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Anticipating Forest and Range Land Development in Central Oregon (USA) for Landscape Analysis, with an Example Application Involving Mule Deer

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Abstract Forest policymakers, public lands managers, and scientists in the Pacific Northwest (USA) seek ways to evaluate the landscape-level effects of policies and management through the multidisciplinary development and application of spatially explicit methods and models. The Interagency Mapping and Analysis Project (IMAP) is an ongoing effort to generate landscape-wide vegetation data and models to evaluate the integrated effects of disturbances and management activities on natural resource conditions in Oregon and Washington (USA). In this initial analysis, we characterized the spatial distribution of forest and range land development in a four-county pilot study region in central Oregon. The empirical model describes the spatial distribution of buildings and new building construction as a function of population growth, existing development, topography, land-use zoning, and other factors. We used the model to create geographic information system maps of likely future development based on human population projections to inform complementary landscape analyses underway involving vegetation, habitat, and wildfire interactions. In an example application, we use the model and resulting maps to show the potential impacts of future forest and range land development on mule deer (*Odocoileus hemionus*) winter range. Results indicate significant development encroachment and habitat loss already in 2000 with development located along key migration routes and increasing through the projection period to 2040. The example application illustrates a simple way for policymakers and public lands managers to combine existing data and preliminary model outputs to begin to consider the potential effects of development on future landscape conditions.

Keywords Spatial land-use models · Landscape change · Wildland–urban interface · Mule deer

Introduction

Forest policymakers, public lands managers, and scientists in the Pacific Northwest (USA) seek ways to evaluate the landscape-level effects of policies and management through the multidisciplinary development and application of spatially explicit analytical methods and models (e.g., Barbour and others 2007; Spies and others 2007). Policymakers and managers desire ways to display and predict socioeconomic and ecological outcomes of policy and management alternatives on public and private lands. Scientists seek ways to work across disciplines to examine interactions among socioeconomic and ecological phenomenon that occur at different temporal and spatial scales. Despite ambitions, conducting multidisciplinary landscape analysis in a cost-effective and timely manner sufficient to be of practical use to policymakers and managers is a persistent challenge. Multidisciplinary landscape studies can be costly to initiate and sustain. They can involve painstaking effort on the part of collaborating scientists to agree upon research objectives, appropriate spatial and temporal scales, procure data, develop and integrate spatially explicit methods and models, and then deliver results to the policymakers and managers who presumably can use them (Kline and others 2010). The observer's quip that,

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"With a crayon and a sheet of paper I could have done in an afternoon what they did with $5 million in 10 years," suggests the degree to which perceptions of the practice of multidisciplinary landscape analysis can be improved.

In the Pacific Northwest, landscape studies typically are designed to address the long-term effects of policy and management on vegetation, wildfire, and terrestrial and aquatic habitat, while accounting for exogenous socioeconomic changes that affect landscapes. Spies and others (2007), for example, sought to examine the effects of forest policies intended to protect spotted owls (*Strix occidentalis caurina*) and coho salmon (*Oncorhynchus kisutch*) and predict future outcomes for the western Oregon Coast Range. Spanning 1996 to 2005 and involving landscape ecologists, aquatic and wildlife biologists, hydrologists, economists, and several geographic information systems analysts and research assistants, the project resulted in high resolution (30-meter pixel) spatial models of biophysical conditions (e.g., vegetation, topography, streams) and projected future conditions over 100 years. Several linked models addressed habitat suitability for select terrestrial and aquatic species, landslide and debris flow, and geomorphic dynamics, and other factors. In another example, Barbour and others (2007) aspired to develop a more streamlined approach to landscape analysis that would enable public land managers to evaluate interactions between management, forest succession, and wildfire in northeastern Oregon's Blue Mountains. Spanning five years and involving up to 20 researchers, the project produced a coarser scaled vegetation modeling system linked where feasible to other resource models describing habitat quality, insect activity, ungulate grazing, timber management, and wood utilization. Management outcomes were projected over 100- and 200-year horizons.

Although such efforts produce data and information of interest to policymakers and managers, they often fail to fulfill expectations that resulting models and model outputs will be immediately useful in policy and management decision-making. Multidisciplinary landscape analyses tend to progress slowly. Difficulties and delays arise from incomplete data and the need to adapt and develop spatial methods and models. Difficulties developing one study component can delay other component applications. Both Spies and others (2007) and Barbour and others (2007), for example, expended significant time developing vegetation simulation methods even as other study components neared completion. Once complete, landscape models often are too complex or cumbersome to be accessible to the policymakers and managers expected to use model outputs. The practice of spatially-explicit multidisciplinary landscape analysis is still evolving and so slowness and complexity as defining characteristics arguably are par for the course. Until practices advance, analysts might best satisfy policy and management expectations through early and earnest technical transfer efforts that address vital resource concerns using study components most readily available and applicable to the task. Additional and more comprehensive model applications can follow iteratively as other study components are completed. Policymakers and managers often are more than willing to overlook imperfections in new information when any new information is especially timely.

