University of Nebraska - Lincoln

DigitalCommons@University of Nebraska - Lincoln

U.S. Environmental Protection Agency Papers | U.S. Environmental Protection Agency

2008

Past and projected rural land conversion in the US at state, regional, and national levels

Eric M. White
Pacific Northwest Research Station, USDA Forest Service, Corvallis, OR 97331, United States

Anita T. Morzilla
Western Ecology Division, National Health and Environmental Effects Research Laboratory, US Environmental Protection Agency, Corvallis, OR 97333, United States

Ralph J. Alig
Pacific Northwest Research Station, USDA Forest Service, Corvallis, OR 97331, United States

Landscape and Urban Planning xxx (2008) xxx–xxx

Contents lists available at ScienceDirect

Landscape and Urban Planning

journal homepage: www.elsevier.com/locate/landurbplan

Past and projected rural land conversion in the US at state, regional, and national levels

Eric M. White[a,*], Anita T. Morzillo[b], Ralph J. Alig[a]

[a] Pacific Northwest Research Station, USDA Forest Service, Corvallis, OR 97331, United States
[b] Western Ecology Division, National Health and Environmental Effects Research Laboratory, US Environmental Protection Agency, Corvallis, OR 97333, United States

ARTICLE INFO

Article history:
Received 26 March 2008
Received in revised form 15 July 2008
Accepted 25 September 2008
Available online xxx

Keywords:
Land use
Urbanization
Modeling
Projections
Resources Planning Act

ABSTRACT

The developed land area of the US increased by 14.2 million hectares between 1982 and 2003. Along with a projected US population increase to more than 360 million individuals by 2030 is an expected continuation of expanding rural land development. Related to population growth, rural land development and the associated loss of rural open space are expected to have a number of social, economic, and ecological implications. To gain greater insight into land development patterns, we used US Census Bureau and National Resources Inventory data to quantify per-housing-unit rates of land development during recent decades and to model future land development to 2030 for states and regions in the US. Based on these data, 0.50 ha of additional land were developed for each additional housing unit in the US. The numbers of hectares of newly developed land per additional housing unit were greatest in the South Central and Great Plains regions and least in the Pacific Coast and Rocky Mountain regions of the country. Combining population projections and trends in people per housing unit with development indices, we projected that developed area in the US will increase by 22 million hectares between 2003 and 2030, with the greatest absolute increases projected to occur in the Southeast and South Central regions of the US. We used sensitivity analysis to examine the impacts of changes in population migration patterns and per housing unit development patterns on increases in projected developed area.

Published by Elsevier B.V.

1. Introduction

The area of developed land in the United States (US) increased by more than 48% between 1982 and 2003 (USDA NRCS, 2007). During this time, approximately 680,000 ha of rural land were converted to developed uses annually (USDA NRCS, 2007). Net loss and fragmentation of rural lands have many potential implications for the goods, services, and functions of natural resources provided by such landscapes (e.g., Alberti et al., 2003; Arnold and Gibbons, 1996; Collins et al., 2000), the species that use them and their habitat (e.g., Faeth et al., 2005; McKinney, 2002; Riley et al., 2003), and the ability of invasive species to establish themselves (e.g., Holway, 2005; Lambropoulos et al., 1999; Yates et al., 2004). Past research also has suggested that the addition of homes and other structures into rural landscapes can increase the probability of wildland fire and complicate fire management efforts (e.g., Berry and Hesseln, 2004; Cardille et al., 2001; Gebert et al., 2007; Sturtevant and Cleland, 2007), can have deleterious effects on water quality (Atasoy et al., 2006; Pijanowski et al., 2002b; Tang et al., 2005), and possibly can reduce the propensity for forest management and timber harvest (Kline et al., 2004; Munn et al., 2002; Wear et al., 1999).

Land-use conversion is expected to continue in the coming decades. In the contiguous US, Stein et al. (2005) projected that residential development will affect an additional 18 million hectares of currently rural private land within forested watersheds by 2030. More specifically, Alig and Plantinga (2004) projected that 10 million hectares of forested land will be converted to developed uses between 1997 and 2030. Nowak and Walton (2005) projected that 5.3% (118,000 km^2) of non-urban forest land will be "subsumed" by urban growth by 2050, with the greatest impacts in the Southern and Eastern forests.

Researchers have employed a number of metrics and projection models for defining and quantifying the development of rural lands, based on available datasets. The USDA Natural Resources Conservation Service (USDA NRCS) National Resources Inventory (NRI) (USDA NRCS, 2000, 2007) data have been used as a basis for numerous land-cover and land-use change studies (e.g., Alig et al., 2003, 2004; Lubowski, 2002; Polyakov and Zhang, 2008). An alternative

* Corresponding author. Tel.: +1 541 750 7422; fax: +1 541 750 7329.
E-mail addresses: emwhite@fs.fed.us (E.M. White), morzillo.anita@epa.gov (A.T. Morzillo), ralig@fs.fed.us (R.J. Alig).

0169-2046/$ – see front matter. Published by Elsevier B.V.
doi:10.1016/j.landurbplan.2008.09.004

source of data, the US Department of Commerce (USDC) Census Bureau data for urban area that is defined based on population and proximity to established urban areas, are updated every 10 years and were used by Nowak and Walton (2005) to project urban area expansion to 2050. Hobbs and Stoops (2002) used the USDC Census Bureau definition of urban area and urban growth over time as an indicator of land development. Likewise, other researchers have adapted USDA Forest Service Forest Inventory and Analysis (FIA) data and definition of urban lands to identify the conversion of forest land to urban uses (e.g., Harper et al., in press; Kline and Alig, 1999; Thompson and Thompson, 2002). Others have quantified losses of agricultural (e.g., Nelson, 1999) and forest land (e.g., Alig and Plantinga, 2004). However, quantifying the overall loss of agricultural or forest land also requires identifying rural lands that will convert to other rural land uses (e.g., agriculture land replanted to forest and vice versa), as well as rural land converted to developed uses. In addition, several spatially explicit land-cover and land-use change models have been constructed using remotely sensed land-cover data and often involve cellular automata, autonomous agents, and/or neural networks (e.g., Clarke and Gaydos, 1998; Evans and Kelley, 2004; Pijanowski et al., 2002a; Zhen et al., 2005). However, such spatially explicit models typically are applied to regional- or local-level analyses rather than national-level analyses.

Land-use studies also have included demographic characteristics as a component of a land development metric. For example, Kline (2000) quantified land developed as the number of additional acres of developed land per additional resident for US states as an indicator of the relative efficiency of developed land use. More broadly, Liu et al. (2003) focused on per capita resource consumption at the household level and how an overall decrease in household size has contributed to a net increase in resource consumption for a given population size.

In this study, we adopted a metric that quantifies land development on a per-housing-unit basis. Our study is an improvement upon past research such that our metric is not complicated by population decreases (as found in Kline, 2000) and extends the approach adopted in Liu et al. (2003) to include housing units that are not currently primary residences (e.g., second homes, newly built vacant houses). To better elucidate the patterns of land development, we quantified the rate of development at the housing unit level over a 15-year period from 1982 to 1997. Using population projections and extrapolations of changes in the number of people per housing unit, we projected changes in developed area for US states and regions to the year 2030 under current conditions and under simulated alternate migration patterns and reduced land development rates.

2. Conceptual model of land development

The developed land added between time T_0 and T_1 (D_{t1-t0}) is the amount of land needed to meet the demand for new residential (D_R), commercial and institutional (D_C), industrial (D_I), and transportation (D_T) development (Fig. 1):

$$D_{t1-t0} = D_R + D_C + D_I + D_T.$$

The amount of land required for new residential development (D_R) is a function of the increase in population, the changing incomes of individuals, changing preferences for housing (e.g., desire for larger houses, second homes, amenity migration), and changes in the number of people per housing unit (e.g., Alig et al., 2004; Montgomery, 2001; Theobald, 2005). Land development for commercial and institutional uses (D_C) (e.g., retail, healthcare facilities, schools, government buildings) is influenced by broad economic conditions, local factors influencing land use (e.g., planning, zoning, land prices), and demands associated with the expanding residential area (D_R). Land development required for industrial sector expansion (D_I) is influenced by broad economic conditions and local factors influencing land use, as well as the availability of production inputs (e.g., labor, capital, intermediate products). Finally, the expansion of transportation networks (D_T) is influenced by growth in the residential (D_R), commercial/institutional (D_C), and industry sectors (D_I) (e.g., Baldwin et al., 2007).

The additional developed land area required at T_1 (D_{t1-t0}) is provided by both land already in some form of developed or urban use ($D_{existing}$) (through in-fill development and renovation of existing developed infrastructure, as in urban renewal, for example) and rural land that is converted to developed uses ($R_{converted}$) (Fig. 1):

$$D_{t1-t0} = D_{existing} + R_{converted}.$$

The amount of rural land converted to developed uses ($R_{converted}$) is a reflection of the rents of those rural lands in rural production (e.g., the rents from agriculture or forestry production) relative to the rents for developed uses and local factors influencing land-use conversion (e.g., zoning and planning and physiographic conditions) (Alig et al., 2003, 2004; Lubowski, 2002; Parks and Murray, 1994). Although rural land historically has converted back and forth between rural uses (e.g., agriculture to forest and vice versa), conversion to developed uses is generally a permanent alteration of rural lands.

