The Changing Urban Landscape of the United States

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Abstract

Sprawling urbanisation has been the hallmark of development in United States. This study intends to provide a comprehensive overview of the changing urban landscape patterns between 2001 and 2006. Using the land cover data from US Geological Survey for these two years, I characterise the landscape metrics for each county in the continental United States. The changes in these metrics are correlated with the drivers of urbanisation including socioeconomic variables. Uneven and heterogeneous patterns of growth in a country this large are not surprising. However, the metrics reveal that while urban counties are becoming less fragmented, some rural counties in South and Western United States are experiencing significant leapfrog development.

Keywords: Landscape metrics, urban patterns, drivers of urbanisation

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1 Introduction

It is well known that urban form in the United States is sprawling, fragmented and leapfrogging (Downs 1999). Despite many laments about such form, it shows no sign of abatement and is only exacerbated by public policy (Knaap et al. 2007). Sprawl is defined in many ways, but most of the indices used to describe the phenomena are based on demographic and economic indicators such as density of housing and mix of land uses (e.g. Cutsinger and Galster 2006). However, these characterisations have not made effective use of widely available land cover data that lends itself to continuous monitoring of urban patterns. While Torrens and Alberti (2000) articulated how landscape metrics can be used to study urban patterns, they did not characterise it. This study provides an empirical assessment of urban patterns through landscape metrics. The results of this study reveal a more nuanced picture of urbanisation pattern in United States. By characterising changes in the urban landscape in each county of the continental United States between 2001 and 2006, using landscape metrics, this study finds that patterns and rates of urbanisation are quite different in different parts of the country and depend greatly on the degree of rurality [1].

Characterising urban patterns through indices are not new, though different types are used for different purposes(Clifton et al. 2008). In particular, landscape ecologists from the perspective of the environmental protection use land cover data to calculate metrics on habitat fragmentation (among other things) whereas economists, along with transportation planners use employment and population data to uncover economic inefficiencies and accessibility patterns. In a comprehensive study of United States, Burchfield et al. (2006) constructed sprawl indices for metropolitan areas based on land cover data from 1976 and 1992 and argues that these indices have not substantially changed. For metropolitan regions, Ewing et al. (2003) created an index that accounted for land use mix, density, street connectivity and centrality variables that included geographic, demographic and economic data. However, Ewing et al. index is a cross sectional index and characterises the metropolitan regions relative to one another. Harvey and Clark (1965) have long ago argued, "The sprawl of the 1950s is frequently the greatly admired compact urban area of the early 1960's. An important question on sprawl maybe, "How long is required for compaction?" as opposed to whether or not compaction occurs at all (p.6)." The indices described in this paper lends themselves to continuous and comprehensive characterisation of urban form as long as the satellite data are available.

Characterising the urban form is not itself, however, is not sufficient. In a pioneering empirical work, Brueckner and Fansler (1983) found in a cross sectional analysis of US cities, population have the largest effect and per capita income, agricultural rent have significant but smaller effect on city sizes and these results have been validated in other studies(e.g. McGrath 2005, Song and Zenou 2006). In their analysis of urbanisation trends in the US, Alig et al. (2004) cite population density, the metropolitan character of the area and per capita income to be key drivers that explains the level of urbanisation. They also allude to regional differences in the effects of these drivers. These studies are primarily concerned with the levels of urbanisation and the relationship with the drivers of urbanisation. In this study, I focus not only on the level but also on the pattern. In a similar study for single metropolitan area of Phoenix, Shrestha et al. (2012) argue that infrastructure availability (water, roads etc.), constraints on development (parks, military bases, topography etc.) and other institutional factors explain the fragmentation of the landscape. These earlier studies point to the need to account for socioeconomic and infrastructure variables in explaining the patterns of urbanisation in the United States.

While Clifton et al. explicitly mention landscape metrics as a mechanism for evaluating frag-

[1]This period represented a housing boom (8.9 million new residential units) unseen since 1975 and at its peak, 2 million houses were constructed in a single year. Data about completed housing units is at `http://www.census.gov/const/www/newresconstindex_excel.html`- Accessed August 15, 2011.

mentation of natural environments such as habitats through urbanisation, they do not mention their use by the geographers such as Seto and Fragkias (2005) and Herold et al. (2002) to describe the urban form itself. This study follows this prior work and evaluates the patterns of human settlements using landscape metrics and characterises the pattern of development for the continental United States. It differs from other studies in a number of ways; it characterises the urban development pattern for the entire country (except Alaska and Hawaii), tries to ascertain the change in patterns during a short period (5 years) and correlates these changes to socioeconomic and infrastructure variables. The interesting results of this exercise is that while US may be experiencing fragmented development over the longer term, over the short term, significant portion of the urban counties are experiencing contiguous development or previously fragmented urbanisation is becoming more. Furthermore, by focusing not just on metropolitan regions but on the whole country, the study reveals interesting differences between urban and rural counties. Furthermore, by correlating demographic and economic variables with the landscape patterns, the study finds that differences exist by types of counties. In particular, some of the key drivers of urbanisation such as density of highways are negatively correlated to amount of urbanisation in urban counties at the same time are associated with increasing fragmentation of the urban landscape in rural counties.