Following this approach, we report on a land use model application developed as part of an ongoing multidisciplinary landscape study in Oregon. In this initial analysis, we characterize the spatial distribution past and potential future forest and range land development in a four-county vicinity of Bend, Oregon. Rapid development there is a primary concern of State resource policymakers and managers for its potential impact on resource industries such as forestry and agriculture (e.g., Lettman 2004) and also declining habitat for mule deer (*Odocoileus hemionus*) (e.g., Oregon Department of Fish and Wildlife 2009b). The empirical model describes the spatial distribution of buildings and new building construction as a function of population growth, existing development, topography, land-use zoning, and other factors. We used the empirical models to create geographic information system maps of potential future forest and range land development based on published human population projections. Maps of future development eventually will be used to inform complementary landscape study components addressing vegetation, habitat, and wildfire interactions—all of which are still in preparation. In this preliminary application, we use maps to show the degree to which future forest and range land development might reduce mule deer winter range in future years.

Study Region

Our land use modeling is part of a pilot landscape analysis of the Interagency Mapping and Analysis Project (IMAP). IMAP is a partnership of federal and state agencies and non-government organizations whose goal is to generate landscape-wide vegetation data, landscape models, and related information with which to evaluate the integrated effects of natural disturbances and management activities on natural resource conditions in the Pacific Northwest (Kline and others 2010). Key concerns of policymakers and managers involved in IMAP are reducing wildfire risks, maintaining and enhancing wildlife habitats, and maintaining timber outputs despite ongoing socioeconomic change. Plans are for IMAP methods and models to eventually include all of Oregon and Washington. However, current efforts focus on a 275,187 ha pilot study area west of Bend, Oregon consisting of 216,103 ha of federal forest, reserves, and wilderness, and 59,084 ha of private lands. For land use modeling purposes, we focus on a larger four-county study region surrounding Bend. Although many IMAP study components remain under development, we report forest and range land development results here along with a model application of immediate relevance to resource policymakers and managers in Oregon involving the maintenance of habitat for mule deer.

Our central Oregon study region includes Crook, Deschutes, and Jefferson Counties and the northern third of Klamath County (Fig. 1). The area has experienced fairly rapid population growth from 1970 to 2000, ranging from 28% in northern most Klamath County to 283% in Deschutes County for a region wide average of 121% (USDC Census Bureau 2000). The region somewhat epitomizes the "new West" in Oregon by experiencing recent declines in natural resource extractive industries in favor of increased tourism, outdoor recreation, and amenity-based in-migration (Judson and others 1999). The study region is bordered on the west by the Deschutes National Forest and includes the scenic towns of Bend and Sisters which are noted as desirable travel destinations in national media (e.g., Laskin 2004; Preusch 2004). The region comprises roughly 2.34 million ha land of which 1.37 million ha is public-owned and 0.97 ha is private-owed. Major land-cover classes identified on private lands show a mix of forest, range, and agriculture with developed areas extending south, northeast, and north of Bend—eastern Oregon's largest (82,280 persons) and most rapidly growing city (Lettman 2004). Other cities include Madras (6,650), Prineville (10,370 persons), and Redmond (25,800 persons) (Proehl 2009), which also have grown in population partly as a result of Bend spillover.

Rapid housing growth, an influx of new residents both permanent and seasonal, and their potential environmental and natural resource impacts are of particular interest to policymakers and land managers in the region. Concerns include loss of forest and range land to development, increased traffic congestion, increased water demand, and potential adverse habitat effects for some species. Of special concern is the desire to maintain viable mule deer populations sufficient to permit continued hunting. Mule deer have declined across the western US as a result of habitat loss and other factors. Mule deer winter range often coincides with new development (e.g., Stein and others 2007:12). In mountainous forest areas, new development tends to be located on relatively flatter and lower elevation valley bottoms where for mule deer the relative absence of persistent snow cover makes winter movement easier and food more abundant. In eastern Oregon (east of the crest of the Cascades), declining mule deer populations owing to development and habitat loss is the single most pressing issue for the Oregon Department of Fish and Wildlife and hunting enthusiasts (Oregon Department of Fish and Wildlife 2009b). Potential disruption of migration patterns owing to increased development density along key routes is of primary concern. Mule deer hunting exceeds 74,000 participants and generates $22 million in economic activity annually (Oregon Department of Fish and Wildlife 2009a). The sale of hunting licenses is the major source of funding for the Oregon Department of Fish and Wildlife.

Methods

Building Count Data

Land-use data describing historical building counts were compiled by the Oregon Department of Forestry and the USDA Forest Service, Pacific Northwest Research Station's Forest Inventory and Analysis program. The data were designed to examine historical forest and range land development, and evaluate wildfire risks to homes and other issues of concern. The data consist of aerial photo observations of building (or structure) counts—the number