In this study, residential development (D_R) served both as a driver of land development by itself and as an input to the development of related commercial/institutional (D_C) and transportation expansion (D_T) (Fig. 1). Industrial development (D_I) could be related positively to residential development to the extent that proximate residential areas provide labor inputs or consume the outputs from industry (e.g., energy production). Alternately, residential development may be related inversely to industrial expansion because of incompatibility of residential areas and industrial production (e.g., noise pollution). Considering the postulated important role of residential expansion in driving land development and readily available housing unit counts from the USDC Census Bureau, we adopted a per-housing-unit metric for characterizing additional land development (our development index). Our projection model focused on linking future changes in population and people per housing unit to future demands for residential expansion. Demands for residential expansion then were translated into future developed land area based on long-term relationships between residential expansion and the addition of developed area. Other factors potentially influencing land development (e.g., local zoning and planning) were held static and were internalized into the long-term relationships between developed area and residential development. We examined the impacts of changes in some of the factors influencing land use on future developed area via sensitivity analyses. The utility of our model is fourfold, such that it: (1) is operationally simple, (2) applies to multiple geographic levels, (3) can accommodate additional complexity, and (4) relies on easily accessible data. Our research differs from Alig et al. (2004) such that we adopted a simulation modeling approach, rather than an econometric modeling approach. Likewise, our research differs from Nowak and Walton (2005) such that we used NRI data to identify developed land area. In addition, our research differs from both Alig et al. (2004) and Nowak and Walton (2005) in that we explicitly incorporated projected residential expansion into the model of future land development.

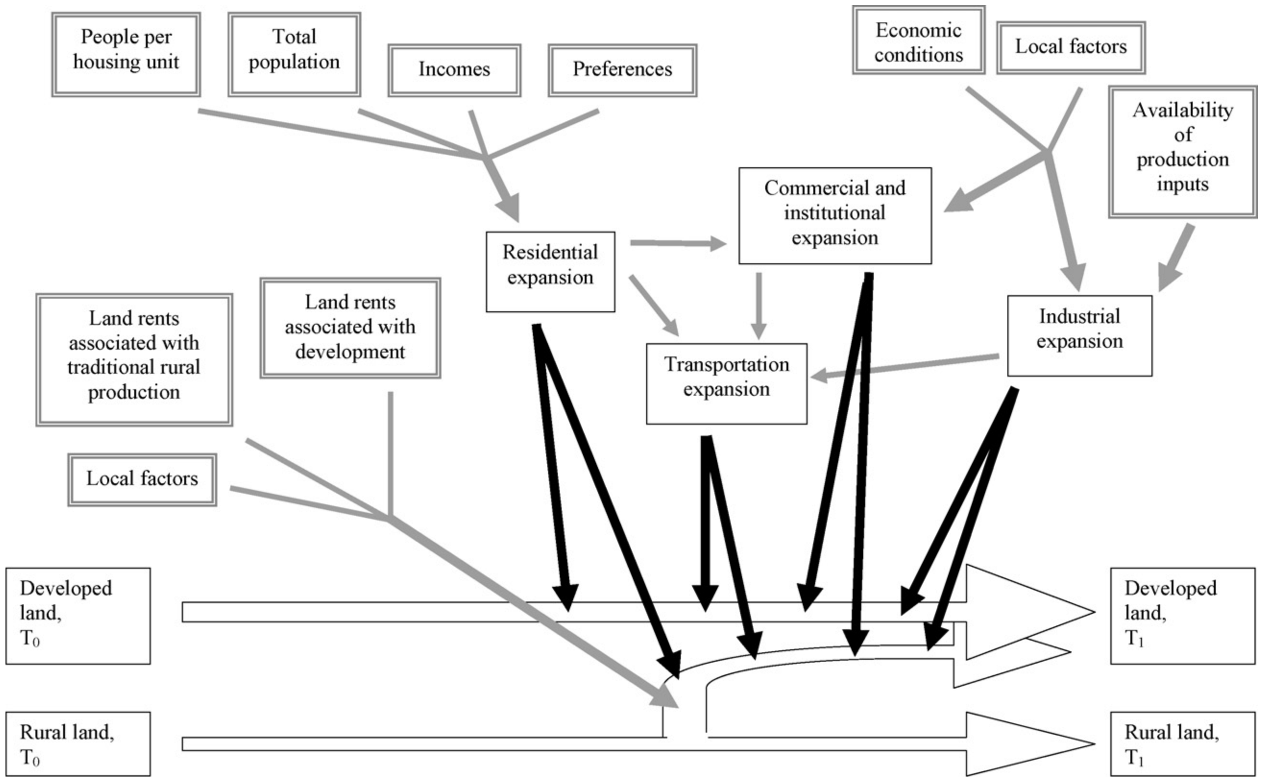

Fig. 1. Conceptual model of land development. Arrows illustrate changes in area of developed and rural land over time (white), factors affecting development (gray and black), and four categories of land-use expansion (residential (D_R), commercial and institutional (D_C), industrial (D_I), and transportation (D_T); black).

3. Methods

3.1. Study area and regions

Development indices and developed area projections were computed at three geographic levels: (1) the 48 contiguous US states plus Hawaii, (2) seven regions of the US, and (3) the Nation. Regional delineations adopted for our analysis were based on those adopted in the periodic US Resources Planning Act (RPA) Assessments and are consistent with delineations adopted by Nowak and Walton (2005). Alaska, Puerto Rico, the US Virgin Islands, and the South Pacific islands were excluded from analyses because appropriate land-use data were not available separately for those areas.

3.2. Construction of development indices

3.2.1. Developed area

We obtained state- and national-level developed area estimates from the NRI results (USDA NRCS, 2000, 2007). Via the NRI, the USDA NRCS estimated the area of non-federally owned land within seven major land-cover/land-use categories: developed land, cropland, forest land, rangeland, pastureland, other rural land, and Conservation Reserve Program land. Developed land included large and small urban and built-up lands and rural transportation lands (USDA NRCS, 2000). Between the 1982 and 1997 sample dates, the NRI was implemented via a periodic panel survey completed every 5 years. Beginning in 2000, NRI sampling was converted to an annual sample. The developed area estimates from the periodic survey data collected for years 1982, 1987, 1992, and 1997 can be used to quantify developed area changes over time (i.e., D_{t1-t0}) and the patterns of transitions between major land uses (USDA NRCS, 2000). Although the post-2000 estimates of developed area at the state-level can be used to describe current conditions, they cannot be compared to previous estimates or be used to estimate transition patterns (USDA NRCS, 2007). A complete description of the NRI periodic survey methods is available in USDA NRCS (2000).

We computed increases in developed area for two 5-year periods, 1982–1987 and 1992–1997, and the long-term 15-year period 1982–1997 (all corresponding to the NRI periodic sample dates) for each state and region and for the US. Based on the definition of developed land adopted in the NRI, additional intensification of development within existing built-up landscapes does not contribute to the gross increase in the area of developed land. Rather, increases in NRI-defined developed land area represent conversions of previously rural lands to developed uses.

3.2.2. Housing units and population

Census Bureau estimates of population and housing units were gathered for 1980–2005 (USDC Census Bureau, 1993, 1999a,b,c, 2005a, 2007). Annual population estimates constructed by the USDC Census Bureau were based on models incorporating natural changes in population (births and deaths) and domestic migration between states and regions (USDC Census Bureau, 1999d). The 1980, 1990, and 2000 censuses served as reference points for the estimates in the succeeding years, respectively. Housing unit estimates were developed using the number of housing units identified in the reference census years and estimates of residential construction, mobile home placement, and housing demolition since the most recent census (USDC Census Bureau, 1999d). Housing estimates included seasonal and vacant housing units. The periodic increase in number of housing units corresponding to the periodic NRI survey years (1982–1987, 1992–1997, and 1982–1997) was computed for each state, region, and the nation. Using the population and housing unit estimates, the average number of individuals per housing unit was computed for each year between 1980 and 2005.

3.2.3. Development index

Following the approach used by Kline (2000), development indices (DevIndex) were calculated as the changes in developed area during the three time periods considered (D_{t1-t0}) (1982–1987, 1992–1997, 1982–1997) divided by the housing unit increases over the same time periods (H_{t1-t0}):

$$\text{DevIndex} = \frac{D_{t1-t0}}{H_{t1-t0}}.$$

The resulting development indices represent the relationships between additional developed area and the establishment of additional housing units during the time periods. In addition, the relationship between developed area and housing units implicitly included the conversion of rural land to developed uses associated with existing housing units and commercial, industrial, and transportation development in rural areas that was unrelated to new housing development.

