Landscape Ecol (2007) 22:217–230
DOI 10.1007/s10980-006-9016-z

RESEARCH ARTICLE

Building patterns and landscape fragmentation in northern Wisconsin, USA

Charlotte E. Gonzalez-Abraham · Volker C. Radeloff · Roger B. Hammer · Todd J. Hawbaker · Susan I. Stewart · Murray K. Clayton

Received: 28 October 2005 / Accepted: 14 May 2006 / Published online: 5 August 2006

Abstract Housing growth is prevalent in rural areas in the United States and landscape fragmentation is one of its many effects. Since the 1930s, rural sprawl has been increasing in areas rich in recreational amenities. The question is how housing growth has affected landscape fragmentation. We thus tested three hypotheses relating land cover and land ownership to density and spatial pattern of buildings, and examined whether building density or spatial pattern of buildings was a better predictor for landscape fragmentation. Housing locations were mapped from 117 1:24,000-scale USGS topographic maps across northern Wisconsin. Patch-level landscape metrics were calculated on the terrestrial area remaining after applying 50, 100 and 250 m disturbance zones around each building. Our results showed that building density and the spatial pattern of buildings were affected mostly by lake area, public land ownership, and the abundance of coniferous forest, agricultural land, and grassland. A full 40% of the houses were within 100 m of lakeshores. The clustering of buildings within 100 m of lakeshores limited fragmentation farther away. In contrast, agricultural and grassland areas were correlated with higher building density, higher fragmentation, and more dispersed building pattern possible legacies of agricultural settlement patterns. Understanding which factors influence building density and fragmentation is useful for landscape level planning and ecosystem management in northern Wisconsin and areas that share similar social and environmental constraints.

Keywords Disturbance zone · Landscape fragmentation · Building density · Spatial pattern of buildings · Landscape legacies · Rural sprawl · Wisconsin

C. E. Gonzalez-Abraham · V. C. Radeloff (✉) ·
T. J. Hawbaker
Department of Forest Ecology & Management, University of Wisconsin – Madison, 1630 Linden Drive, Madison, WI 53706-1598, USA
e-mail: radeloff@wisc.edu

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

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

M. K. Clayton
Department of Statistics, University of Wisconsin – Madison, Madison, WI 53706, USA

Introduction

Anthropogenic land use has altered most landscapes in complex interactions where culture has structured landscapes and landscapes have influenced culture (Nassauer 1995). These interactions affect the environment most in areas where human land use is most intense, such as cities and industrial areas, and where human habitation and wildlands meet (Radeloff et al. 2005a). In such areas the environmental effects, consequences of spatial deconcentration and expansion of settlements, are profound and are receiving close attention from managers and scientists (Hammer et al. 2004). However, housing growth is not limited to urban and suburban areas, and much housing development is occurring in rural areas (Gobster et al. 2000; Hansen et al. 2002; Radeloff et al. 2005b).

Rural areas in the US experienced intense growth in the 1970s when non-metropolitan population growth exceeded metropolitan areas' growth (Fuguitt 1985). This trend reversed in the 1980s, but in the 1990s rural population growth was again vigorous (Long and Nucci 1997). Rural sprawl, i.e., housing growth far from urban centers, is largely driven by the ideal of living in rural amenity-rich areas (Fuguitt and Brown 1990; McGranahan 1999) often affecting areas of high ecological value (Brown 2003). This ideal promotes housing growth for seasonal and retirement homes and as the baby-boom generation approaches retirement age this trend is expected to continue (Dwyer and Childs 2004).

Houses impose landscape patterns and influence ecological processes at a variety of scales (Theobald et al. 1997; Hansen et al. 2002; Brown 2003). Housing development causes destruction of natural vegetation, soil disturbance and erosion; introduces exotic species through landscaping; and limits wildlife movements due to roads and fences (Hostetler 1999). Human activities near houses cause avoidance behavior in species not adapted to human presence (Rodgers and Smith 1995), nest abandonment (Hockin et al. 1992; Miller and Hobbs 2000), increased nest predation (Coleman and Temple 1993), and changes in species interactions (Kareiva 1990). For example, neotropical migrant bird abundance decreases as development increases adjacent to forest patches (Friesen et al. 1995), and bird abundance is significantly lower in forests with moderate housing density when compared to areas with low housing density (Kluza et al. 2000).

The environmental effects of a building can be approximated in a disturbance zone, which is the area around a building where habitat quality is degraded (Theobald et al. 1997). One of the effects of the disturbance zones of many buildings is habitat fragmentation. The cumulative disturbance zone of a development or neighborhood, i.e., the aggregate area of multiple disturbance zones around individual houses, is a function of both density and spatial pattern of buildings (Theobald et al. 1997). At a given building density, habitat fragmentation is highest when buildings are dispersed (Theobald et al. 1997). Impacts of new buildings may be minor if they are located in close vicinity to existing ones (Odell et al. 2003; Arendt 1997).

Despite ecological advantages of clustered development, many townships and counties have zoning codes that promote large lot development to maintain a rural character (Heimlich and Anderson 2001). Dispersed, low density housing patterns spread the impact of housing units and their related activities over the landscape (Theobald et al. 1997). However, there is not much known about the disturbance generated by different spatial patterns of houses in real landscapes; most of the theory has been developed using artificial hypothetical landscapes.

Present landscapes are the result of past land use determined by socioeconomic and cultural aspects and also by the natural characteristics of the landscape. Understanding the linkages between the physical, biological, and social factors and housing development can help anticipate future development and its effects. This knowledge may give managers and policy makers time to implement policies to protect natural resources in the face of growing human populations (Dwyer and Childs 2004).

The main goal of this study was to identify how land ownership and land cover (as proxies of social, economic, biological, and physical conditions) relate to landscape fragmentation. We focused on landscape fragmentation because of its well documented negative effects on the environment (Saunders et al. 1991; Andrén 1994). Prior research has established that building patterns influence fragmentation (Theobald et al. 1997), and highlights the importance of lakes in determining development patterns (Schnaiberg et al. 2002). We thus hypothesized that: (a) land ownership and land cover affect landscape fragmentation indirectly, by determining both density and spatial pattern of buildings; (b) lakes are the single most important factor determining both density and spatial pattern of buildings, and (c) the spatial pattern of buildings is more important in determining landscape fragmentation than is building density.

Methods

Study area

Our study area was northern Wisconsin and included all counties with 60% or more forest cover. This study area exhibits a mixture of public and private land, varied land use history, and high levels of present day recreational use (Ostergren and Vale 1997). These characteristics make northern Wisconsin an appropriate place to investigate relationships between building density, socioeconomic and environmental variables, and landscape fragmentation.

