afecta a áreas más extensas con menor intensidad porque las densidades de viviendas son menores. Sin embargo, los efectos ambientales por vivienda probablemente son mayores en el caso de la expansión rural porque ocurre en áreas menos alteradas. Los esfuerzos de conservación deberán atender ambos tipos de expansión para ser exitosos.

Palabras Clave: censos E.U.A., crecimiento inmobiliario, demografía, desarrollo, expansión, fragmentación de bosques

Introduction

Human domination of ecosystems across the globe is rapidly increasing (Vitousek et al. 1997) and is the root cause of current threats to biodiversity and species extinctions. Housing development and urbanization are key factors in the increase of human domination and pose major threats to biodiversity (Hobbs & Mooney 1997; Liu et al. 2003). In the United States, urbanization is a primary cause of population declines in more than half of all federally listed threatened and endangered species (Czech et al. 2000), and housing development plays a central role in species endangerment.

Housing development removes habitat directly during construction and fragments the remaining habitat (Theobald et al. 1997; Swenson & Franklin 2000), which in turn negatively affects biodiversity (Rochelle et al. 1999). Housing development also fosters tertiary environmental problems (McKinney 2002) such as the introduction of exotic species (Suarez et al. 1998; McKinney 2001), including predatory domestic pets (Crooks & Soulé 1999; Maestas et al. 2003). Finally, housing development increases other aspects of the human domination of ecosystems, such as road density (Forman & Alexander 1998), land-use intensity (White et al. 1997), and recreation (Boyle & Samson 1985).

Empirical studies confirm that housing development limits habitat use, population size, and species diversity of Neotropical migrant birds (Friesen et al. 1995), other bird species (Marzluff et al. 2001), and mammals (Joly & Myers 2001). Results of most studies suggest that housing negatively affects both animal and plant populations (Soulé 1991; McKinney 2002; Liu et al. 2003). However, housing growth (especially at lower densities) may benefit some species such as human commensals and exotic invasives (Johnston 2001; Odell & Knight 2001; Maestas et al. 2003).

Hence, understanding housing growth patterns is essential for successful conservation efforts (Marzluff 2002; Miller & Hobbs 2002). During the 1990s, 13.6 million net new housing units were built in the United States (13% growth). Housing growth has been pronounced both at the fringe of urban areas (suburban sprawl) and in rural areas with attractive natural amenities (rural sprawl; Knight et al. 1995; Theobald 2001). Although both types of sprawl raise concerns about environmental impacts (Sierra Club 1998; Hansen et al. 2002), there are important differences between suburban and rural sprawl. Suburban sprawl tends to be denser, affecting a smaller area per housing unit, but the number of housing units also tends to be greater, thus causing more severe environmental impact. Rural sprawl, also referred to as exurban development (Daniels 1999; Theobald 2001) or rural residential development (Hansen et al. 2002), often occurs at lower densities. The problem with rural sprawl is that it affects much larger areas than suburban sprawl (Theobald 2001), amplifying its environmental impacts. Furthermore, rural sprawl typically occurs in areas with attractive recreational and aesthetic amenities (Johnson & Beale 2002) that are less human dominated, such as lakeshores (Schnaiberg et al. 2002), coasts (Bartlett et al. 2000), and forests (Radeloff et al. 2001). Housing growth is thus more pronounced in habitats particularly valuable for conservation (Hansen et al. 2002). This makes a better understanding of the patterns of rural sprawl and its drivers important for conservation biology.

Nonmetropolitan areas throughout the United States experienced particularly rapid growth in the 1970s, with population growth rates that exceeded those of metropolitan areas for the first time in U.S. history (Fuguitt 1985). Growth trends reverted to their historical patterns during the 1980s (Beale & Fuguitt 1990), but in the 1990s, nonmetropolitan housing growth was again strong (Long & Nucci 1998; Johnson & Fuguitt 2000).

Rural sprawl is driven by Americans' long-held preferences for living in more rural settings (Fuguitt & Brown 1990; Brown et al. 1997), which itself is rooted in the rural/agrarian Jeffersonian ideal (Nelson & Dueker 1990). Changes in the economy, technology, and transportation have made the realization of these preferences more widely achievable in recent decades. The cost of living in rural areas tends to be lower, partially because of lower land prices and property taxes relative to urban areas (Daniels 1999).

Amenity migration is a primary driver of growth in nonmetropolitan counties (Johnson & Beale 2002). During the past several decades, mild climate, varied topography, and abundant water—all amenity resources—have substantially influenced population growth in the nonmetropolitan United States (McGranahan 1999; Bartlett et al. 2000). Seasonal and retirement homes account for a significant portion of the growth in some rural areas (Stewart & Stynes 1994; Beale & Johnson 1998; Radeloff et al. 2001). In the future, amenity migration is likely to increase as the baby-boomer generation approaches retirement age, a trend expected to accelerate rural sprawl (Stewart 2002).

In summary, recent human demographic trends and the well-documented environmental effects of housing development suggest that both suburban and rural sprawl pose major conservation challenges. Spatially detailed, long-term information on housing growth patterns is needed to assist scientists in understanding observed patterns of biodiversity declines and managers in mitigating threats and planning future development. Our objectives were to (1) quantify spatial and temporal patterns of both rural and suburban sprawl across the U.S. Midwest from 1940–2000, (2) identify ecoregions that have been particularly affected by housing growth, (3) assess the extent to which forests occur near housing, and (4) relate housing density to forest fragmentation.

Methods

Study Area

Our study region encompassed the seven states of the U.S. Midwest (Fig. 1). Northern hardwood forests, dominated by sugar maple (*Acer saccharum* Marsh.), yellow birch (*Betula alleghaniensis* Britton), hemlock (*Tsuga canadensis* [L.] Carrière), and early successional aspen (*Populus tremuloides* Michx.) and pine (*Pinus* spp.) forests are widespread in northern Minnesota, Wisconsin, and Michigan. Most of these forests were established after logging occurred, either the initial harvest (1850–1910) or subsequent harvests. Forest cover is also extensive in southern Missouri, Illinois, and Indiana, where oak (*Quercus* spp.) forests are more common and the conifer component is lower. Agricultural land dominates much of Iowa, southern Minnesota, Illinois, and northern Indiana.

The region also encompasses a number of major metropolitan areas (2000 population; national rank): Chicago-Gary-Kenosha (9,157,540; third); Detroit-Ann Arbor-Flint (5,456,428; eighth); Minneapolis/St. Paul (2,968,806; fifteenth), St. Louis (2,603,607; eighteenth), Kansas City (1,776,062; twenty-sixth); Milwaukee-Racine (1,689,572; twenty-seventh); and Indianapolis (1,607,486; twenty-ninth) (U.S. Census Bureau 2001). The classification of counties as metropolitan or nonmetropolitan follows the 2000 designation of the federal Office of Management and Budget. A metropolitan area consists of one or more counties that contain one or more cities with at least 50,000 inhabitants and at least 100,000 inhabitants in each county, as well as adjacent counties that exhibit a high degree of economic and social integration with that nucleus. A metropolitan county can contain rural areas with low housing density and nonmetropolitan counties can contain high-density urban areas (Fig. 2a). Traditionally reliant on manufacturing, most of the metropolitan areas in the Midwest have become more diversified, service-oriented economies. In contrast, many nonmetropolitan areas in the region are popular tourism and seasonal home destinations and are classified as recreation counties, retirement counties, or both (Beale & Johnson 1998). These counties, which are concentrated in the northern Great Lakes, the Ozarks, and smaller water- and forest-rich pockets throughout the region, provide lower-density residential settings.