3.3. Developed area projections

State-, regional-, and national-level projections of the expected increase in developed area between 2003 (the most recent year that NRI data were available for individual states) and 2030 ($D_{2030-2003}$) were constructed using (1) population projections (Pop_{2030}), (2) the expected average numbers of individuals per housing unit for year 2030 (PPU_{2030}), (3) the number of existing housing units in 2003 (H_{2003}), and (4) the long-term developed area indicators estimated for the 1982–1997 time period ($\text{DevIndex}_{1997-1982}$):

$$D_{2030-2003} = \left(\left(\frac{\text{Pop}_{2030}}{\text{PPU}_{2030}} \right) - H_{2003} \right) \text{DevIndex}_{1997-1982}. \quad (1)$$

The year 2030 population projections were obtained from the USDC Census Bureau (2005b). The expected numbers of individuals per housing unit for year 2030 were constructed by extrapolating the 25-year trend (1980–2005) of people per housing unit for each state and region, as well as the nation. All calculations were completed at state, regional, and national levels.

3.4. Model verification and validation

The model was verified by setting 1982 as the baseline year in Eq. (1) and projecting developed area to year 1997. Parameters used included the 1997 population estimate (treated as the given USDC Census Bureau population projection), the 1982–1997 development indices (constructed for this study), and the projected number of people per housing unit for 1997 as estimated by the people per housing unit trend model (constructed for this study with 1997 substituted as the terminal year).

We validated the model against year 2003 NRI developed area figures (which were not used for model construction) (USDA NRCS, 2007). Similar to model verification, year 1982 was treated as the baseline year for validation. Parameters used in Eq. (1) included the 2003 population estimate (treated as the given USDC Census Bureau population projection), the 1982–1997 development indices (constructed for this study), and the projected number of people per housing unit for 2003 as estimated by the people per housing unit trend model (constructed for this study). Model outputs were compared to the observed NRI developed area estimates and the 95% confidence intervals around those estimates for year 2003. The percentage differences between model outputs and NRI estimates also were computed to determine the extent to which model output differed from observed developed area in 2003.

3.5. Impacts of changes in migration patterns and development indices

To examine potential impacts that changes in population growth patterns may have on projected developed area expansion in the US, we modified the population projections for states in the Southeast and Pacific Coast regions (i.e., Pop_{2030}). The rapid population growth in the Southern states over recent decades can largely be attributed to domestic migration to the South. Recently (between 2000 and 2004), domestic net migration to the South has abated slightly (Perry, 2006). Concurrently, domestic net migration rates to the Pacific Coast states have increased (Perry, 2006). Consistent with these recent patterns, we reduced the 2030 population projections to the states in the Southeast region by 10% (approximately 2.5 million individuals) and increased the population projections for the Pacific Coast region by the corresponding number of individuals. The population increases were distributed to the Pacific Coast region states based on the current population distribution across the states in that region. Because California is by far the most populated state in the Pacific Coast region, the majority of the additional population was distributed to California's projected 2030 population.

To examine how developed area projections are affected by changes in the rate of developed area expansion per additional housing unit, we simulated a reduction in developed area expansion rates for the states and regions with the highest development indices (i.e., $\text{DevIndex}_{1997-1982}$). State- and region-level development indices were capped at 110% of the national development index. This reduction simulated an increase in the efficiency of land development in response to new regulations or changing preferences in the states with the highest development indices. States and regions with development indices already at or below 110% of national average were left unchanged.

4. Results

4.1. Developed land area

Developed land constitutes slightly more than 7% of the non-federal land base in the contiguous US. The Southeast and Northeast regions are the most developed in the US, with 15% and 14% of non-federal land areas developed, respectively (Fig. 2). The Great Plains and Rocky Mountain regions are the least developed within the US; approximately 3% of the non-federal land area is developed in each of these regions. Of the 10 most developed states, 7 are in the Northeast region, 2 are in the Southeast region, and 1 is in the North Central region (Fig. 2).

From 1982 to 1997, the greatest absolute and percentage increases (2.6 million hectares or 58%) in developed area were in the Southeast region of the US (Table 1). The smallest increases in developed area were in the Great Plains region (201,000 ha or 11%). At the state-level, the greatest absolute increases in developed area were in Texas (923,000 ha), Florida (770,000 ha), and Georgia (644,000 ha). On a percentage basis, Georgia (67%), North Carolina (60%), and Florida (58%) experienced the greatest increases in developed area. North Dakota (6%), Iowa (8%), and Nebraska (8%) experienced the lowest percentage increases in developed area. In nearly all cases, the percentage increases in developed area during the 1992–1997 period were greater than those during the 1982–1987 period.

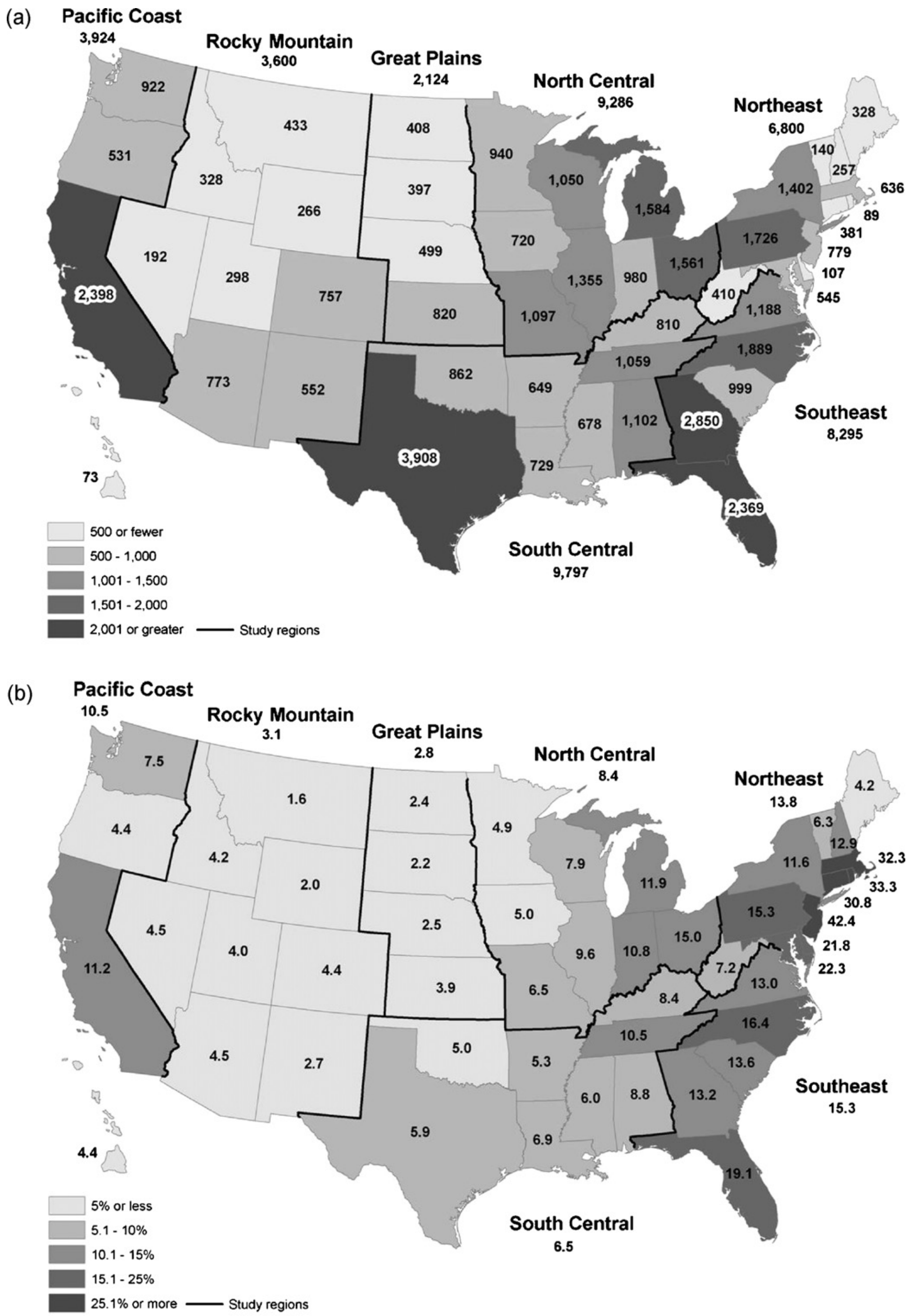

Fig. 2. Developed land area in 1,000 s hectares (a) and as a percentage of non-federal rural land (b) for US states and regions, 2003. *Note*: Hawaii figures are based on 1997 developed area. *Data source*: USDA NRCS (2000, 2007).