The late Wisconsin glaciation had a major influence in shaping the landscape of northern Wisconsin. The advance and retreat of the massive sheets of ice scoured the land and created thousands of lakes (Ostergren and Vale 1997). Climate is characterized by cold winters and short, mild summers. Prior to the European settlement, the landscape was a mix of old-growth hardwoods and mature hemlock (*Tsuga canadensis*), pine forest (*Pinus banksiana*, *P. resinosa* and *P. strobus*), quaking aspen (*Populus tremuloides*), yellow birch (*Betula alleghaniensis*), and sugar maple (*Acer saccharum*) (Radeloff et al. 1999; Schulte et al. 2002). In the mid-1800s, logging began in northern Wisconsin, reaching its peak in 1890. Intense fires followed logging, creating disturbed areas favoring early successional species like quaking aspen, paper birch (*Betula papyrifera*), and pin cherry (*Prunus pennsylvanica*, Fries 1951; Stearns 1997). Current forests are largely dominated by sugar maple and early successional species such as aspen (Mladenoff et al. 1993; Radeloff et al. 1999). Deforested land was often farmed; however, most farms were unsuccessful due to climate limitations and insufficient soil nutrients, and were abandoned in the first half of the 20th century. Tax delinquent private lands reverted to public ownership and were reforested (Carstensen 1958; Bawden 1977). Currently land ownership is a mix of public and private land, with 15% county forests, 5.5% state land, 16% national forests, 4.5% tribal nations, and 59% private ownership (US Forest Service 2001; WI DNR 2002a). Public land ownership in this region reflects the economic value of lands in relation to agriculture and production forestry, and is more common on sites that were less valuable for these purposes early in the 20th century, either because of low productivity or distance to transportation networks. However, reforestation and the combination of abundant lakes and public land have since made northern Wisconsin attractive for recreational use. In the mid-1960s, population in northern Wisconsin began to grow especially in areas where second homes held for recreational use were concentrated, such as near lakes and forests (Carstensen 1958; Radeloff et al. 2001, 2005b; Schnaiberg et al. 2002). During the rural rebound of the 1970s, population growth in our study area was 13% on average, reaching a maximum of 51% in Vilas County. In contrast, housing growth—which includes seasonal homes—was on average 44% and reached 89 and 88% respectively in Menominee and Vilas County. During the 1980s the pace of growth slowed (1% population growth, and 10% housing growth), and while population growth reached 10% during the 1990s, housing growth rates continued to decline to 6%. Today, while timber production continues, the economy of northern Wisconsin is driven by tourism and recreation (Flader 1983).

Data sources and data preparation

We analyzed 118 random samples in our study area out of a total population of 443. Each sample represents one 1:24,000-scale USGS Topographic Quadrangle Map (USGS 1996), or 13,248 ha (Fig. 1). For each quadrangle, we digitized buildings from the latest available topographic maps dating mostly from 1970 to 1980s but some

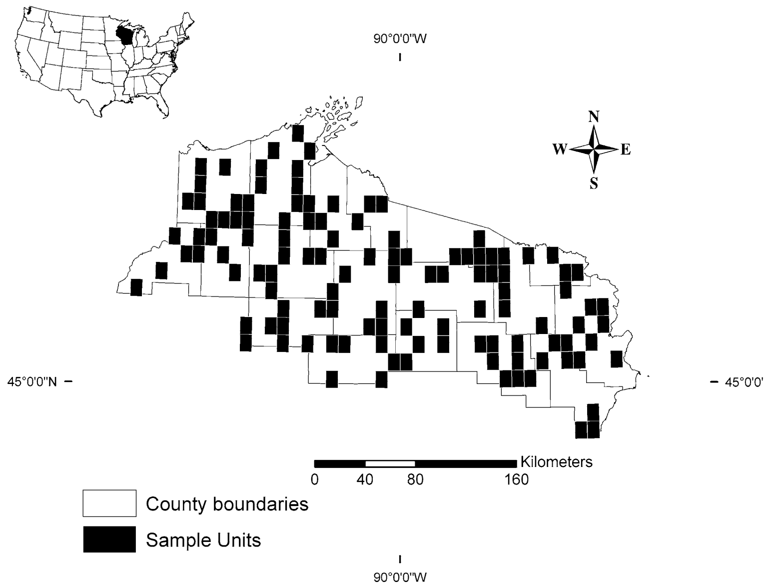

Fig. 1 Study area covering the northern third of Wisconsin, USA. Sample units are equivalent to the area covered by a 1:24,000-scale US Geological Survey Topographic Quadrangle Map (13,248 ha)

are from the late 1960s. On the topographic maps, buildings are identified by black, shaded or white squares with no classification as to the type of building. Due to this characteristic we use the term ''building'' instead of house to refer to the structures that were digitized.

To determine the influence of lakes on building patterns we used lake data from the 1:24,000-scale hydrography coverage (WI DNR 2002b). Around each lake, we established four buffers (100, 250, 500 and 1000 m) and calculated the number of buildings inside each buffer.

To identify how building density relates to land cover and land ownership, we calculated building density (number of buildings/km^2) for each quadrangle based on the terrestrial (i.e., non-aquatic) area only. Land cover variables were derived from WISCLAND, a land cover data set for Wisconsin based on classified multispectral Landsat satellite imagery (WI DNR 1998). The overall accuracy of the WISCLAND classification is 94% at Anderson level 1 (Anderson et al. 1976). Single class user's accuracies were 100% for urban, 90% for agriculture, 73% for grassland, 63% for shrubland, and 100% for water (Reese et al. 2002). For each quadrangle we calculated the area of deciduous forest, mixed forest, coniferous forest, wetlands/cranberry bogs, grassland, agriculture, and shrubland. Total area of public ownership was calculated from the County, State, and Federal land areas in each quadrangle (US Forest Service 2001; WI DNR 2002a); other areas were considered private land.

If necessary, data were transformed to ensure normal distribution as required by the statistical assumptions underlying regression models. Specifically, building density, public and agricultural land, grassland, coniferous forest, water area, and shrubland were log transformed. Mixed forest was square root transformed; wetlands/cranberry bogs, and deciduous forest did not require transformations.

The combined ecological effects generated by a building create a ''disturbance zone'' (Theobald et al. 1997). To simulate the effect that each building might have, we considered all terrestrial area affected by each building as potential habitat independent of its land cover. Based on the ''disturbance zone'' concept, we modeled the effect of each building using buffers of three different radii (50, 100 and 250 m). We varied buffer distances, because the size of the disturbance zone may depend on the ecological process under consideration, and because we wished to assess how sensitive our results were to disturbance zone radius. The combination of all disturbance zones in a quadrangle constitutes the disturbance area.