In the next section, we motivate the use of landscape metrics in various disciplines and visually relate the patterns of landscape to different metrics. Later we discuss the document the data used in the analysis and point out the salient patterns. We then discuss the changes in the resulting metrics and argue that patterns and relationships between urban patterns and drivers need much more closer scrutiny. I conclude by discussing the caveats of using the land cover data for these kinds of analysis and future research questions spawned by this study.

2 Landscape Metrics

Landscape metrics have been extensively used in landscape ecology to examine habitat fragmentation, biodiversity and epidemiology (Haines-Young and Chopping 1996, Stephens et al. 2004). Building upon the pioneering work of O'neill et al. (1988), many such indices are developed over time and different metrics evolved to suit different disciplines (for reviews see e.g. Gustafson 1998, Uuemaa et al. 2009). More often than not, these metrics are used to characterise the categorical maps rather than continuous fields. Areas that are contiguous and of same category are considered patches and the metrics are used to describe the shape, composition, and configuration of these patches. As they are widely implemented in various software environments (e.g. McGarigal and Marks 1995, Rempel 2008), they have become widely used.

Since urbanisation patterns are of great interest to planners, geographers, and urban economists, landscape metrics have been used to study urban morphology (e.g. Yeh and Xia 2001, Irwin and Bockstael 2007, Buyantuyev et al. 2010). Seto and Fragkias (2005) use landscape metrics to describe the patterns of change in the 90's in the rapidly growing Pearl River Delta in China. They find that urban growth is manifested in many patterns, especially during early stages of economic growth. Similarly, Xu et al. (2007) characterise the diffusion-coalescence phases of urban growth where cities grow by leapfrogged expansion at the edges that then become contiguous. Herold et al. (2002) use landscape metric signatures to characterise growth patterns and eventually project not just amount and location of urban growth but their patterns as well.

A key concept in landscape analysis is a 'patch' P, a set of contiguous and similarly characterised cells in a raster image. Since urban form is made up of many land uses, these studies use different kinds of land cover categories to study the patterns of growth of cities. These include low and high density residential, commercial and industrial categories. While these kinds of fine grained analyses are possible and useful at a scale of a city or even a region, since the purpose of the paper is to characterise the urban landscapes of the continental United States, we treat all urban land as a single class. Therefore, many of the metrics such as contagion and dispersion indices are not used in this study. The landscape in this case, is a county, an arbitrary political boundary that does not necessarily make sense from an ecological perspective, but does from a political geography perspective. Some of the advantages of a county level analysis are that the boundaries are relatively stable and much of economic data is collected at this level.

Figure 1 illustrates the key landscape metrics used to characterise the urban area and are used in many studies including Seto and Fragkias (2005) and Herold et al. (2002). The total urban area is essentially count of the cells that are classified urban. The number patches reflect the contiguity of the urbanisation. While large total urban area reflects the high level of urbanisation, low number of patches reflects the contiguity of urbanisation. Similarly, high average patch area is reflective of the larger size of urban development, whereas low values are reflective of the scattered small developments. The standard deviation of the patch area reflects the distribution of the patch sizes. High values indicate different kinds of patch areas where as low values indicate similar patch sizes. Shape index is a ratio of the actual perimeter of the patch to the patch of the same size that is maximally compact, and ranges from 1 to ∞, with 1 being the index for a patch that is shaped like a square. Mean shape index, is the average of the shape indices of the patches in the county. Low values of this index reflect the compactness of individual developments, whereas low number of patches indicates compactness of the urban pattern within the landscape itself. Fractal dimension is the indicator shape complexity and takes on the values between 1 and 2, with 2 being an indicator that the development patterns that are area filling lines. These metrics effectively characterise the spatial structure of a region, with some caveats (e.g. Hargis et al. 1998).

3 Data Description & Methods

Various software environments and packages are used in the analysis including SDMtools (VanDerWal et al. 2011), raster (van Etten 2011) inside R environment. (R Development Core Team 2009). Data and programs used in the analysis are available at {DELETED}.

Land cover data from the United States Geological Survey (USGS) was utilised for this analysis (Homer et al. 2004). The 2001 (version 2) and 2006 land cover data [2] for the lower 48 states in the US are retrieved from Multi-Resolution Land Characteristics Consortium websites[3] . These land cover products are a 30m x 30m resolution raster datasets categorised in National Land Cover Data (NLCD) Level II classes. Each of these 9 billion cells are categorised into one of the 16 different classes with four categories of urban land (Developed Open Space, Low Intensity Developed, Medium Intensity Developed and High Intensity Developed). For this analysis, we treat all these categories as urban land. On average less than 10% of the total area in a county is urbanised. St. Louis City, MO has the largest proportion of the total area classified as urban land (93 %) followed by Alexandria, VA (90 %)[4]. Petroleum, MO and Keweenaw, MI[5] have less than 0.2 % urban area, while San Bernardino, CA was the county with the largest total area.