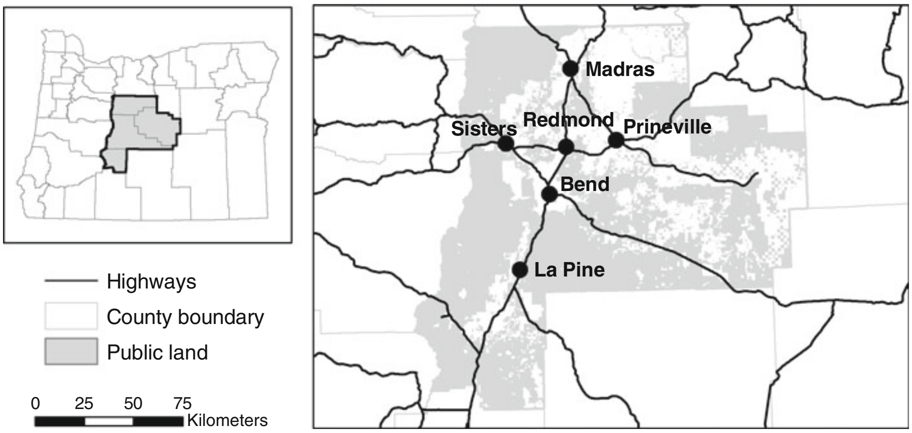

Fig. 1 Central Oregon (USA) study region

of buildings of any size or type—within 32-hectare (ha) circles surrounding sample points located on aerial photos of non-federal land in eastern Oregon (Lettman 2004). With 13,000 sample points and three observation periods, the data comprise almost 40,000 observations of building counts in eastern Oregon varying in space and time.

The 13,000 sample points for the study region were drawn from the "primary sample" of points used for the stratification of secondary sample points that are measured in the periodic forest inventories conducted in eastern Oregon by the Forest Inventory and Analysis Program (Azuma and others 2004:1). The primary sample consists of a grid of nearly 70,000 points established from aerial photos taken in 1982. The sampling was implemented to produce an even geographic distribution of points across eastern Oregon. Details about Forest Inventory and Analysis Program sampling in eastern Oregon can be found in Azuma and others (2004). Details about how buildings actually were counted on aerial photos are described in Lettman (2004).

The building count data do not distinguish the specific uses of counted buildings, such as residential, commercial, industrial, or public infrastructure, because specific uses could not be identified from the aerial photos alone. Also, the limited availability of historical aerial photos for eastern Oregon necessitated that data collection draw upon aerial photos taken at varying dates spanning 1968 to 2001 (Lettman 2004). Photos were selected to provide three temporal observations of building counts for each sample point. From these three temporal observations, building count values for 1975, 1985, and 1995 were derived using a combination of interpolation and extrapolation.

Modeling Approach

Our purpose was to describe potential future forest and range land development within the four-county study region in terms of the spatial distribution and rate of change in new buildings. Our approach was to describe changes in building counts observed between subsequent sample point observations based on socioeconomic and topographic factors hypothesized to influence forest and range land development. This approach involves estimating an econometric model of building count change as a function of explanatory variables that represent relevant socioeconomic and topographic factors, and then using the estimated model coefficients to predict (or compute) future changes in building counts based on anticipated changes in explanatory variable values. Predicted changes in building counts can then be added to existing building densities to forecast future building densities. Tracking building counts on individual sample points at each of the three points in time yielded two observations of building count change (number of new buildings built) for each sample point. We omitted building count observations that already exceeded the development threshold of eight buildings per 32 hectares—roughly equivalent to 25 buildings per square km—to focus our modeling effort on relatively undeveloped forest and range lands. Combining the resulting building counts with data describing explanatory variables yielded 6,131 observations.

Explanatory Variables

Following previous econometric approaches to fine-scaled land use modeling (e.g., Bockstael 1996; Kline and others 2007) we expect that landowners are more likely to develop forest and range land to residential housing or other more intensive uses once the present value of future returns earned by land in development less conversion costs equal or exceed returns earned by land remaining in forest or range. Spatial economic data describing potential returns to forestry and range generally are not available and so proxy variables must be found to permit fine-scaled spatial modeling. Within the relatively localized study region, forest and range lands tend to be rather uniform in the landscape characteristics that influence the economic returns to forestry and grazing. As a result, spatial variability in rates of development is more likely to arise from variation in the potential value of those lands in developed uses than from variation in forestry and farming returns. In the absence of historical data describing developed land values, we used several proxy variables shown in past land use analyses to provide a reasonable accounting of development opportunities faced by landowners in the Pacific Northwest (Kline and others 2003, 2007). Those variables include regional population growth, the driving accessibility of land to cities and other developed areas via existing roads, and topographic characteristics (e.g., slope) that influence the feasibility of developed land uses (Table 1). We also included information describing land use zoning adopted under Oregon's statewide system of land use planning based on evidence of past zoning influence (Kline 2005).

