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Rates and drivers of rural residential development in the Greater Yellowstone

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Abstract

Many natural and semi-natural ecosystems are undergoing dramatic conversions resulting from rapid growth in rural home construction. Yet, rates and drivers of rural residential expansion into previously agricultural and natural landscapes have not been widely analyzed. Immigration and rural development have been exceptionally rapid in the private lands surrounding Yellowstone and Grand Teton National Parks, known as the Greater Yellowstone ecosystem (GYE). Because the GYE has unique ecological value, is still largely undeveloped, and is currently characterized by unrestrictive land use policies, there are prime opportunities for improving regional growth management via the incorporation of scientific knowledge into local land use planning decisions. We quantified rates of growth in rural home construction in the GYE and considered the extent to which biophysical and socio-economic factors explained variation in the spatial pattern of rural home development. We applied generalized linear models and use versus availability analyses to examine specific hypotheses regarding the potential drivers of rural residential development. From 1970 to 1999, the GYE experienced a 58% increase in population and a 350% increase in the area of rural lands supporting exurban housing densities. By 1999, one third of exurban developments were distributed in remote rural locations. Patterns of rural development within the GYE have been strongly influenced by agricultural suitability, transportation and services, natural amenities, past development patterns, and economic and recreational characteristics of nearby towns. The proportion of homes built on highly productive soils and lands proximate to water has remained consistently high throughout the 1900s. We suspect that newer homes continue to be built near water and productive soils because of the influence of early settlement patterns and transportation routes. Our data suggest that the more productive farmlands will likely continue to experience a disproportionate level of development pressure, as will the biologically diverse riparian habitats and the private lands bordering the national parks. This pattern of development has the potential to erode the quality of the lowland habitats most used by park wildlife. Although the possibility exists for continued land use intensification in the GYE, we emphasize the potential for local policy decisions to effectively manage growth in rural residential development.

Keywords: Land use change; Rural residential development; Urban fringe; Exurban; Landscape planning; Growth management

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1. Introduction

In much of the world, rural landscapes are undergoing an intensification of human land use. The goods and services provided by these lands, including agricultural products, wildlife habitat, and the preservation of soil and water quality, are vital for humans as well as for the conservation of biodiversity. Globally, growth in the number of households has out-paced population growth (Liu et al., 2003). Such is the case in the United States, where rural lands are being rapidly converted to home sites. For American retirees, entrepreneurs, and others seeking small-town lifestyles and the natural amenities of rural landscapes, the countryside has become the preferred alternative to city life and suburbia (Rudzitis, 1999; Daniels, 1999).

This renewed preference for rural living can be observed in recent U.S. population trends and is especially prominent in the American West. Starting in the 1970s, U.S. rural population gains exceeded metropolitan population gains for the first time since the early 1800s (Johnson, 1998; Daniels, 1999). The overall trend has been one of dispersed settlement (Brown et al., in press), resulting in impacts upon extensive areas of pasture, cropland, range and forest. Growth in rural residential development (RRD) has been so widespread that a full 25% of U.S. lands are currently occupied at exurban densities of 1 unit per 0.4 hectares to 1 unit per 16.2 hectares (Brown et al., in press). Since 1970, population growth in the Mountain West has been more rapid than in the rest of the nation. Most of this growth has been attributed to immigration (Johnson, 1998), and along with the newcomers, sweeping economic, political and land use change have created the "New" West (Riebsame et al., 1997; Power and Barrett, 2001). The New West is characterized by the preferences of long time residents as well as newcomers, who are often wealthy young adults, professionals in service industries and retirees (Nelson, 1999) desiring ranchette-style homes on large lots. Within some areas of the New West, such as the counties surrounding Yellowstone National Park, RRD has been the primary type of land use change (Rasker and Hansen, 2000).

The factors driving rural development across the U.S. are thought to have evolved with human technology. One proposed paradigm of the drivers of human settlement describes three stages characterized by: (1) natural resource constraints, (2) transportation expansion and (3) pursuit of natural amenities (Huston, in press; Riebsame et al., 1996; Wyckoff and Dilsaver, 1995; James, 1995). According to this model, constraints on transportation required humans to settle close to the points of production of essential natural resources, most notably food crops. The advent of railroads and automobiles allowed resources to be transported from points of production, hence, settlement focused on transportation corridors. More recently, information technology has allowed goods and services to be shipped at very low costs and many people are choosing to live in rural mountain or lake locations distant from markets, but with high natural amenities.

In this study we evaluate the validity of this model for explaining patterns of RRD in the Greater Yellowstone ecosystem (GYE). We first quantify rates of growth in rural homes across the GYE. We then consider the extent to which agricultural suitability, factors related to transportation, and natural amenities explain variation in the spatial pattern of rural home development. The GYE contains Yellowstone and Grand Teton National Parks and the public and private lands adjacent to them. It is a region of distinctive ecological significance within the rapidly growing Rocky Mountain region. With just over 370,000 permanent residents (2.54 persons per square kilometer) in 2000, the GYE has a small but rapidly expanding population. Presently, three quarters of the private land area is undeveloped. However, developed land in the GYE is increasing faster than the rate of population growth, as large-lot rural subdivision continues to be the preferred mode of development. From 1970 to 1999, the GYE experienced an increase in population of 58% and an increase in the area of rural lands supporting residential development (at densities greater than one home per 16.2 hectares) of 350%.

This study is unique in that a database of rural homes has been compiled at a spatial scale resolute enough to analyze the relative importance of various drivers of human settlement for a large and complex region within the Rocky Mountains. We examined patterns of RRD across the GYE for several time periods throughout the 1900s. We first addressed the role of natural resource constraints in driving patterns of RRD from 1900 through 1999. We examined the assertion that growth in RRD during the early 1900s was a function of the quality and distribution of natural resources, particularly agricultural suitability, and that this relationship has weakened over time as transportation improvements and information technology allowed people to live greater distances from agricultural lands. We next addressed the role of natural resources, infrastructure and services, and natural amenities in driving recent growth patterns (1970–1999). This time period was selected due to the boom in RRD in the GYE since 1970 and due to the lack of available pre-1970 spatial datasets to represent these concepts, in particular infrastructure and services. Specific hypotheses for describing recent patterns of development across the GYE are as follows:

H1: Recent growth in RRD is strongly related to the distribution of natural resources.
H2: Recent growth in RRD was driven by transportation infrastructure and associated services.
H3: Recent growth in RRD reflects proximity to natural amenities.

In addition to evaluating these hypotheses, we quantified the role of nearby existing development in promoting the continued subdivision and development of rural lands. As rural housing density increases, more public services (e.g., roads, water lines, and schools) are provided, in turn attracting more development. In addition, the densification of development tends to raise property values, promoting further conversion of undeveloped land when current owners cannot pay property taxes or decide it is an opportune time to sell land.

Knowledge of factors that increase growth potential is needed because several characteristics of development patterns tend to be ecologically problematic. Many mechanisms by which land use change impacts ecological processes have been identified. These include introductions of new species, alteration of biotic interactions, changes in habitat extent and juxtaposition, changes to disturbance regimes, biomass changes, effects on air and water quality, light quality, and noise pollution (Dale et al., in press; Hansen et al., in press). In comparison with urban development, the ecological effects of RRD are likely to be larger (Theobald et al., 2000), because low-density development consumes more land, resulting in more extensive habitat conversion and fragmentation (Noss et al., 1994). Also, RRD tends to be distributed in areas with high biodiversity due to biophysical factors and natural amenities (Hansen et al., in press). The attraction of human-adaptive species and the avoidance by sensitive species may result in highly modified community assemblages near rural homes (McKinney, 2002; Hansen and Rotella, 2000; Garrott et al., 1993). In addition to such local effects, RRD may alter ecological processes on adjacent and even distant public lands (Hansen et al., in press).