Qualitative differences exist between patterns of urbanisation within rural and urban areas and therefore two measures are used to capture the degree of rurality. Index of Relative Rurality (IRR) is a metric that characterises on a continuous scale from 0 to 1, the rural nature of the county, with 1 being the most rural (Waldorf 2006). The index is calculated from four other variables, population size, density, % population in urban area and the distance to the closest metropolitan area. On the other hand, Isserman (2005) formulated a threshold based classification system for the counties that is different from metro and non-metro characterisation by Office of Management and Budget (OMB). Isserman uses thresholds of population density, % urban population and metropolitan characterisation to determine four categories of counties: urban, mixed urban, mixed rural and rural. Furthermore, different categories are not evenly distributed geographically. While over 21% of the counties in Northeast Mid Atlantic Census region are urban, rural counties are predominant in the Mountain West (66%). However, most of the urban counties in the US are in the South Atlantic region (35%) whereas North East (Mid Atlantic as well as New England) has relatively few rural counties (< 2%). While 'urban' counties have IRR ranging from '0–0.3' and rural from '0.3–1' there is a considerable overlap

[2]A strong reason for using the 2001 and 2006 datasets are that the land cover in both years is consistently classified and compatible with the classification scheme used in the other year. While a 1992 land cover dataset is available for the continental US, I did not use to study the longer term trends because of the differences in the classification method and the scheme.

[3]Land cover data for 2006 is available at `http://www.mrlc.gov/nlcd2006_downloads.php.` (Accessed February 25, 2011) and for 2001 is available at `http://www.mrlc.gov/nlcd2001_downloads.php` (Accessed February 23, 2011)

[4]Both of these are independent cities and are county equivalents per US Census definition.

[5]Large portion of Keewenaw is Lake Superior.

of values between mixed urban and mixed rural though the distribution of values is skewed as expected. This analysis uses both as a complementary measure of urban-rural distinctions.

The drivers of urbanisation, as described in the literature on levels of urbanisation are mainly socio economic variables such as population, employment and income growth. Data and projections from US census, Bureau of Economic Analysis Regional Economic Information System (REIS) is also used correlate the demographic and economic changes with changes in the landscape (table 1). Figure 2 reflects some of these demographic and economic changes. The maps are rendered readable by categorising the key variables into four categories. For example, annualised change in population from 2001 to 2006 is calculated from US Census[6]. Values above zero indicate population growth while values below zero indicate population decline; values differing by one standard deviation away from the national average are 'rapidly' changing. Maturity of a county is determined by the point in time at which the county achieved 75% of the current population. Maturity is meant to represent historical changes in the county, and counties that achieved three quarters of its population before 1950 are labelled very mature, and in 60–70's as mature. Developed and developing counties are those that have achieved their three quarters population in 80–90's and 2000 or later, respectively[7]. This variable was used to test whether the historical period in which a county urbanised has influence on the current changes in patterns.

Changes in per capita income are measured as a relative change between 2006 and 2001. While St. Bernard and Orleans, LA counties registered the largest shift in the per capita income change, it is largely a result of the out migration of the low income households due to Hurricane Katrina. Billings, ND, a rural county, has the highest change in the income, while Hamilton, KS registered a 20% decline. Surprisingly it is the urban and mixed urban counties that had less than stellar income growth, while Western mixed rural and rural counties registered larger than average income growth. This is likely due to already high average incomes in the urban counties.

Complementary to per capita income, poverty rates can also be used to assess the relative wealth of a county. Poverty is defined as the fraction of the population falling below 200% of the national poverty level[8]. The mean value is 0.356, i.e. on average, 35% of the households fall below the twice the national threshold of the poverty. Counties with higher than average poverty fractions are labelled 'high' while counties with lower than average poverty fractions are labelled 'low'. Counties with poverty fractions more than one standard deviation from the mean

[6] Dataset is downloaded from `http://www.census.gov/popest/counties/files/CO-EST2009-ALLDATA.csv` (Accessed July 10, 2011)

[7] Historical population data is collected from US census at `http://www.census.gov/population/www/censusdata/cencounts/index.html` (Accessed July 25, 2011). Counties whose boundaries have changed are considered 'no data'.

[8] For the complete Federal definition of household poverty, see `http://www.census.gov/hhes/www/poverty/poverty.html` (Accessed 10 June, 2011)

value are suitably noted as ‘very high’ or ’very low’. Per capita income is heavily influenced by outliers on both ends of the income spectrum, whereas poverty rates are not. Furthermore, changes in income growth reflect the relative economic growth and decline of the county, where as poverty rate provides a static view of the wealth of the county and very little correlation exists between these two variables (< 0.1). While 80% of the Buffalo, SD have household incomes less than 200% of the national threshold, Los Alamos, NM has the least number of households under this category ($\sim$6%). While inner cities are notorious for their high poverty levels, urban counties themselves have relatively low poverty rates (figure 2). This variable does not account for regional differences in costs of living, overestimates the worth of income, which explains the mismatch. However, the variable accurately captures poverty in large portions of the rural counties in Appalachia, upper Midwest and the South, known for their poverty belts often defined by racial lines.