Econometric Model

Following previous spatial land use analysis using similar data (Kline 2005), we constructed a dependent variable—ΔBUILDINGS—as a non-continuous count describing changes in building counts observed between subsequent photo dates. Assuming ΔBUILDINGS is distributed as a Poisson, leads to the negative binomial model,

Table 1 Descriptions of explanatory variables tested in the negative binomial describing building counts changes

Variable	Description
ΔPOPULATION DENSITY	Average annual change in population per square km (USDC Census Bureau 2000) in county where each sample point is located, during time interval for each observation
MARKET CENTER	Estimated travel time (minutes) from sample point to nearest market center given existing roads and assumed travel speeds: 97 km per hour on primary roads, 40 km per hour on secondary roads, and 16 km per hour where there are no roads. Market centers included are: Bend, Prineville, Redmond, and Sisters
BUILDINGS$_{t-1}$	Number of buildings within 32-ha circle surrounding sample point (Lettman 2004) at the beginning of each observation time interval
SLOPE	Average percent slope within 32-ha area surrounding sample point
ELEVATION	Average elevation (meters) within 32-ha area surrounding sample point
LAND USE LAW	The proportion of time from one building count observation to the next that land-use zoning acknowledged by Oregon's Land Use Planning Program (LCDC 1992) was in effect at the sample point; 0 otherwise
FOREST ZONE	Variable equals 1 if point is located in a forest zone; 0 otherwise
RANGE ZONE	Variable equals 1 if point is located in a range zone; 0 otherwise
AGRI ZONE	Variable equals 1 if point is located in a farm zone; 0 otherwise
UGB ZONE	Variable equals 1 if point is located in an urban growth boundary, rural residential, or other developable land-use zone; 0 otherwise

$$pr(\Delta\text{BUILDINGS}_i = y_i|\gamma) = \frac{e^{-\lambda_i}\lambda_i^{y_i}}{y_i!}$$

$$y_i = 0, 1, 2, \ldots; \quad i = 1, 2, \ldots, n;$$

$$\ln(\lambda_i) = \ln(\overset{\wedge}{\lambda_i}) + \gamma = \beta' x_i + \gamma$$

where γ is a random variable and $\exp(\gamma)$ has a gamma distribution with mean 1 and variance α, x_i is a vector of independent variables, and β' is a vector of coefficients to be estimated (Greene 1997). The negative binomial model is a general form of the Poisson model relaxing the Poisson assumption that the dependent variable's mean equals its variance (Wear and Bolstad 1998).

The panel nature of the data—generally two temporal observations of building count change per sample point—creates a potential for correlation among pairs of time-series observations for individual sample points to deflate standard errors and bias estimated coefficients. These potential correlations can be accounted for using a random effects negative binomial model (Greene 1998:629–634). Because group effects are conditioned out (not computed), projected values cannot be computed using the random effects model (Greene 1998:630), but the estimated coefficients can be compared to those of the model estimated without random effects. An alternative approach would be to combine the two temporal observations of building counts per observation into a single observation of change over a single combined time period, which would remove the necessity for a random effects model. However, a disadvantage of this alternative approach would be the significant loss of information owing to reducing by half the number of observations used to estimate the model. Also, because statewide land use planning was implemented during the mid-1980s, using two time-steps worth of observations for model estimation enables us to include several zoning explanatory variables that show land use zoning effects on development.

A final modeling issue is potential spatial autocorrelation among observations of building count changes. Spatial autocorrelation can result from omitted spatial variables, such as location, that influence the development decisions of landowners, and spatial behavioral relationships such as common ownership of sampled land parcels. The first leads to inefficient but asymptotically unbiased estimated coefficients; the second can lead to inefficient and biased estimated coefficients (e.g., Nelson and Hellerstein 1997). Spatial autocorrelation often is addressed in model estimation by including a spatial lag (or neighbor) variable in the regression equation. However, a difficulty in applied work is the lack of simple and universally accepted methods for dealing with spatial lag variables when using estimated model coefficients to compute predicted (or forecasted) values. Previous analysis has suggested that spatial autocorrelation in the building count data likely are minimal and that the inclusion of spatial lag variables in model estimation improved overall predictive accuracy only slightly (Kline and others 2007:326). We suspect that any spatial behavioral relationships unaccounted for by our spatial explanatory variables are minimal and proceeded with model estimation leaving any spatial autocorrelation unaddressed.

Evaluating Prediction Accuracy

One way to evaluate the prediction accuracy of econometric land-use models is to reserve a portion of sample data for computing predicted values based on estimated model coefficients and then comparing these to their actual values. We chose not to use this method, because the building count data included relatively few observations of both higher building counts and building count changes. We were hesitant to reduce these observations further by reserving any portion of the data sample from model estimation. As an alternative, we graphically examined potential spatial patterns in prediction accuracy by plotting residuals ($y_i - \hat{y}_i$) against select explanatory variable values describing key landscape characteristics. Mapping residuals is not permitted by Forest Inventory and Analysis Program confidentiality rules concerning the display of sample point locations. We also used the estimated model coefficients to compute within sample changes ($t - 1$ to t) in building counts. These predicted changes were added to initial building counts (observed at $t - 1$) to estimate an ending building count (observed at t) for each observation i. The percentages of correct building counts predicted by the model are reported for three broad building density categories: <7 buildings per square km (relatively undeveloped), 7 to 25 buildings per square km (moderately developed), and >25 buildings per square km (relatively developed). We evaluated the prediction accuracy by examining the percentage of correct predictions within building count categories and observing the chance-corrected agreement between the actual and predicted values using a Kappa statistic (Cohen 1960).