The socio-economic consequences of RRD are related to environmental degradation, cultural changes, and costs of community services. Rural on-site septic systems for sewage disposal often overflow, leading to water quality problems (Daniels, 1999). Rural residents commuting long distances to work and shopping burn more gasoline, increasing air pollution (Daniels, 1999; Liu et al., 2003). Employment opportunities and traditional ways of life are rapidly changing as farms and ranches are subdivided and converted to home sites (Hansen et al., 2002). Rural development increases the costs of community services by increasing demands for new schools, fire stations, roads, sewer, water and utility lines. Costing more in services than is generated in property taxes, RRD is often a net drain on local government budgets (Urban Land Institute, 1992). In the GYE, most new growth is low-density, dispersed development that is more costly to provide services to than compact development (Haggerty, 1997).

Our hope is that an improved understanding of how and why development patterns occur will allow rural communities to manage residential development in a manner than minimizes ecological and socioeconomic costs. By incorporating knowledge of what drives RRD, policies in the GYE and similar regions can be drafted to more affectively direct future growth to the most suitable areas.

2. Study area

Centered on the Yellowstone Plateau, the Greater Yellowstone ecosystem was originally defined as the range of *Ursus arctos*, the Yellowstone grizzly bear (Craighead, 1991). Subsequently, Rasker (1991) expanded the study area boundary to include the 20 counties within Montana, Wyoming and Idaho that overlap the GYE (Fig. 1) in recognition of the strong ecological and socioeconomic linkages across the public and private lands of this region. The expanded boundary is

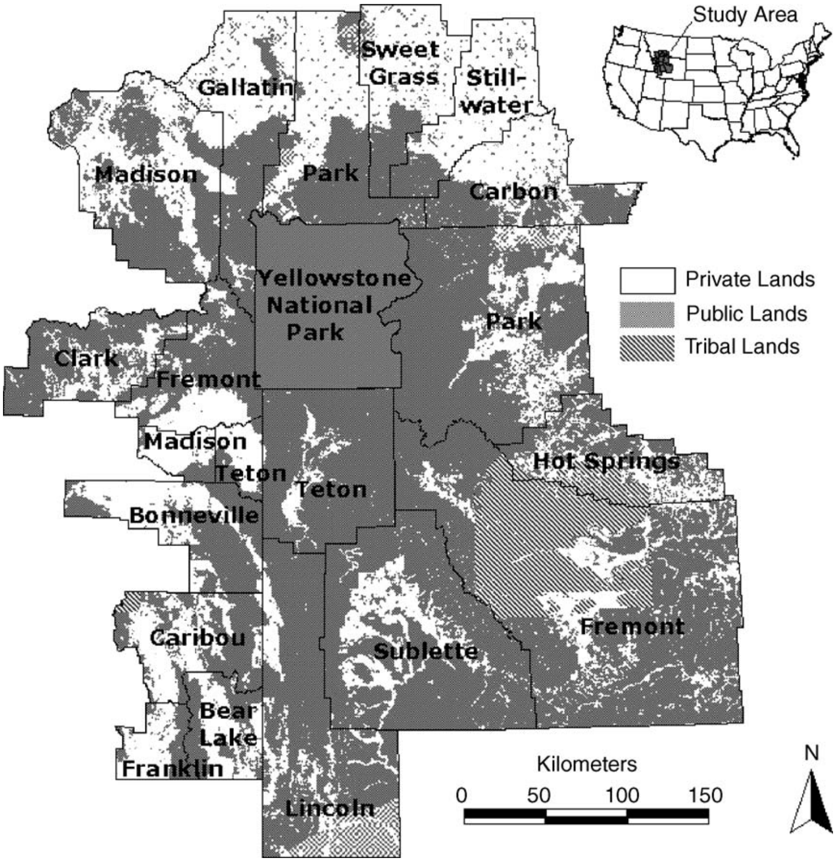

Fig. 1. The study area encompasses those twenty counties of Montana, Wyoming and Idaho that surround Yellowstone National Park. The public and tribal lands shown comprise 68% of the region.

appropriate for this study because in these states development regulations and growth management plans are implemented at the county level.

Of the 145,635 km^2 that make up the 20 counties of the GYE, only 32% of the area (47,249 km) is privately owned (Fig. 1). Another 32% is managed by the USDA Forest Service, and the remaining lands are USDI Bureau of Land Management (19%), Yellowstone and Grand Teton National Parks (7%), Tribal Lands (5%), and State Lands, wildlife refuges and other federal lands (5%). Because of extensive public ownership, it may be assumed that the influence of RRD on the ecosystem will be limited. However, many species of birds, butterflies, amphibians, and mammals in the GYE depend on resources found almost exclusively on private lands, which are primarily in valley bottoms and floodplains containing alluvial soils that are high in nutrients and water-holding capacity (Hansen and Rotella, 2002; Hansen et al., 2002). In contrast, the public lands in the GYE are mainly at high elevations and contain largely nutrient-poor soils (Rodman et al., 1996). Although only one-third of the GYE is privately owned, the private lands are a necessary component of the ecosystem.

The area is unique in the continental U.S. in that it supports several large carnivores and free-roaming populations of ungulates. The headwaters of seven major rivers originate in and around Yellowstone National Park, forming biologically diverse lowland riparian habitats surrounded by the semi-arid uplands. The majority of the region is mountainous with expansive areas of forest, shrubland and grassland. These environmental qualities have been suggested as major drivers of the demographic, economic and land use changes occurring in the New West (Huston, in press; Hansen et al., 2002; Rasker and Hansen, 2000; Riebsame et al., 1996).

3. Methods

3.1. Rural homes database

In order to examine trends in RRD in the GYE, we compiled a spatial database of rural homes. The database describes the locations of all known rural homes and the years in which they were built within the 20 counties of the GYE. Rural homes are defined as homes outside of incorporated city and town site boundaries, including subdivisions and excluding mobile homes, for which location descriptions were not available. The data were collected from County Tax Assessors offices and State Departments of Revenue, and are summarized per section, within township range blocks, according to the U.S. Public Land Survey System (PLSS). The resolution of the database is the area of a section, approximately 2.59 km^2. For every section within the study area, the database describes the number of rural homes present during each year, from 1857 through 1999.

Since errors may have been introduced during the process of data entry and linking spreadsheets to the geographic information system (GIS), we conducted an accuracy assessment of the rural homes database. Within a sample of 76 sections, we compared the number of rural homes reported by the database to the number counted from aerial photographs. The sections were sampled in locations where recent (post 1994) aerial photographs were available at the scale of 1:16,000 or greater. This criteria yielded samples in six GYE counties including Madison, Gallatin, Park, and Sweet Grass in Montana, and Sublette and Fremont in Wyoming. A paired *t*-test was used to test the null hypothesis that the mean of the differences in counts of homes per section between the tax assessor database and the aerial photographs was zero.

3.2. Rural resource constraints (1900–1999)

We evaluated the role of natural resource constraints in driving patterns of RRD (1900–1999); in particular, the assertion that growth during the early 1900s was a function of the distribution of natural resources and that this relationship has weakened as technology allowed people to live greater distances from these resources. Due to the mountainous terrain and semi-arid climate of the GYE, we believe that agricultural suitability and access to water were the primary natural resource constraints affecting early settlement patterns. Consequently, we used spatially explicit datasets describing agricultural suitability and distance to surface water to denote natural resource constraints. The agricultural dataset was calculated as the mean non-irrigated capability class per USDA STATSGO map unit, and rates suitability as a function of soil, topographic, and climatic characteristics. The hydrology dataset describes Euclidian distance to surface water as delineated in the National Hydrography Dataset (NHD) 1999 database. The NHD is based on the USGS 1:100,000-scale Digital Line Graph data, integrated with information from the US EPA Reach File Version 3.0.

We divided the 20th Century into four even time periods (1900–1925, 1925–1950, 1950–1975 and 1975–1999) and employed use versus availability analyses to examine the distribution of homes built within each period with respect to agricultural suitability and access to water. Soils were categorized one to five for least to most suitable for agriculture. Distance to surface water, measured in sections, was converted to five categories (0–1, 1–3, 3–5, 5–10, and 10–30). The observed numbers of homes built per agricultural and distance category during each time period was compared to the “expected” number if homes were distributed randomly with respect to that resource. We calculated the expected number of homes per category as the proportion of area occupied by the category multiplied by the total number of rural homes built during the time period. For example, the highest quality soils for agriculture make up only 6% of the study area, thus only 6% of homes built during each time period were expected to occur in these areas. For each time period a Chi-square goodness of fit test was used to test the hypothesis that the observed and expected values were drawn from the same distribution.