In addition to the socioeconomic variables, level of infrastructure is captured by the density of lane mile. This variable is calculated from the 2002 roads data from National Highway Planning Network version 2.1 published by the Bureau of Transportation Statistics as part of the National Transportation Atlas Databases. Lane miles normalised by gross area of the county are binned according to quartiles. The distinct difference in the density of highway lane miles east and west of Mississippi in rural and mixed rural counties is primarily attributable to the large size of the counties in the West.

Given the past trends in urbanisation, it is unclear if the population and employment growth contributes to sprawling and fragmented development or more infill development that reduce urban fragmentation. Typically income growth is expected to lead to more fragmentation as the preference for detached single family houses in the US is well known. Because automobile and the infrastructure that support it are cited as a prime explanation of spatial structure of population settlement in United States, higher levels of highway miles are expected to be indicative of increasing fragmentation. I try to find evidence for these kinds of explanations through correlation analyses. Li and Wu (2004) identify three kinds of issues with landscape pattern analysis and in particular single out correlation analyses as problematic because of the conceptual flaws and the ecological irrelevance of the landscape indices. This critique does not apply here, because Li and Wu’s concern is primarily about correlations within the landscape metrics not with other variables that may explain the patterning. Nevertheless, these analyses are not without caveats as alluded to, in later sections.

4 Patterns of Change in the US

There are significant regional differences in the type of economic and demographic changes between urban and non-urban counties (figure 2). While most urban and mixed urban counties are growing at rates that are much higher than US average, the largest population growth is registered in the Western United States in the Mixed Rural counties. Not surprisingly, the rural counties in the Midwest continue to experience moderate (less than one standard deviation and negative) to rapid (more than one standard deviation) population decline. However, some rural counties in the South Atlantic region are experiencing significant population increases. While employment increased in most urban counties there are some significant exceptions. While many Midwestern urban counties continue to experience decline in employment due to deindustrialisation trends in the US, the rapidly declining urban counties are in California in the Bay area, mostly due to readjustment of the technology sector post dot-com bust. For the most part, per capita income in urban and mixed urban counties have been growing at a rate lower than the national average, while patterns are much more mixed in the rural and mixed rural counties. However, in general rural counties make up the bulk of counties that registered rapid per capita income gains between 2001 and 2006, relative to the nation.

Unsurprisingly, most urban and mixed urban counties have high density of highway miles, both due to large number of major roads as well as small gross areas. Lane miles and population growth are positively correlated[9] in rural counties (0.30) and negatively correlated in mixed urban and urban counties ($\sim$ -0.38), while no substantively significant correlations are observed for employment changes for this short time period. Income growth and poverty rates are not correlated in rural counties, though they exhibit statistically significant positive correlations in other types of counties, i.e. counties with significantly high proportion of poor households experienced high per capita income growth though they are not substantively significant (0.27, 0.32 and 0.19 for urban, mixed urban and mixed rural counties).

Figure 3 renders the changes in the urban landscape of the US apparent. The total urban areas within a county grew between 2001 and 2006 with rapid land conversion occurring in urban, mixed-urban and some mixed rural counties. By and large the total urban area in rural counties remained the same. While urban counties in the north east and west coast registered moderate gain (in terms of percentage) rapid changes were observed in the western and southern urban counties. On average, urban land in mixed urban counties grew by 5.7% whereas mixed rural counties grew by 2.7%. The fastest growing urban counties are predominantly in the mountain west (11% on average), whereas fastest growing mixed urban counties are in the South Atlantic and West South Central. ($\sim$ 7.5%). Analysis of variance indicates that these differences, both by type of county and region, are statistically significant.

[9]Unless otherwise noted, Spearman's rank correlations are used throughout in the paper.

Regional differences in levels of urbanisation notwithstanding, the heterogeneous patterns of urbanisation are striking. The number of patches in a county by and large declined over this time period, suggesting that urban growth is becoming more contiguous. The largest declines in the number patches are observed in the urban and mixed urban counties across the US. The number of patches in the mixed rural counties are marginally lower in 2006 than in 2001. This coupled with the fact that mean patch size is increasing in almost all types of counties except rural counties, Given the relentless urban growth, it is worthwhile to note that the urban form is becoming more contiguous in the US.

However, the patch sizes are becoming more divergent within a county, irrespective of the type of the county or the region except west south central and mountain west rural counties. These are the same counties that also experienced decrease in mean patch area. Jointly, they point to the fact that new development in these counties are not only discontinuous (increase in patch numbers) but also these patches are of similar or slightly smaller sizes as earlier patches. Thus, fragmented urban development in these counties continue as before.

Shape index and fractal dimension index, indicators of the shape of the patterns, show only relatively minor changes. The mean fractal dimension index stayed the same in most rural and mixed rural counties. However, this index exhibited a decline in many urban counties especially in the north east and Midwest. The decline is reflective of shapes becoming simpler in these urban counties. Very few counties exhibited an increase in this index over this time period.

The correlations between socioeconomic variables and landscape metrics reveal strong differences in the types of counties as well (table 2). By and large the correlations (whether negative or positive) are not large, however, they are statistically significant. While larger urban counties experienced larger amount of urbanisation, the converse is true in mixed rural and rural counties. More so than employment, it is the change in the population that has significant impact total urbanisation in all types of counties and is inversely correlated to fragmentation as evidenced by the negative correlation with number of patches and mean patch size.