Estimating Past Housing Growth with High Spatial Resolution

We used housing density instead of population as our measure of human presence and disturbance. Housing density and housing growth (percent increase in housing density) are better indicators of environmental impacts because they account for declining household size (Liu et al. 2003) and second-home ownership (Radeloff et al. 2001). We analyzed housing density as a continuous variable rather than classifying it into, for example, urban, suburban, and exurban density classes. We decided against housing-density classes because there are no generally accepted housing-density thresholds for these classes (Theobald 2004). Our analysis of past rural housing growth was based on 2000 U.S. Census data (Summary File 3A) and the associated data from geographic information systems (GIS; TIGER/Line files).

Measurement of housing growth necessitated estimation of pre-2000 housing density. Changes in census block and block group boundaries greatly complicate historical analysis of housing growth (Hammer et al. 2004). We addressed this boundary-change problem by using information from the "year housing unit built" question in the 2000 census to backcast historic housing densities by decade from 1990 to 1940 and historic county-level

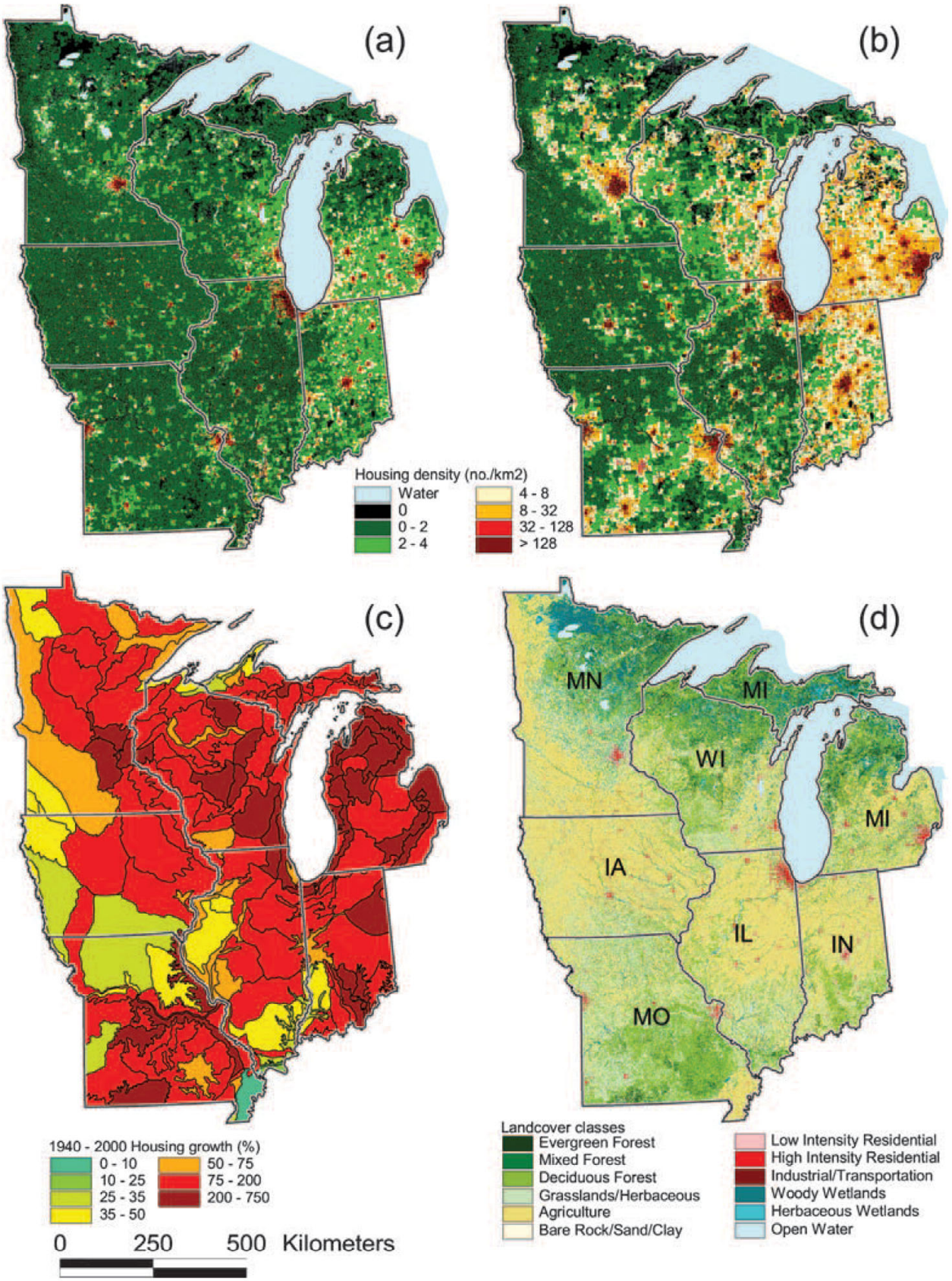

Figure 1. Housing density (a) in 1940 and (b) 2000, (c) housing growth 1940–2000 summarized for ecological subsections, (d) 1992/1993 National Land Cover Data for the U.S. Midwest study area (Illinois, IL; Indiana, IN; Iowa, IA; Michigan, MI; Minnesota, MN; Missouri, MO; and Wisconsin, WI).

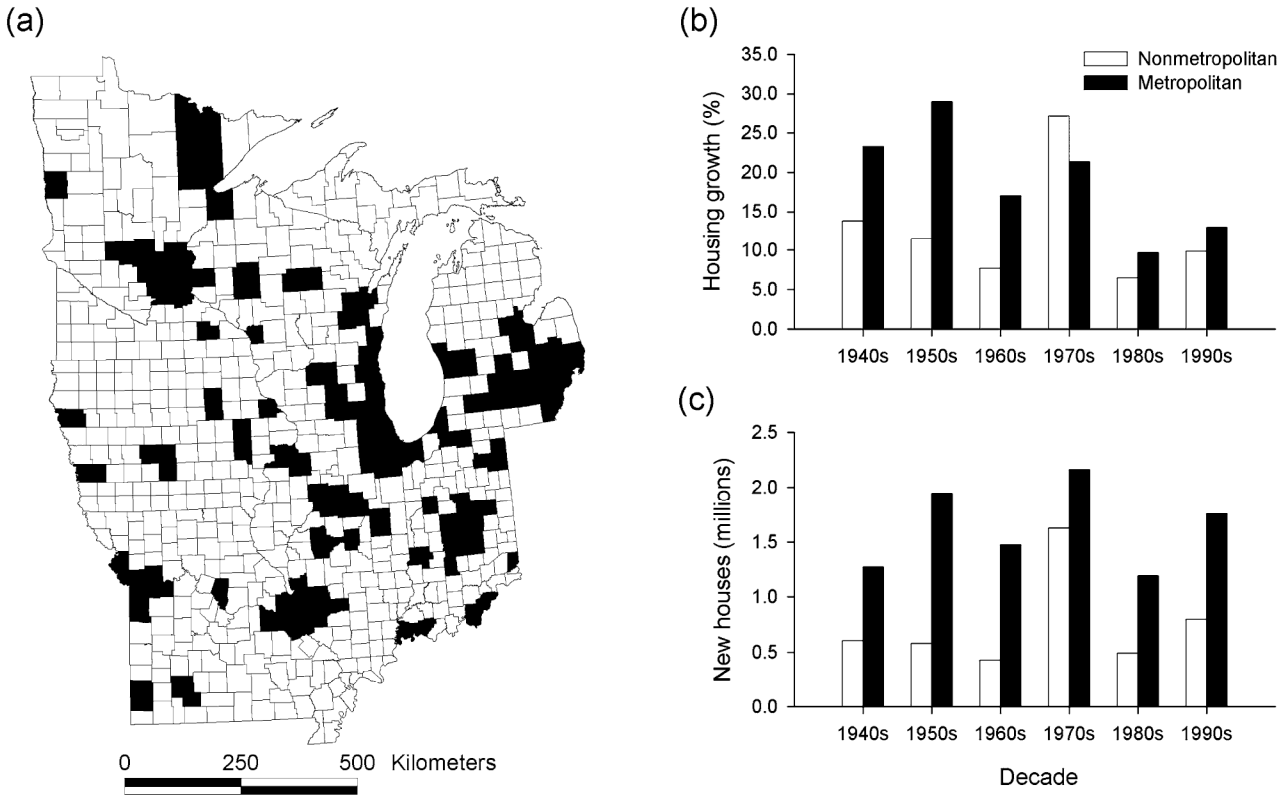

Figure 2. (a) Metropolitan and nonmetropolitan counties in the U.S. Midwest, (b) percent decadal housing growth, and (c) absolute decadal housing growth.

housing counts to adjust housing counts for historic units that are missing in the 2000 Census (Radeloff et al. 2001; Theobald 2001; Hammer et al. 2004).