3.3. Correlates of recent growth (1970–1999)

We used a combination of exploratory statistical analyses and evaluation of specific hypotheses in order

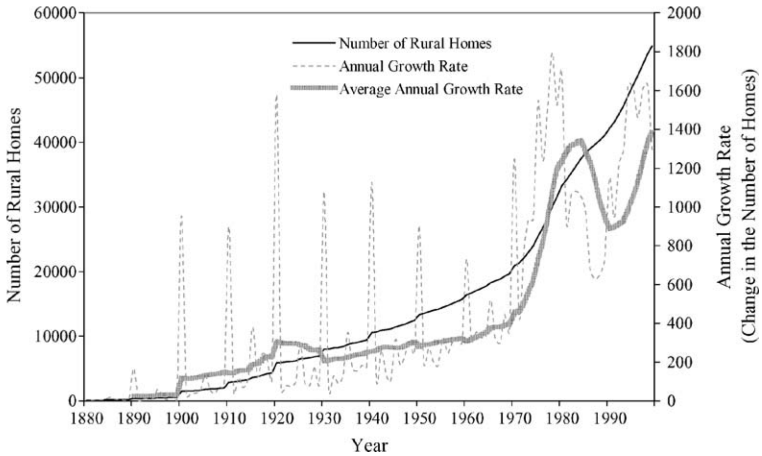

Fig. 2. Growth rates and increase in the number of rural homes in the GYE. Given n is equal to the number of homes during year t, the annual growth rate was calculated as $n_t - n_{(t-1)}$. The average annual growth rate was calculated as $(n_t - n_{(t-10)})/10$. Decadal spikes in the annual growth rate are a result of tax assessor's estimation of the year in which homes were built in the cases where the exact year is unknown.

to investigate recent trends in RRD. The response variable was the change in rural homes per section over the time period 1970–1999. The time period considered for this analysis was selected due to the acceleration in RRD since 1970 (Fig. 2), and due to the lack of available pre-1970 spatial datasets to represent infrastructure and services. We used exploratory analyses to identify those datasets within each of seven classes that explained the most variation in growth in RRD (Table 1). Within each class, all variables were fit to the response data using univariate generalized linear models and ranked according to Akaike's information criteria (AIC) (Burnham and Anderson, 2000). The variables selected in exploratory analyses were used to build four statistical models of growth in RRD (representing H1, H2, H3, and the influence of past development). In order to identify the most explanatory model overall, the four statistical models were grouped in all possible combinations and ranked according to AIC.

3.3.1. Explanatory variables

Potential explanatory variables were compiled for analyzing recent growth in RRD. These variables, summarized in the following paragraphs, describe the study area with respect to natural resources, transportation, services, natural amenities, and past development (Table 1). For further documentation of the rural homes data and all datasets collected as potential explanatory variables of growth in RRD see Hernandez et al., 2004.

We used transportation variables to measure accessibility to roads and airports. The road density variable describes kilometers of road per square kilometer. Distance to the nearest major road was measured in Euclidian or straight-line distance. The travel capacity index takes into account both road density and road class. The highest travel capacity values occur in areas containing both major highways and high road densities. The variables representing travel time to the nearest airport were calculated using cost-distance grid functions incorporating distance and automobile speed limits, following the methods of Nelson, (2001).

We used another group of variables to describe the availability of regional services, town-level economic services and town-level recreational services. Regional service-related variables included the travel time from schools, hospitals, and towns containing populations greater than 1000. This population threshold was used to identify towns with shopping and commercial resources. Town-level variables were used to explain variation in growth within rural areas bordering towns. The town-level economic services describe local employment opportunities and educational attainment, compiled from the 2000 U.S. Census Bureau DP-2 demographic profile tables. The town-level recreational services describe the per capita number of recreation-related businesses, as well as the accessibility and extent of surrounding lands that are protected

Table 1
Potential explanatory variables of growth in RRD from 1970 to 1999 were compiled from the listed sources

Model factors	Source	Scale
Natural resources		
Suitability for agriculture	DA State Soil Geographic Database	1:250,000
Transportation		
Road density	CB 2000 TIGER/Line Files	1:100,000
Euclidian distance from major roads	CB 2000 TIGER/Line Files	1:100,000
Travel capacity index	CB 2000 TIGER/Line Files	1:100,000
Airport travel time (all commercial airports)	GS/DOT 1998 National Atlas	1:2,000,000
Airport travel time (enplanement >25,000)	GS/DOT 1998 National Atlas	1:2,000,000
Airport travel time (enplanement >50,000)	GS/DOT 1998 National Atlas	1:2,000,000
Services		
School travel time	CB 2000 TIGER/Line Files	1:100,000
Hospital travel time	CB 2000 TIGER/Line Files	1:100,000
Town travel time (population >1000)	CB 2000 TIGER/Line Files	1:100,000
Services per town – economic		
Per capita income	CB 2000 DP-2 Demographic Profiles	1:100,000[a]
Professional employment	CB 2000 DP-2 Demographic Profiles	1:100,000[a]
Services employment	CB 2000 DP-2 Demographic Profiles	1:100,000[a]
Health services employment	CB 2000 DP-2 Demographic Profiles	1:100,000[a]
Construction employment	CB 2000 DP-2 Demographic Profiles	1:100,000[a]
Educational attainment	CB 2000 DP-2 Demographic Profiles	1:100,000[a]
Poverty index	CB 2000 DP-2 Demographic Profiles	1:100,000[a]
Unemployment index	CB 2000 DP-2 Demographic Profiles	1:100,000[a]
Services per town – recreational		
Entertainment services employment	CB 2000 DP-2 Demographic Profiles	1:100,000[a]
Seasonal housing proportion	CB 2000 DP-2 Demographic Profiles	1:100,000[a]
Guides/resorts index	YellowPages.com, Inc. 2001	1:100,000[a]
Lodging index	YellowPages.com, Inc. 2001	1:100,000[a]
Sports equipment index	YellowPages.com, Inc. 2001	1:100,000[a]
National park travel time	GS 2000 Political Boundaries	1:100,000
Euclidian distance to protected land	Various Sources[b] 1996–2002	1:100,000
Proportion protected land within 5-mile radius	Various Sources[b] 1996–2002	1:100,000
Proportion protected land within 10-mile radius	Various Sources[b] 1996–2002	1:100,000
Proportion protected land within 15-mile radius	Various Sources[b] 1996–2002	1:100,000
Natural amenities		
Mean annual precipitation	University of MT 1997 DayMet	1:24,000
Mean annual temperature	University of MT 1997 DayMet	1:24,000
Variation in elevation	GS 1999 National Elevation	1:24,000
Euclidian distance to all surface water	GS/EPA 1999 National Hydrography	1:100,000
Travel time to major surface water	GS/EPA 1999 National Hydrography	1:100,000
Euclidian distance to major surface water	GS/EPA 1999 National Hydrography	1:100,000
Euclidian distance to forested areas	GS 1992 National Land Cover	1:24,000
National park travel time	GS 2000 Political Boundaries	1:100,000
Euclidian distance to protected land	Various Sources[b] 1996–2002	1:100,000
Proportion protected land within 5-mile radius	Various Sources[b] 1996–2002	1:100,000
Proportion protected land within 10-mile radius	Various Sources[b] 1996-2002	1:100,000
Proportion protected land within 15-mile radius	Various Sources[b] 1996-2002	1:100,000
Past development		
Homes within 1 section radius	County Tax Assessors 1999–2001	1:100,000[a]
Homes within 2 section radius	County Tax Assessors 1999–2001	1:100,000[a]
Homes within 5 section radius	County Tax Assessors 1999–2001	1:100,000[a]
Homes within 10 section radius	County Tax Assessors 1999–2001	1:100,000[a]
Homes within 20 section radius	County Tax Assessors 1999–2001	1:100,000[a]

Federal agencies from which data were acquired are abbreviated (DA, Department of Agriculture; CB, Census Bureau; GS, Geological Survey; DOT, Department of Transportation; EPA, Environmental Protection Agency).

[a] Tabular source data, such as U.S. Census figures, were joined to spatial datasets with the listed scale.

