Just What is Sprawl, Anyway?

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> "In the next three or four years Americans will have a chance to decide how decent a place this country will be to live in, and for generations to come. Already huge patches of once green countryside have been turned into vast, smog-filled deserts that are neither city, suburb, nor country, and each day - at a rate of some 3,000 acres a day - more countryside is being bulldozed under. You can't stop progress, they say, yet much more of this kind of progress and we shall have the paradox of prosperity lowering our standard of living. … The problem is the pattern of growth – or, rather, the lack of one." (Whyte 1958)

1.0. INTRODUCTION

Sprawl is a hot topic in America. Articles about sprawl have appeared in many magazines and newspapers, including *Time*, *US News and World Report*, *The New Yorker*, *Atlantic Monthly*, *Sierra*, *The New York Times*, and *USA Today* (Katz and Bradley 1999; Goldberger 2000; Moberg 2000; Thompson 2000; Tolson 2000; El Nasser and Overberg 2001; Firestone 2001). Search for "urban sprawl" on the World Wide Web and you will be inundated with a combination of research, reports, reviews, and rants. In the academic literature indexed by the *Institute for Scientific Information's Science Citation Database*, the number of titles including the word "sprawl" had increased more than exponentially (Figure 1).

Indeed, sprawl has become the term people use to describe almost anything they do not like about American cities, from traffic jams on endless commercial strips to cookie cutter communities on former farmland. Negative effects attributed to sprawl include economic and racial segregation, crime, poverty, loss of community, increased infrastructure costs, deteriorating air and water quality, loss of farmland and open space, increased traffic congestion, and a general degradation in the quality of human life.

At the same time, a few voices have been questioning the conventional wisdom that sprawl is bad and "Smart Growth" policies are the cure. Among those voices are Peter Gordon and Harry Richardson (1997a), professors in University of Southern California's School of Urban Planning and Development. They contend that compact development is not a cure for traffic congestion. Staley (1999) argued that urban growth boundaries do not reduce traffic congestion, that farmland is not imperiled by urban growth, and that sprawl, itself, is not bad.

Yet despite all the purported effects and proposed solutions, a number of researchers noted that the term "sprawl" was rarely quantified until recently (e.g., Burchell et al. 1998; Downs 1998; Galster et al. 2000; Myers and Kitsuse 1999; Malpezzi 1999). There is also a paucity of correlative analysis between measures of sprawl and measures of social, economic, and environmental quality — in part because sprawl itself has not been well defined (Downs 1998; Galster et al 2000).

One of the difficulties in understanding sprawl is that different observers have defined it by a combination of its causes (e.g., zoning and poor planning), characteristics (e.g., low-density development), and effects (e.g., traffic congestion and air pollution). Galster et al. (2000) noted that sprawl has been defined as an aesthetic judgement; as the cause of an externality (e.g., high automobile dependence, job-housing spatial mismatch); as the consequence of some independent variable (e.g., zoning); as a development pattern (e.g., low density, leapfrogging); as a process of development through time; and by example (e.g., with reference to a particular city such as Atlanta or Los Angeles).

2.0. Objectives

Ewing (1994), Malpezzi (1999), and Galster et al. (2000) argued convincingly that separating the causes, characteristics, and effects of sprawl is essential to reaching consensus on what sprawl is. We agree and chose to focus our efforts on the spatial characteristics of sprawl. Our primary objective was to identify and quantify characteristics of sprawl on the landscape. What does sprawl look like on the ground? What characteristics should one look for on the landscape to declare a city sprawled or sprawling?

In this paper, we

- characterize sprawl from a landscape perspective;
- present quantitative indices for some of the characteristics of sprawl on the landscape;
- use these indices to compare sprawl among the US Census-defined urbanized areas in the mid-Atlantic United States; and
- measure the correlation among our indices and a few purported effects of sprawl.

3.0. Landscape Characteristics of Sprawl

The word sprawl has been used to describe the urban environment since the mid 20th Century (Table 1). The *Oxford English Dictionary* (2001) defines it as "the straggling expansion of an indeterminate urban or industrial environment into an adjoining countryside; the area of this advancement." Sprawl has been used as an adjective describing the pattern of a city's growth, a verb describing the process of that growth, and as a noun describing an urban land form.

Although the first use we found was by Buttenheim & Cornick (1938), the term became relatively commonplace in the 1940's and 1950's, coincident with two fundamental life changes in the United States — an increase in private automobile use and the expansion of the interstate highway system. While some people were defining and deriding sprawl during the early 1950's, others were advocating the decentralization of American cities as a defense against the possibility of nuclear war (Monson and Monson 1950, 1951; Wigton 1953). However, these advocates of city decentralization favored well-planned, concentrated nodes and were very much against the poorly planned sprawl of central cities (Monson and Monson 1950).