Mapping units were partial block groups (PBGs; Hammer et al. 2004), which have a finer spatial resolution than the more commonly used block groups but coarser resolution than census blocks. We have demonstrated that PBGs improve the spatial precision of housing-unit estimates considerably (Hammer et al. 2004). Census blocks could not be used because the age of housing units is not reported at this level. The PBG boundaries are based on block-group boundaries, congressional district, place, minor civil division (township), and urban/rural boundaries. Census blocks with zero housing units and lakes were retained in the PBG boundaries, further refining spatial precision. In our study area, the mean PBG size was 3.4 km^2 (SD = 38.8 km^2). Our unit of measure was housing density, the number of housing units per square kilometer. According to the U.S. Census, a housing unit may be a house, an apartment, a mobile home, a room, or group of rooms, including those intended for seasonal, recreational, or occasional use, and units can be occupied or vacant (U.S. Census Bureau 2002). We mapped housing density at the PBG level and summarized it both as the absolute number of homes added each decade and as the percent growth for the decade. Summaries were calculated for both metropolitan and nonmetropolitan counties. We defined rural sprawl as housing growth occurring in nonmetropolitan counties.

Housing by Ecoregion

Housing density and housing growth are not spatially homogeneous across the Midwest. We used subsections of the ecological units delineation for the eastern United States, as defined by the U.S. Department of Agriculture Forest Service (Fig. 1c; Keys et al. 1995), to identify ecoregions that have been particularly affected by housing growth. Subsection boundaries are based on Bailey's ecoregions (Bailey et al. 1994) but represent a lower hierarchical level in the ecoregion classification system at a finer spatial resolution (average size 3600 km^2). Summary variables were decadal housing growth; total housing growth (1940–2000), percent area with low ($\leq$4 housing units/km^2), medium (4–32), and high (>32) housing density; and 1940–2000 areal growth (percentage) of these three density classes. These thresholds were chosen so that low-density housing represents a distance between housing units of 500 m, assuming a regular spatial pattern. At this density landscape patterns are connected as long as the disturbance zone has a radius of <250 m (Theobald et al. 1997). High-density housing represents a distance between regularly spaced housing units of 175 m, which

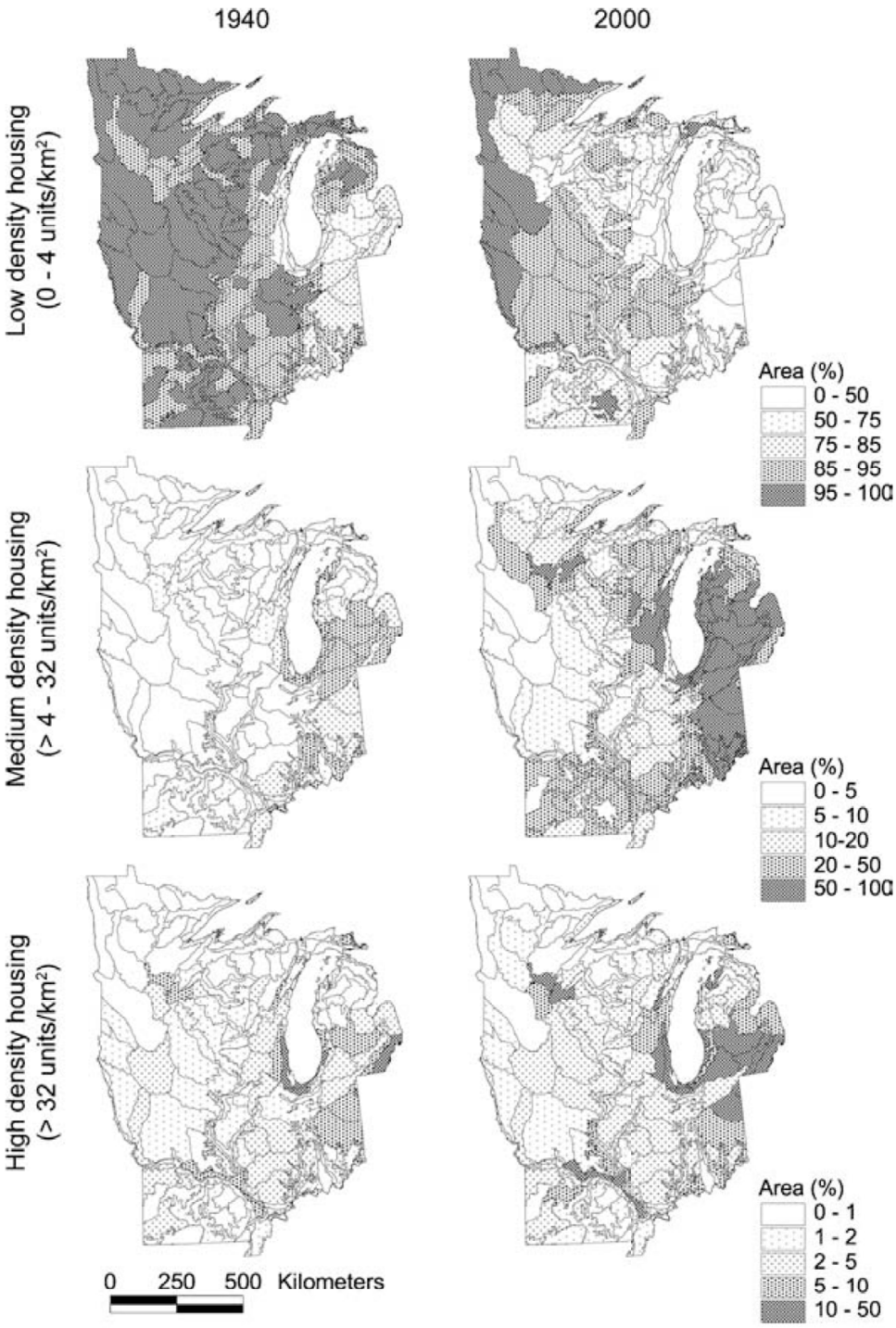

Figure 3. The relative area of low, medium, and high housing density in each ecological subsection of the U.S. Midwest in 1940 and 2000.

eliminates landscape connectivity at a disturbance-zone radius of only 90 m.

Housing Growth and Forests

Sprawl in forested areas is of particular concern in our study area because these areas often constitute important habitat. Among the major midwestern habitat types, forested areas resemble presettlement landscape conditions most closely, despite substantial changes in tree species composition and forest structure. Prairies and savannas, the other major natural habitat types present in the presettlement landscape, exist today only as small remnants, with most having been replaced by agriculture and urban areas. Forest-cover data was provided by the National Land Cover Data (NLCD) land cover classification scheme of the U.S. Geological Survey (Vogelmann et al. 2001, Fig. 1d). The NLCD is based on 1992/1993 Landsat Thematic Mapper imagery with 30-m pixel resolution. For our analysis, we defined forests as all areas classified in

the NLCD as deciduous, coniferous, or mixed forest. No comparable forest cover data exists for previous decades, precluding an analysis of forest cover change and housing growth.