[b] Sources for public land boundaries included the Montana Natural Heritage Program, the University of Wyoming Spatial Data and Visualization Center, and the Idaho Cooperative Fish and Wildlife Research Unit.

from development, including public lands and conservation easements.

We used variables describing climate, topography, hydrology, vegetation, and land ownership to represent natural amenities. Mean annual precipitation and temperature were used to represent local climatic variation. Topographic variation was calculated as the standard deviation in elevation per square mile neighborhood. Euclidian distance and travel time variables were used to represent access to surface water, forests, national parks, and lands protected from development, including public lands and conservation easements. Proportions of surrounding public lands and conservation easements were represented with three variables using neighborhoods of 5, 10, and 15-mile radii.

The past development variables were based on tax assessor records and represented the number of rural homes built prior to 1970. Past development was calculated within five neighborhoods, including a 1, 2, 5, 10, or 20-section radius.

3.3.2. Statistical analysis

We used generalized linear models and assumed a negative binomial distribution because the change in rural homes was represented as count data, with a non-normal distribution, and a variance greater than the mean (Proc GENMOD, SAS Institute Inc., 2001). After visually examining univariate plots of the response to the individual explanatory variables, we specified a log link in order to transform non-linear to linear relationships. We used Pearson's Chi-square statistics to assess goodness of fit. For a true model, the Pearson's Chi-square statistic divided by the degrees of freedom should asymptotically approach one (SAS Institute Inc., 1989).

Area was incorporated in the models as an offset variable because the area of all sections was not exactly 2.59 km^2. For example, sections along lake shores and county boundaries deviated substantially. An offset variable serves as a component of the linear predictor that has a fixed coefficient. Whereas regression coefficients are normally unknown parameters to be estimated by the procedure, area was assumed to have the constant coefficient of one per observation. This assumption was made because the relationship between change in home number and area of a section was expected to be multiplicative; all else being equal, twice the area should experience twice the increase in homes.

Exploratory analyses were used to identify the datasets within each of the seven classes (natural resources, transportation, general services, economic services, recreational services, natural amenities, and past development) that explained the most variation in growth in RRD (Table 1). Within each class, all variables were fit to the response data using univariate generalized linear models and ranked according to AIC. The highest ranked variables per class were used to build four statistical models representing H1, H2, H3, and the influence of past development. In cases where a second non-correlated variable within the same class improved the fit by more than 50 AIC units, the second variable was selected as well. Although the conventionally accepted cutoff for identifying the "best" model is a difference of two units, the cutoff was raised to 50 units to account for inflated delta AIC values resulting from the large sample size ($n = 24{,}999$).

The natural resources model represents our hypothesis (H1) that recent growth in RRD is related to a legacy of dependence upon agriculturally productive lands. The infrastructure model represents our hypothesis (H2) that transportation infrastructure and access to services explain growth in RRD. The natural amenities model represents our hypothesis (H3) that natural amenities drive the expansion of RRD, particularly in areas that were previously isolated, defined as sections (approximately 2.59 km^2 blocks) that prior to 1970 supported no homes. The past development model represents the influence of past development in promoting further development by affecting accessibility and land markets.

To represent these hypotheses, indicator variables were used in both the natural amenities and infrastructure models. In the natural amenities model, we used an indicator variable to identify previously isolated areas and interaction terms to incorporate the influence of natural amenities in these areas. In the infrastructure model, we used an indicator variable to identify areas considered to be within the zone of influence of towns, defined as those areas that are within a 10 min drive of towns. Of the 74 GYE towns, a sample of 30 was selected to represent the full range of populations and economies characteristic of GYE towns. This sample was small enough to enable data collection, and large enough to detect whether the incorporation of town characteristics significantly improved the explanatory power of the infrastructure model. The 10 min travel time zones around sampled towns were calculated following the methods of Nelson (2001). In these areas, local economic and recreational opportunities were modeled using the indicator town variable and interaction terms.

The four statistical models were grouped in all possible combinations and ranked according to AIC (Burnham and Anderson, 2000). The model that most accurately described growth in RRD from 1970 to 1999 was thereby identified.

3.3.3. Model validation

One quarter of private lands in the study area, a randomly selected 6217 sections, were used as a hold-back dataset, and were therefore excluded from all model building for later use in assessing model accuracy. To do this, each section was assigned a random number (between 0.0 and 1.0) generated from the uniform distribution, and those sections with numbers greater than 0.75 were excluded from the model building. For the remaining 75% of the sections, generalized linear models were fit as described above. To test for spatial autocorrelation, Pearson residuals from the "best" model, calculated as the raw residuals divided by the predicted standard deviation, were mapped in the GIS and plotted in variograms. The "best" model was then run for the hold-back dataset, and errors of overestimation and underestimation were summarized.

4. Results

4.1. Rural homes data validation and home distribution

In a comparison of the tax assessor rural homes database with homes identified on aerial photographs, the mean difference in counts of rural homes was 0.17 rural homes per section with a standard deviation of 1.65. Using a paired *t*-test, we failed to reject the hypothesis that the mean of the differences in counts between the tax assessor database and the aerial photographs was zero ($P = 0.37$). Thus, we maintain a high degree of confidence in the database developed using the tax assessor information.

The tax assessor rural homes database describes the distribution of homes in the GYE at the section scale (approximately 2.59 km^2 blocks) for each year between 1857 and 1999. Within the 145,635 km^2 study area, there are approximately 56,000 sections, of which 45% (24,999 sections) contain some private land. As of 1999, homes were distributed on 27% (6883 sections) of the sections containing private land. Of the rural sections containing homes, 11% (738 sections) exceeded the exurban density threshold of greater than one home per 16.2 hectares (Brown et al., in press). This threshold is meaningful because at this home density, areas are generally considered to be more populated than working agricultural lands. Within the GYE, 66% of areas containing exurban densities were within a 10-min drive of the nearest town. However, canyons and valleys that provide access to Yellowstone National Park, including Gallatin Canyon, Paradise Valley, Jackson Hole, and the mouth of Shoshone Canyon, supported exurban densities beyond the 10-min town zones.

4.2. Rates of rural home growth

The rate of rural home construction within the GYE rose in stages between 1900 and 1999, slowing only during two brief periods (Fig. 2). The average annual growth in rural home development spiked during the economic boom of the 1920s, slowed briefly during the Great Depression of the 1930s, but resumed and increased gradually throughout the following three decades. A dramatic spike in the 1970s increased the annual rate of rural home construction from 356 homes in 1969 to 1793 homes during 1978. Although the annual growth rate waned in the 1980s, it remained higher than the average pre-1970 annual growth rates, and recovered in the 1990s, reaching a peak rate in 1998, when 1633 rural homes were built. During the 1970s, 1980s, and 1990s, the growth rate of the GYE's population, fueled largely by immigration, exceeded that of three-quarters (78.2%) of counties in the U.S. (Hansen et al., 2002).

Among GYE counties, there has been wide variation in growth of rural home development. Between 1970 and 1990, the 5 counties with the largest increase in rural homes gained 12 times more rural homes than the 5 counties with the smallest increase (Fig. 3). The average annual growth rate of RRD in the 5 fastest growing counties was 127.43 rural homes per year as compared to the growth rate of the 5 slowest growing counties, 10.17 homes per year. Contained within the five fastest-

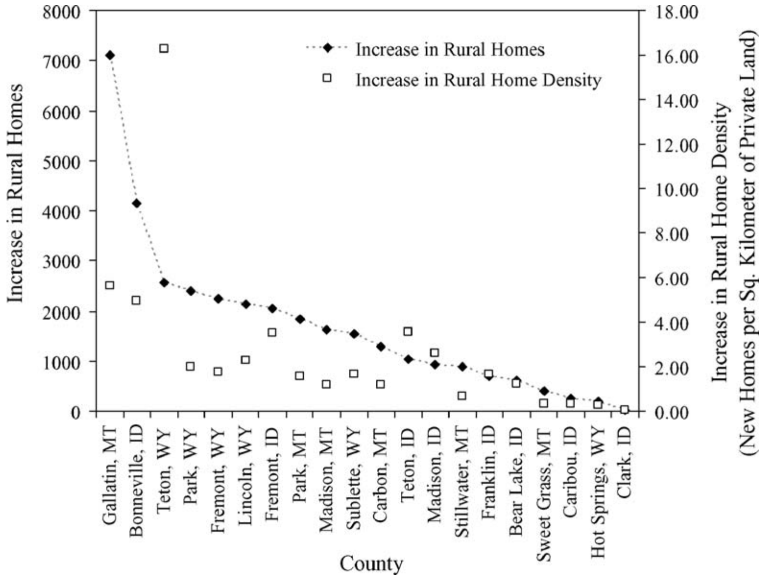

Fig. 3. Increase in rural homes and rural home density during 1970–1999, represented per GYE County.

