Landscape Ecology (2005) 20:773–789
DOI 10.1007/s10980-005-2149-7

© Springer 2005

Research Article

The relationship between environmental amenities and changing human settlement patterns between 1980 and 2000 in the Midwestern USA

Eric J. Gustafson[1,*], Roger B. Hammer[2], Volker C. Radeloff[3] and Robert S. Potts[1]
*[1]USDA Forest Service, North Central Research Station, 5985 Highway K, Rhinelander, WI 54501 USA; [2]Applied Population Laboratory, Department of Rural Sociology, University of Wisconsin-Madison, Madison, WI 53706 USA; [3]Department of Forest Ecology and Management, University of Wisconsin-Madison, Madison, WI 53706 USA; *Author for correspondence(e-mail: egustafson@fs.fed.us)*

Received 19 February 2004; accepted in revised form 9 February 2005

Key words: Causes of change, Ecological amenities, Environmental perceptions, Housing density, Human settlement patterns, Landscape change, Predictive model

Abstract

Natural resource amenities may be an attractor as people decide where they will live and invest in property. In the American Midwest these amenities range from lakes to forests to pastoral landscapes, depending on the ecological province. We used simple linear regression models to test the hypotheses that physiographic, land cover (composition and spatial pattern), forest characteristics, land use on undeveloped land, public ownership, soil productivity and proximity to urban centers predict changes in population, housing, and seasonal housing densities over a 10-year interval (1980–1990). We then generated multiple-regression models to predict population, total and seasonal housing density change in the most recent decade (1990–2000) based on ownership and ecological conditions in 1990 and tested them by comparing the predictions to actual change measured by the US Census Bureau. Our results indicate that the independent variables explained between 25 and 40% of the variability in population density change, 42–67% of the variability of total housing density change, and 13–32% of the variability in seasonal housing density change in the 1980s, depending on the province. The strength of the relationships between independent and dependent variables varied by province, and in some cases the sign varied as well. Topographic relief was significantly related to population growth in all provinces, and land cover composition and the presence of water was significantly related to total housing growth in all provinces. There was a surprisingly limited association of any of the independent variables to seasonal housing growth in the northern province, which is commonly perceived to attract seasonal use because of ecological amenities. Proximity to urban centers is related to population and housing density change, but not seasonal housing density change. Our tests indicated that models for population density change showed some utility, but the models for total and seasonal housing density generally performed poorly. Ecologic variables were consistently poor at predicting seasonal housing density change. Our results show that environmental characteristics appear to have some influence on the spatial distribution of population and housing change in the Midwest, although other factors that were not modeled are clearly dominant.

Introduction

Because of the long-term trends of population deconcentration in the US, human population and housing density have changed markedly across the American Midwest over the last several decades (Long and Nucci 1997; Hammer et al. 2004). While much of this change has occurred at the ever-broadening outlying fringe of metropolitan areas, not all population growth can be characterized as suburban sprawl (McGranahan 1999; Radeloff et al. 2001, in press; Hammer et al. 2002, 2004; Potts et al. 2004) (Figure 1). Previous studies have shown that changes in population and housing development patterns are proximately determined by socio-economic factors (Wear and Bolstad 1998; Ahn et al. 2000; Gobster et al. 2000). This study focuses primarily on the environmental determinants (natural amenities) of those changes within the seven states of the Midwestern US (Minnesota, Wisconsin, Michigan, Iowa, Missouri, Illinois and Indiana). Typically, natural amenities evolve around human aesthetic perceptions associated with forests and open space, water (lakes, rivers and coastline), topography (mountains, canyons, and hills), and climate (Marcouiller

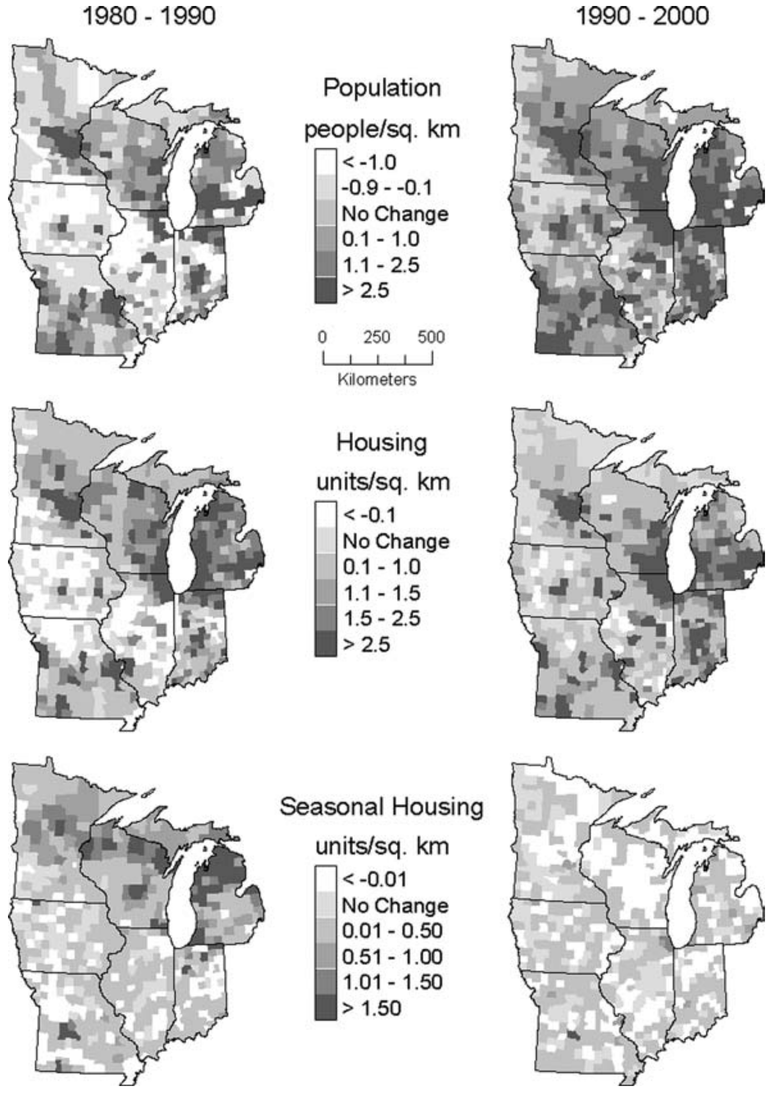

Figure 1. Spatial distribution of changes in population, total housing and seasonal housing density, by decade.

et al. 2002). We do not attempt to replicate the comprehensive, socio-economic equilibrium-based models of county population growth developed by Carlino and Mills (1996) and expanded upon by a variety of other studies (Boarnet 1998; Rey and Montouri 1999) including the incorporation of natural amenities (Henry et al. 1997, 2001; Deller et al. 2001). Instead, our models uniquely focus on the environmental factors that influence changes in population and housing density and the variation of that influence across ecological regions. Because proximity to urban centers is a dominant driver of population and housing growth (So et al. 2001; McGranahan and Beale 2002), we include it in our models to allow meaningful assessment of the significance of environmental factors.

Natural amenities are thought to be an important factor considered by people when they decide where they will live, or where they will invest in vacation or retirement property (Stewart and Stynes 1994; McGranahan 1999). This appears to be particularly true in the northern and southern portions of the Midwest, where lakes and forests serve as a powerful attractor, providing scenic beauty, abundant recreational opportunities and a clean environment (Schnaiberg et al. 2002). However, it is not clear to what extent each of these features is driving population and housing growth, nor if the determinants of change are uniformly distributed across the region. To predict future changes, and to develop policies to guide future change, the factors that lead to changes must first be identified by studying recent change (Gobster et al. 2000). This knowledge can be used to develop predictive models that can be tested against changes that are now occurring.

Three distinct ecological provinces (Keys et al. 1995) intersect the Midwest. The Laurentian Mixed-Forest Province covers the northern portions of Minnesota, Wisconsin and Michigan, the Prairie Parkland (temperate) Province is roughly synonymous with the 'corn belt' region of Iowa, and Illinois, and the Eastern Broadleaf Forest Province covers the remainder of the region. Because the distribution of land use and ecological characteristics vary greatly among these provinces, the importance and relative value of ecological amenities may differ among provinces. While some amenities are universally valued, their relative importance may vary by province. Other specific amenities may be important only in some provinces.