Landscape metrics

The disturbance zones around houses remove potential habitat and cause fragmentation by altering the pattern of the remaining habitat patches (Forman and Godron 1986; Turner 1989). Habitat area and habitat patch size affect species abundance and the probability of population extinction (Andrén 1994; Fahrig 1997). Patch perimeter, a measure of edge, can have a strong influence on ecological processes such as exotic species invasions and increased predation on interior species (Brittingham and Temple 1983).

Highly convoluted shapes exhibit more edge, which generates greater exposure to human disturbance and limits the amount of interior habitat within a patch (Forman 1995). To quantify landscape fragmentation we used four landscape metrics: proportion of undisturbed area, decrease in largest patch area, decrease in median patch area, and change in total edge. All measurements were conducted for each quadrangle. To measure total habitat availability, we calculated the proportion of undisturbed area as terrestrial area outside of the disturbance area (km^2) divided by the total terrestrial area (km^2). In order to determine the amount of fragmentation created by buildings and their disturbance zones, we measured the decrease in largest patch area by dividing the largest undisturbed patch (km^2) by the largest patch assuming no houses and no disturbance area (km^2). The decrease in median patch area was measured using the same method. The term 'decrease' in these two measures reflects the change in landscape pattern, i.e., the increase in fragmentation, that occurred since pre-European settlement (around 1850 in Northern Wisconsin). Total perimeter, a measure of total edge, was measured as the sum of the perimeter of all patches. Change in total edge (km) was calculated by subtracting the total perimeter without the disturbance area (km) from the total perimeter with the disturbance area (km). These metrics were chosen for their ability to describe the variations in landscape pattern in simple terms, their ecological significance (Forman and Godron 1986; Vos et al. 2000), and the lack of correlation among them.

Spatial pattern of buildings

In addition to building density, the spatial pattern of buildings is the most important factor in determining the disturbance area (Theobald et al. 1997). We identified the spatial pattern of building units using two different grids, one with a cell size of 50×50 m and the other 500×500 m. We chose these two cell sizes so that the smaller one would represent an average building lot size, while the larger one would be twice the radius of our largest disturbance zone. Three summary variables were used. The first summary variable was the proportion of occupied cells, calculated as the proportion of cells per quadrangle with at least one building. For a given building density, a value closer to one indicates higher dispersion of buildings. The second summary variable was a chi-squared test (χ^2), which compares the observed number of cells in each sample area (qt) with a given number of buildings to the expected number of cells with that same number of buildings, assuming a Poisson distribution. Using the two grid sizes for each quadrangle (ht), we counted the number of buildings in each cell (h) and the observed number (O) of cells with 1, 2, 3,...8, and more than 9 buildings (bins). To calculate the expected number (E) of cells in each bin we counted the total number of buildings in each quadrangle and calculated the total number of buildings divided by the total number of cells in each quadrangle (λ):

$$\lambda = \frac{ht}{qt}$$

We calculated the expected number of cells having h buildings using a Poisson formula:

$$E = qt \times \frac{\lambda^h \times e^{-\lambda}}{h!}$$

Then we calculated the χ^2 value for each bin:

$$\chi^2 = \frac{(O - E)^2}{E}$$

We summed all the χ^2 values per quadrangle and compared each sum to the Poisson distribution using the probability tables and a P-value of number of bins minus two. The null hypothesis is random; the alternative is two-sided, admitting both possibilities of clustered or regular patterns.

The third summary variable used to examine building patterns was an index of dispersion (*id*) calculated for each quadrangle. This statistic is calculated based on mean ($\bar{x}$) and standard deviation (s^2) of the number of buildings in all cells in a given quadrangle:

$$\mathrm{id} = \frac{s^2}{\bar{x}}$$

If this ratio is 1, the data are randomly distributed and if the ratio is close to 0, the data present a clustered distribution (Upton and Fingelton 1985).

Statistical analysis

We used regression models to explore land ownership, land cover, density and spatial pattern of buildings, and landscape fragmentation (Pinheiro and Bates 2000). Model choice was guided using backwards selection procedures in which we removed variables that had *P*-values greater than 0.05 or that exhibited 60% correlation with other variables.

Our first hypothesis was that land cover and land ownership are significant predictors of both building density and spatial patterns of buildings, and hence indirectly affect landscape fragmentation by buildings. To test this hypothesis, we modeled building density and the clustering of buildings as a function of land cover and land ownership using three different regression models. The first model regressed building density (dependent variable) against the area of different land cover classes as well as public land. The second model regressed the proportion of 50 m grid cells occupied by at least one building against the same land cover and land ownership variables, but also included building density as an explanatory variable. Lastly, we built a similar model to explain the proportion of 500 m cells occupied by at least one building. The explanatory power of the models (*R*-squared) was used to either confirm or reject our hypothesis.

Our second hypothesis was that lakes are the single most important factor determining the density and the spatial pattern of buildings in the landscape. This hypothesis was tested using these same three regression models described above, but focusing on the *t*-value of lake area in the multivariate models, and comparing it to the *t*-value of the other significant variables.

Our third hypothesis was that the spatial patterns of buildings are more important in determining landscape fragmentation than building density. This hypothesis was tested using another set of regression models. Separate models were created for each of the four fragmentation indices described in detail above, and for the three different buffer sizes (50, 100 and 250 m), resulting in a total of 12 models. The dependent variables for each of these twelve models were building density, public land ownership, and a suite of land cover classes (abundance of coniferous forests, deciduous forests, wetland bogs, grasslands, and agriculture).

In order to identify the relative importance of building density versus spatial pattern of buildings, we constructed a second and third set of these 12 models in which building density was omitted from the list of explanatory variables. Instead, we added the proportion of either 50 or 500 m grid cells occupied by at least one building. The magnitude of the *t*-values for building density 50 m grid cells occupied, and 500 m grid cells occupied in their respective models, was the criteria for rejecting our third hypothesis.

The assumptions of constant variance, independence among observations, and normally distributed errors were validated by examining residual plots (Chatterjee et al. 2000). The presence of autocorrelation in the residuals can affect regression coefficients by underestimating standard errors, thus producing false measures of significance (Chatterjee et al. 2000). Once the variables were selected, we tested for the presence of spatial autocorrelation in the residuals using a variogram fitting procedure (Pinheiro and Bates 2000). We did not find significant spatial autocorrelation in any of the models generated.

Results

Building density

We digitized a total of 61,897 buildings in the 118 sample units of the study area. The model describing building density showed an r^2 of 72% suggesting that land cover and land ownership can model building density well. Total lake area was the variable with the strongest relationship to building density (Table 1). Quadrangles with greater lake area exhibited higher building densities. Agricultural and grassland areas were also positively, but more weakly, correlated with building density. Negative correlation occurred between building density and public land, wetlands and cranberry bogs, and deciduous forest (Table 1).