We used the forest data to address two issues: the proportion of the forest that contains housing and the proportion of the forest that is remote (i.e., distant from settlements). We summarized the proportion of Midwest forest in areas with housing by calculating the number of forested pixels across seven housing-density classes (0, 0–2, 2–4, 4–8, 8–16, 16–32, >32 housing units/km^2) and comparing these with the total number of forested pixels for the study area and for each state.

Forests that do not contain houses may, nevertheless, be affected by proximate settlements. We quantified the proportion of forests that are remote with a buffer analysis to assess the proportion of all forests located =1, 2, 5, 25, or 100 km from PBGs with high (>128) or medium-low (>8) housing density in 2000. We did not use smaller buffer sizes, although edge effects may be strongest within a few hundred meters of a house (Rochelle et al. 1999) because the census data are not sufficiently spatially detailed. It is not possible to determine the particular location of housing units within a given PBG.

Finally, we examined the relationship between housing density and forest fragmentation. Riitters and his colleagues (2002) conducted a detailed analysis of forest fragmentation across the United States based on the NLCD. We related their forest fragmentation indices to housing density. This raised the problem of differences in spatial scale and the disparate types of information contained in census and fragmentation data. Although PBGs represent census data with relatively high spatial resolution, their grain is still about three orders of magnitude coarser than the 30-m resolution fragmentation data. Furthermore, census data present aggregate housing count information for an entire PBG, making disaggregation of PBGs unworkable. We thus aggregated forest and fragmentation information at the PBG level and computed the percent area in each PBG composed of forest cover and of interior forest (defined as a pixel that is entirely surrounded by forested pixels based on an eight-neighbor rule), with four different sizes of analysis windows (5 × 5, 9 × 9, 27 × 27, and 81 × 81 pixels). Larger window sizes identify interior forests that are farther away from forest edges. We excluded PBGs <1 ha from this analysis to ensure that percentage calculations were based on at least 10 pixels of the land cover data.

Results

Housing Density Change

Housing in the U.S. Midwest grew by 14,314,969 units (146%) from 9,831,111 units in 1940 to 24,146,080 units in 2000 (Figs. 1a & 1b). About one-third of this growth (31.6%, equivalent to 4,521,812 housing units) occurred in nonmetropolitan counties (Fig. 2a), contributing to rural sprawl. Among states in the region, Michigan and Indiana experienced the highest overall growth, whereas Iowa grew the least. Growth occurred both at the fringe of urban areas (Fig. 1b) and in forested rural amenity areas including southern Missouri, the northern lower peninsula of Michigan, northern Wisconsin, and parts of northern Minnesota. Growth in predominantly agricultural areas was strong in the southern lower peninsula of Michigan and in central and northern Indiana.

Across the six decades, rural sprawl (i.e., housing growth in nonmetropolitan counties) in the U.S. Midwest was particularly strong in the 1970s (Figs. 2b & 2c). In absolute terms rural housing growth was also strong in the 1990s, but proportionally was less pronounced because many areas had already reached substantial housing densities. Metropolitan counties exhibited their highest growth—suburban sprawl—before 1970 (Figs. 2b & 2c).

Housing growth varied markedly by ecoregion (Fig. 1c). The highest absolute growth between 1940 and 2000 occurred in subsection 222Kg (1,124,981 housing units), which, before European settlement, was dominated by prairie of big bluestem Indian grass. This subsection is now encompassed by the Chicago-Gary-Kenosha and the Milwaukee-Racine metropolitan areas. Other ecoregions with more than 500,000 new housing units since 1940 include 222If (originally swamp forests, now Detroit), 222Hb and 222Ha (pine-oak flatwoods, Indianapolis and Detroit), and 222Ki (cordgrass wet prairie, Chicago). Suburban sprawl has substantially altered these subsections.

Rural sprawl also altered ecoregions in the Midwest. Relative growth from 1940 to 2000 showed different high-growth areas than absolute growth areas. The highest growth rate occurred in subsections 212Hq (673%, originally jack pine barrens in Michigan) and 222Jj (596%, hemlock-sugar maple forests in Wisconsin). During the 1990s, growth rates were also highest in the lower peninsula of Michigan (subsection 212Hn, 36.4% growth, hemlock-sugar maple forest). The subsections ranked second to fourth in relative growth, however, were all located in southern Missouri (222Ag, 222Ah, 222Ac, little bluestem glades and oak woodlands). Rural sprawl shifted to southern Missouri in the most recent decade, and housing growth can be expected to continue there.

The spatial distribution of housing changed dramatically over the six decades of this study. In 1940, housing was clustered; areas typically exhibited either low or high housing density. Medium-density housing (4–32 housing units/km^2) was much less common in 1940 (Fig. 1a) than in 2000 (Fig. 1b, Fig. 3). The area of medium-density housing grew by >250% between 1940 and 2000 (Fig. 3). In comparison, the area of high-density housing grew considerably less and the area of low-density housing declined in many areas by more than 50%.

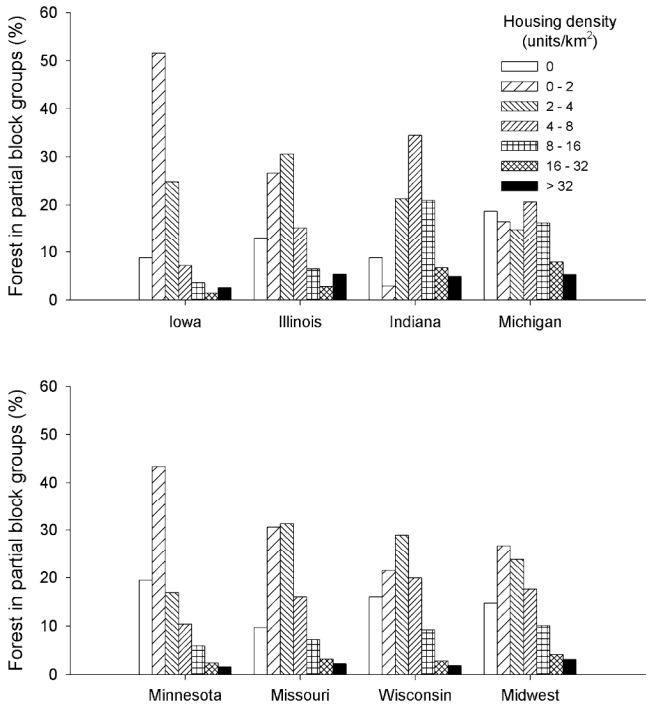

Figure 4. The percentage of forest that occurs in partial block groups (PBGs) in each state and across the U.S. Midwest.

Housing and Forests

The majority of the forests in the U.S. Midwest were located in areas with at least some housing (Fig. 4). Only 14.8% of forests were in PBGs with no housing, and just over one-third (34.9%) were in PBGs with fewer than 4 housing units/km^2 (Fig. 4). Indiana forests contained the highest housing density (67.1% of forests with >4 housing units/km^2) compared with other states in the region. Minnesota had the largest proportion of forests in low- or no-housing density areas (79.7% with <4 housing units/km^2, 19.4% with 0 housing units/km^2). Paradoxically, Michigan had both the second highest percentage of forests in areas with no housing (18.7% with 0 housing units/km^2) and the second highest percentage of forests with >8 housing units/km^2 (16.3%), a pattern attributable to the differences between the sparsely populated Upper Peninsula and the more developed Lower Peninsula. In general, the proportion of forests in low-density or no-housing areas was affected by both the abundance of forest cover (states with low forest cover, such as Iowa, tended to exhibit higher housing density in the forests) and the proximity of forests to metropolitan areas (forests in Michigan's Upper Peninsula contain fewer houses than those in the Lower Peninsula).