Results

The general regression equation describing changes in building counts on sample points from one photo date $t - 1$ to the next t was,

$$\begin{aligned}\Delta\text{BUILDINGS} &= f\,(\Delta\text{POPULATION DENSITY},\\ &\quad \text{MARKET CENTER},\ \text{BUILDING COUNT}_{t-1},\\ &\quad \text{SLOPE},\ \text{LAND USE LAW},\ \text{FOREST ZONE},\\ &\quad \text{RANGE ZONE},\ \text{AGRI ZONE},\ \text{UGB ZONE}).\end{aligned}$$

Model coefficients were estimated using LIMDEP (Greene 1998). The negative binomial model is highly statistically significant based on log-likelihood ratio tests (Table 2) and the signs and statistical significance of the estimated coefficients for explanatory variables generally are consistent with previous analyses of forest and range land development: positive for ΔPOPULATION DENSITY, negative for MARKET CENTER, positive for BUILDINGS_{t-1}, and negative for SLOPE (Kline 2005; Kline and others 2007). Estimated coefficients for land-use zoning variables suggest that zoning has focused new building construction within urban growth boundaries, rural-residential, or other developable zones, relative to lands in forest, range, and agricultural zones, consistent with land use planning effects found in Oregon by previous studies (e.g., Kline 2005). The random effects version of the estimated model yielded similar results.

Model predicted residuals ($y_i - \hat{y}_i$) plotted against estimated travel times to the nearest market center (MARKET CENTER) indicate a fairly even balance between under-prediction ($y_i > \hat{y}_i$) and over-prediction ($y_i < \hat{y}_i$) (Fig. 2). Residuals plotted against initial building counts (BUILDINGS_{t-1}) indicate that a core group of observations also are fairly evenly balanced between under- and over-prediction. Although, several outlier observations are under-predicted at BUILDINGS_{t-1} values of 4 and below, and over-predicted at BUILDINGS_{t-1} values of 5 and above, these observations represent relatively few of the 6,131 observations examined. Residuals plotted against SLOPE also indicate a fairly even balance between under-prediction and over-prediction on those slopes most feasible for construction—generally less than 35 percent (Fig. 2). Taken together, the residual plots do not indicate significant spatial patterns in predicted value errors. They do, however, suggest a smoother pattern of predicted development than is evident in the data when viewed relative to outlier values.

Within-sample prediction accuracy indicates that the percentages of correct predictions within each of three building density categories are: 96.3% (<7 buildings per square km), 66.7% (7 to 25), and 63.2% (>25), for an overall prediction accuracy of 93.3% and a chance-corrected prediction accuracy of 65.9% (Table 3). Our comparison of the distributions of actual predicted values among the three building density categories indicates that the model tends to over-predict development. The distribution of actual values is: 90.2% (<7), 7.6% (7 to 25), and 2.2% (>25); the distribution of predicted values is: 88.3% (<7), 9.0% (7 to 25), and 2.7% (>25). Because the method used to compute each successive future building count depends on the previous period's building count, prediction errors will magnify with successive prediction iterations for future time periods. The problem potentially becomes multiplied when development model predictions are combined with the predicted outputs of other models describing other study components. Although error propagation often is par for the course with predictive models, particularly in multidisciplinary research where numerous models are combined, analysts will want to consider how error propagation may influence landscape analysis results and research outcomes.

Example Model Application Involving Mule Deer

The estimated model coefficients can be used to inform other IMAP components describing ecological conditions

Table 2 Estimated coefficients of negative binomial models describing changes in building counts within 32-ha circles surrounding sample points

Variable	Negative binomial regression		Model with random effects
	Estimated coefficient	Marginal effect	Estimated coefficient
Constant	−1.029*** (−8.61)	−0.522	−1.129*** (−5.64)
ΔPOPULATION DENSITY	0.109*** (10.51)	0.055	0.074*** (6.99)
MARKET CENTER	−0.024*** (−14.17)	−0.012	−0.028*** (−9.90)
BUILDINGS$_{t-1}$	0.340*** (12.45)	0.172	0.255*** (14.83)
SLOPE	−0.013*** (−7.89)	−0.007	−0.017*** (−7.36)
LAND USE LAW × FOREST ZONE	−1.277*** (−6.39)	−0.647	−0.771*** (−3.62)
LAND USE LAW × RANGE ZONE	−1.264*** (−9.53)	−0.641	−1.295*** (−5.46)
LAND USE LAW × AGRI ZONE	−0.129 (−1.17)	−0.066	−0.203** (−1.44)
LAND USE LAW × UGB ZONE	1.822*** (14.07)	0.924	0.893*** (6.37)
α	3.804*** (16.98)	–	3.183*** (6.49)
b	–	–	4.568*** (3.50)
Summary statistics:	$N = 6{,}131$, LL $= -2{,}571$, $\chi^2 = 2{,}545$, $df = 1$, $P < 0.001$[a]		LL $= -2{,}424$