The explanatory power of our models explaining the spatial pattern of buildings was even higher than the one for building density (r^2 of 90 and 79% respectively for 50 and 500 m grid cells occupied, Table 1). Building density was the strongest positive factor influencing the spatial pattern of buildings (proportion of occupied cells) at both grid sizes, but the *t*-values indicated that it was more strongly correlated with the proportion of occupied cells in the 50 m grid size model than the 500 m model. Lake area negatively affected this proportion of grid cells occupied in both grid size models. For a given building density, fewer grid cells were occupied when more lakes were present, highlighting that lakes cluster buildings. Deciduous forest, grassland, and agriculture were present as additional factors in both grid size models, with varying signs of their relationships, but their *t*-values were relatively small, suggesting less importance.

Table 1 Regression model *t*-values for building density and the spatial pattern of building (proportion of occupied cells for grid cell size of 50 and 500 m) versus land ownership and land cover (Variables without *t*-values were not significant at $P > 0.05$)

Variables	Building density	Grid cell size	
		50 m	500 m
Building density	na	32	13
Public land	–2		
Lake area	11	–5	–3
Coniferous forest			
Deciduous forest	–5		–3
Mixed forest			
Wetland-cranberry bogs	–3		
Shrubland			
Grassland	6		4
Agriculture	4		3
r^2	0.72	0.90	0.79

Variables without *t*-values were not significant ($P > 0.05$) in final models

We expected a significant relationship between building density and lake area, however the strength of this relationship exceeded our expectations. Forty one percent of buildings were found within 100 m of lakeshores. An additional 12% of buildings occurred between 100 and 250 m from lakeshores, and 15% occurred between 250 and 500 m (Fig. 2). In the 0–100 m interval the total building density was 50.1 buildings/km^2, compared to 6.0 buildings/km^2 for the 100–250 m interval and 7.4 buildings/km^2 for the 250–500 m interval.

The two measures of the spatial patterns of buildings confirmed strong clustering at both scales (50 and 500 m grids). Chi-squared tests indicated that the spatial pattern of buildings was not random at both grid cell sizes; only three out of 118 quadrangles exhibited a random spatial pattern at 50 m, and only one presented a random pattern at 500 m. The index of dispersion showed that all quadrangles had a clustered pattern at both scales (grid sizes).

Landscape fragmentation

We measured landscape fragmentation as: (1) a decrease in the proportion of undisturbed area,

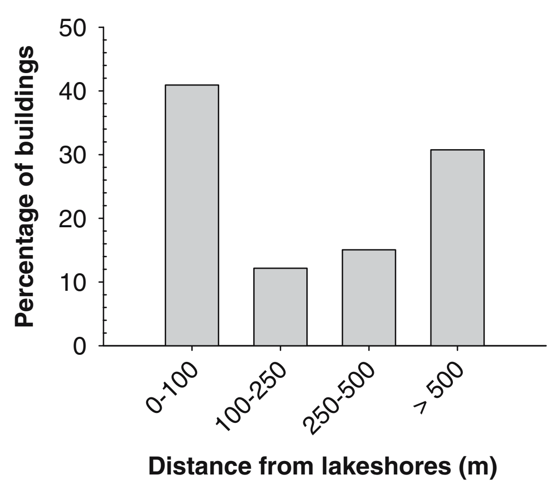

Fig. 2 Distribution of buildings at different distances from lakeshores

(2) a decrease in the largest and median patch areas, and (3) a change in total amount of edge. On average, the undisturbed area was reduced by 19% with a 250 m disturbance zone, 5% with 100 m disturbance zone and 2% with a 50 m disturbance zone (Table 2). The largest patch size outside the disturbance zone decreased by 20, 6 and 2% for 250, 100 and 50 m disturbance zones respectively (Table 2). The highest increase in total edge was 8.4 km for the 250 m buffer. Fragmentation varied across the landscape independent of the buffer applied to calculate the disturbance area (Fig. 3). In general, the proportion of disturbed area, and the decrease in the largest patch show similar patterns across northern Wisconsin, but the increment in edge is spatially more different, especially when assuming a 250 m disturbance zone (Fig. 3).

In the models explaining fragmentation using building density, public land ownership and land cover, building density was always the most significant factor explaining landscape fragmentation (Fig. 4). Regardless of the buffer size applied to calculate the disturbance area, building density was always negatively correlated with the proportion of undisturbed area and with the proportion of the largest remaining patch, and positively correlated with the change in total edge (Fig. 4). Lake area was negatively correlated with an increment in total edge and positively correlated with the proportion of undisturbed area (with the exception in this case of the 50 m buffer that did not present any relationship) (Fig. 4). Grassland and agricultural area were positively correlated with increase in total edge and negatively correlated with the proportion of undisturbed area (Fig. 4). Public land was not an important variable in the models of fragmentation. It was only retained in one of the twelve models (positive correlation with the proportion of undisturbed area at 250 m buffer, (Fig. 4). Other land cover types (coniferous forest, deciduous forest, mixed forest, wetlands/cranberry bogs, and shrubland) did not exhibit constant and significant relationships with the landscape metrics (Fig. 4). We tested residuals for spatial autocorrelation and found no significant autocorrelation in any of the model residuals.

Our final sets of models explaining fragmentation replaced building density with measures of the spatial patterns of buildings. We found that the new models included largely the same variables independent of grid size (Figs. 5, 6). The spatial pattern of buildings was the most significant variable followed by lake area, grassland, and agricultural area. The higher the proportion of cells occupied by at least one building, the higher the fragmentation. Similarly, lake area was significant in determining the landscape metrics, but its influence over total edge changed from positive when using 50 m buffers to negative when examining 100 and 250 m buffers (Fig. 5). Public land was negatively significant for change in total edge when examining 100 and 250 m buffers (Figs. 5, 6). All other cover types (coniferous forest, deciduous forest, mixed forest, wetlands/cranberry bogs, and shrubland) did not exhibit

Table 2 Summary statistics of landscape metrics of terrestrial patches beyond 50, 100 and 250 m buffer from buildings (n = 18)

Buffer size		Undisturbed area (%)	Decrease in largest patch area (%)	Decrease in median patch area (%)	Change in total edge (km)
50 m	Mean	98	2	–52	6.7
	Variance	< 0.01	< 0.01	13	24.8
	Median	98	1	–51	5.4
100 m	Mean	95	6	–28	8.0
	Variance	< 0.01	< 0.01	13	35.7
	Median	96	4	–17	6.3
250 m	Mean	81	20	71	8.4
	Variance	1	2	4.25	45.4
	Median	84	17	7	6.7

Negative values for the decrease in median patch area reflect an increase in this metric