Forest cover was abundant in the U.S. Midwest, but almost all forests were within close vicinity of settlements (Fig. 5). Only 13.4% of the forests were >25 km from a PBG with >128 housing units/km^2. No forests were >100 km from areas with >128 housing units/km^2. When settlements of >8 housing units/km^2 were considered, only 3.5% of all forests were >25 km from housing, and 54.2% were within 5 km of settlements. Only the northernmost forests in Minnesota and Wisconsin, the Upper Peninsula of Michigan, and the central Ozarks of Missouri were >25 km from settlements with >8 housing units/km^2 (Fig. 5). There is substantial forest cover in the Lower Peninsula of Michigan, southern Indiana, southern Wisconsin, and throughout Missouri, but it is all within close vicinity of housing.

Among states with abundant forests, Minnesota contained the largest proportion of forests located >25 km from settlements with >128 housing units/km^2 (29.6%). In Michigan and Wisconsin, 17.6% of the forests were located >25 km from settlements with >128 housing units/km^2. Only 6.4% and 0.2% of forests in Michigan and Wisconsin, respectively, were more than 25 km from PBGs with >8 housing units/km^2.

Scatterplots of housing density versus percent forest at the PBG level indicated a negative relationship, but one with high dispersion (Fig. 6). Some PBGs with housing density up to 215 units/km^2 still exhibited 100% forest cover, and one PGB with housing density of 2384 units/km^2 exhibited 30% forest cover.

The relationship between housing density and forest fragmentation was more pronounced. Scatterplots of housing density versus interior forest demonstrated that although forests can be present even at high housing densities, interior forests are lost at much lower housing density thresholds. Based on the least rigorous 5 × 5 pixel analysis window to identify interior forest, no PBG with 193 housing units/km^2 or more contained even 10% interior forest. As the window size increased, the housing density at which interior forests were observed decreased. With a 9 × 9 pixel window, interior forest was always below 10% at 117 housing units/km^2. With a 27 × 27 pixel window, this threshold decreased to 46 housing units/km^2, and an 81 × 81 pixel window did not find 10% interior forest at housing density above zero.

Discussion

Our results highlight the magnitude and pervasiveness of sprawl in the U.S. Midwest and its relation to forest resources. The region experienced strong housing growth between 1940 and 2000, both at the fringe of metropolitan areas (suburban sprawl) and in nonmetropolitan counties that are often forested (rural sprawl). Suburban sprawl has greater impacts on smaller areas because of the higher number and density of housing units, whereas rural sprawl affects larger areas with less intensity because associated housing densities are usually lower. From a conservation perspective, however, the effects of rural sprawl are arguably more significant because much larger

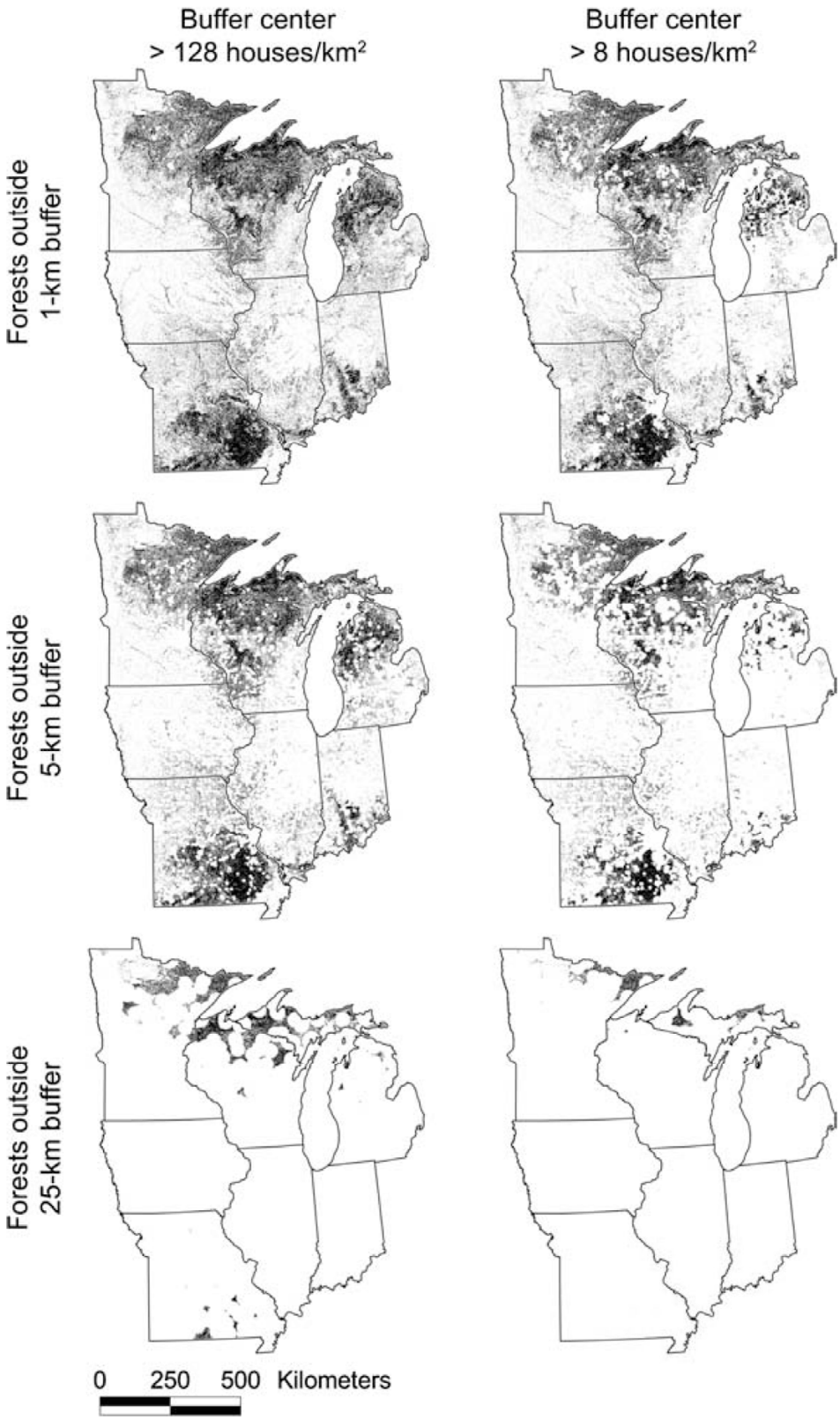

Figure 5. Remote forest areas in the U.S. Midwest (i.e., forested pixels outside a 1-, 5- or 25-km buffer surrounding partial block groups with a housing density of >128 or >8 housing units/km^2).

areas are affected and rural sprawl occurs in relatively less-altered landscapes. Even though the effect per unit area may be less in the case of rural sprawl compared with urban sprawl, the total effect across the entire Midwest is potentially greater because of the much higher total area affected by rural sprawl. Over the past six decades, the growth of medium-density housing areas greatly exceeded the growth of higher-density settlements in