The objectives of our study were to: (1) test the hypothesis that change (between 1980 and 1990) in population density, total and seasonal housing density at the county level is related to the ecological conditions there, (2) assess the relative importance of various ecological factors for attracting people to an area (as primary or seasonal residents), (3) determine if the importance of specific ecological determinants of change varies by ecological province, (4) develop models to predict future change in population, housing and seasonal housing density, and (5) test the models by predicting change between 1990 and 2000.

Methods

The study area was stratified by the three ecological provinces (Keys et al. 1995) comprising the region (Figure 2), and each hypothesis was tested separately for each province. We selected counties as the unit of analysis because they provide a much finer geographic scale than states and their boundaries did not change between 1980 and 2000, unlike other fine-scale geographies such as municipalities and census tracts. We assigned each county to the province containing the greatest proportion of its area (Eastern Broadleaf Forest Province $n = 322$; Laurentian Mixed Forest Province $n = 97$; Prairie Parkland Province $n = 224$). Seven counties in the 'bootheel' of Missouri, falling primarily in the lower Mississippi Riverine Forest Province, were excluded from the study. Because the factors driving change in population, total and seasonal housing density may operate at a scale larger than provinces, we also tested each hypothesis for the entire study area.

Data

We used simple linear regression models to test the hypotheses that physiographic characteristics, land cover (composition and spatial pattern), forest characteristics, land use on undeveloped land, public ownership and soil productivity can each be used to predict relative changes in population, housing, and seasonal housing density from 1980 to 1990 (Table 1, Figure 1). We excluded variables that may be important at a national scale, but are less so at a regional scale (e.g., mean temperature,

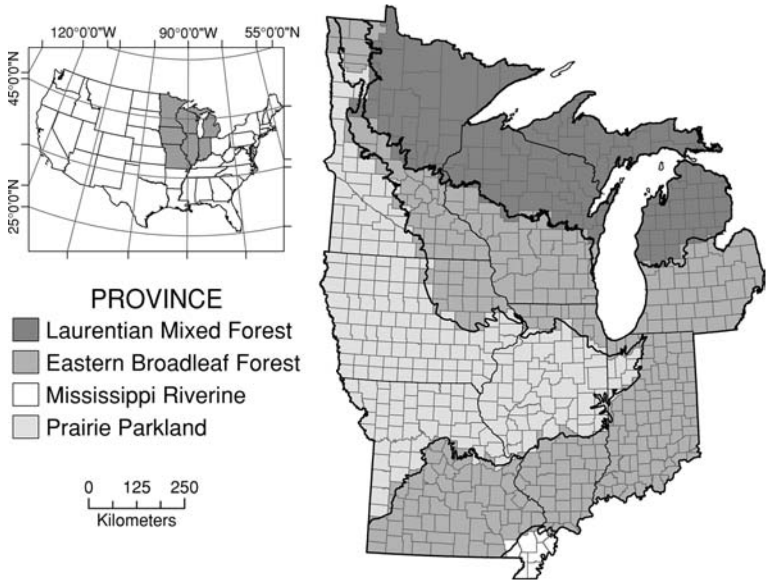

Figure 2. Map of the study area showing county boundaries (lines) and ecological provinces (shading).

Table 1. Dependent variables and the sign of the expected relationship with each independent variable, by ecological province.

Variable	Population/housing	Seasonal housing
Physiographic		
Index of topographic relief	+/–	+
Density of shoreline (lakes and major rivers) (km/km^2)	+	+
Soil capability class	–	–
Land cover composition		
% forest, including forested wetlands	+	+
% agriculture	–	–
% wetlands	+	+
Ratio of forest to agriculture (area)	+	+
Land cover configuration		
GISfrag (m)	+	+
Contagion (% of maximum possible)	+/–	+/–
Forest characteristics		
% of forest in sawtimber size class	+	+
Ownership characteristics		
% of forest in public ownership	+	+
% of locality in reserved status[a]	+/–	+/–
Proximity to urban centers		
Distance to small (0.65^4–10^5 people) city (km)	–	+/–
Distance to medium (10^5–10^6 people) city (km)	–	+
Distance to large ($>10^6$ people) city (km)	–	+

When the expected sign was unclear, two-tailed hypothesis tests were conducted.

[a] Percent of the land in a county and all adjacent counties in a formal reserve status.

summer humidity, McGranahan 1999). Population, permanent housing, and seasonal housing data were obtained from the US Census Bureau. Seasonal homes were defined as housing units that are vacant at the time of the census (April 1) and held for occasional use. The physiographic variables were derived from USGS Digital Elevation Models (DEM) and USGS Land Use Data Analyses (LUDA) data, among other sources. The land cover composition was derived directly from LUDA. The LUDA vector format maps were converted to a 30 m grid for compatibility with

National Land Cover Dataset (NLCD) land cover maps (derived from TM imagery), which were used in the model-testing phase of the study. Forest and ownership characteristics were derived from summaries of all USDA Forest Service Forest Inventory and Analysis (FIA) plots in each county. FIA survey crews inventory the trees and determine the ownership type for each plot. Because we hypothesized that people value the presence of publicly owned land, or land set aside from development (reserved) in a county, we calculated the percent of the area of each county owned by public agencies and the percent in a formal reserve status. Prior to 2000, FIA crews collected forest characteristics data in each state at approximately 13-year intervals. For FIA inventories for which the nominal dates differed from those used in our study (1980 or 1990), we interpolated values from the two inventories on either side of the date used (Table 2), which assumes a constant rate of change within counties over a span of 10–15 years. Long-term FIA monitoring in the region suggests that this is a reasonable assumption (T. Schmidt, personal communication, April 2002). Two indices of topographic relief were calculated from the USGS 1:250,000 digital elevation model (DEM); the range of elevations sampled on a 3×3 arc-second grid (USGS 1990) within each county, and the coefficient of variation (standard deviation/mean) of elevations. Density of shoreline was calculated as the ratio of the length of shoreline measured in kilometers to the land area measured in square kilometers. A square root transformation of shoreline density was used to make the relationship between shoreline density and the dependent variables more linear. A soil capability class index representing the suitability of the soils for agriculture was calculated for each county from the STATSGO dataset (US Department of Agriculture 1994). We calculated the average proportion of soils in each county that are in capability classes 1 and 2 (least limited soils) based on an area-weighted average of the abundance of each capability class in each STATSGO mapping unit.

Table 2. Dates of FIA inventories used to interpolate forest and ownership characteristics for 1980 and 1990.

State	1980	1990
Iowa	1974/1990	1990
Illinois	1985	1985/1998
Indiana	1967/1986	1986/1998
Michigan	1980	1980/1993
Minnesota	1977/1990	1990
Missouri	1976/1989	1989
Wisconsin	1983	1983/1996

Data prior to 1980 were not available for Illinois or Wisconsin.

Land cover composition was computed directly from the land cover maps. Land cover configuration is commonly quantified using spatial pattern indices. This was problematic for our study because our use of counties as analysis units had the potential to introduce boundary effects. Most patch-based indices are susceptible to boundary effects, where the index value is affected by patches that are truncated by map (county) boundaries (Gustafson 1998). We selected indices that are the least susceptible to boundary effects. To estimate forest fragmentation, we used the GISfrag index (Ripple et al. 1991). GISfrag represents the average distance of each forested pixel from the nearest non-forest land cover pixel. Lower values of GISfrag are found in more fragmented forests, where pixels tend to be closer to an edge. We minimized boundary effects by producing a region-wide map of the distance of each forested pixel from the nearest edge, and calculated the mean GISfrag value of each county from that map. Contagion quantifies adjacency relationships among land cover classes, and was calculated from the land cover maps using Fragstats 3.0 (McGarigal and Marks 1995; McGarigal et al. 2002). Contagion (C) measures both the intermixing of different land covers and the spatial distribution of land cover classes (dispersed or clumped), and is given by

$$C = 1 + \sum_{i=1}^{n} \sum_{j=1}^{n} p_{ij} \ln(p_{ij})/2\ln(n)$$

where p_{ij} is the probability of land cover type i being adjacent to land cover type j, and n is the total number of land cover types on the landscape (Li and Reynolds 1993). Low values of C result when a cell tends to be adjacent to cells of a different land cover type.