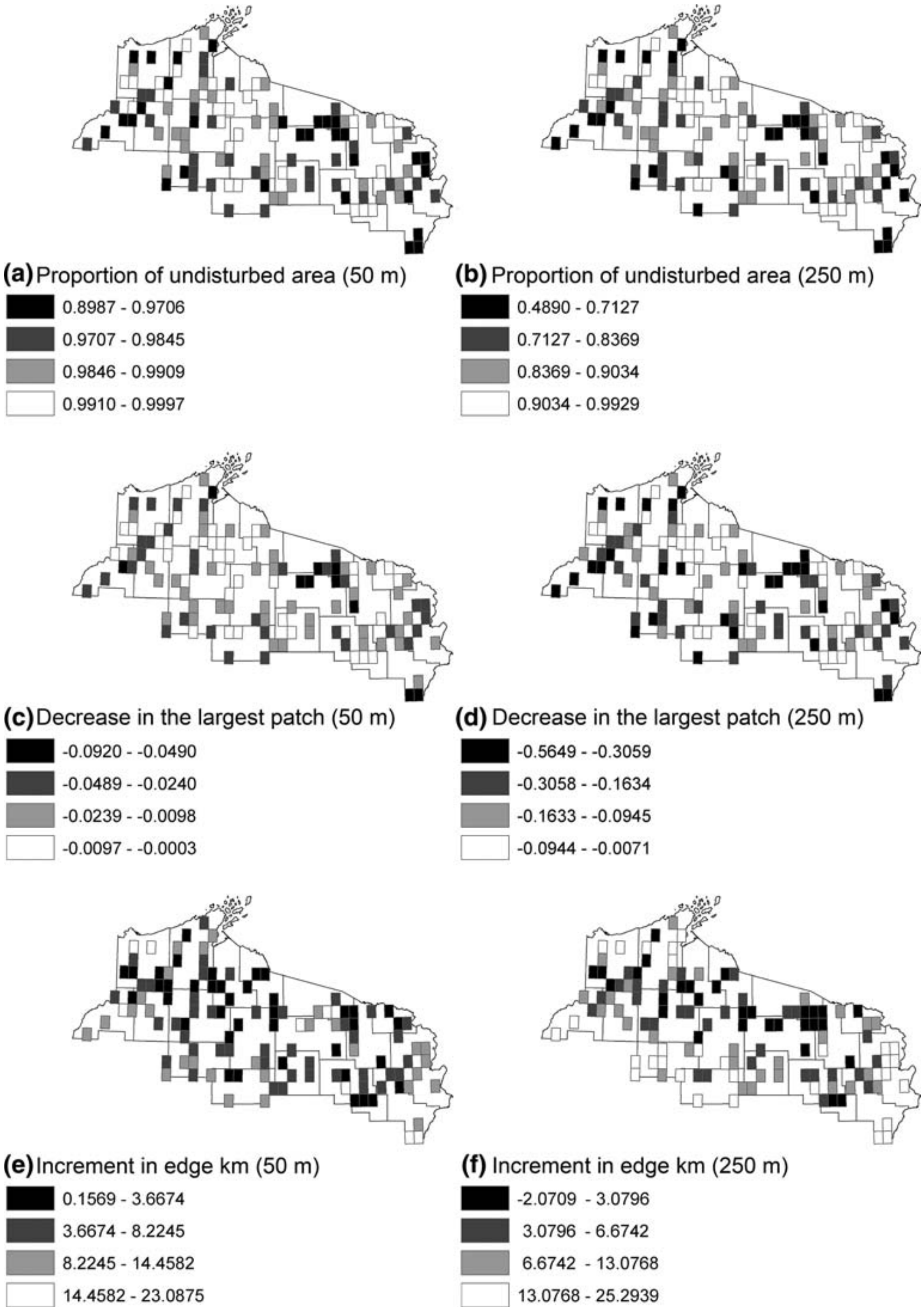

Fig. 3 Landscape pattern of terrestrial patches outside buffered class: (a) proportion of disturbed area for a 50 m buffer zone, (b) proportion of disturbed area for a 250 m buffer zone, (c) decrease in the largest patch for a 50 m buffer zone, (d) decrease in the largest patch for a 250 m buffer zone, (e) increment in edge for a 50 m buffer zone, (f) increment in edge for a 250 m buffer zone. Class breaks represent data distribution quartiles

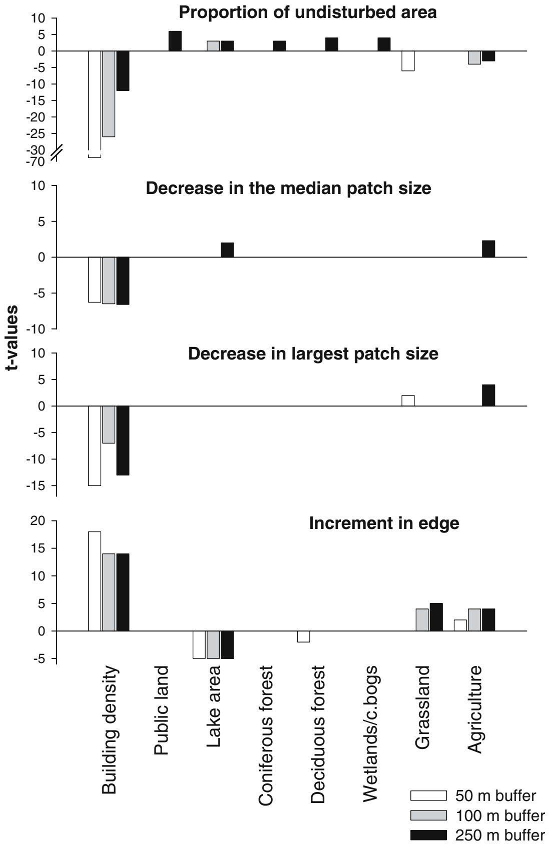

Fig. 4 *T*-values for building density, public land and land cover as predictor variables of landscape fragmentation. Separate models were created for each landscape index, and for each disturbance zone size. The plotted values represent the *t*-value for the significant variables at $P < 0.05$