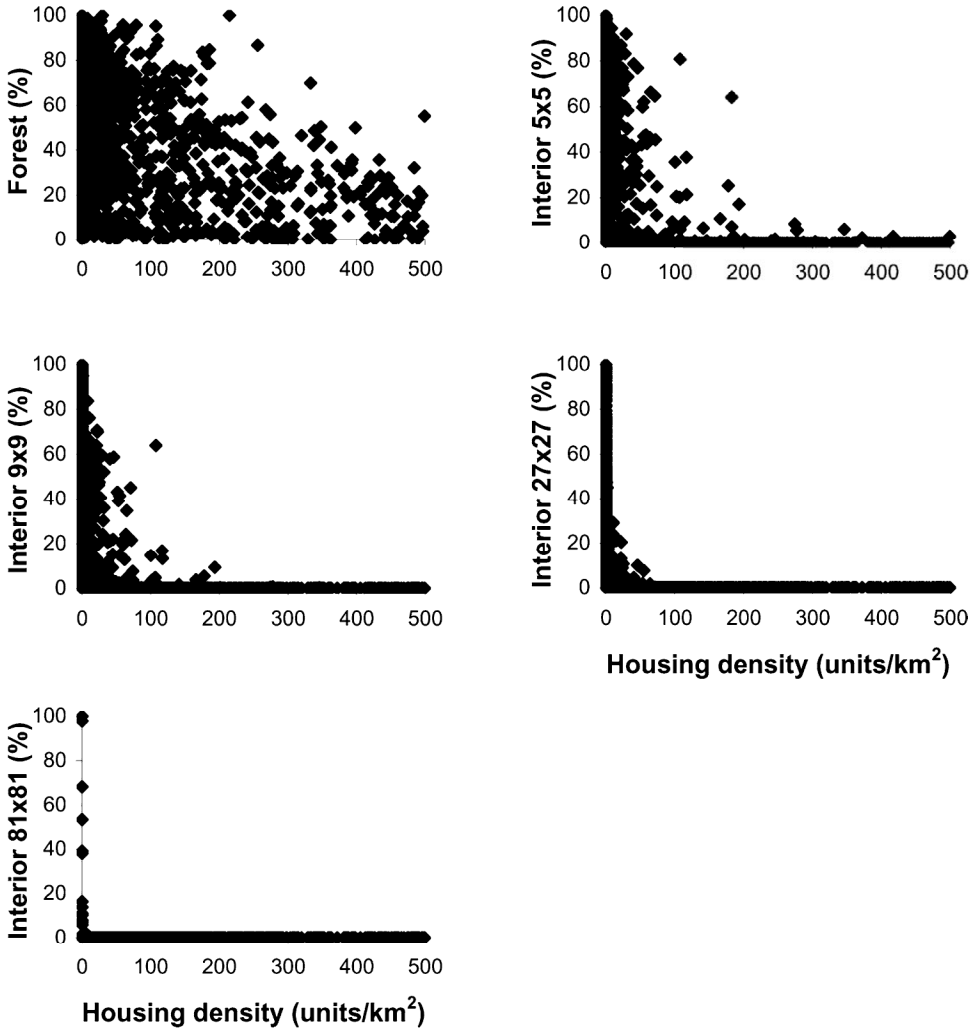

Figure 6. Housing density and the proportion of a partial block group (PBG) covered by forest or interior forests. Forest was defined as either coniferous, decidous, or mixed forest or forested wetlands in the U.S. Geological Society National Land Cover Data (Vogelmann et al. 2001). Interior forest was defined as a pixel that is entirely surrounded by forest pixels and was assessed in analysis windows of 5 × 5, 9 × 9, 27 × 27, or 81 × 81 pixel size. In the largest window size a forested pixel would have to be surrounded by at least 40 pixels of forest in every direction to qualify as interior forest.

the Midwest. Furthermore, areas currently in the low- to mid-density range will likely experience future housing growth. Rural sprawl may thus initiate future growth. As a result of housing growth and changing settlement patterns, the majority of all forests now contain housing or are in close proximity of housing.

Spatial Patterns of Sprawl

One reason to be concerned about rural sprawl is that houses in nonmetropolitan areas tend to be more dispersed, causing higher levels of habitat loss and fragmentation per housing unit (Theobald et al. 1997). The actual amount of habitat loss is difficult to quantify because the appropriate radius of the disturbance zone for different types of housing and for different species is unknown. But if each new housing unit adds a new disturbance zone, the cumulative effects of housing growth can be substantial, particularly in areas that were previously undisturbed.

The dispersed nature of rural sprawl results in disproportionate increases in road density on a per-housing-unit basis, which in turn contributes to greater habitat fragmentation (Forman & Alexander 1998). Housing growth occurring near or within forested areas also magnifies the potential for introduction of exotic species in landscaping and predation of native species by pets (Crooks & Soulé 1999; Maestas et al. 2003). Furthermore, rural sprawl often occurs in areas of high ecological value such as riparian zones (Schnaiberg et al. 2002), coastal zones (Bartlett et al. 2000), and near protected areas (Rasker & Hansen 2000).

Temporal Patterns of Sprawl

Although housing growth has occurred throughout the past 60 years in the Midwest, some decades witnessed particularly strong growth. Both metropolitan and nonmetropolitan counties grew at unprecedented rates during the 1970s. In metropolitan counties, the second-highest number of new housing units was added in the 1950s, whereas nonmetropolitan counties exhibited their second-highest absolute growth in the 1990s. Rural sprawl, then, is a more recent phenomenon than suburban sprawl.

The temporal patterns of growth raise the question of time lags such as extinction debt (i.e., a delayed decrease in species richness following habitat loss and fragmentation; Tilman et al. 1994). Semistochastic processes, such as local extinctions following habitat fragmentation, may occur over decades. For example, amphibian biodiversity loss resulting from road construction near wetlands exhibits a temporal lag of several decades (Findlay & Bourdages 2000). Exotic plant species introductions and spread show a delayed response to the time of settlement (McKinney 2001). This suggests that the full ecological impacts of recent sprawl have not yet materialized.

Conservation Implications

The U.S. Midwest is a region where housing development can proceed without the limitations imposed by extensive public landownership, topography, or water availability that constrain growth in other areas of the country. Road networks are dense and well established (Hawbaker & Radeloff 2004). In short, there is little to impede rural sprawl. But the two major contiguous forested regions of the Midwest, the first in the northern lake states (Minnesota, Wisconsin, and Michigan) and the second in the Ozarks, are of crucial importance for conservation.

Rural sprawl in these areas is potentially disastrous. For example, nest success of breeding birds in the fragmented forests of the central Midwest is too low to sustain viable populations (Robinson et al. 1995). The forests of the Northwoods and the Ozarks thus likely function as population sources that maintain sink populations elsewhere (Temple & Cary 1988), and declines in forest habitat quality resulting from rural sprawl could affect avian populations throughout the Midwest.

Similarly, the Northwoods of Wisconsin and Michigan have been crucial to the range expansion and population growth of wolves in the Midwest. Habitat-use models show, however, that wolves avoid areas with high road density (Mladenoff et al. 1995). Rural sprawl in northern Wisconsin, and the associated increase in road density and human disturbance, is potentially detrimental to large carnivore habitat availability and the dispersal of wolves from Minnesota to Wisconsin and the Upper Peninsula of Michigan.

Suburban sprawl was given much-deserved attention in the 1990s as an emerging threat to conservation. Rural sprawl is another manifestation of the same forces, but it has a different set of environmental consequences that have not been fully explored. The environmental effects per house are likely higher in the case of rural sprawl when compared with suburban sprawl, because rural sprawl occurs in more remote areas that have been altered less. When comparing rural and suburban sprawl on a per-unit area basis, environmental effects are most likely higher in the case of suburban sprawl because of the higher number of homes involved. Rural sprawl, however, occurs over much larger areas. We speculate that the total impact of rural sprawl is higher when taking the extent of the area over which it occurs into account. Relatively low land prices and weak land-use regulations in nonmetropolitan counties (Nelson & Dueker 1990) can result in disproportionate environmental impacts. This combination leads to the "commodification of nature" in which developers and landowners use natural rural landscapes as a marketable product in response to consumers' preferences for rural living (Esparza & Carruthers 2000). It is growth in rural, amenity-rich regions of the United States that most imperils forests—especially intact interior forests—and the unique habitat they provide.