4.2. Development indices

During the 15-year NRI remeasurement period (1982–1997), approximately 20 million housing units were added within the US (Table 2). Approximately 7.5 million housing units were added between 1982 and 1987, whereas about 6.5 million housing units were added between 1992 and 1997. Consistent with concurrent population increases, the greatest regional increase in housing units was in the Southeast region (5.2 million housing units). In contrast, the Great Plains region added 273,000 housing units over the same period. At the state level, California (2.3 million), Florida (2.1 million), and Texas (1.7 million) added the greatest number of housing units between 1982 and 1997. In comparison, 12,000 housing units were added in Wyoming during the same time period.

Nationally, 0.50 additional hectares of rural land were converted to developed uses for each housing unit added between 1982 and 1997 (Table 2). Only the Western US (Pacific Coast and Rocky Moun-

Table 1
Expansion in developed land in the United States, 1982–1997.

Region/state	Area increase (1000s ha)			Percentage increase		
	1982–1987	1992–1997	1982–1997	1982–1987	1992–1997	1982–1997
Southeast	596.6	1,169.2	2,620.9	13.1	19.5	57.6
Florida	150.0	333.9	774.3	11.3	18.9	58.5
Georgia	106.1	344.8	643.6	11.1	27.4	67.2
North Carolina	177.2	205.0	582.6	18.1	15.1	59.6
South Carolina	66.5	146.5	302.9	12.2	20.9	55.5
Virginia	96.8	139.0	317.5	13.0	15.1	42.6
Northeast	395.5	767.6	1,612.4	8.5	14.0	34.7
Connecticut	18.5	15.9	49.9	6.1	4.7	16.4
Delaware	7.3	9.3	23.7	10.8	11.4	35.0
Maine	19.6	45.0	81.9	9.5	18.5	39.7
Maryland	32.3	71.9	130.6	8.7	16.8	35.3
Massachusetts	42.7	85.7	180.2	10.2	16.7	43.1
New Hampshire	36.4	25.3	84.8	23.7	11.9	55.3
New Jersey	90.6	86.4	207.5	17.7	13.7	40.5
New York	40.3	128.5	221.7	3.8	11.1	20.8
Pennsylvania	73.8	220.6	471.2	6.5	15.9	41.3
Rhode Island	3.9	2.7	13.4	5.8	3.4	19.8
Vermont	15.0	4.7	30.3	15.3	3.8	30.8
West Virginia	15.1	71.5	117.2	6.4	25.4	49.6
North Central	416.1	762.4	1,624.5	5.9	9.6	23.1
Illinois	57.9	99.8	199.2	5.3	8.4	18.3
Indiana	49.3	79.0	172.2	6.6	9.5	23.2
Iowa	10.0	28.0	48.5	1.6	4.2	7.6
Michigan	81.2	147.3	331.9	7.4	11.4	30.1
Minnesota	49.8	93.8	188.4	7.2	11.9	27.1
Missouri	40.5	90.7	175.4	4.8	9.8	20.8
Ohio	81.4	147.6	335.3	7.2	11.2	29.8
Wisconsin	46.1	76.2	173.5	5.7	8.4	21.6
South Central	652.0	1,025.2	2,313.4	10.3	13.5	36.5
Alabama	77.1	127.6	257.3	11.8	16.3	39.3
Arkansas	14.7	68.4	107.5	3.2	13.6	23.2
Kentucky	78.9	96.0	239.7	17.0	15.8	51.7
Louisiana	61.4	54.1	157.8	12.3	9.0	31.6
Mississippi	29.5	83.5	143.2	6.5	16.3	31.6
Oklahoma	34.1	71.5	134.7	5.3	10.1	20.9
Tennessee	84.9	162.6	350.4	13.9	20.4	57.5
Texas	271.5	361.6	922.9	10.7	11.6	36.3
Pacific Coast	176.0	366.2	867.3	6.4	11.3	31.6
California	107.8	224.0	533.4	6.4	11.3	31.9
Hawaii	1.6	2.8	12.3	2.6	3.9	20.4
Oregon	35.7	42.0	107.9	9.2	9.3	27.9
Washington	31.0	97.4	213.6	5.0	13.2	34.3
Great Plains	24.3	98.0	200.6	1.3	5.0	10.8
Kansas	10.8	39.1	89.6	1.6	5.2	12.9
Nebraska	6.9	22.3	38.2	1.5	4.8	8.5
North Dakota	4.0	13.3	23.3	1.0	3.4	6.2
South Dakota	2.6	23.4	49.5	0.8	6.4	14.6
Rocky Mountain	254.0	305.2	786.1	10.8	10.7	33.3
Arizona	74.0	46.1	163.0	16.8	8.3	37.0
Colorado	60.9	45.5	168.0	12.2	7.3	33.6
Idaho	24.4	37.2	82.8	10.9	13.9	37.2
Montana	4.7	30.9	62.2	1.3	8.0	17.5
Nevada	19.5	10.8	44.2	17.7	7.5	40.1
New Mexico	33.2	87.9	150.4	10.5	23.2	47.6
Utah	18.4	32.9	77.5	9.7	14.0	40.7
Wyoming	19.1	13.9	38.0	8.6	5.6	17.1
United States	2,532.8	4,539.4	10,119.5	8.5	12.9	34.1

Data source: USDA NRCS (2000).

tain regions) had development indices that were less than the national average: 0.27 and 0.38 ha, respectively. In all other regions, the hectares of developed land gained per additional housing unit were equal to or greater than the national average. The greatest number of hectares of additional development per additional housing unit was in the Great Plains region, which was mostly related to high development indices in the Dakotas. The South Central region had the second greatest development index. In most cases, the per-housing-unit expansion of developed area that took place during the 1990s was greater than that during the 1980s. At the national-level, the development index for the 1992–1997 period was double the development index for the 1982–1987 period.

At the state level in the Southeast region, development indices were greater than the national average in Georgia (0.65 ha), North

Carolina (0.63 ha), and South Carolina (0.68), but less than the national average in Virginia (0.45 ha) and Florida (0.36 ha) (Table 2). In the South Central region, development indices for all states were greater than the national average. Seven of the 12 states in the Northeast region had development indices that were greater than the national average. All states in the Pacific Coast region had development indices below the national average.

4.3. *Projections of developed area*

4.3.1. *Model verification and validation*

Model verification indicated that the model was functioning as expected. All model projections of 1997 developed area matched the observed NRI 1997 developed area. The results of model validation indicated that the model provided reasonable estimates of

Table 2
Housing unit expansion and per housing unit land development in the United States, 1982–1997.

Region/state	Housing unit change			Additional hectares of land development per additional housing unit		
	1982–1987	1992–1997	1982–1997	1982–1987	1992–1997	1982–1997
Southeast	1,984,217	1,635,796	5,203,847	0.3007	0.7147	0.5038
Florida	898,189	533,152	2,136,211	0.1671	0.6265	0.3626
Georgia	356,305	362,063	991,528	0.2978	0.9522	0.6491
North Carolina	318,608	360,980	927,142	0.5560	0.5678	0.6285
South Carolina	160,477	167,414	443,568	0.4144	0.8749	0.6827
Virginia	250,638	212,187	705,398	0.3861	0.6552	0.4500
Northeast	1,077,414	707,772	2,891,054	0.3670	1.0846	0.5577
Connecticut	83,222	34,585	190,065	0.2218	0.4609	0.2626
Delaware	25,370	22,234	77,275	0.2869	0.4205	0.3063
Maine	40,542	24,357	109,688	0.4832	1.8458	0.7470
Maryland	173,229	119,593	456,880	0.1866	0.6010	0.2857
Massachusetts	136,731	58,521	312,140	0.3120	1.4646	0.5771
New Hampshire	62,384	20,520	132,964	0.5832	1.2347	0.6378
New Jersey	163,200	93,808	403,001	0.5552	0.9215	0.5148
New York	178,949	125,595	531,677	0.2254	1.0234	0.4168
Pennsylvania	155,190	176,668	539,820	0.4755	1.2485	0.8729
Rhode Island	19,371	8,770	49,329	0.2027	0.3047	0.2715
Vermont	22,875	10,949	54,731	0.6564	0.4249	0.5532
West Virginia	16,351	12,172	33,484	0.9231	5.8781	3.5013
North Central	698,071	1,190,028	2,826,891	0.5961	0.6406	0.5747
Illinois	82,896	176,327	402,961	0.6985	0.5658	0.4945
Indiana	69,023	165,610	346,851	0.7135	0.4771	0.4965
Iowa	2,591	46,588	61,626	3.8579	0.6001	0.7875
Michigan	108,388	202,407	488,937	0.7491	0.7280	0.6791
Minnesota	119,151	111,161	343,903	0.4180	0.8438	0.5479
Missouri	117,280	139,098	349,561	0.3452	0.6524	0.5018
Ohio	111,742	201,054	482,188	0.7288	0.7341	0.6952
Wisconsin	87,000	147,783	350,864	0.5293	0.5152	0.4945
South Central	1,690,122	1,244,439	3,505,255	0.3857	0.8239	0.6600
Alabama	111,109	136,318	333,744	0.6940	0.9360	0.7709
Arkansas	62,252	67,512	163,287	0.2359	1.0125	0.6584
Kentucky	70,824	107,895	249,725	1.1137	0.8895	0.9595
Louisiana	112,491	70,641	183,409	0.5455	0.7653	0.8604
Mississippi	57,876	70,319	161,460	0.5099	1.1878	0.8867
Oklahoma	117,718	41,256	162,753	0.2894	1.7333	0.8276
Tennessee	157,995	197,772	492,684	0.5378	0.8223	0.7114
Texas	999,857	552,726	1,758,193	0.2715	0.6544	0.5249
Pacific Coast	1,153,378	787,944	3,261,153	0.1526	0.4646	0.2659
California	948,646	415,446	2,353,091	0.1137	0.5390	0.2266
Hawaii	22,125	29,383	85,592	0.0712	0.0935	0.1441
Oregon	34,424	129,570	248,385	1.0356	0.3246	0.4346
Washington	148,183	213,545	574,085	0.2088	0.4565	0.3719
Great Plains	86,900	124,604	272,839	0.2792	0.7867	0.7353
Kansas	52,164	58,682	142,087	0.2072	0.6653	0.6305
Nebraska	16,755	32,374	68,592	0.4108	0.6888	0.5568
North Dakota	9,991	12,278	25,663	0.3970	1.0809	0.9081
South Dakota	7,990	21,270	36,497	0.3294	1.0995	1.3561
Rocky Mountain	771,229	828,728	2,048,332	0.3294	0.3683	0.3836
Arizona	336,391	236,155	732,809	0.2197	0.1951	0.2226
Colorado	176,914	178,702	412,000	0.3444	0.2550	0.4079
Idaho	18,013	64,462	103,045	1.3525	0.5771	0.8041
Montana	18,685	17,172	42,182	0.2489	1.7980	1.4747
Nevada	74,135	152,530	356,029	0.2626	0.0708	0.1242
New Mexico	73,279	81,579	194,706	0.4528	1.0773	0.7725
Utah	67,620	90,255	195,442	0.2724	0.3646	0.3966
Wyoming	6,192	7,873	12,119	3.0784	1.7681	3.1323
United States	7,506,706	6,522,271	20,065,500	0.3375	0.6961	0.5042