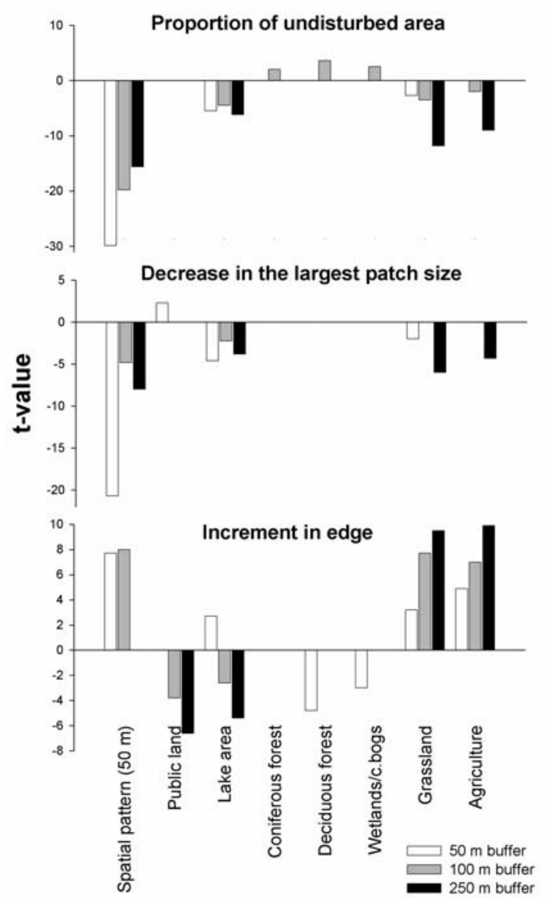

Fig. 5 *T*-values for the proportion of 50 m grid cells occupied, public land and land cover as predictor variables of landscape fragmentation by buildings. Separate models were created for each landscape index, and for each disturbance zone size. The plotted values represent the *t*-value for the significant variables at $P < 0.05$

constant and significant relationships with the landscape metrics (Figs. 5, 6).

Discussion and conclusions

Human preference for certain attributes on the landscape results in the modification of its patterns (Nassauer 1995). In turn, this modification alters human perceptions of the landscape and promotes different uses of it. Understanding which factors, such as land ownership and land cover, influence people's perception and the activities they conduct in the landscape contributes to our understanding of the interaction between culture and landscape change (Turner et al. 2001). The patterns of buildings in the landscape reveal the geographic and environmental attributes that people prefer and provide information about environmental consequences of those preferences, which ultimately help manage landscapes.

Our analysis indicated that buildings in northern Wisconsin result in substantial habitat loss and fragmentation. If we assume a 250 m disturbance zone around each house, the result is a loss of 20% of the potential habitat, and significantly reduced mean and median patch size of patches (Table 2). However, the fragmentation was limited to certain areas, because the presence of

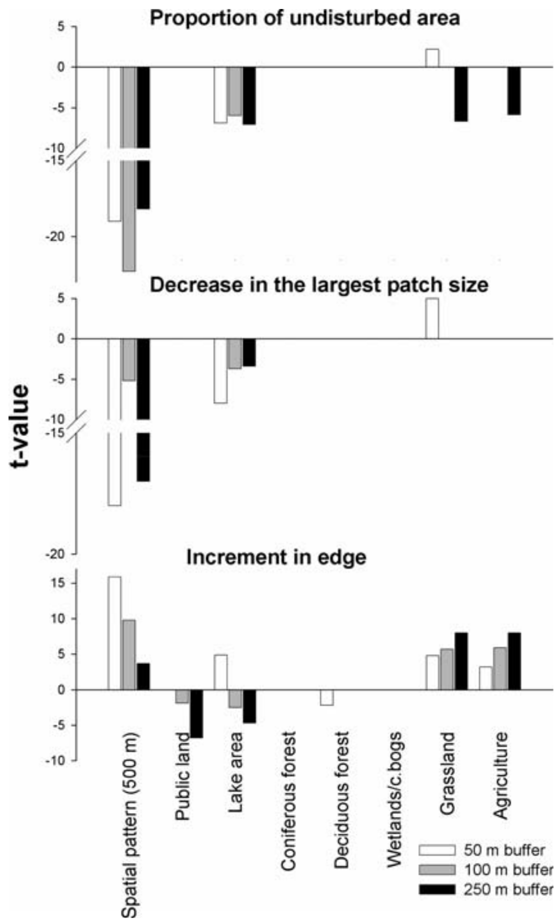

Fig. 6 *T*-values for the proportion of 500 m grid cells occupied, public land and land cover as predictor variables of landscape fragmentation by buildings. Separate models were created for each landscape index, and for each disturbance zone size. The plotted values represent the *t*-value for the significant variables at $P < 0.05$

lakes results in clustering of buildings in northern Wisconsin. A full 41% of buildings are located within 100 m of lakes, where building density was 50.1 buildings/km^2 (Fig. 3).

The clustering of houses around lakes reflects homeowners' preferences for building sites, as few barriers exist to development across the landscape. In mountainous areas lakeshores may be preferred sites for road building, with housing development occurring as a secondary effect. However, northern Wisconsin exhibits very little relief, and except in wetlands, road building in the soils of this region is cheap and easy. The abundance of roads both near and far from lakes (Hawbaker et al. 2005) suggests that transportation networks do not constrain housing development away from lakes. Homeowners' preference for buildings close to the lakes of northern Wisconsin has a long tradition. By 1931, summer homes were already present on most of the accessible lakes in the region (Murphy 1931). People like to live in open and natural-looking areas (Nassauer 1995; Dwyer and Childs 2004; Gobster and Rickenbach 2004) and open water acts as a center of organization within the landscape (Naiman 1996). Our study provides empirical evidence of the result of these preferences and shows how strongly lakes cluster development.

Lakes in northern Wisconsin are such an attraction that building units are located within 50 m of each other. As Table 2 shows, lake area was the only variable for the 50 m grid that was significant for clustering buildings. This indicates that people would prefer to live close to a lake even if this means living close to other people. Lakeshore development thus limits fragmentation by promoting clustered development. In our results, all tests used to determine the spatial distribution of buildings indicated clustered development and lake area were significant in explaining the clustering of buildings (Table 2.1). Clustered development causes overlap in the disturbance zone created by neighboring buildings, thus minimizing the amount of area that is affected (Odell et al. 2003) and leaving the remaining landscape area more suitable for wildlife, especially those species sensitive to human disturbances (Theobald et al. 1997). Because lakes in northern Wisconsin have a tendency to concentrate building development, the remaining landscape is less affected by buildings.

The drawback of clustering development around lakes is that it impacts critical lakeshore habitat, which is threatened by development in northern Wisconsin (Radeloff et al. 2001; Schnaiberg et al. 2002; Dwyer and Childs 2004). At least half of all the disturbance zones in our sample units affected lakeshores. Building development along lakeshores is linked to changes in the composition of bird communities (Lindsay et al. 2002), low adult green frog (*Rana clamitans melanota*) abundance (Woodford and Meyer 2003), local extinction of wood turtle

(*Clemmys insculpta*) populations (Garber and Burger 1995), and the destruction of riparian vegetation and diminution of coarse woody debris (Christensen et al. 1996). In order for clustered development to reduce the potential impacts of building development in the landscape, the developed portion must be located away from critical habitats such as riparian zones (Odell et al. 2003). Thus, when considering management strategies we ought to bear in mind not only the development pattern but also where development might be located in order to minimize impacts on the landscape.