The t-statistics are in parentheses

[a] Tested against the null of the corresponding Poisson model

and processes. One way is to characterize development is to compute predicted values of ΔBUILDINGS as,

$$\Delta\text{BUILDINGS}_i = e^{\beta x_i}.$$

The ΔBUILDINGS values can then be added to a base map of existing building counts to create maps depicting future building counts. In this way, anticipated future population densities—such as would be derived from official population projections—could be used as a basis for describing future development scenarios while controlling for topography and zoning. Alternatively, some landscape analysis applications call for a probabilistic treatment of potential future development. A second approach then is to compute the probability of a specific building count increase using a set of recursive equations. Following Greene (1998:607), the probability that ΔBUILDINGS equals zero ($y_i = 0$) for observation i is:

$$prob(\Delta\text{BUILDINGS}_i = 0) = \left[\frac{\theta}{(\theta + \lambda_i)}\right]^{\theta}$$

$$\text{where: } i = 1, 2, \ldots, n; \theta = \frac{1}{\alpha}; \lambda_i = e^{\beta x_i}.$$

The probability that ΔBUILDINGS equals a given value greater than zero ($y_i = 1, 2, \ldots$) is:

$$prob(\Delta\text{BUILDINGS}_i = y_i) = \left[\frac{(\theta + y_i - 1)}{y_i}\right] \cdot \left[\frac{\theta}{(\theta + \lambda_i)}\right] \cdot [prob(\Delta\text{BUILDINGS}_i = y_i - 1)].$$

Applying these equations at the pixel level enables analysts to create maps describing the probability of specific building count increases to facilitate probabilistic landscape simulations at fine spatial scales.

To illustrate example model predictions, we took the first approach and used the estimated model coefficients to predict future increases in building counts based on projected county population density changes to 2040 (Oregon Office of Economic Analysis 2004). Following procedures described in Kline and others (2003:357–358), a base year 2000 map of building counts was developed from 2000 sample point data by interpolating between sample-point building count values. The estimated negative binomial regression coefficients (Table 2) were combined with projected population densities for study region counties and other explanatory variable data to compute predicted changes in building counts at 10-year time intervals. Predicted changes in building counts for each 10-year time interval were added to the beginning ($t - 1$) building count value for that interval to obtain the ending building count. For example, the predicted changes occurring between the 2000 base year and 2010 were added to the 2000 base year building count map, to create a 2010 building count map. The 2010 map was combined with 2010 to 2020 predicted changes in building counts to create a 2020 map. Projected population growth in the central region ranges from a low of 14% for the portion located in northern Klamath County to a high of 84% for Deschutes County, for a region-wide area-weighted average of 73%. The resulting maps (Fig. 3) suggest noticeable expansion of development on lands near existing cities, with notable increases in building counts along major transportation corridors and in select locations between existing cities.

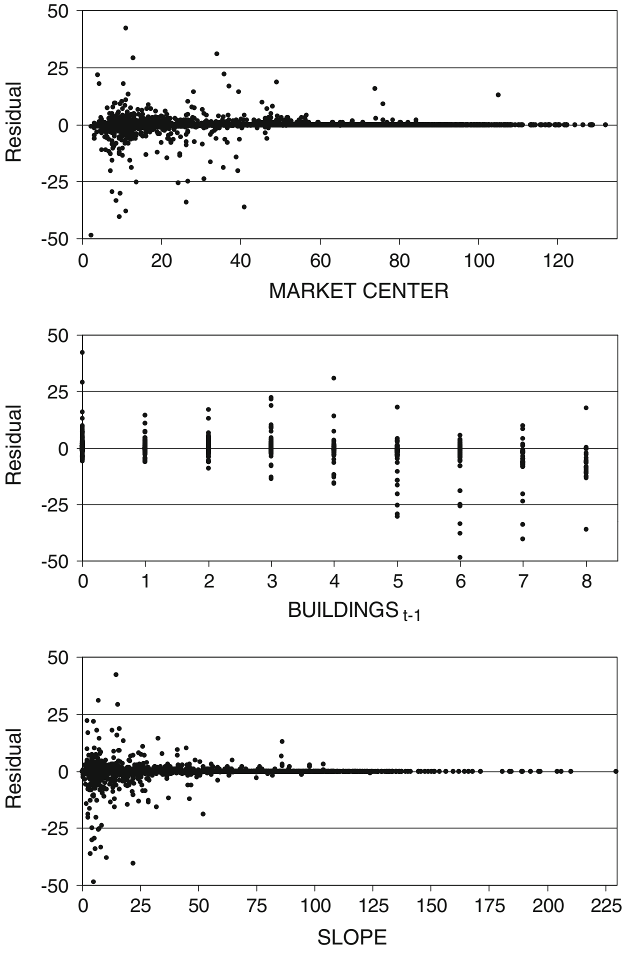

Fig. 2 Model predicted residuals $(y_i - \hat{y_i})$ plotted against select explanatory variables: MARKET CENTER, BUILDINGS$_{t-1}$, and SLOPE. *Note*: *y*-axis scaling omits 5 outlier observations to enhance view of distribution

The maps of future development can be combined with other information to describe the intersection of development with ecological conditions and processes of interest. In a simple application, we combined projected building counts with a map of current mule deer winter range available from the Oregon Department of Fish and Wildlife. In our four-county study region, mule deer winter range largely is a function of elevation which constrains winter range extent on the west with significant winter snow cover at higher elevations of the eastern slope of the Cascades range and in sporadic central locations to the east of urban areas with generally drier conditions at lower elevations (Fig. 3). The map overlay shows that by 2000 development was already present in many locations within mule deer winter range—some of it at sufficiently high densities to adversely affect animal movement from one portion of range to another. Notable examples are the large area of development at densities of from 7 to 25 to greater than 25 buildings per square km northwest of Bend, as well as the smaller area of development at greater than 25 buildings per square km filling a narrow strip of winter range just south of Bend.