Housing data source: USDC Census Bureau (1999a,b).

Table 3
Projected expansion in developed area in the United States, 2003–2030.

Region/state	Projected 2030 housing units (1000s)	Projected developed land increase		
		Area increase (1000s ha)	Percentage increase	Percent of current non-federal rural land
Southeast	33,909	6,950.5	83.8	15.1
Florida	13,769	2,159.4	91.2	21.5
Georgia	5,675	1,356.9	73.3	11.2
North Carolina	6,716	1,839.7	97.4	19.1
South Carolina	3,017	791.2	79.2	12.5
Virginia	4,631	704.2	59.3	8.9
Northeast	30,821	2,673.8	39.3	6.3
Connecticut	1,639	60.7	16.0	7.1
Delaware	504	44.1	41.2	11.5
Maine	870	149.3	45.6	2.0
Maryland	3,133	259.4	47.6	13.7
Massachusetts	3,242	337.1	52.9	25.2
New Hampshire	781	135.6	52.8	7.8
New Jersey	4,074	352.1	45.2	33.2
New York	8,298	212.5	15.1	2.0
Pennsylvania	6,372	891.9	51.7	9.4
Rhode Island	509	17.4	19.6	9.8
Vermont	404	56.3	40.2	2.7
West Virginia	1,103	420.9	102.8	7.9
North Central	31,677	3,600.5	38.8	3.6
Illinois	5,798	374.7	27.7	2.9
Indiana	3,440	390.1	39.8	4.8
Iowa	1,505	183.3	25.5	1.3
Michigan	5,513	765.7	48.3	6.5
Minnesota	3,104	509.1	54.2	2.8
Missouri	3,212	340.3	31.0	2.1
Ohio	5,921	694.0	44.5	7.9
Wisconsin	3,226	394.6	37.6	3.2
South Central	30,475	6,272.6	64.0	4.5
Alabama	2,827	610.3	55.4	5.3
Arkansas	1,701	318.5	49.1	2.8
Kentucky	2,531	680.3	84.0	7.7
Louisiana	2,468	489.7	67.2	4.9
Mississippi	1,575	325.0	47.9	3.1
Oklahoma	1,936	313.2	36.3	1.9
Tennessee	3,896	952.2	89.9	10.6
Texas	13,324	2,440.7	62.5	3.9
Pacific Coast	21,788	1,220.9	31.1	2.9
California	15,417	629.7	26.3	3.3
Hawaii	635	23.1	31.5	1.6
Oregon	2,156	278.8	52.5	2.4
Washington	3,755	441.5	47.9	3.9
Great Plains	3,039	354.5	16.7	0.5
Kansas	1,390	137.6	16.8	0.7
Nebraska	878	71.6	14.4	0.4
North Dakota	365	61.5	15.1	0.4
South Dakota	407	93.9	23.6	0.5
Rocky Mountain	13,493	2,049.3	56.9	1.8
Arizona	4,827	542.7	70.2	3.3
Colorado	2,727	307.2	40.5	1.9
Idaho	863	239.6	72.9	3.2
Montana	529	161.1	37.2	0.6
Nevada	1,797	107.2	55.7	2.6
New Mexico	1,033	167.5	30.4	0.8
Utah	1,303	188.6	63.3	2.7
Wyoming	286	88.6	33.4	0.7
United States[a]	164,754	22,418.8	51.2	4.0

[a] Does not include Alaska, Puerto Rico, Virgin Islands, or Pacific Basin islands.

developed area. For 37 of 48 states, model projections for the 2003 developed area were not statistically different from the 2003 NRI developed area estimates (based on the NRI 95% confidence intervals). Across all states, the average difference between the model projections and the NRI developed area estimates was 3.1%. Percentage differences at the state level ranged (in absolute value terms) from 0.04% to 37.9%. Thirty-two (66%) of the state-level developed area projections were within 5% of the NRI estimates of developed area. For the 16 states where the projections were more than 5% different from the NRI estimates, seven still fell within 95% confidence intervals for the NRI developed area for the respective states. Nine states had projections of developed area that were outside of the NRI 95% confidence interval estimate of developed area and were more than 5% different from the NRI estimates: Idaho (11.8%), Illinois (7.1%), Kentucky (6.9%), Massachusetts (5.1%), Minnesota (5.9%), Ohio (6.7%), Tennessee (9.0%), West Virginia (37.9%), and Wyoming (19.5%). At the national level, the developed area projection for 2003 was within 3% of the NRI developed area estimate but outside the NRI developed area 95% confidence interval.

4.3.2. Developed area projections

Nationally, we projected that 22 million hectares of rural lands will be converted to developed uses between 2003 and 2030, which is a 51% increase in developed area (Table 3). Regionally, the greatest increases in developed area were projected for the Southeast (6.9 million hectares, or 84%) and the South Central (6.3 million hectares, or 64%) US (Table 3, Fig. 3). Significant, though lesser, increases were projected in the Rocky Mountain region (2 million hectares, or 57%). Developed areas in the North Central and Northeast regions were projected to expand by approximately 39%, which equals a projected increase of 3.6 million hectares in the North Central region and 2.7 million hectares in the Northeast region. The Great Plains region was projected to undergo the smallest absolute increase in developed area (354,000 ha, 17%) followed by the Pacific Coast region (1.2 million hectares, 31%).

At the state-level, North Carolina and Florida were each projected to experience a greater than 90% increase in developed area during the 2003–2030 time period, or 1.8 and 2.1 million hectares of additional development, respectively (Table 3, Figure 3). Georgia was projected to experience an increase in developed area of approximately 1.3 million hectares (73%). In the South Central region, Texas was projected to add 2.4 million hectares of developed land by 2030, which was the greatest absolute increase in developed area projected for any state. Other significant increases were projected in the South Central states of Tennessee (952,000 ha, 90%) and Kentucky (680,000 ha, 84%). For the Rocky Mountain region, the greatest absolute increase in developed hectares was projected in Arizona (543,000 ha) with the greatest percentage increases projected for Idaho (73%), Arizona (70%), and Utah (63%). For the Pacific Coast region, the greatest absolute increases were projected for California (630,000 ha) and Washington (441,000 ha) while the greatest percentage increase was projected for Oregon (52%).