Early uses of the term sprawl suggest that it consumes excessive space in an uncontrolled, disorderly manner leading to loss and poor distribution of open spaces, excessive demand for transportation, and social separation. The essential elements of these early definitions have remained relatively unchanged through time. In her report, *Revisiting Sprawl: Lessons From the Past*, Burgess (1998:1) defined sprawl as " …

expanding physical development, at decreasing densities, in metropolitan regions, where the spatial growth exceeds population growth." Lee and Tian (1998) suggested that urban sprawl leads to inefficient land-use, leapfrogging, and low-density development of the urban fringe. The Sierra Club (1998) defined sprawl as "low-density development beyond the edge of service and employment, which separates where people live from where they shop, work, recreate, and educate — thus requiring cars to move between zones." Brueckner (2000) defined urban sprawl as excessive spatial growth of cities.

After a comprehensive literature review (Hess 2001), we noted a number of common characteristics among sprawl definitions (Table 2). Ewing (1994, 1997), Malpezzi (1999), and Galster et al. (2000) provided valuable reviews of sprawl definitions. The characteristics associated most frequently with sprawl were low-density development, strip development, scattered development away from the central city, leapfrog development, and separation of land uses. Density is by far the most common measure, followed by comparisons between the rate at which land is urbanized and the rate of population growth (e.g., land was urbanized at three times the rate of population growth). Ewing (1997) argued that poor accessibility — difficulty moving among widely separated land uses — and a lack of functional, public open spaces are the primary hallmarks of sprawl.

There seems to be general agreement that sprawl is a matter of degree. For example, it is difficult to say at what density a city becomes sprawled, but relatively easy to say that one city is less dense than another and therefore more sprawling in that aspect.

Some researchers consider time to be a critical component in the measurement of sprawl (US EPA 2000; Ewing 1994; Harvey and Clark 1965). Harvey and Clark (1965) noted that sprawl cannot be measured and described at one moment in time, because sprawl is a form of growth. They argued that it is the trend in population density, rather than current population density, that determines whether a city is sprawling or not. A city becoming less densely populated through time is said to be sprawling, even if it is currently quite densely populated in comparison to other cities.

4.0. Approaches to Measuring Sprawl

Several authors have decried the lack of quantitative approaches to defining sprawl, yet few have developed comprehensive ways to measure sprawl. The Sierra Club (1998) ranked US Census-defined urbanized areas by considering trends in population and land area growth, traffic congestion and open space loss indicators. They also accounted for loss of important wildlife habitat and historical sites. In *USA Today*, El Nasser and Overberg (2001) ranked all of the US census-defined Metropolitan Statistical Areas by considering trends in the proportion of the population in the Metropolitan Statistical Areas living in urbanized areas.

Malpezzi (1999) and Galster et al. (2000) have done the most cogent work to date, focusing primarily on measuring the spatial characteristics of urban landscapes. Malpezzi (1999) examined several measures of the spatial distribution of population density among census tracts of all US Metropolitan Statistical Areas. He compared overall density; maximum and minimum tract density; density of the median, tenth, and nintieth percentile population-weighted tracts; coefficient of variation of the tract densities; Theil's information measure; the Gini coefficient; parameters of the densities' fit to a spatial exponential or other function; the r-square statistics thereof; and the average distance of each person to the central business district. He found strong correlations among the percentile measures, and weaker correlations among the other measures. Malpezzi also examined the correlation between spatial measures and commuting measures, and found (with strong correlation) that denser areas have shorter commutes, and that areas with high median home prices also have shorter commutes.

Galster et al. (2000) examined six different measures of residential development:

1) density, the average number of residential units per square mile;

2) concentration, the degree to which development is located within a relatively few square miles of the urbanized area;
3) compactness, the degree to which development has been clustered;
4) centrality, the degree to which development is located close to the central business district;
5) nuclearity, the extent to which an urbanized area is characterized by a single center of development; and
6) proximity of land uses, the degree to which different land uses are close to one another.

They applied these measures to thirteen large US cities, and ranked them from least to most sprawled according to each of the above six measuremes. They further summed all of the ranks for a city to provide an overall measure of sprawl for each city. Galster et al. (2000) also proposed two other measures for future development: *continuity*, the degree to which land has been developed in an unbroken fashion; and *diversity of land uses*, the degree to which different land uses exist within portions of the urbanized area.

Yeh and Li (1998, 2001) used a geographical information system (GIS) analysis of remotely sensed data to measure and monitor the degree of urban sprawl for cities and towns in China. They characterized sprawl as scattered new development on isolated tracts separated from other areas by vacant land. To quantify the degree of scattering they calculated Shannon’s entropy, a statistical measurement of dispersion based on the relative numbers of an item (the amount of new development, in this case) in each of several compartments (concentric rings around a city, in this case). Cities and towns with higher entropy values were characterized as more sprawled because they exhibited more dispersed development — the new development was spread evenly among the compartments. Yeh and Li also used entropy to measure dispersal of development along major roads and highways. Although Yeh and Li did not do so, a series of entropy measures through time can be used to determine changes in the degree to which a city’s development is dispersed or compact.