growing counties are eight of the 10 largest towns in the GYE (Idaho Falls, Bozeman, Riverton, Cody, Lander, Ammon, Jackson, and Powell), indicating a strong link between RRD and the location of socioeconomic centers. Also during the 1970s, 1980s, and 1990s, there was wide variation in the increase in rural home density on private lands per county. The five counties that experienced the largest increases in rural home density grew by 2.03 homes per square kilometer. In comparison, the five counties that experienced the smallest increases in rural home density grew by only 0.15 homes per square kilometer.

Sub-county analyses of growth patterns are particularly useful in the Rocky Mountain West, where counties tend to be extremely large, 6845 km^2 on average. Due to their size, GYE counties tend to include a wide range of socio-political components, including more populated as well as extremely remote areas. Examining growth at the section level within the GYE was therefore necessary for detecting and explaining smaller scale development patterns. For example, although many of the fast growing counties during 1970 through 1999 contained larger towns, not all of the growth in RRD occurred adjacent to those towns. Much of the recent growth within these counties occurred in more isolated regions. Local regions that experienced rapid growth in RRD were more prevalent in the northwest, west and southwest portions of the study area (Fig. 4). This subset of the study area is characterized by greater average annual precipitation and more productive soils. Due to topographic relief and existing road corridors, the national parks are more easily accessed from these regions.

4.3. Natural resource constraints (1900–1999)

As expected, during the early 1900s, home sites were disproportionately located in highly productive soils and lands proximate to water (within 0–3 sections) (Table 2). Although we expected this relationship to weaken over time, it remained consistent throughout the four time periods considered (1900–1925, 1925–1950, 1950–1975 and 1975–1999). For each time period we rejected the hypotheses that rural homes were distributed randomly with respect to soil productivity and proximity to surface water ($P < 0.001$).

4.4. Correlates of recent growth (1970–1999)

4.4.1. Exploratory analyses

As a result of the exploratory analyses, variables within each of seven classes were selected for use in evaluating H1-3 (Table 3). Within the natural resources

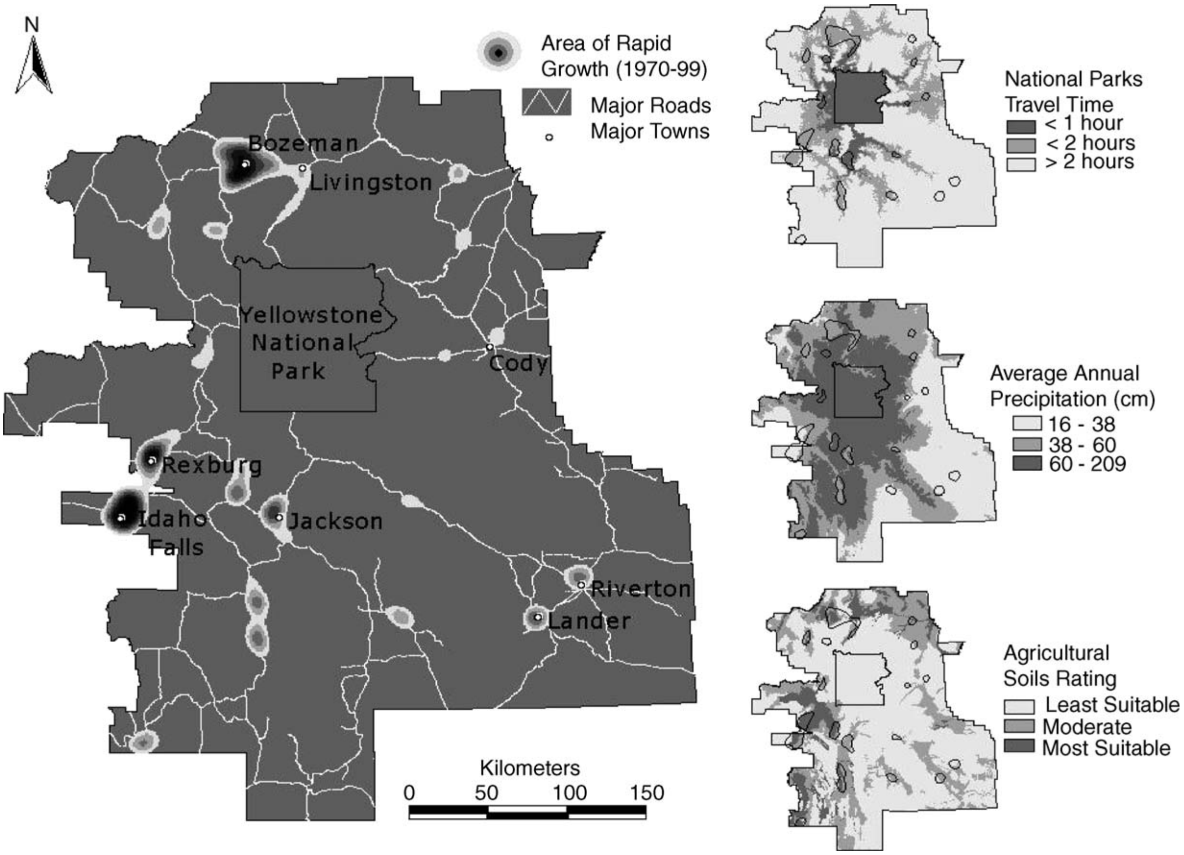

Fig. 4. Areas of rapid growth in RRD during 1970–1999 are represented as kernel density polygons. Within these polygons are high densities of sections in which growth was greater than one standard deviation above the mean (light gray) to greater than three standard deviations above the mean (black). Some of the factors correlated with these growth patterns include: travel time from the national parks, mean annual precipitation, and agricultural suitability.

class, the suitability for agriculture variable was positively related to growth in RRD (P-value < 0.0001). All transportation-related variables were significantly related to growth patterns (P-value < 0.0001). Growth was positively related to travel capacity and negatively related to distance from major roads and travel time from airports. Among the transportation variables, road density performed the best, according to the AIC weights (β = 0.0169, S.E. = 0.0003, χ^2/d.f. = 1.64), and was positively correlated with growth in RRD during 1970 through 1999. Within the services class, growth was negatively related to travel time from towns and schools (P-value < 0.0001). Travel time to the nearest hospital ranked the highest (β = −0.0058, S.E. = 0.0004, χ^2/d.f. = 5.09). Thus, sections near hospitals tended to experience more growth in RRD.

Within the town-level economic services class, several of the variables were insignificant at $\alpha = 0.05$, including the proportion of population below poverty, and the proportion of construction, service, and health-related employment. The proportion of professional employment, including scientific, administrative, and waste management services, was positively related to growth in RRD (P-value < 0.0001). Both per capita income and unemployment were positively related to growth (P-value < 0.01). Within the town-level economic services class, the education attainment index performed the best ($\beta = 0.0581$, S.E. = 0.0080, χ^2/d.f. = 3.76). Thus, towns in which a large proportion

Table 2
Differences between observed numbers of rural homes and expected numbers of rural homes per agricultural suitability class and distance to surface water class presented over four time periods

Landscape attribute	Observed − expected[c]			
	1900–1925	1925–1950	1950–1975	1975–1999
Agricultural rating[a]				
1	−159	−32	−178	−907
2	−632	−228	−755	−2210
3	−146	−732	−1228	−1530
4	657	655	1495	2793
5	280	336	667	1853
Distance to surface water[b]				
0–1	812	1306	2486	5636
1–3	328	589	872	2413
3–5	−143	−301	−358	−504
5–10	−493	−892	−1713	−3873
10–30	−504	−703	−1286	−3672

[a] Soils are ranked 1 for least suitable for agriculture to five for most suitable for agriculture.
[b] Distance to surface water is measured in sections.
[c] Expected numbers signify a random distribution with respect to agriculture and distance classes, and were calculated as the proportion of area occupied by the class multiplied by the total number of observed rural homes.

of the population over 25 years of age had attained a bachelor's degree or higher tended to experience faster growth in adjacent rural areas.