4.4. Alternative migration patterns and development indices

Nationally, a 10% reduction in projected population growth in the Southeast states and a corresponding population increase in the Pacific Coast region resulted in a national-level net reduction in projected 2030 developed area of 386,000 ha. The simulated 10% reduction in projected population growth for the Southeast region states yielded the greatest absolute reduction in 2030 population in Florida (1.3 million individuals). Population reductions in Georgia and North Carolina each were approximately 400,000 individuals, with smaller reductions in Virginia (274,000 individuals) and South Carolina (113,000). The simulated reduction in projected population for states within the Southeast region reduced the projected expansion in developed area for that region by 619,000 ha (a 1% reduction from the Southeast's baseline projection). The greatest reductions in the projected developed area increase were in Florida (221,000 ha), North Carolina (144,000 ha) and Georgia (117,000 ha). The projected 2030 developed areas for Virginia and South Carolina were reduced by 58,000 and 45,000 ha, respectively, under the scenario.

The simulated increase of 2.5 million in 2030 population in the Pacific Coast region yielded an additional 232,000 ha of projected developed land in that region. Consistent with how the population was distributed among the Pacific Coast states, 140,000 and 56,000 ha of additional 2030 developed area were projected for California and Washington, respectively. For Oregon, the developed area expansion was 14% (38,000 ha) greater under this scenario than under the baseline population scenario. The simulated increase in population yielded an additional 4000 ha of projected development in Hawaii.

We also simulated the change in projected developed area resulting from a cap on development indices at 110% of the national development index. The simulated cap led to reduced development indices in 26 states and 4 regions. The average decrease in development index across the states impacted by the cap was 0.31 ha. Excluding Wyoming and West Virginia (the states with the highest development indices), the average reduction was 0.24 ha

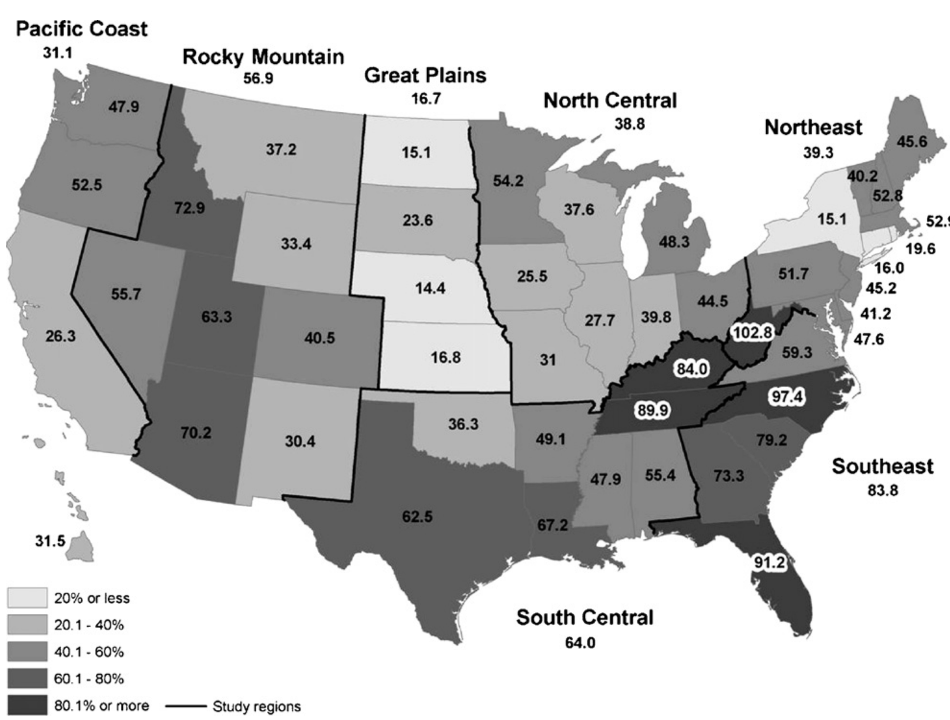

Fig. 3. Projected percentage increase in developed land in the United States, 2003–2030.

Please cite this article in press as: White, E.M., et al., Past and projected rural land conversion in the US at state, regional, and national levels. Landscape Urban Plann (2008), doi:10.1016/j.landurbplan.2008.09.004

across impacted states. Nationally, the simulated cap in development indices was projected to yield 1.2 million fewer hectares of developed area by 2030, which was equivalent to 5% of the baseline projected increase in developed area between 2003 and 2030.

5. Discussion

5.1. Model performance

State-level projections of year 2003 developed area were either within the observed NRI 95% confidence interval of developed area, within 5% of the NRI estimate of developed area, or both for 39 (81%) of the states included in this study. However, there were large differences between model projections and observed year 2003 developed area in West Virginia and Wyoming. These differences are likely the result of inflated development indices. West Virginia's development index was 3.5 ha per housing unit, whereas Wyoming's was 3.1 ha per housing unit. During the 1982–1997 time period, both states experienced small increases in the number of homes along with a more substantial increase in developed area, which likely was the result of development expansion other than housing. These unknown factors yielded development indices that were significantly greater than those found for any other state. Similarly large development indices for Wyoming and West Virginia were found in Kline (2000). Thus, the projections of year 2030 developed area for Wyoming and West Virginia should be interpreted with caution.

The national-level projection of 2003 developed area was 3% greater than the observed NRI developed area figure, but did fall outside the NRI developed area 95% confidence interval. The difference between our projection and the NRI estimate likely is related to two factors. First, unlike the national-level estimates of developed area used to initiate and parameterize our validation model, the 2003 national-level NRI developed area estimate does not include developed land in Hawaii, Puerto Rico, the Virgin Islands, and portions of the Pacific Basin (USDA NRCS, 2000, 2007). Second, the 2003 NRI land-use estimates are based on annual surveys that occurred between 2000 and 2003 (USDA NRCS, 2007). Inclusion of 2000, 2001, and 2002 data likely results in an underestimation of developed area in 2003 because some plots sampled between 2000 and 2002 would likely have been developed by 2003 (recall that developed land area increased by approximately 680,000 ha per year during 1982–2003).

5.2. Comparison with other national-level developed area projections

The year 2030 projections of developed area from this study were consistent with those of Alig et al. (2004) and Nowak and Walton (2005). The National-level projections reported in this study fell between the "low" and "baseline" projections of Alig et al. (2004) and were slightly greater than those reported by Nowak and Walton (2005) for year 2030. In their analysis, Nowak and Walton (2005) used the USDC Census Bureau definition of "urban area," whereas Alig et al. (2004) and the present study used NRI data and the NRI definition of developed land. Alig and White (2007) have previously found for western Washington that the projections from Nowak and Walton were slightly less than NRI-based projections of future developed area.

5.3. Conversion of undeveloped lands

At the state level, the area of land projected to be converted to developed uses ranged between 0.4% (Nebraska and North Dakota) and 33% (New Jersey) of currently existing non-federal rural land (Table 3). Regionally, projected rural land development as a percentage of current non-federal rural land area is largest in the Southeast and Northeast regions (15% and 6%, respectively), and smallest in the Great Plains (0.5%) and Rocky Mountain (1.8%) regions.

Although aggregate losses of rural land may be small at the state and regional level, local-level impacts may be significant. For example, projected development in Colorado represents 2% of the current non-federal rural land in that state. However, continued rapid development along the Front Range and southwestern portions of Colorado will impact greater percentages of non-federal rural lands in those areas of the state. Ultimately, it is at the local level where social and ecological impacts of urbanization of rural lands may be greatest (see Stein et al., 2007 for examples of some local implications of residential development). Additionally, the spatial arrangement of rural lands that are converted to developed uses, even for small areas, may magnify the ecological impacts from urbanization (e.g., wildlife habitat use; Dixon et al., 2006; Johnson and Collinge, 2004; Ng et al., 2004; Riley et al., 2003).

5.4. Factors influencing development rates

We used long-term 15-year development indices to project the increase in developed area between 2003 and 2030. Development indices for the 1980s and 1990s differed within the 15-year period. Reflecting the strong economic growth during the 1990s, the development indices for the 1990s generally were greater than those of the 1980s. If we had used the development indices found for 1992–1997 to parameterize the model constructed for this study, projected increases in developed area would have been greater (see Alig and Plantinga, 2004 for an example of developed area projections using the 1990s growth rates). Conversely, if the 1980s development indices were used, developed area would have been less than was projected here. Long-term economic conditions in the upcoming decades that differ appreciably from those experienced in the period 1982–1997 may lead to greater or lesser expansions in developed area. However, our projections provided a conservative estimate of future developed area increases based on long-term patterns of developed area expansion.

Other factors may also influence rates of rural development in the upcoming decades. Significant changes in individual preferences for housing characteristics and locations (e.g., smaller lot-sizes and changes in the desire to live in rural amenity-rich areas [Garber-Yonts, 2004]), reductions in the housing purchasing power of individuals (in response to decreases in real income), or changes in site preferences for commercial and industrial entities could affect developed area expansion.

Our sensitivity analysis of changes in the domestic migration patterns of 2.5 million individuals indicated a national-level net reduction in projected 2030 developed area of 386,000 ha—1.8% of the baseline projected increase. This reduction reflected regional differences in both the people per housing unit and development indices found in this study for the Southeast and Pacific Coast regions. With the exception of Florida, states within the Southeast region have development indices that are greater than those of the Pacific Coast states. Additionally, on average, the number of people per housing unit is greater in the Pacific Coast region than in the Southeast region. All else being equal, population increases in the Pacific Coast region currently result in fewer housing units, and less rural land conversion, than in the Southeast states.