The trends in housing growth we report highlight the need for ecological principles in land-use planning and growth management policies (Marzluff 2002; Broberg 2003). Under the "smart-growth" rubric many states are standardizing the comprehensive planning process across jurisdictions and requiring the coordination of plans among adjacent municipalities and even counties (Burby & May 1997). These efforts ensure regulatory consistency, avoid conflict among municipalities, and discourage spillover growth (Gale 1992). Rural areas are adopting policies that directly affect the processes governing the supply and demand for land, including property taxation, development fees, conservation areas, community land trusts, and the transfer of development rights (Esparza & Carruthers 2000). Agricultural communities have achieved some success in preserving farmland by developing methods for identifying the most valuable lands, such as the U.S. Department of Agriculture land evaluation and site assessment system (Lapping et al. 1989). Similar methods are needed for the identification of ecologically important lands. But rural forested communities are newer than farm communities and individual households are more isolated, which may make community collaboration more difficult.

Ecoregions are increasingly used to set conservation priorities (Myers et al. 2000), and demographic analysis has identified elevated population and household growth in ecoregions that are global biodiversity hotspots (Liu et al. 2003). Our results reveal marked differences in housing growth and housing density among Midwest ecoregions at the subsection level (Fig. 1c). The data show that the highest relative housing growth from 1940 to 2000 occurred predominantly in areas affected by rural sprawl, such as the forests of the lower peninsula of Michigan and northern Wisconsin. During the 1990s, the Missouri Ozarks emerged as a rural sprawl hotspot, and high housing growth is likely to continue. Such information can potentially assist in setting conservation priorities within a region and at the local scale.

Effective wildlife management polices may be able to mitigate some of the negative effects associated with housing growth (Linnell et al. 2001). Another suggestion emerging from studies in the western United States is to

cluster future development, affecting a smaller total area compared with dispersed development (Theobald et al. 1997; Odell et al. 2003). Clustered development, however, affects smaller areas with greater intensity and could result in abrupt ecosystem change in an area, especially if housing growth and environmental response have a nonlinear relationship. The prevalence of dispersed housing development in the Midwest suggests that ownership of large blocks without housing is crucial in areas where landscape-level management or restoration of presettlement landscape patterns and disturbance processes is desired (Radeloff et al. 2001). Large public land holdings and large-block ownership by timber companies are particularly valuable for conservation efforts, raising concerns about the current trend of ownership fragmentation and the sale of timber industry land for development purposes.

Conclusions

The net migration of people from metropolitan to nonmetropolitan counties is the primary driver behind the widespread rural sprawl that has taken place in the past 60 years. The situation in many midwestern counties is ironic in that the forests attract the migration, which drives home building, which degrades the forest resources. Today's rural sprawl may be tomorrow's high-density housing areas. Ecological research has traditionally focused on "natural" areas and more recently on urban ecosystems (Miller & Hobbs 2002). But large portions of the Midwest fall in neither category; instead, they exhibit low-density dispersed housing. Long-term ecological implications of such patterns are not well understood, but previous studies suggest that they may be substantial. Interdisciplinary research is needed to understand the effects of past and future housing growth on the environment across the full range of housing densities. The analytical flexibility provided by GIS and spatially referenced data facilitates changing the units of analysis to offer new insights into linked processes, such as human demographic change and ecological change. Ultimately, a larger debate on population and housing growth will be essential for conservation efforts to succeed (Meffe et al. 1993).

Acknowledgments

We gratefully acknowledge financial support for this study by the U.S. Department of Agriculture Forest Service North Central Research Station in Evanston, Illinois. Discussions with J. Dwyer, D. Field, P. Gobster, P. Jakes, and P. Voss were valuable in designing this study. J. Dwyer, R. Haight, R. Knight, C. Lepczyk, J. Marzluff, D. Mladenoff, R. Stedman, and three anonymous reviewers provided very helpful comments on the manuscript, improving it greatly.

Literature Cited

Bailey, R. G., P. E. Avers, T. King, and W. H. McNab, editors. 1994. Ecoregions and subregions of the United States (map 1:7,500,000). U.S. Department of Agriculture Forest Service, Washington, D.C.

Bartlett, J. G., D. M. Mageean, and R. J. O'Connor. 2000. Residential expansion as a continental threat to U.S. coastal ecosystems. Population and Environment **21:**429–468.

Beale, C. L., and G. V. Fuguitt. 1990. Decade of pessimistic nonmetro population trends ends on optimistic note. Rural Development Perspective **6:**14–18.

Beale, C. L., and K. M. Johnson. 1998. The identification of recreational counties in nonmetropolitan areas of the USA. Population Research and Policy Review **17:**37–53.

Boyle, S. A., and F. B. Samson. 1985. Effects of nonconsumptive recreation on wildlife: a review. Wildlife Society Bulletin **13:**110–116.

Broberg, L. 2003. Conserving ecosystems locally: a role for ecologists in land-use planning. Bioscience **53:**670–673.

Brown, D. L., G. V. Fuguitt, T. B. Heaton, and S. Waseem. 1997. Continuities in size of place preferences in the United States, 1972–1992. Rural Sociology **62:**408–428.

Burby, R., and P. May. 1997. Making government plan. The Johns Hopkins University Press, Baltimore, Maryland.

Crooks, K. R. and M. E. Soulé. 1999. Mesopredator release and avifaunal extinctions in a fragmented system. Nature **40:**563–566.

Czech, B., P. R. Krausman, and P. K. Devers. 2000. Economic associations among causes of species endangerment in the United States. BioScience **50:**593–601.

Daniels, T. 1999. When city and country collide: managing growth in the metropolitan fringe. Island Press, Washington, D.C.

Esparza, A. X., and J. I. Carruthers. 2000. Land use planning and exurbanization in the rural mountain west: evidence from Arizona. Journal of Planning Education and Research **20:**23–36.

Findlay, C. S., and J. Bourdages. 2000. Response time of wetland biodiversity to road construction on adjacent lands. Conservation Biology **14:**86–94.

Forman, R. T. T., and L. E. Alexander. 1998. Roads and their major ecological effects. Annual Review of Ecology and Systematics **29:** 207–231.

Friesen, L. E., P. F. J. Eagles, and R. J. MacKay. 1995. Effects of residential development on forest dwelling Neotropical migrant songbirds. Conservation Biology **9:**1408–1414.

Fuguitt, G. V. 1985. The nonmetropolitan turnaround. Annual Review of Sociology **11:**259–180.

Fuguitt, G. V., and D. L. Brown. 1990. Residential preferences and population redistribution: 1972–1988. Demography **27:**589–600.

Gale, D. 1992. Eight state-sponsored growth management programs: a comparative analysis. Journal of the American Planning Association **58:**425–439.

Hammer, R. B., S. I. Stewart, R. Winkler, V. C. Radeloff, and P. R. Voss. 2004. Characterizing spatial and temporal residential density patterns across the U.S. Midwest, 1940–1990. Landscape and Urban Planning **69:**183–199.

Hansen, A. J., et al. 2002. Ecological cause and consequence of demographic change in the New West. BioScience **52:**151–162.

Hawbaker, T. J., and V. C. Radeloff. 2004. Roads and landscape pattern in northern Wisconsin: a comparison of four different road data sources. Conservation Biology **18:**1233–1244.

Hobbs, R. J., and H. A. Mooney. 1997. Broadening the extinction debate: population deletions and additions in California and Western Australia. Conservation Biology **12:**271–283.

Johnson, K. M., and C. L. Beale. 2002. Nonmetro recreation counties: their identification and rapid growth. Rural America **17:**12–19.

Johnson, K. M., and G. V. Fuguitt. 2000. Continuity and change in rural migration patterns, 1950–1995. Rural Sociology **65:**27–49.

Johnston, R. F. 2001. Synanthropic birds of North America. Pages 569–578 inJ. M. Marzluff, R. Bowman, and R. Donnelly, editors. Avian

ecology and conservation in an urbanizing world. Kluwer Academic Publishers, Norwell, Massachusetts.