Distance from each county seat to the nearest urban center was calculated using three different criteria to define an urban center, based on the 1990 census. Local market centers were defined as cities with a population between 6500 and 100,000; medium cities (metropolitan statistical areas) had a population of 100,000 to 1,000,000; large cities (consolidated metropolitan statistical areas) had a population > 1,000,000 ($n = 8$). Driving distances were calculated between each county seat and the centroid of the city based on the USGS Major Roads of the United States DLG dataset using ArcView 3.2a Network Analyst. We included cities outside the study area when they were closer to counties than cities within the study area.

Hypothesis tests

We used simple regression to test each hypothesis for each independent variable (by province), testing for slope parameters that were significantly different from zero, using Table 1 to specify the sign of the expected relationship, and determine the number of tails for each hypothesis test. We transformed the three dependent variables to produce lognormal distributions, after adding 101 units to each measure to avoid negative values. Because we made multiple comparisons ($n = 15$) using the same data set, we applied a Bonferroni adjustment to t_{crit} to ensure that the probability (α) of committing a Type I error across all tests was no more than 0.05. One-tailed tests were applied when the sign of the relationship was part of the hypothesis (Table 1); ($t_{\alpha/15}$, $t_{\text{crit}} = 0.0033$). Two-tailed tests were conducted when the sign of the relationship was not hypothesized; ($t_{\alpha/(2*15)}$, $t_{\text{crit}} = 0.0017$). We used t-values to test the hypothesis that the slope coefficient for a variable equals zero, and to determine the sign of the relationship. The probability of a greater $|\,t\,|$-value for each factor was used to assess the relative importance of the factor for attracting people to live in an area. We determined whether the rates of population and housing density change varied by province by including dummy variables for province in the models, omitting a single province in turn and testing if the coefficients for the remaining provinces were significantly different from the omitted province.

Fortin (1999) argued that data aggregated over geographical space might violate the independence assumptions of conventional linear models because "everything is related to everything else, but near things are more related than distant things" (Tobler 1970, p. 236). Spatially autocorrelated errors yield severely biased variance estimators and in the case of positive autocorrelation, as would be expected here, underestimation of variance and overestimation of statistical significance (Griffith 1996). In the presence of spatial autocorrelation and the misspecification of the standard regression model caused by heteroscedasticity and/or correlated error terms, there are two principal model alternatives, the spatial error model (SEM) and the spatial lag model (SLM). In the SEM, the spatial autocorrelation pertains to the error term in the model. The dependent variable is represented by y, the independent variables by x, the regression parameters are represented by α and β_x, and the spatially autocorrelated error term is represented by u as follows (Anselin 1988):

$$y_i = \alpha + \sum_{j=1}^{k} \beta_x x_i + u_i$$

The error term u is comprised of two components:

$$u_i = \rho \sum_{j=1}^{n} w_{ij} u_j + \varepsilon_i \quad j \neq i$$

The familiar uncorrelated error term is ε with $N(0, \sigma^2 I)$. The spatial autoregressive error coefficient, ρ, is estimated for the w_{ij} elements of the $n \times n$ positive and symmetric spatial weights matrix, representing the specified spatial relationship among observations. In the SLM, the spatial autocorrelation pertains to the dependent variable, y, and is formalized in a mixed regressive, spatial autoregressive model, in which y_j is a spatially-lagged dependent variable and ρ, is the spatial autoregressive coefficient (Anselin 1988):

$$y_i = \alpha + \sum_{j=1}^{k} \beta_x x_i + \rho \sum_{j=1}^{n} w_{ij} y_j + \varepsilon_i \quad j \neq i$$

The spatial autoregressive lag coefficient, ρ, is estimated for the w_{ij} elements of the $n \times n$ positive and symmetric spatial weights matrix, representing the specified spatial relationship among observations. The coefficient ρ indicates the extent to which variation in the vector y is explained by neighboring values (LeSage 1997).

In our models, the spatial weights matrix was expressed as a first-order spatial contiguity matrix that delineates the neighborhood structure among adjacent counties. In this specification, the elements w_{ij} of the unstandardized weights matrix are 1 when counties i and j are neighbors and 0 when they are not (Bailey and Gatrell 1995; Lee and Wong 2001). We tested for spatial autocorrelation in the residuals derived from the initial ordinary least squares (OLS) models using Moran's *I* (Anselin 1988), and found that it was statistically significant. We also tested for spatial autocorrelation in the residuals derived from the initial SEM and SLM models using Morans *I*, and found that they were not statistically significant, indicating that both models adequately account for the spatial autocorrelation in the data. Although Moran's *I* is the most commonly used procedure for determining spatial autocorrelation, it is fairly unreliable (Anselin and Rey 1991), and more importantly for our purposes, does not provide guidance in terms of spatial autoregressive model selection between SEM and SLM. Based on Lagrange multiplier tests (Burridge 1980; Anselin 1988), we selected the SLM as being more appropriate than the SEM with regard to the spatial autocorrelation process present in the data and overall model fit.

Predictive models

We constructed multiple-regression models predicting change in population, total and seasonal housing density as a function of the significant variables for each province, and for the entire study area. When variables measuring a similar ecological characteristic (Table 1) within each county were highly correlated with each other, we selected the variable most correlated with the dependent variable, which also minimized collinearity within the model (as measured by the regression variance inflation factor (Mendenhall and Sincich 1989)). The R^2-values of the models were used to provide an indication of the importance of the independent variables in determining population and housing change, compared to economic, social and other factors that were not modeled. We compared the final models for each ecological province, looking for variables that were significant in more than one province, and for variables for which the strength of the relationship (as indicated by the significance of the t-statistic) varied by province, to understand how the ecological characteristics driving population and housing change may differ among ecological subregions within the study area.

Testing the models

To test the multiple-regression models, we used them to generate predictions of change in population, total and seasonal housing density in the most recent decade (1990–2000) based on ownership and ecological conditions in 1990 (derived from 1990–1992 Landsat TM and FIA data). We then compared those predictions to actual change as measured by the 1990 and 2000 censuses. Forest and landscape pattern characteristics in 1990 were estimated from NLCD land cover maps derived from TM imagery (Vogelmann et al. 2001). Patches smaller than 16 ha (4 ha for urban and water) were reclassified to the dominant land cover surrounding each patch, to match the minimum mapping unit of the LUDA maps used for 1980 land cover. We also used a common road, water and wetland layer in both maps, so that only changes in the location of forest, agriculture and developed land (urban) between the decades affected the analysis. Forest characteristics and ownership patterns in 1990 were interpolated from FIA data, using data available for the year closest to 1990 for each state (Table 2). The amount of water, shoreline and topographic relief were assumed to be unchanged from the model development data (ca. 1980).

We evaluated the three models (population, total housing and seasonal housing density) separately by plotting the density observed in 2000 US Census data against the density predicted by each model, and tested the hypothesis that the slope = 1.0. The average magnitude of population and housing change in the study area was not consistent for the 1980s and the 1990s, with population growth being greater in the 1980s and housing growth being greater in the 1990s. The statistical test of model utility is affected by these differences, and we adjusted our predictions by the difference in the average of each dependent variable for the two periods examined (1980–1990 and 1990–2000) for each province. Because this adjustment is quite coarse, we did not jointly test the hypothesis that the intercept was also 0.0 in our plots of the model tests (Dent and Blackie 1979). Slopes different than 1.0 imply an intercept different from 0.0. Because the data used to estimate some independent variables for model development and model testing were derived from different data sources (LUDA vs. NLCD), some prediction error was expected to result from measurement error of the input values. Model tests were therefore conservative (i.e., if the models have predictive value even in the face of this error, they can be considered relatively robust).