IRR is strongly correlated to most of the landscape metrics only for rural and mixed rural counties. Since IRR expresses the relative rurality within a particular type of county, the correlations of the landscape metrics provide a richer picture of urbanisation pattern. For example as expected, within urban counties, the less urban it is, the more likely, it is to experience higher levels of urbanisation (ρ = 0.38). Likewise, within rural and mixed rural counties, the more rural they are, they are more likely to have experienced low levels of urbanisation (ρ = -0.45 and -0.48) within the period of study. In particular, the more rural a mixed rural county is, it experienced higher fragmentation, but that relationship is not as pronounced in rural counties and completely absent in urban and mixed urban counties.

While relative change in income is not correlated with any of the landscape metrics to a significant degree, poverty indicator is relevant in mixed urban and mixed rural counties. Poverty is moderately and negatively correlated with change in urban area, mean patch size and standard deviation of patch size. i.e. high poverty counties in these types of counties are likely to be more fragmented. Surprisingly the density of highway miles is negatively correlated with total urban area in urban and mixed urban counties, but is positively associated with urbanisation in mixed rural and rural counties. As noted earlier, highways are also associated with increasing fragmentation in urban counties, but brought about more continuous development in rural and mixed rural counties. The metrics of patch shapes are not necessarily correlated to many of the socioeconomic variables, suggesting the importance of deliberate designs rather than natural processes in determining the shapes of individual urban developments.

5 Caveats and Conclusions

We need to be aware of number of caveats that circumscribe the analysis. While counties are natural political boundaries in the US that are relatively stable, they are arbitrary from the perspective of the metropolitan regions. Many cities and their suburbs span multiple counties. Even within a county, the urbanised area and non-urbanised areas exhibit different characteristics of patterns. In other words, this analysis suffers from the well-known Modifiable Areal Unit Problem (MAUP) that plagues many geographical analyses (Openshaw 1984). While this analysis is a first cut at characterising the changes in landscape patterns throughout the United States, the micro scale at which local infrastructure development policies and real estate development decisions should rely on more fine grained analysis and is left for future work.

Furthermore, the resolution of the data is 900 m^2 pixel (0.25 acre). While, this is roughly a size of a single family residence in a medium sized urban area (5 units per acre), more rural areas are characterised by urban development that is lot less dense (2 acres per unit or more). Because of this, the rural areas have more urban patches surrounded by other land cover such as grasslands or forests (Irwin and Bockstael 2007). Because this issue is present in both 2001 and 2006 land cover data, the metrics are comparable even when they underestimate the impact of fragmentation of urban landscape in more rural areas. This is one possible explanation of for the paradoxical patterns exhibited by some counties that have high population growth accompanied by low urbanisation rates. In more urban areas, even when urban cells are adjacent to non-urban cells, they are usually classified as developed open space and because this paper treats them as urban area, the metrics are more accurate in capturing the shape of the urban areas. Furthermore, roads being linear urban features that they are, skew the metrics in rural areas and is evident from the sample land cover maps in figure 1.

This paper provided an analysis of patterns of urbanisation during one of the boom periods in US history. Correlating the metrics of urban landscapes with the drivers of urbanisation, it found that there are significant differences in the patterns by type and by region. While this is a broad brush to use to paint the urbanisation patterns, it provides an initial window into the processes of urbanisation. Different metropolitan regions and urban regions within a county might show different results, but the metrics suggest that overall the coalescence phase of the urbanisation is in effect between 2001 and 2006 within urban counties. Rural counties in specific regions (such as Texas and Utah) are experiencing fragmentary development patterns. Understanding the reasons of these differing patterns would require more detailed analyses of the institutional structures that facilitate them. Nevertheless, this study points to the need for nuanced understanding of heterogenous urban patterns in the US and their implications.

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	Min	1^{st} Qu	Median	Mean	3^{rd} Qu	Max	NA
Gross area (sq. mi)	2.0	436.7	623.2	967.9	932.5	20110.0	
Highway miles	0.0	162.0	244.0	305.7	364.0	5310.0	
IRR in 2000	0	0.39	0.51	0.50	0.61	1.00	1
% poverty	6.44	28.42	35.41	35.57	42.37	79.94	5
Δ Population (annual)	−26.28	−0.50	0.17	0.30	0.95	8.90	
Δ Employment (annual)	−7.99	−0.36	0.57	0.67	1.54	11.73	7
Δ Income	−19.74	15.11	19.62	20.14	24.51	175.60	53
Δ Urban area	−0.49	0.05	0.46	1.75	1.92	37.98	
Δ number of patches	−53.46	−1.15	0.00	0.26	0.00	255.93	
Δ mean patch size	−71.22	0.00	0.47	2.52	3.03	134.31	
Δ std.dev of patch size	−46.31	0.00	0.45	2.20	2.67	61.64	4
Δ mean fractal dimension	−16.07	−0.16	−0.01	−0.24	0.00	2.91	
Δ mean shape index	−52.50	−0.06	0.00	−0.25	0.23	23.29	
n = 3109	All changes are percentage changes between 2001 and 2006.						