Projections suggest greater development in the future especially in western portions of winter range, with continued infill of buildings northwest of Bend (Fig. 3). Development projections suggest that the proportion of winter range falling into the 7 to 25 and >25 building density categories collectively will rise from 0.045 (0.028 + 0.017) in 2000 to 0.067 (0.017 + 0.050) by 2040 (Table 4). Conversely, the proportion of winter range falling into the public land and <7 building density categories collectively will decline from 0.955 (0.493 + 0.462) in 2000 to 0.933 (0.493 + 0.440) by 2040. Although the magnitudes of these shifts do not appear all that significant relative to the total amount of winter range present, expected development could result in policy-relevant impacts to winter range if it occurs as anticipated at key choke points where it could hinder movement between different portions of winter range. The notable examples are again the area northwest of Bend which shifts from 7 to 25 buildings per square km or less in 2000 to >25 buildings per square km by 2020 to add to the already developed narrow strip of winter range just south of Bend. Even at low densities, development could adversely affect mule deer migration if new housing is accompanied by the installation of fencing to accommodate horses and other livestock as is often the case in central Oregon. Management challenges can be exacerbated if housing

Table 3 Percentage of correctly predicted within-sample ending building density categories ($N = 6{,}131$)

Buildings per square kilometer[a]	Actual percent in sample	Predicted percent in sample	Percent correctly predicted
<7	90.2	88.3	96.3
7 to 25	7.6	9.0	66.7
>25	2.2	2.7	63.2
All	100.0	100.0	93.3
Kappa[b]	–	–	65.9

[a] Building per square km based on ending building counts computed by adding predicted building count increases to beginning building counts