Within the town-level recreational services class, many of the variables were insignificant at $\alpha = 0.05$, including measures of per capita recreation-related business, measures of the extent of surrounding public land ownership and conservation easement, and the proportion of seasonally occupied homes. The proportion of employment in entertainment services was positively correlated with growth (P-value = 0.03). Travel time to the national parks was ranked highest ($\beta = -0.0116$, S.E. = 0.0020, χ^2/d.f. = 3.75). Thus, sections near towns near Grand Teton and Yellowstone National Parks tended to experience more growth in RRD. Interestingly, distance from public lands and easements was positively related to growth. Thus, rural areas bordering towns further from public lands and easements tended to experience more growth.

Within the natural amenities class, all of the variables were significantly related to growth in RRD at $\alpha = 0.05$. Travel time to the national parks was ranked highest ($\beta = -0.0041$, S.E. = 0.0004, χ^2/d.f. = 3.75). Thus, undeveloped sections distant from the national parks were less likely to be developed. There was strong evidence favoring the travel time from national parks variable in describing growth around both around towns and in previously isolated areas (χ^2/d.f. = 3.75 and 9.45, respectively). However, travel time from national parks inadequately described variation in RRD within the study area as a whole (χ^2/d.f. = 499.06). Euclidian distance to major streams, rivers and water bodies was not strongly correlated with travel time from national parks (V.I.F. = 1.03) and was negatively correlated with growth ($\beta = -0.0001$, S.E. < 0.0001). Precipitation and temperature were positively related to growth (P-value < 0.0001). Euclidian distance from forested areas was negatively correlated with growth (P-value < 0.0001). Similar to the town level analyses, all measures of proximity to public lands and conservation easements were positively related to growth (P-value < 0.0001).

Within the past development class, the variable that performed the best based on the AIC weights was past development per section (β = 0.1052, S.E. = 0.0032, χ^2/d.f. = 5.28). The quadratic form of past development within a 20-section radius was not strongly correlated with past development per section (V.I.F. = 1.13) and positively related to growth (β = 0.0019, S.E. = 0.0001, χ^2/d.f. = 3.71). The estimated coefficient for the squared term in the quadratic was negative (β = −0.0001, S.E. < 0.0001), reflecting that the change in the rate of growth slowed with increasing rural home density.

Table 3
Exploratory selection results are provided for the univariate models of growth in RRD from 1970–1999

Model factors	Sign	Delta AIC	χ^2/d.f.[c]	*P*-value
Natural resources				
Suitability for agriculture[a]	+	na	3.09	<0.0001
Transportation				
Road density[a]	+	0	1.64	<0.0001
Travel capacity index	+	892	1.62	<0.0001
Airport travel time (enplanement >50,000)	−	2524	43.33	<0.0001
Euclidian distance from major roads	−	2568	2.85	<0.0001
Airport travel time (enplanement >25,000)	−	2760	13.02	<0.0001
Airport travel time (all commercial airports)	−	3066	9.03	<0.0001
Services				
Hospital travel time[a]	−	0	5.09	<0.0001
Town travel time (population >1000)	−	82	5.19	<0.0001
School travel time	−	106	3.64	<0.0001
Services per town – economic				
Educational attainment[a]	+	0	3.76	<0.0001
Professional employment	+	28	3.73	<0.0001
Unemployment index	+	52	3.73	0.0016
Per capita income	+	54	3.73	0.0044
Poverty index	+	60	3.73	0.1785
Services employment	+	62	3.73	0.6731
Construction employment	+	62	3.73	0.533
Health services employment	+	62	3.73	0.7697
Services per town – recreational				
National park travel time[a]	−	0	3.75	<0.0001
Entertainment services employment	+	28	3.73	0.0332
Euclidian distance to public land	+	30	3.73	0.0465
Guides/resorts index	+	32	3.73	0.3101
Sports equipment index	+	32	3.73	0.2766
Proportion public land within 5-mile radius	−	32	3.73	0.2282
Proportion public land within 10-mile radius	−	32	3.73	0.3083
Proportion public land within 15-mile radius	−	32	3.73	0.2138
Seasonal housing proportion	+	34	3.73	0.5608
Lodging index	−	34	3.73	0.3198
Natural amenities				
National park travel time[a]	−	0	9.45	<0.0001
Euclidian distance to major surface water[b]	−	26	9.41	<0.0001
Travel time to major surface water	−	34	9.53	<0.0001
Mean annual precipitation	+	62	9.36	<0.0001
Euclidian distance to forested areas	−	64	9.34	<0.0001
Euclidian distance to all surface water	−	68	9.33	<0.01
Euclidian distance to public land	+	72	9.32	<0.0001
Proportion public land within 15-mile radius	−	74	9.49	<0.0001
Mean annual temperature	+	74	9.33	<0.0001
Variation in elevation	−	74	9.32	<0.0001
Proportion public land within 10-mile radius	−	76	9.33	<0.0001
Proportion public land within 5-mile radius	−	76	9.32	<0.0001
Past development				
Homes within 1 section radius[a]	+	0	5.28	<0.0001
Homes within 2 section radius	+	206	5.24	<0.0001
Homes within 5 section radius	+	620	5.34	<0.0001
Homes within 10 section radius	+	1168	4.74	<0.0001
Homes within 20 section radius[b]	+	1670	3.71	<0.0001

Potential explanatory variables within each category (natural resources, transportation, services, etc.) were ranked according to Delta AIC values

[a] AIC weights equal 1 for these factors and 0 for the remaining factors within the same class.

[b] Factors not strongly correlated with the highest ranked factor within the same class which were selected for use in model comparisons.

[c] Pearson's statistic divided by the degrees of freedom was used as an approximate guide to the measure of fit.

Table 4
The structure of the hypothesized models of growth in RRD from 1970 to 1999 was determined via exploratory analysis

Hypothesis	Description	Model structure
H1	Natural resources	Ag
H2	Transportation and services	RdDens + Hosp + Twn + (Twn × Np) + (Twn × Edu)
H3	Natural amenities	Wat + Isol + (Isol × Np)
Dev	Past development	Dev1 + Dev20 + (Dev20 × Dev20)

Ag, rating for agricultural suitability; RdDens, road density; Hosp, travel time from nearest hospital; Twn, within town zone of influence (indicator); Np, travel time from national parks; Edu, education attainment; Wat, euclidian distance from major rivers and water bodies; Isol, previously isolated area (indicator); Dev1, past development per section; Dev20, past development within 20 section neighborhood.

4.4.2. *Statistical models*

The variables selected in exploratory analyses were used to build four multivariate statistical models of growth in RRD (Table 4). These models were used to evaluate the hypotheses stated in the introduction. Among the four individual models of growth in RRD during 1970–1999 (Table 5), the data most strongly supported the transportation and services model (H2), which incorporated the effects of towns (AIC weight = 1). The natural amenities model (H3) was ranked second highest after the transportation and services model (Delta AIC = 124). The past development model ranked third (Delta AIC = 1273), followed by the agricultural suitability model (H1, Delta AIC = 3710).

Table 5
Model selection results for all possible combinations of the hypothesized models of growth in RRD from 1970 to 1999

Model structure	*k*	Delta AIC
H1 + H2 + H3 + Dev[a]	14	0
H2 + H3 + Dev	13	88
H1 + H2 + H3	11	425
H2 + H3	10	459
H1 + H2 + Dev	11	1805
H2 + Dev	10	1825
H1 + H3 + Dev	9	2444
H3 + Dev	8	2459
H1 + H2	8	3136
H2	7	3156
H1 + H3	6	3254
H3	5	3275
H1 + Dev	6	4424
H4	5	4425
H1	3	6858

k, number of estimated parameters per model; H1, natural resource constraints; H2, transportation infrastructure and services (including town effects); H3, natural amenities; Dev, past development.