Recently, it has been suggested that increases in the retail price of motor vehicle fuels may reduce rural residential development rates (e.g., Cortright, 2008; Goodman, 2008; Penalver, 2007). The previously low cost of commuting had not inhibited the movement of people outward from the city centers, but continued high

Please cite this article in press as: White, E.M., et al., Past and projected rural land conversion in the US at state, regional, and national levels. Landscape Urban Plann (2008), doi:10.1016/j.landurbplan.2008.09.004

transportation costs could result in a slowing of residential development in rural commuting environs and changes in rural development patterns. Our sensitivity analysis of reductions in development index mimics a decrease in the rate of rural land development per additional housing unit. The reduction in development index in the 26 states and four regions with higher than average rates of rural development yielded a 5% (1.2 million hectares) reduction in rural land development compared to baseline projections. Greater than 80% of that 1.2 million hectare decrease was associated with a decrease in projected developed area across the South Central states, where all states had development indices above the national average. Reductions in development index that are more extensive or of greater magnitude may lead to greater reductions in rural land conversion.

Changes in demand for goods and services produced from rural lands may also lead to reductions in the rate of rural land development. For example, increased demands for land for bioenergy production (e.g., corn-based ethanol) to address fossil fuel concerns may lead to increases in value of rural land for nontraditional agricultural or forest production relative to the value of rural land for developed uses. The demand for bioenergy production may increase further with technological advances, such as those allowing for greater use of cellulosic ethanol for bioenergy.

Finally, increased emphasis on open space conservation through regulatory, incentive, or other programs may decrease the rates of rural land conversion in the coming decades. As the area of rural land decreases, there are greater demands placed on remaining open space. This may result in changes in the behavior of individuals and communities with regard to the conservation of rural landscapes. For example, Kline (2006) found that the likelihood of passing referenda related to the protection of undeveloped land increases as the per capita amount of undeveloped area decreases. Scarcity of undeveloped land also may lead to greater values on the amenities received from rural lands, particularly non-market goods and services that are associated with living in proximity to rural lands (e.g., Irwin, 2002; Thorsnes, 2002; White and Leefers, 2007). In response to declines in the amount of open space and rural land, local and regional planning entities may initiate efforts that focus on conserving open space.

6. Conclusions

Rapid rural development is projected to continue, with the greatest absolute and percentage increases in developed area projected for the Southeast and South Central regions. High levels of developed area expansion also are expected in states with both high rates of additional development per additional housing unit and large projected population increases. Continued declines in the number of people per housing unit also will contribute to the rate of rural development as more housing units are required to accommodate the population. Goods and services associated with rural landscapes likely will continue to be threatened by rural development, placing additional pressure on natural resource managers to incorporate the changing rural landscape in resource planning.

The lack of consistent, regularly updated land-use data at national, regional, and local levels in the US presents difficulties for timely monitoring of land-use and land-use change. The most recent national-level data available to estimate land-cover and land-use transitions for this research are more than a decade old. Additional research efforts to identify a monitoring framework for land use within the US may significantly improve our understanding of ongoing land-use change and improve our ability to model land-use change. For example, technological advances may enhance prospects for increased integration of remotely sensed and ground-based measurements of land-use changes. Such a framework would be useful for improving our ability to examine the potential impacts of economic and policy dynamics (e.g., increasing energy prices and demand for bioenergy production) on rates of rural land development.

Acknowledgements

We thank Scott Bearer, Jeff Kline, and four anonymous reviewers for their constructive comments on earlier drafts of this manuscript. The information in this document has been funded in part by the US Environmental Protection Agency and the USDA Forest Service. It has been subjected to review by the National Health and Environmental Effects Research Laboratory's Western Ecology Division and approved for publication. Approval does not signify that the contents reflect the views of the Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use. This is contribution number WED-08-107 of the Western Ecology Division.

References

Alig, R.J., Plantinga, A.J., 2004. Future forestland area: impacts from population growth and other factors that affect land values. J. Forestry 102 (8), 19–24.
Alig, R.J., Kline, J.D., Lichtenstein, M., 2004. Urbanization on the US landscape: looking ahead in the 21st century. Landscape Urban Plan. 69 (2–3), 219–234.
Alig, R.J., Plantinga, A.J., Ahn, S., Kline, J., 2003. Land use changes involving forestry in the United States: 1952 to 1997, with projections to 2050. USDA For. Ser. Gen. Tech. Rep. PNW-GTR-587, Portland, OR.
Alig, R.J., White, E.M., 2007. Projections of forestland and developed land areas in western Washington. West. J. Appl. Forestry 22 (1), 29–35.
Alberti, M., Marzluff, J.M., Shulenberger, E., Bradley, G., Ryan, C., Zumbrunnen, C., 2003. Integrating humans into ecology: opportunities and challenges for studying urban ecosystems. Bioscience 53, 1169–1179.
Arnold, C.L., Gibbons, C.J., 1996. Impervious surface coverage. J. Am. Plan. Assoc. 62, 243–257.
Atasoy, M., Palmquist, R.B., Phaneuf, D.J., 2006. Estimating the effects of urban residential development on water quality using microdata. J. Environ. Manage. 79, 399–408.
Baldwin, R.F., Trombulak, S.C., Anderson, M.G., Woolmer, G., 2007. Projecting transition probabilities for regular public roads at the ecoregion scale: a northern Appalachian/Acadian case study. Landscape Urban Plan. 80 (2007), 404–411.
Berry, A., Hesseln, H., 2004. The effect of the wildland-urban interface on prescribed fire burning costs in the pacific northwestern United States. J. Forestry 102 (6), 33–37.
Cardille, J.A., Ventura, S.J., Turner, M.G., 2001. Environmental and social factors influencing wildfires in the upper Midwest, United States. Ecol. Appl. 11, 111–127.
Clarke, K.C., Gaydos, L.J., 1998. Loose-coupling a cellular automaton model and GIS: long-term urban growth prediction for San Francisco and Washington/Baltimore. Int. J. Geogr. Inf. Sci. 12 (7), 699–714.
Collins, J.P., Kinzig, A., Grimm, N.B., Fagan, W.F., Hope, D., Wu, J., et al., 2000. A new urban ecology. Am. Sci. 88, 417–425.
Cortright, J., 2008. Driven to the brink: how the gas price spike popped the housing bubble and devalued the suburbs. Retrieved on June 6 2008 from http://www.ceosforcities.org/newsroom/pr/files/Driven%20to%20the%20Brink%20FINAL.pdf.
Dixon, J.D., Oli, M.K., Wooten, M.C., Eason, T.H., McCown, J.W., Paetkau, D., 2006. Effectiveness of a regional corridor in connecting two Florida black bear populations. Conserv. Biol. 20, 155–162.
Evans, T.P., Kelley, H., 2004. Multi-scale analysis of a household level agent-based model of landcover change. J. Environ. Manage. 72, 57–72.
Faeth, S.H., Warren, P.S., Shochat, E., Marussich, W.A., 2005. Trophic dynamics in urban communities. Bioscience 55, 399–407.
Garber-Yonts, B.E., 2004. The economics of amenities and migration in the Pacific Northwest: review of selected literature with implications for national forest management. USDA For. Ser. Gen. Tech. Rep. PNW-GTR-617, Portland, OR.
Gebert, K.M., Calkin, D.E., Yoder, J., 2007. Estimating suppression expenditures for individual large wildland fires. West. J. Appl. Forestry 22 (3), 188–196.
Goodman P.S., 2008. Rethinking the country life as energy costs rise. The New York Times. Retrieved June 25, 2008 from http://www.nytimes.com/2008/06/25/business/25exurbs.html?_r=1&scp=1&sq=Rethinking%20the%20Country%20Life%20as%20Energy%20Costs%20Rise&st=cse&oref=slogin.
Harper, R.A., McClure, N., Johnson, T.G., Green, F., Johnson, J., Dickinson, D. et al. Georgia's Forests, 2004. USDA For. Serv. Southern Research Station, Asheville, NC, in press.
Hobbs, F., Stoops, N., 2002. Demographic trends in the 20th century. Retrieved February 29, 2008 from http://www.census.gov/prod/2002pubs/censr-4.pdf.
Holway, D.A., 2005. Edge effects of an invasive species across a natural ecological boundary. Biol. Conserv. 121 (4), 561–567.