[b] Kappa computed following Cohen (1960), and multiplied by 100

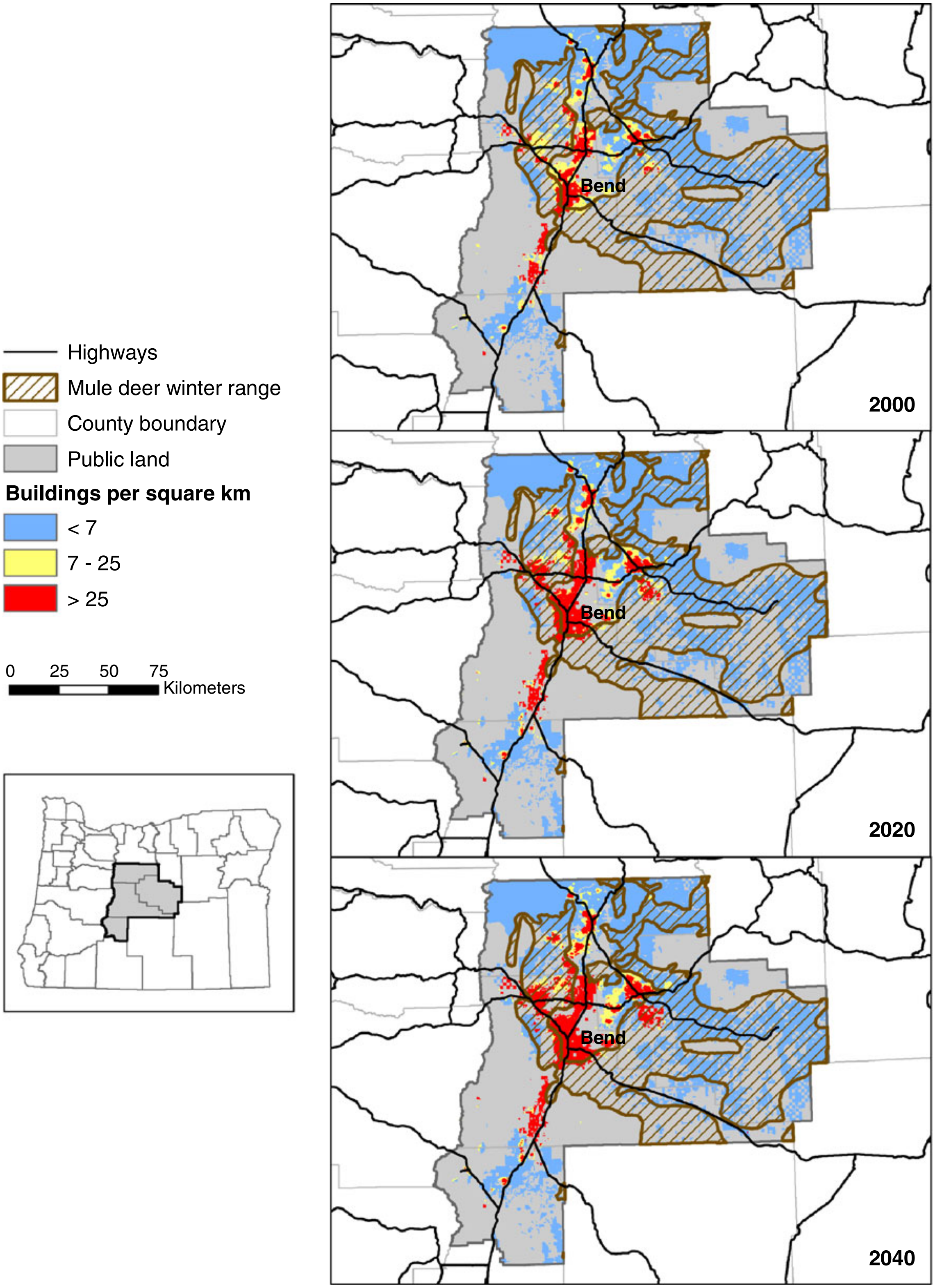

Fig. 3 Projected building density categories for 2000, 2020, and 2040 based on Table 2 model coefficients, combined with mule deer (*Odocoileus hemionus*) winter range

Table 4 Area and proportion of 2000 mule deer (*Odocoileus hemionus*) winter range falling into projected public land and building density categories in 2020 and 2040

Buildings per square kilometer	2000	2020	2040
Area (ha)			
Public land	447,368	447,368	447,368
<7	418,992	403,872	399,303
7 to 25	25,917	19,801	15,602
>25	15,389	36,625	45,393
Proportion			
Public land	0.493	0.493	0.493
<7	0.462	0.445	0.440
7 to 25	0.028	0.022	0.017
>25	0.017	0.040	0.050

Computed from Fig. 3

encroachment leads to increased property damage from wildlife—browsing landscaping, for example—which can cause tension between landowner interests and State mule deer population targets.

The extent and nature of development within mule deer winter range in central Oregon would seem to call for more comprehensive investigation of resulting habitat impacts. Toward that end, another team of scientists has initiated a companion landscape pattern analysis to examine habitat fragmentation, forage quality, hiding and thermal cover impacts by combining development predictions with detailed vegetation data (Duncan and Burcsu 2010). The Oregon Department of Fish and Wildlife also has initiated radio-collar tracking of mule deer to better understand migration patterns and disturbance impacts. Development predictions provided in this paper enable other researchers to identify favorable locations for more geographically focused studies of these fine-scaled habitat impacts. Additional analyses could examine the extent of "disturbance zones" associated with building densities (e.g., Vogel 1989; Theobald and others 1997) and incorporate empirical simulation of changes in winter range extent over time based on dynamic modeling of vegetation, wildfire, and other factors (e.g., Hemstrom and others 2007). Although together these efforts can provide a richer body of information with which to evaluate development impacts and define appropriate policy and management responses, they are unlikely to change the basic result that development is leading to habitat loss.

Conclusions and Research Implications

We have presented a relatively simple way to characterize the spatial distribution of forest and range land development in a four-county region of central Oregon (USA) using data describing building densities, population growth, topography, and other factors. The estimated empirical model and resulting development forecasts can be combined with other information and models characterizing ecological conditions and processes and wildfire to inform ongoing multidisciplinary landscape analyses in the region. Because the building count data and econometric approach used in the analysis enable development to be characterized at relatively fine spatial scales, the method is sufficiently flexible to accommodate integration with other models at a variety of development thresholds and spatial scales. For example, much of the IMAP analysis likely will aggregate model output—including land use model output—at the hydrological unit code (or HUC) four level. However, the ability to describe finer degrees of development in terms of actual and predicted building densities also is useful if analysts are to examine ecological conditions and processes across development gradients (e.g., Wimberly and Ohmann 2004). Our example application shows how model outputs can be combined with existing habitat or other resource maps to provide policymakers and managers with initial and timely information about development and its effects regarding habitat and other resource issues as they await the completion of other study components.

Our analysis indicates that continued development encroachment onto central Oregon mule deer winter range is likely through 2040, with expansion of new development out from existing urban areas as well as infill development especially along major transportation corridors. Relatively simple applications such as these can help policymakers and managers begin to anticipate and respond to potential future development even as more comprehensive analysis of habitat fragmentation effects may be unavailable. For example, resource managers may want to initiate or expand efforts to work with landowners, local land use planning officials, and nonprofit conservation organizations to consider what combination of planning and programmatic responses are warranted given anticipated development impacts on winter range. Modifications to existing land use zoning and the targeted purchase of conservation easements and land for preservation and management are just a few actions that could be taken now to help to maintain existing migration corridors and minimize the extent of disturbance zones associated with new development. Policymakers might consider providing more consistent or increased funding to existing state programs that protect and enhance habitat (e.g., Deer Enhancement and Restoration Program, Habitat Improvement Program) and assist landowners who experience damage caused by wildlife (e.g., Green Forage Program) (Oregon Department of Fish and Wildlife 2003). It is through the cost-effective and timely application of science focused on examining critical natural resource issues where multidisciplinary landscape studies might best meet policy and management expectations.

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