Our models indicated that agricultural areas were correlated with more dispersed building patterns (Table 2). This result was obtained using a satellite classification with an user's accuracy for agriculture of 91%. Had classification accuracy been higher, an even stronger relationship might have been found. One possible explanation for this relationship is related to the settlement history of agricultural lands. After the massive logging of the state's forests, much of the available land in northern Wisconsin was subdivided into farming plots (Black and Gray 1925). These plots typically had at least one housing unit where the family owner of the land lived (Black and Gray 1925), creating scattered individual farms (Goodman 1932). Most of the agricultural land has been abandoned since, and only small remnants of agricultural land cover remain. However, the dispersion of buildings associated with agriculture in our models appears to be a legacy of the building patterns that originated at settlement time (Brown 2003). An alternative hypothesis is that agricultural abandonment itself may have created building development with a dispersed pattern. Where lakes are not present to draw a cluster of homes, the pattern of development in rural areas may reflect a gradual parcelization occurring around still-active farms. Brown (2003) suggests that the patterns of agricultural settlement persist for a long time and continue to influence current building development patterns.

Public land had little explanatory power in any of our models predicting fragmentation (Fig. 5). This may be due in part to the origins of public lands. Recreational development around lakes in northern Wisconsin started before the majority of the public lands were established in the 1920s and 1930s (Murphy 1931; Goodman 1932). State forests were established mainly to preserve the stream flow in the important rivers and to provide outdoor recreational areas. National forests were created from tax delinquent lands. The federal policy of land acquisition was more aggressive in the sense that the National Forest system invested more resources to obtain land within their administrative boundaries resulting in fairly consolidated blocks of land with fewer private inholdings. County forests were established out of tax delinquent private lands and their primary use was (and remains) timber production. County forests represent the largest single class of public land in northern Wisconsin; many encompass private land inholdings. Our examination of historic orthophotos suggests that these county forest inholdings have been developed for residential use, mostly as seasonal homes. Despite these differences in the establishment of public lands, our models did not improve when including separate dependant variables for each type of public ownership (results not shown). This is likely due to sample size problems, especially in the case of National Forests, and State Forests. This is why we presented only the results for aggregated public land ownership.

The lack of explanatory power in the case of the public land variable was a surprise, but highlights the continued preference for living in forested and rural landscapes (Fuguitt and Brown 1990), which causes some homeowners to locate their homes intentionally close to public forests (Dwyer and Childs 2004). Development on inholdings (i.e., islands of private land ownership) and along the boundaries of public lands causes the disturbance created by these buildings to permeate public lands. This means that development inside and bordering public lands might be nullifying the beneficial effect of public lands as habitat reserves, watershed protectors, and multiple use forests.

In summary, both historic legacies and current patterns of settlement have played a large role in shaping the current landscape. The desire to live in rural areas, close to natural amenities or open space, is causing unintentional environmental consequences, even in areas that are protected from building development. Housing development will continue in northern Wisconsin and other rural areas rich in natural amenities, particularly as the Baby Boom generation reaches retirement age. Clustered development is a useful method for limiting fragmentation, and our study supports the use of clustered development, demonstrating that under the right circumstance, homeowners prefer clustering. However, it also shows that clustering development alone does not suffice; planning and zoning must also address the location of housing clusters to conserve critical habitats. Incidental clustering of homes around lakes is no substitute for careful, ecologically-sensitive land use planning.

Acknowledgements We are most grateful for support for the research by the North Central Research Station of the US Forest Service. D.J. Mladenoff, and two anonymous reviewers made valuable comments on earlier versions of this manuscript, and we greatly appreciate their helpful suggestions.

References

Anderson JR, Hardy EE, Roach JT, Witmer RE (1976) A land use and land cover classification system for use with remote sensor data. Geological Survey Professional Paper 964. US Department of the Interior Geological Survey, Washington, DC

Andrén H (1994) Effects of habitat fragmentation on birds and mammals in landscapes with different proportions of suitable habitat: a review. Oikos 71:355–366

Arendt R (1997) Basing cluster techniques on development densities appropriate to the area. J Am Plann Assoc 63:137–145

Bawden DL (1977) Four papers on farm family response to a negative income tax. Institute for Research on Poverty, University of Wisconsin, Madison, Wisconsin, USA

Black JD, Gray LC (1925) Land settlement and colonization in the Great Lakes states (Department Bulletin No. 1295). Washington, DC: United States Department of Agriculture in cooperation with the Agricultural Experiment Station of the University of Minnesota

Brittingham MC, Temple SA (1983) Have cowbirds caused forest songbirds to decline? BioScience 33:31–35

Brown DG (2003) Land use and forest cover on private parcels in the Upper Midwest USA, 1970 to 1990. Landsc Ecol 18:777–790

Carstensen VR (1958) Farms or forest; evolution of a state land policy for northern Wisconsin, 1850–1932. University of Wisconsin Press, Wisconsin

Chatterjee S, Hadi AS, Price B (2000) Regression analysis by example, 3rd edn. John Wiley and Sons, Inc, New York, USA

Christensen DL, Herwig BR, Schindler DE, Carpenter SR (1996) Impacts of lakeshore residential development on coarse woody debris in north temperate lakes. Ecol Appl 6:1143–1149

Coleman JS, Temple SA (1993) Rural residents' free-ranging domestic cats – a survey. Wildl Soc Bull 21:381–390

Dwyer JF, Childs GM (2004) Movement of people across the landscape: a blurring of distinctions between areas, interests, and issues affecting natural resource management. Landsc Urban Plann 69:153–164

Fahrig L (1997) Relative effects of habitat loss and fragmentation on population extinction. J Wildl Manage 61:603–610

Flader SL (1983) The Great Lakes forest. University of Minnesota Press and Forest Historic Society, Santa Cruz, USA

Forman RTT (1995) Land mosaics: the ecology of landscapes and regions. Cambridge University Press, Cambridge, UK

Forman RTT, Godron M (1986) Landscape ecology. John Wiley & Sons Ltd, New York, USA

Fries RF (1951) Empire in pine: the story of lumbering in Wisconsin 1830–1900. Wisconsin State Historical Society, Madison, Wisconsin, USA

Friesen LE, Eagles PFJ, Mackay RJ (1995) Effects of residential development on forest-dwelling neotropical migrant songbirds. Conserv Biol 9:1408–1414

Fuguitt GV (1985) The nonmetropolitan population turnaround. Ann Rev Sociol 11:259–280

Fuguitt GV, Brown DL (1990) Residential preferences and population redistribution – 1972–1988. Demography 27:589–600

Garber DS, Burger J (1995) A 20-year study documenting the relationship between turtle decline and human recreation. Ecol Appl 5:1151–1162

Gobster PH, Haight RG, Shriner D (2000) Landscape change in the Midwest: an integrated research and development program J For 98:9–14

Gobster PH, Rickenbach MG (2004) Private forestland parcelization and development in Wisconsin's Northwoods: perceptions of resource-oriented stakeholders. Landsc Urban Plann 69:165–182