[a] AIC weight equals 1 for the most inclusive model and 0 for all the remaining models; AIC value = −83765.

Among the 15 models of growth in RRD during 1970–1999 (representing all possible combinations of the four multivariate models) (Table 5), there was clear support for one model according to the AIC weights. This model incorporated agricultural suitability, past development, transportation infrastructure and accessibility to services, as well as the effects of towns and natural amenities (χ^2/d.f. = 3.11). All variables in this model were significant except for the interaction between the town indicator and the education attainment index (*P*-value = 0.53). The signs of the coefficient estimates remained the same as in the exploratory analyses, except for the estimate for agricultural suitability. The estimate changed to a negative value indicating that the variable was redundant with other variables in the model, despite having a low V.I.F. (1.15). Growth was positively related to road density, past development and the education attainment index, and negatively related to distance from surface water, travel time to hospitals and travel time to national parks.

4.4.3. *Model validation*

Leaving out the agricultural suitability variable, Pearson residuals were calculated for the best model, mapped in GIS, and plotted in a variogram (Fig. 5). No spatial pattern was evident in the GIS map of Pearson residuals, and the variogram showed only weak spatial autocorrelation in the residual variation. It is therefore likely that the best model captured the relevant variables to explain existing spatial patterns in RRD.

The best model was run for the hold-back dataset, and errors of overestimation and underestimation were calculated. The mean difference between predicted growth in the number of rural homes and observed growth per section was −1.18 homes with a standard deviation of 9.59. Of the 6217 sections evaluated, the increase in the number of rural homes was correctly predicted for 80% (4953 sections). In 104 sections growth was overestimated, and in 1160 sections growth was underestimated (Fig. 6). Of those sections in which growth was underestimated, the mean difference was 7 homes. Of the sections in which growth was overestimated, the mean difference was 4 homes.

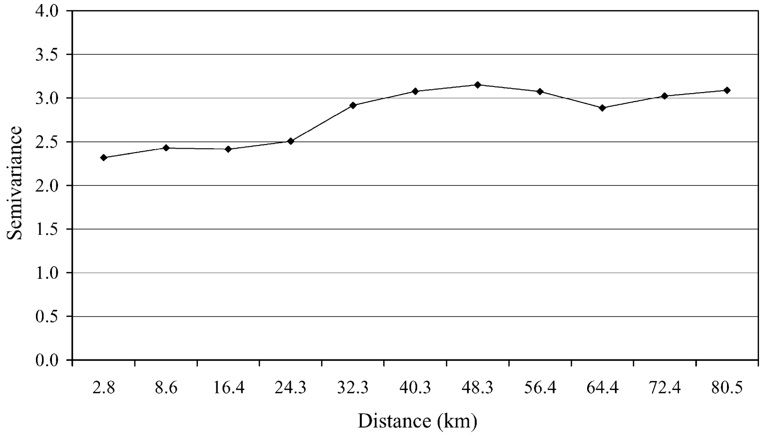

Fig. 5. Weak spatial autocorrelation is evident in the variation in Pearson residuals of the "best" model. Spatial independence increases slightly with increasing distance and plateaus at roughly 30 km.

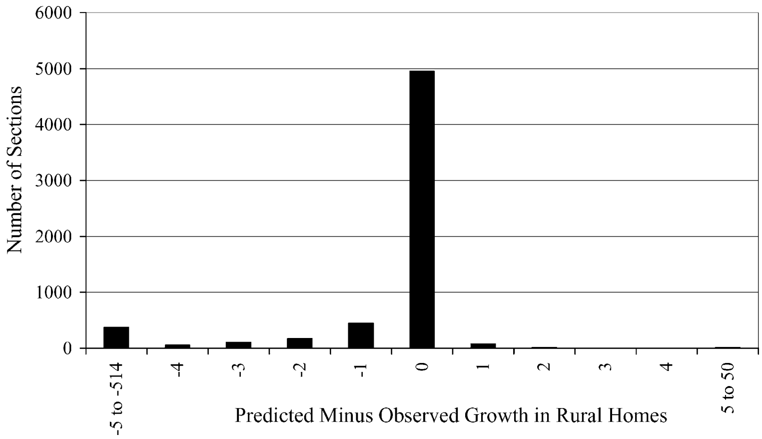

Fig. 6. A linear equation representing the "best" model was used to calculate the predicted values of growth in rural homes per section within the hold-back dataset. The observed growth in rural homes was subtracted from the predicted growth, and the differences were plotted according to frequency. Errors of over and underestimation are represented.

Using a paired *t*-test, we failed to reject the hypothesis that the mean of the differences between observed and predicted change in rural homes was zero ($P = 0.11$).

5. Discussion

5.1. Rates of RRD

During the past century, the rate of rural home construction within the GYE rose in stages, responding to cultural shifts and periods of national economic growth and recession (Fig. 2). Growth in rural home development spiked during the economic boom of the 1920s, when the automobile began to enable more dispersed settlement. Rural home construction then slowed for a brief period during the Great Depression of the 1930s, but resumed and increased slowly throughout the following three decades. The 1970s were known nationally as the time of "rural renaissance", during which the populations of non-metropolitan counties grew at a faster pace than metropolitan counties, and rural development trends in the GYE mirror this national trend. The large-scale immigration to rural areas during the

1970s has been linked to the crime and racial conflicts associated with metropolitan areas, as well as the social movement to reconnect with nature (Daniels, 1999). Our data support that natural amenities have been a key driver of RRD within the GYE throughout the 1970s, 1980s and 1990s. Several researchers believe that immigration to areas rich in natural amenities will continue, and the population of the GYE will grow faster than the nation as a whole (Cromartie and Wardell, 1999). It has also been suggested that, in many regions of the world, the primary pressure on local biodiversity will come from sprawl and impacts associated with increased numbers of households (Liu et al., 2003). Indeed, this may be the case for the GYE.

5.2. Drivers of RRD

Our results indicate that the proportion of rural homes built on highly productive soils and lands proximate to water has remained consistently high throughout the 1900s. We expected access to these natural resources to be the primary determinant of home site locations during earlier time periods, when the lack of existing transportation infrastructure necessitated self-sufficiency. This expectation was supported by the data. Due to technological advances allowing for the efficient transport of goods, we expected the tie between natural resources and RRD to have weakened during the later half of the century. However, this theory was not supported. One possible explanation is that the natural resources measured, soil quality and proximity to water, continue to constrain growth. However, farming and other natural resource industries have become increasingly marginal to rural economies (Galston and Baehler, 1995; Power and Barrett, 2001). Thus, this scenario is improbable and not supported by the literature. We suspect that newer homes continue to be built near water and productive soils because of the influence of early settlement patterns and transportation routes established during the period of natural resource constraints. That growth begets growth has been well documented in both transportation and planning literature (Daniels, 1999; Hills, 1996). It is also probable that the role of natural resources in attracting growth has changed over time. Historically home sites may have been situated proximate to water out of necessity, whereas current development trends may reflect the aesthetic and recreational value of river and lakeshores. Lastly, although the proportion of rural housing on less suitable agricultural lands has remained roughly constant, the number has dramatically increased. For example, between 1950 and 1999 the number of rural homes in sections bordering federal land increased by 302% (from 9942 to 39,944 homes). Because the federal lands in the GYE are relatively high in elevation and are comprised of largely nutrient-poor soils (Rodman et al., 1996), these homes deviate from traditional agricultural housing locations. Fire and wildlife management policies will surely be affected by this increase in rural housing at the wildland interface.

Our analysis of recent drivers of RRD supported that natural resource constraints, represented as suitability for agriculture, drove patterns of RRD in the GYE (H1). Our analysis also confirmed the influence of transportation infrastructure and associated services in driving RRD patterns in the GYE (H2). Infrastructure and service related factors, including road density and travel time from hospitals, were the most influential category of explanatory variables of RRD. Several natural amenities were found to be significantly and positively correlated with increasing rural home density (H3), including warmer and wetter climates, as well as all variables related to proximity of national parks, forested areas, and surface water. However, the extent and proximity to public lands was inversely related to growth. We suspect that this occurred for two reasons: (1) the majority of RRD occurred in valley bottoms as opposed to the foothills and mountains flanking the public lands; and (2) this variable did not distinguish between public land types and management objectives. For example, Bureau of Land Management areas are often intensively managed for extractive purposes, occur in drier shrub environments, and may be considered less scenic than other types of public land.