Results

We found significant spatial autocorrelation in the OLS model residuals for all independent variables ($\alpha = 0.05$), and based on Lagrange multiplier tests, we fit the SLM for all tests of hypotheses. In addition to the all-provinces model reported below, we estimated models that included dummy variables for province. The coefficients for the province dummy variables were all significant ($\alpha = 0.05$), except for a lack of difference in population growth between the Laurentian and Broadleaf Provinces. The significance of these province dummy variables indicates that even when controlling for the significant ecological determinants, the provinces were still significantly different from one another on all three dependent variables. Our tests of hypotheses using the individual province models demonstrated that the relationships between independent and dependent variables also vary by province, and that population, housing and seasonal housing densities responded to somewhat different ecological factors in each province.

Change in population density

Environmental factors were significantly related to population change between 1980 and 1990 (Table 3). Eleven of the 15 predictor variables were significant across the study area, and one

Table 3. Results of hypotheses tests about the relationship between the change in population density (1980 and 1990) and the independent variables. t-Values take the sign of the slope estimate, and test the hypothesis that the slope coefficient for the variable equals zero. Significant relationships are indicated by bold type, with t_{crit} adjusted using the Bonferroni method, and dependent on the number of tails tested (Table 1).

Independent variable	Broadleaf Province (n = 322)		Laurentian Province (n = 97)		Prairie Province (n = 224)		All provinces (n = 643)	
	t	Pr > $\lvert t\rvert$	t	Pr > $\lvert t\rvert$	t	Pr > $\lvert t\rvert$	t	Pr > $\lvert t\rvert$
Physiographic								
Index of topographic relief[a]	**3.34**	**0.0009**	**−3.60**	**0.0005**	**3.58**	**0.0004**	**3.95**	**0.0001**
SQRT Density of shoreline	**7.24**	**< 0.0001**	−1.73	0.0876	2.62	0.0094	**8.40**	**< 0.0001**
Soil capability class	**−4.16**	**< 0.0001**	−1.89	0.0620	−0.57	0.5683	**−6.07**	**< 0.0001**
Land cover composition								
% forest	**3.74**	**0.0002**	−1.86	0.0657	1.99	0.0480	**5.45**	**< 0.0001**
% agriculture	−2.84	0.0048	1.68	0.0952	**−3.05**	**0.0025**	**−6.13**	**< 0.0001**
% wetland	0.69	0.4930	−1.27	0.2078	−0.02	0.9859	**2.96**	**0.0031**
Ratio of forest to agriculture	1.49	0.1366	−2.98	0.0037	1.44	0.1526	−2.47	0.0136
Land cover configuration								
GISfrag (m)	2.24	0.0254	−2.77	0.0067	2.02	0.0444	1.15	0.2509
Contagion	**−5.17**	**< 0.0001**	−2.13	0.0360	**−4.10**	**0.0001**	**−14.24**	**< 0.0001**
Forest characteristics								
% of forest in sawtimber size class	0.45	0.9638	−0.76	0.4469	1.13	0.2581	−0.68	0.4948
Ownership characteristics								
% of forest in public ownership	0.55	0.5841	0.52	0.6018	0.48	0.6338	**3.28**	**0.0011**
% of locality in reserved status	1.24	0.2175	−2.55	0.0125	**3.55**	**0.0005**	−0.90	0.3675
Proximity to urban centers								
Distance to small (0.65^4–10^5 people) city (km)	−2.61	0.0095	1.58	0.1172	**−6.81**	**< 0.0001**	**−4.07**	**< 0.0001**
Distance to medium (10^5–10^6 people) city (km)	**−3.77**	**0.0002**	−0.26	0.7963	**−7.45**	**< 0.0001**	**−5.44**	**< 0.0001**
Distance to large (>10^6 people) city (km)	**−4.34**	**< 0.0001**	−2.68	0.0086	**−6.28**	**< 0.0001**	**−7.73**	**< 0.0001**

[a] The range in elevation within a county was used except for the Prairie Province, where the coefficient of variation of elevations within a county was used.

additional variable was significant in an individual province. In the Broadleaf Province populations declined in counties with productive soils and greater contagion of land cover, and increased in counties with more topographic relief, forests and water. In the Laurentian Province, populations grew more in counties with less varied terrain. In the Prairie Province, populations tended to grow more rapidly in counties with more topographic relief, and declined in agricultural counties and those with greater contagion of land cover. Faster growing counties also had a higher proportion of reserved land. When all provinces were combined, most explanatory variables were significant. The strongest relationships were with contagion, several land cover composition variables, soil capability and shoreline density. The relationships with proximity to urban center variables were significant for the Broadleaf and Prairie Provinces, but not the Laurentian Province.

Change in total housing density

Environmental variables also showed significant relationships with housing density change from 1980 to 1990 (Table 4). In the Broadleaf Province housing growth was greatest in counties where forests and water are abundant, where the ratio of forest to agriculture is greater, and where terrain is varied. Counties with the most productive soils and a high proportion of agriculture had less housing growth. In the Laurentian Province, housing growth was greatest where water is most abundant, and least where soil capability and

Table 4. Results of hypotheses tests about the relationship between the change in total housing density (1980 and 1990) and the independent variables. t-Values take the sign of the slope estimate, and test the hypothesis that the slope coefficient for the variable equals zero. Significant relationships are indicated by bold type, with t_{crit} adjusted using the Bonferroni method, and dependent on the number of tails tested (Table 1). Probability estimates indicated with an asterisk are not significant because the sign was different than hypothesized.

Independent variable	Broadleaf Province (n = 322)		Laurentian Province (n = 97)		Prairie Province (n = 224)		All provinces (n = 643)	
	t	$\Pr > \lvert t \rvert$	t	$\Pr > \lvert t \rvert$	t	$\Pr > \lvert t \rvert$	t	$\Pr > \lvert t \rvert$
Physiographic								
Index of topographic relief[a]	**4.14**	**<0.0001**	−1.21	0.2289	**4.32**	**<0.0001**	**5.87**	**<0.0001**
SQRT Density of shoreline	**10.24**	**<0.0001**	**4.98**	**<0.0001**	**8.80**	**<0.0001**	**20.78**	**<0.0001**
Soil capability class	**−4.91**	**<0.0001**	**−3.79**	**0.0003**	−0.80	0.4246	**−9.48**	**<0.0001**
Land cover composition								
% forest	**4.99**	**<0.0001**	2.75	0.0071	**4.38**	**<0.0001**	**14.65**	**<0.0001**
% agriculture	**−3.87**	**0.0001**	**−3.2**	**0.0018**	**−6.58**	**<0.0001**	**−14.81**	**<0.0001**
% wetland	2.66	0.0082	−0.51	0.6109	**4.63**	**<0.0001**	2.56	0.0108
Ratio of forest to agriculture	**3.05**	**0.0025**	0.19	0.8508	**4.71**	**<0.0001**	**4.15**	**<0.0001**
Land cover configuration								
GISfrag (m)	**3.54**	**0.0005**	0.58	0.5633	**4.55**	**<0.0001**	**9.40**	**<0.0001**
Contagion	**−5.37**	**<0.0001**	1.02	0.3117	**−6.96**	**<0.0001**	**−7.61**	**<0.0001**
Forest characteristics								
% of forest in sawtimber size class	−1.40	0.1619	−0.79	0.4323	1.24	0.2154	**−3.03**	**0.0025**
Ownership characteristics								
% of forest in public ownership	1.18	0.2372	2.06	0.0420	**4.71**	**<0.0001**	**10.42**	**<0.0001**
% of locality in reserved status	1.33	0.1856	−0.03	0.9733	**3.53**	**0.0005**	**3.99**	**0.0001**
Proximity to urban centers								
Distance to small (0.65^4–10^5 people) city (km)	1.47	0.1417	4.26	$<0.0001^*$	**−5.37**	**<0.0001**	3.97	$<0.0001^*$
Distance to medium (10^5-10^6 people) city (km)	−0.33	0.7383	3.23	0.0017^*	**−4.73**	**<0.0001**	4.70	$<0.0001^*$
Distance to large ($>10^6$ people) city (km)	−1.51	0.1319	1.97	0.0518	**−4.64**	**<0.0001**	2.38	0.0177

[a] The range in elevation within a county was used except for the Prairie Province, where the coefficient of variation of elevations within a county was used.

agriculture are high. In the Prairie Province, housing growth was higher in counties where topographic relief, water, wetlands and forest are relatively abundant, and where the ratio of forest to agriculture is high. Counties with a relatively high proportion of forest in public ownership and reserved status experienced greater housing growth. In the Broadleaf and Prairie Provinces, the relationship of population change with contagion and fragmentation had opposite signs. However, both provinces have large areas where the matrix is agriculture, and areas with larger and more contiguous forests will show less contagion of the agricultural matrix. The relationships with proximity to small and medium urban center were significant for the Laurentian and Prairie Provinces, but the sign of the relationship was opposite that expected in the Laurentian Province. When the provinces were combined in one model, all variables but wetland abundance and distance to large cities were significant. The strongest relationships were with land cover composition variables, forest fragmentation, shoreline density and percent of forest in public ownership.