Irwin, E.G., 2002. The effects of open space on residential property values. Land Econ. 78 (4), 465–480.
Johnson, W.C., Collinge, S.K., 2004. Landscape effects on black-tailed prairie dog colonies. Biol. Conserv. 115, 487–497.
Kline, J.D., 2000. Comparing states with and without growth management analysis based on indicators with policy implications comment. Land Use Policy 17, 349–355.
Kline, J.D., 2006. Public demand for preserving local open space. Soc. Nat. Resour. 19, 645–659.
Kline, J.D., Alig, R.J., 1999. Does land use planning slow the conversion of forest and agricultural land? Growth Change 30 (1), 3–22.
Kline, J.D., Azuma, D., Alig, R.J., 2004. Population growth, urban expansion, and private forestry in western Oregon. Forest Sci. 50 (1), 33–43.
Lambropoulos, A.S., Fine, J.B., Perbeck, A., Torres, D., 1999. Rodent control in urban areas: an interdisciplinary approach. J. Environ. Health 61, 12–17.
Liu, J., Daily, G.C., Ehrlich, P.R., Luck, G.W., 2003. Effects of household dynamics on resource consumption and biodiversity. Nature 421, 531–533.
Lubowski, R.N., 2002. Determinants of land-use transitions in the United States: econometric analysis of changes among the major land-use categories. Doctoral dissertation, Harvard University.
McKinney, M.L., 2002. Urbanization, biodiversity, and conservation. Bioscience 52, 883–890.
Montgomery, C.A., 2001. The future of housing in the United States: an econometric model and long-term predictions for the 2000 RPA Timber Assessment. USDA For. Serv. Res. Pap. PNW-RP-531, Portland, OR.
Munn, I.A., Barlow, S.A., Evan, D.L., Cleaves, D., 2002. Urbanization's impact on timber harvesting in the south central United States. J. Environ. Manage. 64, 65–76.
Nelson, A.C., 1999. Comparing states with and without growth management: analysis based on indicators with policy implications. Land Use Policy 16, 121–127.
Ng, S.J., Dole, J.W., Sauvajot, R.M., Riley, S.P.D., Valone, T.J., 2004. Use of highway undercrossings by wildlife in southern California. Biol. Conserv. 115, 499–507.
Nowak, D.J., Walton, J.T., 2005. Projected urban growth (2000–2050) and its estimated impact on the U.S. forest resource. J. Forestry 103 (8), 383–389.
Parks, P.J., Murray, B.C., 1994. Land attributes and land allocation: nonindustrial forest use in the Pacific Northwest. Forest Sci. 40 (3), 558–575.
Penalver, E.M., 2007. The end of sprawl? The Washington Post. Retrieved on June 6, 2008 from http://www.washingtonpost.com/wp-dyn/content/article/2007/12/28/AR2007122802449.html.
Perry, M.J., 2006. Domestic Net Migration in the United States: 2000 to 2004. Retrieved on February 29, 2008 from http://www.census.gov/prod/2006pubs/p25-1135.pdf.
Pijanowski, B.C., Brown, D., Shellito, B., Manik, G., 2002a. Using neural networks and GIS to forecast land use changes: a land transformation model. Comput. Environ. Urban 26, 553–575.
Pijanowski, B.C., Shellito, B., Pithadia, S., Alexandridis, K., 2002b. Forecasting and assessing the impact of urban sprawl in coastal watersheds along eastern Lake Michigan. Lakes Reserv. Res. Manage. 7, 271–285.
Polyakov, M., Zhang, D., 2008. Property tax policy and land use change. Land Econ. 84 (3), 396–408.
Riley, S.P., Sauvajot, R.M., Fuller, R.K., York, E.C., Kamradt, D.A., Bromley, C., et al., 2003. Effects of urbanization and habitat fragmentation on bobcats and coyotes in southern California. Conserv. Biol. 17, 566–576.
Stein, S.M., Alig, R.J., White, E.M., Comas, S.J., Carr, M., Eley, M., et al., 2007. National forests on the edge: development pressures on America's national forests and grasslands. USDA For. Serv. Gen. Tech. Rep. PNW-GTR-728, Portland, OR.
Stein, S.M., McRoberts, R.E., Alig, R.J., Nelson, M.D., Theobald, D.M., Dechtar, M., et al., 2005. Forests on the edge: housing development on America's private forests. USDA For. Ser. Gen. Tech. Rep. PNW-GTR-636, Portland, OR.
Sturtevant, B.R., Cleland, D.T., 2007. Human and biophysical factors influencing modern fire disturbance in northern Wisconsin. Int. J. Wildland Fire 16, 398–413.
Tang, Z., Engel, B.A., Pijanowski, B.C., Lim, K.J., 2005. Forecasting land use change and its environmental impact at a watershed scale. J. Environ. Manage. 76, 35–45.
Theobald, D.M., 2005. Landscape patterns of exurban growth in the USA from 1980 to 2020. Ecol Soc. 10(1), article 32 (online). Retrieved on March 25, 2008 from http://www.ecologyandsociety.org/vol10/iss1/art32/ES-2005-1390.pdf.
Thompson, M.T., Thompson, L.W., 2002. Georgia's forests, 1997. USDA For. Serv. Resour. Bull. SRS-RB-72, Asheville, NC.
Thorsnes, P., 2002. The value of a suburban forest preserve: estimates from sales of vacant residential building lots. Land Econ. 78 (3), 426–441.
U.S. Department of Agriculture, Natural Resources Conservation Service (USDA NRCS), 2000. Table 1 – Surface area of nonfederal and federal land and water areas, by state and year (data per 1,000 acres). Retrieved on June 22, 2007 from http://www.nrcs.usda.gov/TECHNICAL/NRI/1997/summary_report/table1.html.
U.S. Department of Agriculture, Natural Resources Conservation Service (USDA NRCS), 2007. National Resources Inventory 2003 NRI, land use. Retrieved on March 25, 2008 from http://www.nrcs.usda.gov/TECHNICAL/NRI/2003/Landuse-mrb.pdf.
U.S. Department of Commerce Census Bureau (USDC Census Bureau), 1993. Intercensal estimates of the total resident population of states: 1980 to 1990. Retrieved on February 29, 2008 from http://www.census.gov/popest/archives/1980s/st8090ts.txt.
U.S. Department of Commerce Census Bureau (USDC Census Bureau), 1999a. (ST-98-51) Estimates of housing units, households, households by age of householder, and persons per household of states: annual time series, July 1, 1991 to July 1, 1998. Retrieved on February 29, 2008 from http://www.census.gov/popest/archives/1990s/ST-98-51.txt.
U.S. Department of Commerce Census Bureau (USDC Census Bureau), 1999b. (ST-98-52) Intercensal estimates of total housing units by state: July 1, 1981 to July 1, 1989. Retrieved on February 29, 2008 from http://www.census.gov/popest/archives/1990s/ST-98-52.txt.
U.S. Department of Commerce Census Bureau (USDC Census Bureau), 1999c. (ST-99-3) State population estimates: annual time series, July 1, 1990 to July 1, 1999. Retrieved on February 29, 2008 from http://www.census.gov/popest/archives/1990s/ST-99-03.txt.
U.S. Department of Commerce Census Bureau (USDC Census Bureau), 1999d. State household and housing unit estimation methodology: 1990–1998. Retrieved on February 29, 2008 from http://www.census.gov/popest/archives/methodology/90s_hh_meth.txt.
U.S. Department of Commerce Census Bureau (USDC Census Bureau), 2005a. Table 1: Annual estimates of the population for the United States and states, and for Puerto Rico: April 1, 2000 to July 1, 2005. Retrieved on June 26, 2007 from http://www.census.gov/popest/states/tables/NST-EST2005-01.xls.
U.S. Department of Commerce Census Bureau (USDC Census Bureau), 2005b. Table 1: Interim projections: ranking of census 2000 and projected 2030 state population and change: 2000 to 2030. Retrieved on February 29, 2008 from http://www.census.gov/population/projections/PressTab1.xls.
U.S. Department of Commerce Census Bureau (USDC Census Bureau), 2007. Annual Estimates of housing units for the United States and states: April 1, 2000 to July 1, 2006 (HU-EST2006-01). Retrieved on February 29, 2008 from http://www.census.gov/popest/housing/tables/HU-EST2006-01.xls.
Wear, D.N., Liu, R., Foreman, J.M., Sheffield, R.M., 1999. The effects of population growth on timber management and inventories in Virginia. Forest Ecol. Manage. 118, 107–115.
White, E.M., Leefers, L.A., 2007. Influence of natural amenities on residential property values in a rural setting. Soc. Nat. Resour. 20, 659–667.
Yates, J.M., Levia, D.F., Williams, C.L., 2004. Recruitment of three non-native invasive plants into a fragmented forest in southern Illinois. Forest Ecol. Manage. 190, 119–130.
Zhen, L., Pijanowski, B.C., Alexandridis, K.T., Olsen, J., 2005. Distributed modeling architecture of a multi-agent-based behavioral economic landscape (MABEL) model. Simulation 81 (7), 503–515.

Please cite this article in press as: White, E.M., et al., Past and projected rural land conversion in the US at state, regional, and national levels. Landscape Urban Plann (2008), doi:10.1016/j.landurbplan.2008.09.004