Table 1: Summary Statistics of Key Variables

		Urban		Mixed Urban		Mixed Rural		Rural	
Δ urban area	IRR	0.38	***	−0.08		−0.48	***	−0.45	***
	Gross Area	0.29	***	0.12		−0.13	***	−0.10	***
	Δ Population	0.65	***	0.62	***	0.61	***	0.40	***
	Δ Employment	0.46	***	0.48	***	0.46	***	0.26	***
	Δ Income	−0.25	**	−0.26	**	0.01		0.07	**
	Poverty	−0.13		−0.37	***	−0.29	***	−0.18	***
	Highway miles	−0.47	***	−0.23	**	0.31	***	0.27	***
Δ number of patches	IRR	0.00		0.10		0.39	***	0.09	***
	Gross Area	−0.21	**	−0.19	*	0.03		0.11	***
	Δ Population	−0.22	**	−0.33	***	−0.35	***	−0.07	**
	Δ Employment	−0.12		−0.27	***	−0.24	***	−0.02	
	Δ Income	0.18	*	0.08		0.01		0.04	
	Poverty	0.06		0.23	**	0.23	***	−0.06	**
	Highway miles	0.13		0.08		−0.20	***	−0.15	***
Δ mean patch size	IRR	0.10		−0.05		−0.46	***	−0.29	***
	Gross Area	0.23	**	0.14		−0.11	***	−0.18	***
	Δ Population	0.33	***	0.49	***	0.51	***	0.27	***
	Δ Employment	0.21	**	0.39	***	0.34	***	0.14	***
	Δ Income	−0.21	*	−0.20	*	−0.05		−0.02	
	Poverty	−0.07		−0.34	***	−0.30	***	−0.07	**
	Highway miles	−0.20	**	−0.15		0.30	***	0.29	***
Δ Std.dev of patch size	IRR	0.18	*	−0.04		−0.44	***	−0.32	***
	Gross Area	0.22	**	0.12		−0.13	***	−0.20	***
	Δ Population	0.43	***	0.53	***	0.54	***	0.29	***
	Δ Employment	0.30	***	0.43	***	0.36	***	0.16	***
	Δ Income	−0.22	**	−0.22	**	−0.05		−0.02	
	Poverty	−0.09		−0.37	***	−0.30	***	−0.09	***
	Highway miles	−0.25	**	−0.17	*	0.31	***	0.31	***
Δ mean fractal dimension	IRR	−0.13		−0.13		0.13	***	0.15	***
	Gross Area	−0.17	*	−0.04		0.09	**	0.02	
	Δ Population	−0.14		−0.13		−0.08	**	−0.17	***
	Δ Employment	−0.05		−0.08		−0.06		−0.14	***
	Δ Income	0.24	**	0.17	*	0.02		−0.07	**
	Poverty	0.20	*	0.35	***	0.09	**	0.07	**
	Highway miles	0.11		−0.05		−0.14	***	−0.07	**
Δ shape index	IRR	0.00		−0.13		−0.24	***	0.01	
	Gross Area	0.14		0.08		0.07	*	−0.05	*
	Δ Population	0.08		0.22	**	0.24	***	0.00	
	Δ Employment	0.04		0.16	*	0.15	***	−0.01	
	Δ Income	0.07		0.04		0.02		−0.04	
	Poverty	0.02		0.04		−0.14	***	0.10	***
	Highway miles	−0.12		0.00		0.08	*	0.07	**