Change in seasonal housing density

The results of each hypothesis test concerning change in seasonal housing density between 1980 and 1990 varied by province (Table 5). In the Broadleaf Province seasonal housing growth was positively related to the presence of water and to topographic relief. The negative association with contagion suggests that seasonal home location may be related to a greater interspersion of land

Table 5. Results of hypotheses tests about the relationship between the change in seasonal housing density (1980 and 1990) and the independent variables. t-values take the sign of the slope estimate, and test the hypothesis that the slope coefficient for the variable equals zero. Significant relationships are indicated by bold type, with t_{crit} adjusted using the Bonferroni method, and dependent on the number of tails tested (Table 1).

Independent variable	Broadleaf Province (n = 322)		Laurentian Province (n = 97)		Prairie Province (n = 224)		All provinces (n = 643)	
	t	$\Pr > \lvert t \rvert$	t	$\Pr > \lvert t \rvert$	t	$\Pr > \lvert t \rvert$	t	$\Pr > \lvert t \rvert$
Physiographic								
Index of topographic relief[a]	**2.99**	**0.0030**	0.98	0.3295	2.75	0.0064	**5.58**	< **0.0001**
SQRT Density of shoreline	**7.93**	< **0.0001**	1.48	0.1423	**6.93**	< **0.0001**	**14.70**	< **0.0001**
Soil capability class	−2.62	0.0091	0.52	0.6065	−1.14	0.2537	−**5.94**	< **0.0001**
Land cover composition								
% forest	2.47	0.0141	1.92	0.0573	**3.89**	**0.0001**	**9.95**	< **0.0001**
% agriculture	−1.13	0.2587	−1.81	0.0729	−**4.58**	< **0.0001**	−**9.64**	< **0.0001**
% wetland	**4.90**	< **0.0001**	1.23	0.2206	**4.74**	< **0.0001**	**6.50**	< **0.0001**
Ratio of forest to agriculture	1.61	0.1077	0.48	0.6297	**3.86**	**0.0001**	2.63	0.0086
Land cover configuration								
GISfrag (m)	2.17	0.0306	1.54	0.1271	**4.38**	< **0.0001**	**8.96**	< **0.0001**
Contagion	−**4.05**	**0.0001**	1.91	0.0592	−**5.09**	< **0.0001**	−**7.40**	< **0.0001**
Forest characteristics								
% of forest in sawtimber size class	−0.25	0.7999	0.06	0.9522	2.02	0.0446	−1.76	0.0787
Ownership characteristics								
% of forest in public ownership	1.34	0.1821	−0.13	0.8959	**3.09**	**0.0023**	**7.37**	< **0.0001**
% of locality in reserved status	−0.35	0.7255	1.28	0.2044	1.93	0.0543	**3.32**	**0.0009**
Proximity to urban centers								
Distance to small (0.65^4–10^5 people) city (km)	2.40	0.0169	−0.88	0.3793	−0.51	0.6074	2.23	0.0264
Distance to medium (10^5–10^6 people) city (km)	2.01	0.0456	0.63	0.5310	0.76	0.4475	**4.28**	< **0.0001**
Distance to large ($>10^6$ people) city (km)	1.03	0.3026	0.80	0.4240	−0.47	0.6397	2.90	0.0039

[a] The range in elevation within a county was used except for the Prairie Province, where the coefficient of variation of elevations within a county was used.

cover types within a county. In the Laurentian Province, seasonal housing growth was not related to any of the predictor variables studied. In the Prairie Province, seasonal housing growth was higher in counties where water, forests and wetlands were abundant, where land cover was less fragmented, and in counties with a higher proportion of forests in public ownership. When all provinces are taken together, all ecologic variables were significant except the ratio of forest to agriculture and the abundance of the sawtimber size class. However, of the proximity variables, only the distance to medium cities was significant. The strongest relationships were with land cover composition variables, shoreline density, land cover configuration and percent of forest in public ownership.

Predictive models

The matrix of correlations among independent variables (not shown) indicated that a number of variables were highly correlated in all provinces. These included proportion of forest, proportion of agriculture, ratio of forest to agriculture, indices of topographic relief, measures of forest fragmentation and soil capability. These are not spurious correlations. Forests commonly are found on soils that are marginal for agriculture, and where terrain makes other uses less attractive (Shands and Healy 1977; Foster 1992). These geophysical conditions tend to be spatially autocorrelated, so land uses tend to be clustered at the county scale. To avoid multicollinearity in our predictive regression models, we chose variables that reduced the variance inflation factor (VIF) for the variables in the model (Mendenhall and Sincich 1989). VIFs for all first-order variables included in the models were <0.6, and most were <0.25. We also eliminated variables that did not contribute significantly ($\alpha = 0.05$) to the model.

The SLM models predicting change in population, total and seasonal housing density over a 10-year period (1980 and 1990) are given below. The coefficients predict the log-transformed values of the dependent variables. Because we added 101 to each dependent variable prior to transformation to eliminate negative values, back transformation requires subtracting 101 from the antilog of the predicted density change. Because spatial autocorrelation was significant ($\alpha = 0.05$) in all models, we include the spatial lag coefficient (ρ). The R^2-values give an unbiased estimate of goodness-of-fit of the SLM models.

Broadleaf Province

Δ population density = 3.50 + .024 spatial lag + 0.0062 SQRT (shoreline density) + 0.0019% forest−0.0024% forest publicly owned−0.0001 distance to large city−0.0004 distance to medium city. R^2 = 0.35.

Δ total housing density = 2.91 + 0.36 spatial lag + 0.0107 SQRT (shoreline density) + 0.0024% forest + 0.0060% wetland−0.0043% forest publicly owned. R^2 = 0.49.

Δ seasonal housing density = 3.81 + 0.13 spatial lag + 0.0799 SQRT (shoreline density) + 0.0705% wetland + 0.0008 GISfrag. R^2 = 0.22.

Laurentian Province

Δ population density = 5.20−0.23 spatial lag−0.0003 range in elevation + 0.0020% forest publicly owned−0.0006 ratio forest:agriculture−0.00004 GISfrag. R^2 = 0.25.

Δ total housing density = 3.54 + 0.25 spatial lag + 0.0139 SQRT (shoreline density)−0.0026 soil capability + 0.0012 distance to small city. R^2 = 0.45.

Δ seasonal housing density = 4.75 + 0.13 spatial lag + 0.0171% forest + 0.0466% wetland−0.0196% forest publicly owned. R^2 = 0.13.

Prairie Province

Δ population density = 3.73 + 0.22 spatial lag−0.0010% agriculture − 0.0002 distance to large city−0.0004 distance to medium city−0.0009 distance to small city. R^2 = 0.40.

Δ total housing density = 4.01 + 0.16 spatial lag− 0.0016% agriculture + 0.0090 SQRT (shoreline density)−0.0001 distance to large city−0.0002 distance to medium city−0.0007 distance to small city. R^2 = 0.42.