Joly, K., and W. L. Myers. 2001. Patterns of mammalian species richness and habitat associations in Pennsylvania. Biological Conservation **99:**253–260.

Keys, J. E., Jr., C. A. Carpenter, S. L. Hooks, F. G. Koeneg, W. H. McNab, W. E. Russell, and M. L. Smith. 1995. Ecological units of the eastern United States—first approximation. Technical publication R8-TP 21. U.S. Department of Agriculture Forest Service, Atlanta, Georgia.

Knight, R. L., G. N. Wallace, and W. E. Riebsame. 1995. Ranching the view: subdivisions versus agriculture. Conservation Biology **9:**459–461.

Lapping, M., T. Daniels, and J. Keller. 1989. Rural planning and development in the United States. Guilford Press, New York.

Linnell, J. D. C., J. E. Swenson, and R. Andersen. 2001. Predators and people: conservation of large carnivores is possible at high human densities if management policy is favourable. Animal Conservation **4:**345–349.

Liu, J., G. C. Daily, P. R. Ehrlich, and G. W. Luck. 2003. Effects of household dynamics on resource consumption and biodiversity. Nature **421:**530–533.

Long, L., and A. Nucci. 1998. Accounting for two population turnarounds in nonmetropolitan America. Research in Rural Sociology and Development **7:**47–70.

Maestas, J. D., R. L. Knight, and W. C. Gilgert. 2003. Biodiversity across a rural land-use gradient. Conservation Biology **17:**1425–1434.

Marzluff, J. M. 2002. Fringe conservation: a call to action. Conservation Biology **16:**1175.

Marzluff, J. M, R. Bowman, and R. Donnelly, editors. 2001. Avian ecology and conservation in an urbanizing world. Kluwer Academic Publishers, Norwell, Massachusetts.

McGranahan, D. A. 1999. Natural amenities drive population change. Agricultural economics report 781. U.S. Department of Agriculture Economic Research Service, Washington, D.C. Available from www.ers.usda.gov/Publications/AER781/(accessed August 2004).

McKinney, M. L. 2001. Effects of human population, area, and time on non-native plant and fish diversity in the United States. Biological Conservation **100:**243–252.

McKinney, M. L. 2002. Urbanization, biodiversity and conservation. BioScience **52:**883–890.

Meffe, G. K., A. H. Ehrlich, and D. Ehrenfeld. 1993. Human population control: the missing agenda. Conservation Biology **7:**1–3.

Miller, J. R., and R. J. Hobbs. 2002. Conservation where people live and work. Conservation Biology **16:**330–337.

Mladenoff, D. J., T. A. Sickley, R. G. Haight, and A. P. Wydeven 1995. A regional landscape analysis and prediction of favorable gray wolf habitat in the northern great lakes region. Conservation Biology **9:**279–294.

Myers, N., R. A. Mittermeier, C. G. Mittermeier, G. A. B. da Fonseca, and J. Kent. 2000. Biodiversity hotspots for conservation planning. Nature **403:**853–858.

Nelson, A., and K. Dueker. 1990. The exurbanization of America and its planning policy implications. Journal of Planning Education and Research **9:**91–100.

Odell, E. A., and R. L. Knight. 2001. Songbird and medium-sized mammal communities associated with exurban development in Pitkin County, Colorado. Conservation Biology **15:**1143–1150.

Odell, E. A., D. M. Theobald, and R. L. Knight. 2003. Incorporating ecology into land use planning—the songbirds' case for clustered development. Journal of the American Planning Association **69:**72–82.

Radeloff, V. C., R. G. Hammer, P. R. Voss, A. E. Hagen, D. R. Field, and D. J. Mladenoff. 2001. Human demographic trends and landscape level forest management in the northwest Wisconsin Pine Barrens. Forest Science **47:**229–241.

Rasker, R., and A. J. Hansen. 2000. Natural amenities and populations growth in the Greater Yellowstone region. Human Ecology Review **7:**30–40.

Riitters, K. H., J. D. Wickham, R. V. O'Neill, K. B. Jones, E. R. Smith, J. W. Coulston, T. G. Wade, and J. H. Smith. 2002. Fragmentation of continental United States forests. Ecosystems **5:**815–822.

Robinson, S. K., F. R. Thompson, T. M. Donovan, D. R. Whitehead, and J. Faaborg. 1995. Regional forest fragmentation and the nesting success of migratory birds. Science **267:**1987–1990.

Rochelle, J. A., L. A. Lehman, and J. Wisniewski, editors. 1999. Forest fragmentation: wildlife and management implications. Brill Academic Publishers, Leiden, The Netherlands.

Schnaiberg, J., J. Riera, M. G. Turner, and P. R. Voss. 2002. Explaining human settlement patterns in a recreational lake district: Vilas County, Wisconsin, USA. Environmental Management **30:**24–34.

Sierra Club. 1998. Sprawl: the dark side of the American dream. Sierra Club, San Francisco. Available from www.sierraclub.org/sprawl/report98/(accessed June 2003).

Soulé, M. E. 1991. Land-use planning and wildlife maintenance—guidelines for conserving wildlife in an urban landscape. Journal of the American Planning Association **57:**313–323.

Stewart, S. I. 2002. Amenity Migration. Pages 369–378 in K. Luft and S. MacDonald, editors. Trends 2000: shaping the future. 5th Outdoor Recreation & Tourism Trends Symposium. Department of Park, Recreation and Tourism Resources, Michigan State University, Lansing.

Stewart, S. I., and D. J. Stynes. 1994. Toward a dynamic model of complex tourism choices: the seasonal home location decision. Journal of Travel and Tourism Marketing **3:**69–88.

Suarez, J. G., D. T. Bolger, and T. J. Case. 1998. Effects of fragmentation and invasion on native ant communities in coastal southern California. Ecology **79:**2041- -2056.

Swenson, J. J., and J. Franklin. 2000. The effects of future urban development on habitat fragmentation in the Santa Monica Mountains. Landscape Ecology **15:**713–730.

Temple, S. A., and J. R. Cary. 1988. Modeling dynamics of habitat—interior bird populations in fragmented landscapes. Conservation Biology **2:**340–347.

Theobald, D. M. 2001. Land use dynamics beyond the urban fringe. The Geographical Review **91:**544–564.

Theobald, D. M. 2004. Placing exurban land-use change in a human modification framework. Frontiers in Ecology and the Environment **2:**139–144.

Theobald, D. M., J. R. Miller, and N. T. Hobbs. 1997. Estimating the cumulative effects of development on wildlife habitat. Landscape and Urban Planning **39:**25–36.

Tilman, D., R. M. May, C. L. Lehman, and M. A. Nowak. 1994. Habitat destruction and the extinction debt. Nature **371:**65–66.

U.S. Census Bureau. 2001. Census 2000 summary file 1. U.S. Census Bureau, Washington, D.C.

U.S. Census Bureau. 2002. Census 2000 summary file 3A technical documentation. U.S. Census Bureau, Washington, D.C.

Vitousek, P. M., H. A. Mooney, J. Luchenko, and J. M. Melillo. 1997. Human domination of earth's ecosystems. Science **277:**494–499.

Vogelmann, J. E., S. M. Howard, L. Yang, C. R. Larson, B. K. Wylie, and N. van Driel. 2001. Completion of the 1990s National Land Cover Data Set for the conterminous United States from Landsat Thematic Mapper data and ancillary data sources. Photogrammetric Engineering & Remote Sensing **67:**650–662.

White, D., P. G. Minotti, M. J. Barczak, J. C. Sifneos, K. E. Freemark, M. V. Santelmann, C. F. Steinitz, A. R. Kiester, and E. M. Preston. 1997. Assessing risks to biodiversity from future landscape change. Conservation Biology **11:**349–360.