Table 2: Correlations between landscape metrics and urbanisation drivers

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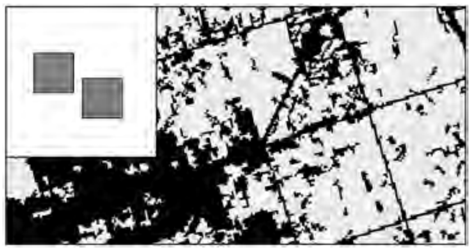
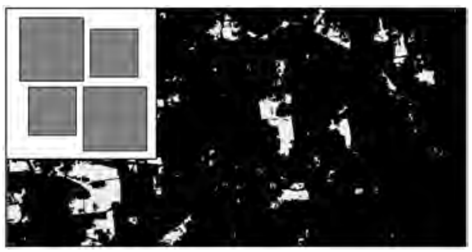
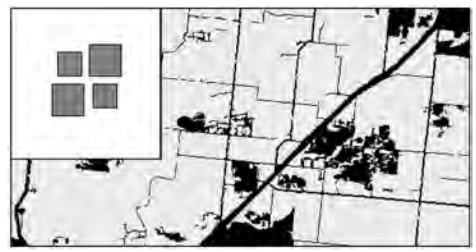
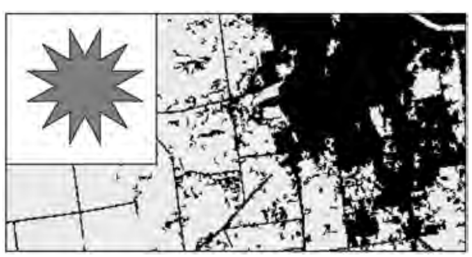
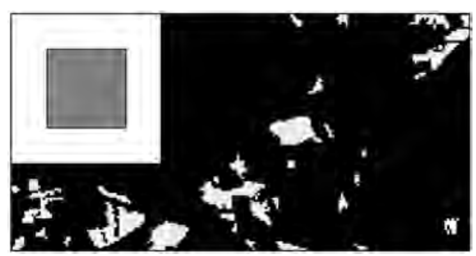
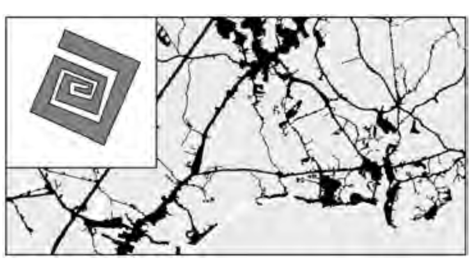
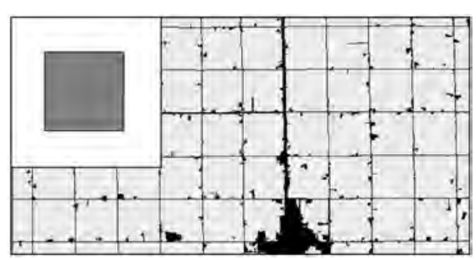
Metric	High	Low
Total urban area $\sum_{P_i \in C} a_i$, where a_i is the area of the patch P_i and C is the county		
Number of patches $N \equiv \sum_{P_i \in C} i$		
Mean patch area $\bar{a} \equiv \frac{\sum_{P_i \in C} a_i}{N}$		
Std. dev of patch area $\sqrt{\frac{\sum_{P_i \in C} (a_i - \bar{a})^2}{N-1}}$		
Mean shape index $\frac{1}{N} \sum_{P_i \in C} \frac{p_i}{q_i}$ where p_i and q_i are the perimeters of the patch P_i and a maximally compact patch of same area		
Mean fractal dimension $\frac{\sum_{P_i \in C} 2ln(0.25 p_i)/ln(a_i)}{N}$		