Δ seasonal housing density = 4.28−0.02 spatial lag + 0.1358 SQRT(shoreline density). R^2 = 0.175.

All provinces combined

Δ population density = 3.40 + 0.26 spatial lag + 0.0013% forest + 0.0032 SQRT(shoreline density)−0.0002 distance to large city−0.0002 distance to medium city−0.0003 distance to small city. R^2 = 0.36.

Δ total housing density = 2.84 + 0.37 spatial lag + 0.0127 SQRT(shoreline density) + 0.0022% forest –0.0001 distance to medium city. R^2 = 0.67.

Δ seasonal housing density = 4.03 + 0.07 spatial lag + 0.0854 SQRT (shoreline density) + 0.0091% forest + 0.0715% wetland. R^2 = 0.32.

Model testing results

In all provinces, both separately and combined, the models for population density change showed some utility (Figures 3a, 4a, c and e). The slope of the relationship between predicted and observed values of population density change was clearly statistically equal to 1.0 for the Broadleaf ($\mathrm{Pr} > F = 0.39$) and Laurentian Province ($\mathrm{Pr} > F = 0.61$), and marginally equal to 1.0 for all provinces combined ($\mathrm{Pr} > F = 0.04$). The slope in the Prairie Province was not statistically equal to 1.0 ($\mathrm{Pr} > F = 0.006$), but it is positive (Figure 4e). Conversely, none of the models for total (Figures 3b, 4b, d and f) and seasonal housing density change Figure 3c, not shown by province) inspired confidence. None of the plots had a slope statistically equal to 1.0, although tests of the models predicting total housing density in the Broadleaf and Prairie Provinces produced a positive, nonzero slope ($\mathrm{Pr} > t < 0.0001$) (Figure 4b, f), suggesting that the models have some predictive power. Ecologic and proximity variables were consistently poor at predicting seasonal housing density change.

Discussion

Our hypothesis tests demonstrated that the changes (between 1980 and 1990) in population, housing and seasonal housing density in a county were significantly related to ecological conditions, with the significant variables varying by ecological province. We found that 13–67% of the variability in population, total and seasonal housing density change could be explained by environmental variables and proximity to urban centers, depending on the dependent variable and the province. We were able to generate predictive models, but only those predicting population density changes showed any utility. Because we considered only environmental and proximity to urban center variables as explanatory variables, these are not comprehensive predictive models, but they do suggest that environmental variables may improve models that include a wider range of driving factors.

Our results provide tests of specific hypotheses that are based on the assumption that people make choices about where to live and own seasonal homes at least partly based on environmental amenities. We generally assumed that people are attracted to water, forests and landscapes with diverse land uses. We also assumed that people prefer natural-appearing forests, and so would favor areas with less forest fragmentation and a higher level of protection from development and logging (Table 1). Proximity to urban centers was assumed to favor population and total housing growth, but that counties more distant from urban centers would have more seasonal housing growth. When a hypothesis was supported by the empirical data, we interpret this to mean that our assumption is not obviously faulty, but we must be cautious in inferring a causal relationship between environmental amenities and where people choose to live and recreate. Such inferences require more extensive evidence. However, where our tests of models do show predictive ability in the subsequent decade, our results can be viewed with some confidence.

Taken in total, our results generally supported our hypotheses that environmental amenities are associated with changes in population density, but we did not find evidence for a concurrent association with total and seasonal housing density. This result caused us to wonder if the poor relationship with seasonal housing density may have clouded the relationship with total housing density, but a cursory examination of the relationship with primary residence density (not reported) gave results similar to those for total housing density. *R*-squared values of individual hypothesis tests suggested that environmental amenities are better at predicting changes in total housing density than population density, but this was not borne out by

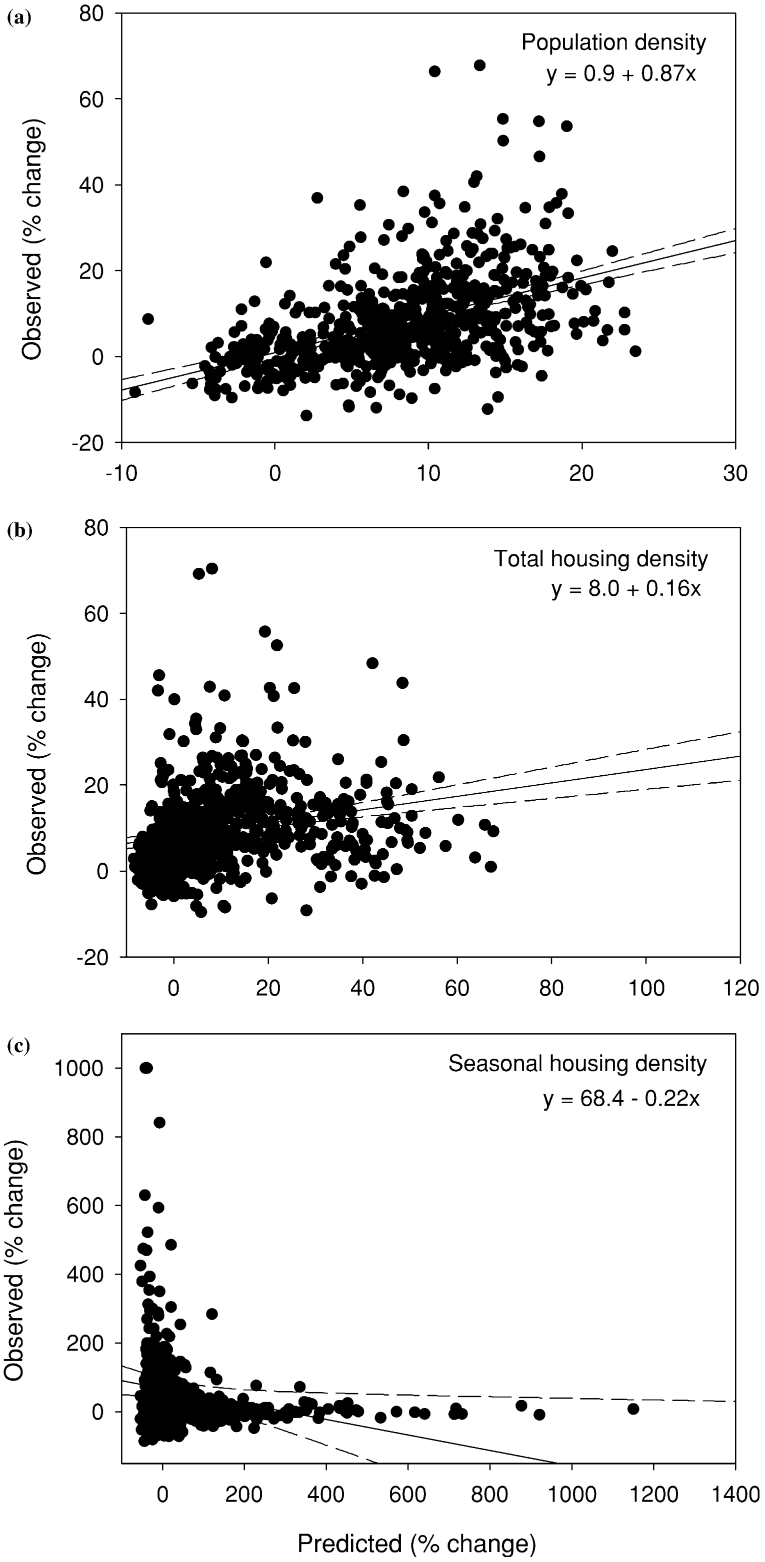

Figure 3. Plots of predicted change vs. observed change for all provinces combined in: (a) population density, (b) total housing density and (c) seasonal housing density.