Goodman RB (1932) Forest land use in Wisconsin. Report of the Committee on Land Use and Forestry. Madison, Wisconsin, USA

Hansen AJ, Rasker R, Maxwell B, Rotella JJ, Johnson JD, Partmenter AW, Langner U, Cohen WB, Lawrence RL, Kraska MPV (2002) Ecological cause and consequence of demographic change in the New West. BioScience 52:151–162

Hammer RB, Stewart SI, Winkler RL, Radeloff VC, Voss PR (2004) Characterizing dynamic spatial and temporal residential density patterns from 1940–1990 across the North Central United States. Landsc Urban Plann 69:183–199

Hawbaker TJ, Radeloff VC, Hammer RB, Clayton MK (2005) Road density and landscape pattern in relation

to housing density, land ownership, land cover, and soils. Landsc Ecol 20:609–625
Heimlich RE, Anderson WD (2001) Development at the urban fringe and beyond: impacts on agriculture and rural land. ERS Agricultural Economic Report No. 803, US Department of Agriculture, Economic Research Service, Washington, DC
Hockin D, Ounsted M, Gorman M, Hill D, Keller V, Barker MA (1992) Examination of the effects of disturbance on birds with reference to its importance in ecological assessments. Environ Manage 36:253–286
Hostetler M (1999) Scale, birds, and human decisions: a potential for integrative research in urban ecosystems. Landsc Urban Plann 45:15–19
Kareiva P (1990) Population-dynamics in spatially complex environments – theory and data. Philos Trans R Soc Lond Ser B-Biol Sci 330:175–190
Kluza DA, Griffin CR, DeGraaf RM (2000) Housing developments in rural New England: effects on forest birds. Anim Conserv 3:15–26
Lindsay AR, Gillum SS, Meyer MW (2002) Influence of lakeshore development on breeding bird communities in a mixed northern forest. Biol Conserv 107:1–11
Long L, Nucci A (1997) The 'clean break' revisited: is US population again deconcentrating? Environ Plann 29:1355–1366
McGranahan DA (1999) Natural amenities drive rural population change. Agricultural Economics Report No. 781. Economic Research Service, US Department of Agriculture, Washington, DC
Miller JR, Hobbs NT (2000) Effects of recreational trails on nest predation rates and predator assemblages. Landsc Urban Plann 50:227–236
Mladenoff DJ, White MA, Pastor J, Crow TR (1993) Comparing spatial pattern in unaltered old-growth and disturbed forest landscapes. Ecol Appl 3:294–306
Murphy RE (1931) The geography of the northwestern pine barrens of Wisconsin. Trans Wis Acad Sci, Arts Lett 26:96–120
Naiman RJ (1996) Water, society and landscape ecology. Landsc Ecol 11:193–196
Nassauer JI (1995) Culture and changing landscape structure. Landsc Ecol 10:229–237
Odell EA, Theobald DM, Knight RL (2003) Incorporating ecology into land use planning: the songbirds' case for clustered development. J Am Plann Assoc 69:72–81
Ostergren RC, Vale TR (1997) Wisconsin land and life. University of Wisconsin Press, Wisconsin, USA
Pinheiro JC, Bates DM (2000) Mixed-effects models in S and S-plus, statistics and computer. Springer, USA
Radeloff VC, Hammer RB, Stewart SI, Fried JS, Holcomb SS, McKeefry JF (2005a) The wildland urban interface in the United States. Ecol Appl 15:799–805
Radeloff VC, Hammer RB, Stewart SI (2005b) Sprawl and forest fragmentation in the US Midwest from 1940 to 2000. Conserv Biol 19:793–805
Radeloff VC, Hammer RB, Voss PR, Hagen AE, Field DR, Mladenoff DJ (2001) Human demographic trends and landscape level forest management in the northwestern Wisconsin Pine Barrens. For Sci 47:229–241
Radeloff VC, Mladenoff DJ, He HS, Boyce MS (1999) Forest landscape change in the northwestern Wisconsin Pine Barrens from pre-European settlement to the present. Can J For Res 29:1649–1659
Reese HM, Lillesand TM, Nagel DE, Stewart JS, Goldmann RA, Simmons TE, Chipman JW, Tessar PA (2002) Statewide land cover derived from multiseasonal Landsat TM data – A retrospective of the WISCLAND project. Remote Sens Environ 82:224–237
Rodgers JA, Smith HT (1995) Set-back distances to protect nesting bird colonies from human disturbance in Florida. Conserv Biol 9:89–99
Saunders DA, Hobbs RJ, Margules CR (1991) Biological consequences of ecosystem fragmentation: a review. Conserv Biol 5:18–32
Schnaiberg J, Riera J, Turner MG, Voss PR (2002) Explaining human settlement patterns in a recreational lake district: Vilas County, Wisconsin, USA. Environ Manage 30:24–34
Schulte LA, Mladenoff DJ, Nordheim EV (2002) Quantitative classification of a historic northern Wisconsin landscape: mapping forests at regional scales. Can J For Res 32:1616–1638
Stearns FW (1997) Physical environment supporting Lake States forests. St. Paul, USA. Gen. Tech. Rep. NC-189, pp 1–7
Theobald MD, Miller JR, Hobbs NT, Miller RJ, Thompson HN (1997) Estimating the cumulative effects of development on wildlife habitat. Landsc Urban Plann 39:25–36
Turner MG (1989) Landscape ecology: the effect of pattern on process. Ann Rev Ecol Syst 20:171–197
Turner MG, Gardner RH, O'Neill RV (2001) Landscape ecology in theory and practice. Springer-Verlag, New York, USA
Upton G, Fingelton B (1985) Spatial data analysis by example: point pattern and quantitative data. John Wiley & Sons Ltd, New York, USA
USFS (2001) Chequamegon – Nicolet National Forest. http://www.fs.usda.gov/r9/cnnf/general/history/index.html.Last accessed 6/4/2005
USGS National Mapping Program Standards (1996) 2/03/2003
Vos CC, Verboom J, Opdam PFM, Ter Braak CJF (2000) Toward ecologically scaled landscape indices. Am Nat 183:24–41
Wisconsin Department of Natural Resources (WI DNR) (1998) WISCLAND Land Cover (WLCGW930). Madison, Wisconsin, USA
Wisconsin Department of Natural Resources (WI DNR) (2002a) 1:100,000 Scale DNR-Managed Lands, Geodisc 2.1. Wisconsin Department of Natural Resources, Madison, WI, USA
Wisconsin Department of Natural Resources (WI DNR) (2002b) 1:24,000 Scale Hydrography, Geodisc 2.1. Wisconsin Department of Natural Resources, Madison, WI, USA
Woodford J, Meyer M (2003) Impact of lakeshore development on green frog abundance. Biol Conserv 110:277–284