Our results confirm that development of new home sites encourages further conversion of nearby undeveloped land, as shown by the strong correlation between past development and new development. This phenomenon has been explained by the associated construction of roads, schools, and utility lines as well as rises in property value (Daniels, 1999). We also found that RRD continues to occur disproportionately on highly productive lands near water. When coupled, these relationships may be particularly undesirable in their implications for both agricultural and biological conservation in the GYE. The more productive farmlands will likely continue to experience a disproportionate level of residential development, as will the biologically diverse lowland riparian habitats. In order for GYE communities to maintain a balance between future growth and environmental quality, planning practices such as zoning and the purchase of development rights will become increasingly important.

The best model for explaining growth in RRD combined agricultural suitability, transportation and services, natural amenities, and past development as the primary determinants of RRD across the GYE. However, agricultural suitability was strongly correlated with other variables in the model. This suggests that the agricultural phase of development left a "legacy" on the landscape. Patterns of settlement during the agricultural period influenced settlement during the transportation period, and both of these have affected the pattern of rural development during the natural amenities period. Hence, current patterns of rural home construction integrate the effects of all three periods. For example, rural areas surrounding Bozeman, MT, were developed within the rich agricultural lands of the Gallatin Valley. The resulting population growth led to the construction of an airport, increasing a key form of accessibility for rural home construction. Growth in tourism led to airport expansion, allowing for the influx of high-tech businessmen and women seeking relocation to areas rich in natural amenities.

The most explanatory model also incorporated the concept of zones of influence around each town. Within these zones, growth in RRD could not be adequately explained without socio-economic and recreation-related qualities of the respective towns. This finding emphasizes that not all towns are equally likely to attract RRD. Towns near Yellowstone and Grand Teton National Parks were more likely to experience home construction in adjacent rural lands, as were towns characterized by a highly educated population and a large proportion of employment in the professional sector. Such towns included Rexburg, Driggs, and Victor in Idaho, Bozeman, Ennis, and West Yellowstone in Montana, and Pinedale and Jackson in Wyoming. This trend is likely a result of the large-scale immigration of workers, new businesses and affluent retirees leaving urban areas for more scenic rural environments (Power and Barrett, 2001; McDaniel, 2000; Johnson and Rasker, 1995). These new residents require physicians, accountants, lawyers, and other services, resulting in an increase in professional jobs. Responding to this demand, service and high technology businesses take advantage of their footloose nature to move to areas rich in natural amenities (McDaniel, 2000), thereby increasing the number of professional jobs and the number of educated workers in and around natural amenity rich towns.

Outside of the zone of towns' influence, natural amenities continue to play a driving role in the expansion of RRD into previously undeveloped areas. Remote rural areas were more likely to become home sites if they were near the national parks. This trend likely reflects the increase in vacation homes, as well as the number of retirees and professionals that work from home in the GYE (U.S. Census Bureau, 1990, 2000).

Based on our results, several profiles exist for communities with high potential for rapid growth in RRD. Although many booming rural areas in the GYE are located in highly productive agricultural valleys, the legacy of agriculture dependant early settlement has not always resulted in rapid rural growth. Communities such as Thermopolis, WY and Soda Springs, ID with highly productive agricultural soils have thus far experienced relatively little rural growth, likely due to a lack of natural amenities. In addition, some boom areas did not descend from agricultural economies. Communities such as Jackson, WY, Big Sky, MT, and national park gateway communities such as West Yellowstone, MT and Driggs, ID developed well after the agricultural period. These communities may have fostered rural growth by drawing on the viewsheds and recreation opportunities provided by their natural setting. For communities utilizing their natural amenities to promote growth, we expect that preservation of environmental quality will be instrumental in sustaining economic growth.

5.3. Limitations

Our current understanding of the drivers of RRD is limited by our inability to directly infer causation. We have identified bio-physical and socio-economic variables that are highly correlated with growth in RRD. In some cases, however, these variables have been shown to both cause growth and result from growth. Expansion of transportation infrastructure, either through new miles of roadway or through expanded capacity along existing roadways, is one such variable (Charlier, 2003;

Hills, 1996; Goodwin, 1996). For example, growth and increased demand often lead to roadway additions, which induce additional traffic via encouragement of increases in vehicle trips and encouragement of commercial and residential development along the improved route (Charlier, 2003).

The bio-physical and socio-economic factors we have identified add to a growing body of literature investigating the drivers of human settlement patterns (Walsh et al., 2003; Hansen et al., 2002; Huan et al., 2002; Schnaiberg et al., 2002; Schneider and Pontius, 2001; Kok and Veldkamp, 2001; Serneels and Lambin, 2001; Verburg et al., 1999). In general, these studies have been hampered by the lack of available spatially explicit socio-economic data (Veldkamp and Lambin, 2001). Our application of town-scale, socio-economic data to describe nearby rural development patterns was a novel approach that proved to have significant explanatory power in our modeling. We conservatively assumed that rural areas within a 10 min drive of town limits were within the town's zone of influence. However, more research is needed to further understand the scales at which rural lands are connected to neighboring urban centers.

The extrapolation of these results to rural areas outside the GYE should be undertaken with caution. One major difference between the GYE and many other regions of the U.S. lays in the strength of the land use regulations. Despite high rates of development and population growth, 15 of the 20 GYE counties have no county-wide zoning, and 4 GYE counties have no full-time planners on staff. The variation in topography and extensive public lands are also unique compared to most regions. The drivers of RRD within the GYE are likely representative of other rocky mountain regions rich in natural amenities with minimal land use planning.

5.4. Implications

Our analyses support that three stages of human settlement (natural resource constraints, transportation expansion, and pursuit of natural amenities) have shaped patterns of RRD within the GYE. Additionally, our research suggests that each phase of development has left a legacy upon the landscape, and that factors that drove early settlement patterns remain strongly correlated with patterns of land use today.

The patterns of RRD we have described potentially threaten biodiversity within the Yellowstone and Grand Teton National Parks. Because the parks lack significant amounts of lowland habitat, several wildlife species, such as grizzly bears and certain migratory songbirds, commonly seen in the national parks, may not be able to persist there without access to habitats outside the parks (Hansen and Rotella, 2002). Our results suggest that RRD during recent decades has occurred disproportionately on lands bordering the parks, potentially eroding the quality of the lowland habitats most used by park species. This configuration of RRD may result in a barrier between wildlife species and the undeveloped lowland habitats upon which they depend. Ungulates, such as pronghorn antelope, moose, elk and mule deer, migrate to winter ranges often on private lands, and may be especially vulnerable (Boccadori, 2002; Yellowstone National Park, 1997). The consequence of land use change on nature reserves, when adjacent lands are developed, deserves more attention. Also, the extent to which RRD has contributed to the introduction of non-indigenous species, and the alteration of natural fire and flooding cycles, remains largely unknown.

Our findings highlight the importance of local policy decisions in affecting RRD, and, in turn, wildlife, air and water quality, and the stability of local economies and communities. Because new home sites tend to encourage further residential development, subdivisions proposed in undeveloped areas should be conscientiously reviewed. Also, because growth is strongly related to the characteristics of nearby towns, municipal and county planners should cooperate to develop a comprehensive regional vision (Daniels, 1999). This is especially the case for municipalities characterized by factors highly correlated with rapid RRD, including close proximity to the national parks, a highly educated workforce and a large proportion of employment in professional services.

As RRD continues to expand into rural landscapes, the incorporation of scientific knowledge into local government decision-making will become increasingly important to support local decisions about the impacts of development on the environment. Analytical tools for simulating future growth can be used by local governments to visualize growth scenarios and evaluate land use policies. However, realistic simulations require knowledge of the relevant parameters and the extent to which they influence growth. The knowledge gained from this study will enable the parameterization of simulations of RRD within the GYE and similar regions.

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