Figure 1: Schematic Illustration of Urban Landscape Metrics

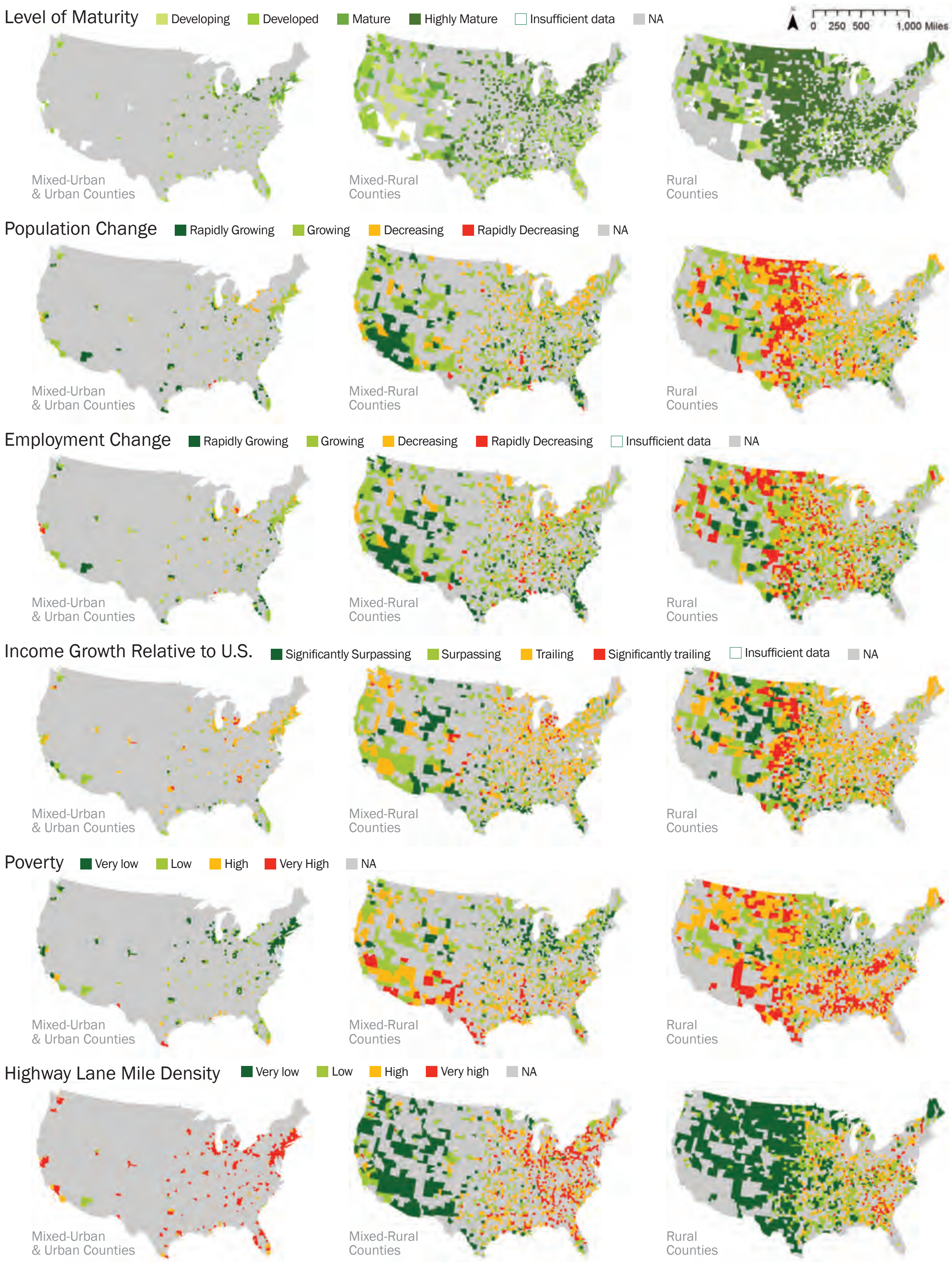


Figure 2: Socioeconomic patterns in the US

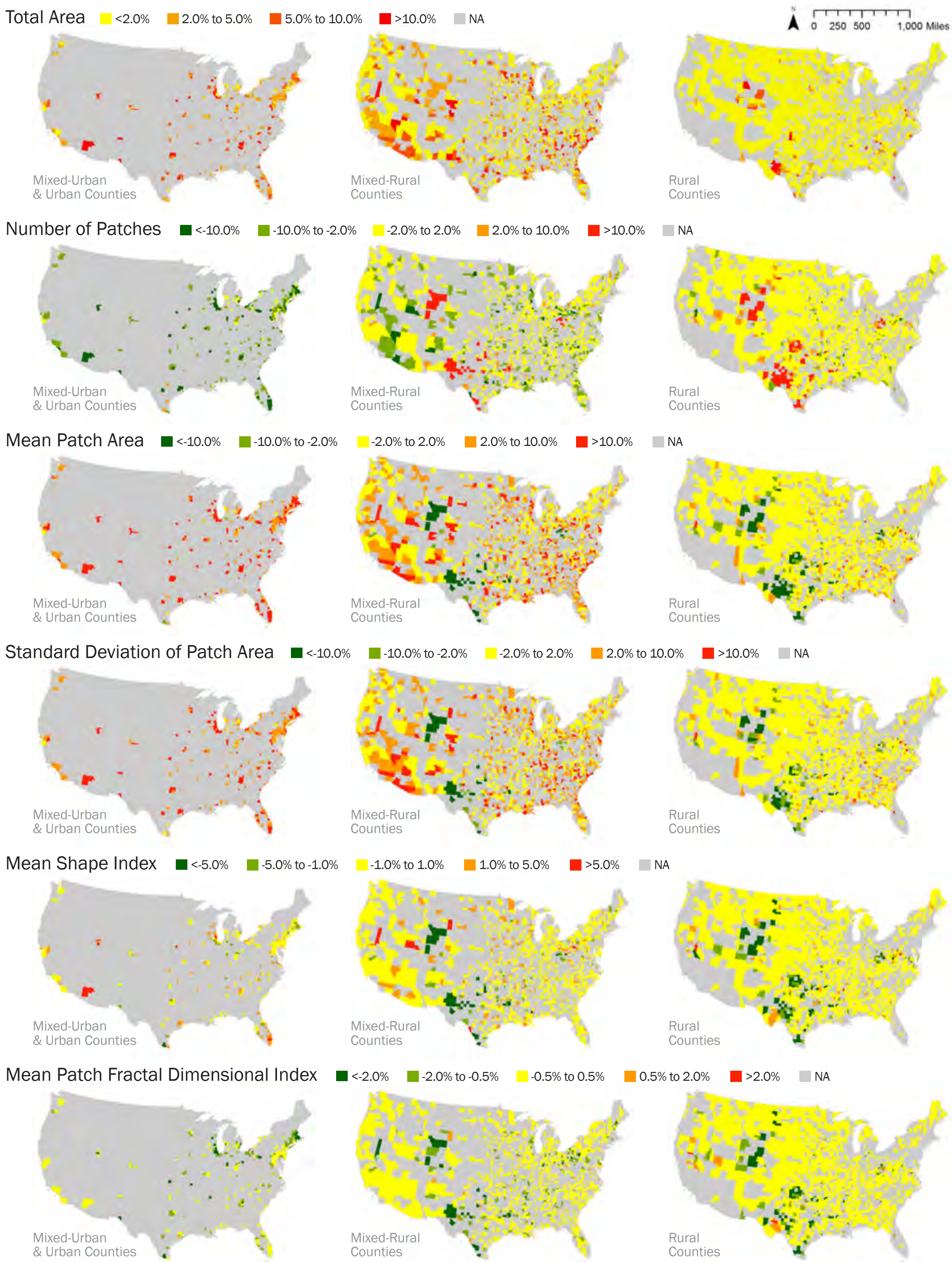


Figure 3: Changes in Landscape Metrics 2001-2006