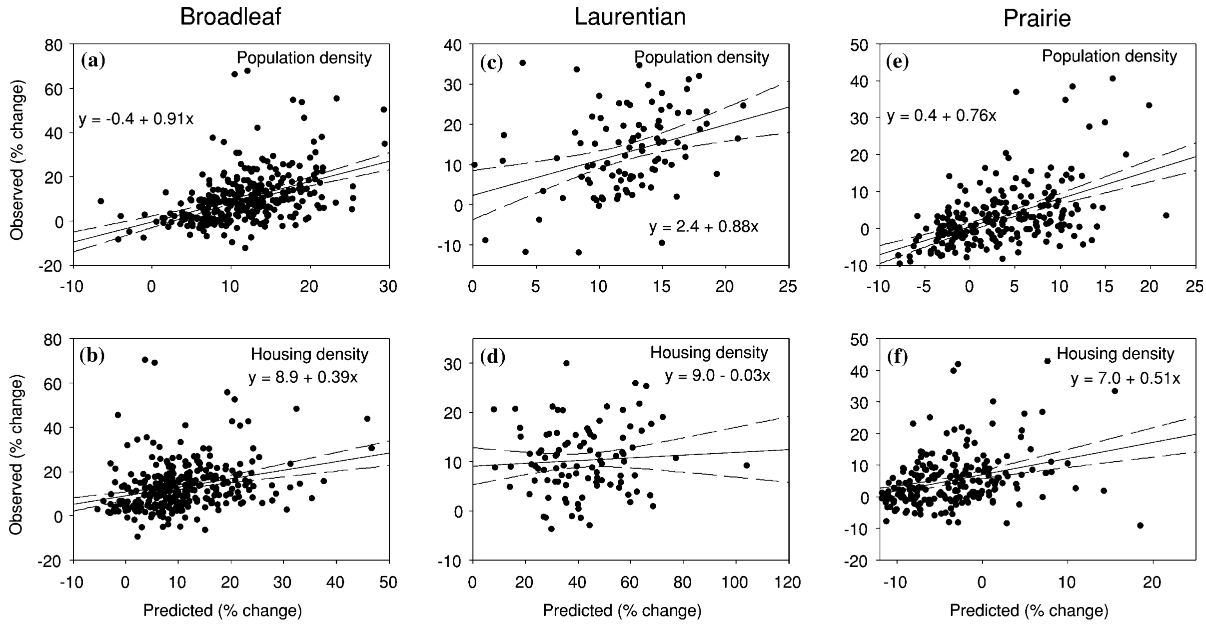

Figure 4. Plots of predicted change vs. observed change for each province in population density and total housing density.

the model tests. This inconsistency suggests that while environmental characteristics have some role in determining the distribution of people and housing, other factors likely have a stronger role, or that the relative importance of other factors changed between decades. High growth in a county in one decade may consume most of the land with the most desirable characteristics. In subsequent decades other counties with other characteristics may become more attractive. Our results also indicate that proximity to urban centers is not as dominant a factor in determining population and housing growth as may be assumed.

Understanding model shortcomings

Environmental determinants of change differ among the provinces. This is not surprising given marked differences in environmental conditions. For example, topographic relief and forests are not as common in the Prairie Province as elsewhere. The values and expectations relative to environmental amenities of people living in different provinces may also vary, partly based on what they are accustomed to, and on the amenities that are commonly available in the province. The negative relationship between the dependent variables and agricultural land cover reflects the widely reported exodus of people from rural agricultural counties. Conversely, seasonal housing growth was highest in counties that were less urban. Water was strongly associated with population and housing growth in the Broadleaf and Prairie Provinces, and forests only slightly less so. The poor performance of models predicting seasonal housing density is somewhat surprising, considering that seasonal housing decisions are affected by environmental factors, though as Stewart and Stynes (1994) note, many social factors are also important in seasonal home location choice. The relationship is weak even in the Laurentian Province, which is most strongly dominated by natural amenities of lakes and forests. Much of the Laurentian Province has experienced a dramatic increase in primary and seasonal housing density, especially in 'lakes districts' (Radeloff et al. 2001, in press; Hammer et al. 2004; Potts et al. 2004). It may be that the ubiquity of natural amenities makes it difficult to discover relationships because variability in independent variables is relatively low. Or perhaps the conversion of existing seasonal homes to permanent housing, especially driven by the first wave of baby boomer early retirements during the 1990s, confounded our analysis. We also speculate that the county may not be the appropriate scale to model these effects.

For example, lakes are known to be an attractive characteristic for seasonal housing location. But people are not satisfied to buy a seasonal just anywhere within a county having a lot of lakes; they want to be on or at least very near a lake. Accordingly, a finer spatial scale (e.g., township) may be a more appropriate scale to model such a relationship. Other variables that may be more appropriately modeled at a finer scale include topography, land cover composition, and forest characteristics. However, variables of land cover configuration, ownership and reserve status patterns are not likely important at a finer scale, and those found unimportant in our study may be safely ignored in future studies.

Because landscape configuration variables were highly correlated with the proportion of forest in a county, it was difficult to distinguish the importance of landscape configuration compared to landscape composition as a driver of change. Our predictive models never included both proportion of forest and a landscape configuration variable, to avoid multicollinearity problems. In choosing among several collinear variables, we struggled with whether to select the one we thought was the ultimate driver of amenity characteristics, or the characteristic that is observable by people. For example, forests often grow in locations with marginal soil for agriculture, or on less accessible terrain. Although soil capability may be driving the extent and location of forests, people directly observe the forests, not soil capability. We tended to choose more observable characteristics.

Our model testing results Figures 3 and 4) showed that some of the models have ability to predict the relative amount of change (regression lines show a significant slope), but do not accurately predict the absolute magnitude of the changes (scaling of the x and y axes are quite different). Rates of population growth and housing growth are not stable, and can vary markedly between decades Johnson and Fuguitt 2000; Hammer et al. 2004; Radeloff et al. in press). Although we attempted to correct for this difference, these attempts were unsuccessful. Our use of percent change as a dependent variable resulted in some large values in counties with an initially low density of population or housing, but an analysis of absolute change values (not presented) did not produce better performing models. Nonetheless, these problems are likely only a partial cause of the models' relatively poor performance. It is apparent that ecologic variables are not powerful predictors of population and housing density changes at this scale, especially for seasonal housing.

Understanding drivers of change

Our results (R^2-values) indicate that ecologic conditions and proximity to urban centers explained between 25 and 40% of the variability in population density change, 42–67% of the variability of total housing density change, and 13–32% of the variability in seasonal housing density change in the 1980s, depending on the province. The remaining non-random variation is presumably caused by economic and social factors, which are the subject of companion studies. The relatively strong relationship between ecologic factors and population and total housing growth is surprising, given the putative dominance of economic and social factors in driving decisions about where to live and work Johnson and Fuguitt 2000). Other studies found that environmental amenities are associated with population change at the national scale (McGranahan 1999). Our results suggest that environmental conditions may play some role in the spatial distribution of change at a regional scale. The poor performance of our models predicting seasonal housing density change suggests that other factors are dominant, such as past familiarity with an area (Stewart and Stynes 1994). When ecologic factors are included in more comprehensive models that include economic and social factors, we expect that the proportion of variability explained by ecologic factors may decrease, but remain significant.

Our results must be interpreted carefully in terms of the causes of population and housing density change. Are the changes observed driven by environmental amenities, or are the current amenities the result of a long-term trajectory of past population changes? For example, in the Prairie Province, do we see a positive relationship between population growth and land in forest reserves because people are being drawn to the reserves, or because these areas have had steady population growth in the past, and reserves were established to protect forests from development? A longer time series is required to answer this type of question. Although our results cannot definitively identify the extent to which amenities drive population and housing change, the fact that our models have some predictive value suggest that we can use these relationships to understand current and future change. Although preferences for living in more rural/natural settings have been stable over several decades (Fuguitt and Zuiches 1975; Fuguitt and Brown 1990), a next step for this analysis might be a survey to determine if people deciding where to live actually consider the specific ecological factors that we found significant and if those preferences vary across space.

Conclusions

Our study shows that environmental characteristics and proximity to urban centers influence the spatial distribution of population and housing change across seven Midwestern states, although other factors that were not modeled are clearly dominant. Our results provide some insight into which amenities are important at the county level, but additional work at a finer scale (e.g., township) is needed to elucidate this further. Our results provide information that complements our current understanding of the economic and social determinants of changes in the distribution of population and housing by documenting the effect of specific environmental amenities. Our modeling approach can also be applied to study economic and social factors, and models combining all three factors can provide a comprehensive tool to predict the distribution of future change.

Acknowledgments

We thank Dennis May, Tom Schmidt, Lisa Earle and John Vissage for providing FIA data and assistance in processing them for this study. Kathleen Bergen helped us procure LUDA data. We thank Sue Lietz, Liz Wenos and Brian Miranda for procuring and developing data sets from various sources. We thank Louis Iverson and Anantha Prasad for providing the topographical data. Bob Haight, Dan Brown and John Dwyer provided helpful comments on the study design, and Sue Stewart, Rachel Riemann, Ken Johnson and three anonymous reviewers helped us improve the manuscript. Funding was provided by North Central Research Station Research Work Units 4153 (Rhinelander WI) and 4902 (Evanston IL).

References

Ahn S., Plantinga A.J. and Alig R.J. 2000. Predicting future forestland area: a comparison of econometric approaches. Forest Sci. 46: 363–376.

Anselin L. 1988. Spatial Econometrics: Methods and Models. Kluwer Academic Publishers, Boston, MA, USA.

Anselin L. and Rey S. 1991. Properties of tests for spatial dependence in linear regression models. Geogr. Anal. 23: 112–131.

Bailey T.C. and Gatrell A.C. 1995. Interactive Spatial Data Analysis. Longman Limited, Essex, England.

Boarnet M.G. 1998. Spillovers and the locational effects of public infrastructure. J. Region. Sci. 38: 381–400.

Burridge P. 1980. On the Cliff-Ord test for spatial autocorrelation. J. R. Stat. Soc. B 42: 107–108.

Carlino G. and Mills L. 1996. Testing neoclassical convergence in regional incomes and earnings. Region. Sci. Urban Econ. 26: 565–590.

Deller S.C., Sue Tsai T.-H., Marcouiller D.W. and English D. 2001. The role of amenities and quality of life in rural economic growth. Am. J. Agric. Econ. 83: 352–365.

Dent J.B. and Blackie M.J. 1979. Systems simulation in agriculture. Applied Science Publishers Ltd., London, UK.

Fortin M.-J. 1999. Spatial statistics in landscape ecology. In: Klopatek J.M and Gardner R.H. (eds), Landscape Ecological Analysis: Issues and Applications. Springer-Verlag, New York, USA pp. 253–279.

Foster D.R. 1992. Land-use history (1730–1990) and vegetation dynamics in central New England, USA. J. Ecol. 80: 753–772.

Fuguitt G.V. and Brown D.L. 1990. Residential preferences and population redistribution: 1972–1998. Demography 27: 589–600.

Fuguitt G.V. and Zuiches J. J. 1975. Residential preferences and population redistribution. Demography 12: 491–504.

Gobster P.H., Haight R.G. and Shriner D. 2000. Landscape change in the Midwest: an integrated research and development program. J. Forest. 98(3): 9–14.

Griffith D.A. 1996. Introduction: the need for spatial statistics. In: Arlinghaus S.L., Griffith D.A., Arlinghaus W.C., Drake W.D. and Nystuen J.D. (eds), Practical Handbook of Spatial Statistics. CRC Press, New York, USA, pp. 1–15.

Gustafson E.J. 1998. Quantifying landscape spatial pattern: what is the state of the art? Ecosystems 1: 143–156.

Hammer R.B, Voss P.R. and Radeloff V.C. 2002. Sub-County Spatial Patterns of Residential Development from 1940–1990 in Wisconsin's North Woods. University of Wisconsin Center for Demography and Ecology, Working Paper 2002–13.

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

Henry M.S., Barkley D.L. and Bao S. 1997. The hinterland's stake in metropolitan growth: evidence from selected southern regions. J. Region. Sci. 37: 479–501.

Henry M.S., Schmitt B and Piguet V. 2001. Spatial econometric models for simultaneous systems: application to rural community growth in France. Int. Region. Sci. Rev. 24: 171–193.

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

Keys J.Jr., Carpenter C., Hooks S., Koenig F., McNab, W.H., Russell W. and Smith M.L. 1995. Ecological Units of the Eastern United States: First Approximation. USDA Forest Service, Southern Region, Atlanta, Georgia, USA.

Lee J. and Wong D.W.S. 2001. Statistical Analysis with ArcView GIS. John Wiley & Sons Inc., New York, USA.

LeSage J.P. 1997. Regression analysis of spatial data. J. Region. Anal. Policy 27: 83–94.

Li H. and Reynolds J.F. 1993. A new contagion index to quantify spatial patterns of landscapes. Landscape Ecol. 8: 155–162.

Long L. and Nucci A. 1997. The Hoover Index of population concentration: a correction and update. Environ. Plan. A 49: 431–440.

Marcouiller D.W., Kedzior R. and Clendenning J.G. 2002. Natural amenity-led development and rural planning. J. Plan. Lit. 16: 515–542.

McGarigal K. and Marks B.J. 1995. FRAGSTATS: Spatial pattern analysis program for quantifying landscape structure. General Technical Report, PNW-GTR-351. USDA Forest Service, Pacific Northwest Research Station, Portland, Oregon, USA.

McGarigal K., Cushman S.A., Neel M.C. and Ene E. 2002. FRAGSTATS: Spatial pattern analysis program for categorical maps. Published on URL server: http://www.umass.edu/landeco/research/fragstats/fragstats.html.

McGranahan D.A. 1999. Natural Amenities Drive Rural Population Change. USDA Economic Research Service, Agricultural Economic Report 781, Washington, DC, USA.

McGranahan D.A. and Beale C.L. 2002. Understanding rural population loss. Rural Am. 17: 2–11.

Mendenhall W. and Sincich T. 1989. A Second Course in Business Statistics: Regression Analysis. Dellen Publishing Co, San Francisco, CA, 864pp.

Potts R.S., Gustafson E.J., Brown D.G., Bergen K.M., Radeloff V.C., Hammer R.B., Bengston D. and Lietz S. 2004. The changing Midwest assessment: land cover, natural resources and people. USDA Forest Service, General Technical Report, NC-GTR-250, North Central Research Station, St. Paul, Minnesota, USA.

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

Radeloff V.C., Hammer R.B. and Stewart S.I. in press. Sprawl and forest fragmentation in the US Midwest from 1940 to 2000. Conserv. Biol.

Rey S.J. and Montouri B.D. 1999. US regional income convergence: A spatial econometric perspective. Regional Stud. 33: 143–156.

Ripple W.J., Bradshaw G.A. and Spies T.A. 1991. Measuring landscape pattern in the Cascade Range of Oregon USA. Biol. Conserv. 57: 73–88.

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

Shands W.E. and Healy R.G. 1977. The Lands Nobody Wanted. The Conservation Foundation, Washington, DC, USA.

So K.S., Orazem P.F. and Otto D.M. 2001. The effects of housing prices, wages, and commuting time on joint residential and job location choices. Am. J. Agric. Econ. 83: 1036–1048.

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

Tobler W. 1970. A computer movie simulating urban growth in the Detroit region. Econ. Geogr. 46(Supplement): 234–240.

US Department of Agriculture. 1994. State Soil Geographic (STATSGO) data base: data use information. USDA Natural Resource Conservation Service, National Soil Survey Center Misc. Pub. 1492., Washington, DC, USA.

USGS. 1990. Digital elevation models: US Geological Survey Data User's Guide 5. US Geological Survey, Reston, Virginia, USA.

Vogelmann J.E., Howard S.M., Yang L., Larson C.R., Wylie B.K. and Van Driel N. 2001. Completion of the 1990s national land cover data set for the conterminous United States from Landsat Thematic Mapper data and ancillary data sources. Photogr. Eng. Remote Sens. 67: 650–662.

Wear D.N. and Bolstad P. 1998. Land-use changes in southern Appalachian landscapes: spatial analysis and forecast evaluation. Ecosystems 1: 575–594.