4.1. Our Measures of Sprawl

We defined seven measures that relate directly to several spatial characteristics of sprawl (Table 3). We restricted our efforts to measures that could be calculated using data readily available in a standardized format for cities nationwide. We focused our efforts on US Census-defined urbanized areas, because they are defined consistently throughout the United States. We used 1990 United States Census and related Federal Highway Administration data, because they are the most recent data available for urbanized areas in the United States. Most of the measures reflect land consumption, differences between land consumption in the center and fringe of the urbanized area, and changes in land consumption rates through time.

The US Census Bureau defines an urbanized area as one or more central places and the adjacent densely settled urban fringe that together contain a minimum of 50,000 persons (US-DC 1994). The definition has been used since 1950 to provide a better separation of urban and rural territory, population, and housing in the vicinity of places with relatively large populations. The definition has changed somewhat through time, but has been relatively consistent since 1970. The urban fringe generally consists of contiguous territory having a density of least 1,000 persons per square mile. The urban fringe also includes outlying territory, if it is connected to the core of the contiguous area by road and is within 1.5 road miles of that core, or within five road miles of the core but separated by water or other undevelopable territory. Other territory with a population density of fewer than 1,000 people per square mile is included in the urban fringe if it eliminates an enclave or closes an indentation in the boundary of the urbanized area.

Our early analyses showed that the size (square miles) and population (number of people) of urbanized areas were correlated at the total (r=0.97), fringe (r=0.99), and center (r=0.70) scales. Because we were focusing on landscape characteristics, we chose to work with area measures instead of population measures. Similarly, we used measures of land consumption — the amount of land used per person — which is the inverse of population density. One can also measure land used per housing unit; however, housing unit density and population density were completely correlated in our study area (r=1.0).

Separation of land uses and accessibility are important and related dimensions of sprawl that are difficult to measure directly. The term “accessibility” is used in the sprawl literature to represent the ease of movement among different land uses, especially home, work, and services (e.g., Koenig 1980). Accessibility is influenced by the degree to which these land uses are separated on the landscape. Personal transportation surveys (e.g., US-FHA 2001) are the best approach to measuring accessibility, because they provide information about what people are doing, where they are going, and how they are getting there. Unfortunately, they are costly to implement and available for only a limited number of Metropolitan Statistical Areas.

We used average daily vehicle miles traveled per person as a surrogate measure for degree of accessibility and separation of land uses. Daily vehicle miles traveled per person are reported by Census-defined urbanized area in the annual US Department of Transportation *Highway Statistics* publication. The data are based on a statistical analysis of traffic counts using the Highway Performance Monitoring System (Office of Highway Policy Information 2000). We used data from the 1993 Highway Statistics (Office of Highway Information Management 1994), because these were the first developed using 1990 urbanized area boundaries.

One must be careful when comparing cities of different densities, because vehicle miles traveled decreases with increasing population density (e.g., Ewing 1997). Therefore, we developed a "DRIVE" index that accounts for population density. By fitting a curve to daily vehicle miles traveled per person as a function of population density, we were able to calculate the expected daily vehicle miles traveled (DVMT) based on the density of a city (Figure 2). Our index was obtained by calculating

$$\text{DRIVE} = \frac{\text{Observed DVMT / person}}{\text{Expected DVMT/person, based on urbanized area density}}$$

Because the index is normalized by urbanized area density, it is only comparing cities of like density. We argue that higher values of this index are related to relatively high automobile use that results from greater separation of land uses and poorer accessibility..

4.3. Applying Our Measures of Sprawl to the Mid-Atlantic Urbanized Areas

We applied our seven measures (Table 3) to the forty-nine cities in the seven mid-Atlantic states (Delaware, Maryland, New Jersey, North Carolina, Pennsylvania, Virginia, West Virginia) that (1) were considered urbanized areas in both 1980 and 1990, and (2) for which Federal Highway Administration data were available.

We ranked the cities according to the degree of sprawl for each characteristic (Table 4). We also evaluated the linear correlation among the seven measures, and found that none of the measures were highly correlated (Table 5). The highest magnitude of any correlation (0.48) was between the fringe-to-center area and land consumption ratios; most correlations were much weaker. This lack of strong correlation implies that each index is measuring something different.

Agglomerative Cluster and Principal Components Analyses

An agglomerative cluster analysis was used to identify groups of cities with similar characteristics. Clustering is a mathematical technique that groups entities with similar attributes by measuring the distance between them in multidimensional space. At each step in an agglomerative cluster analysis, the two entities or groups of entities that are most similar to one another are grouped into a single cluster. A number of approaches can be taken to measure the distance between clusters. We used Ward's Method, which measures the variance between clusters at each step and joins the clusters with the minimum variance. The cluster analyses were performed using JMP (SAS 2001).

We also performed a principal components analysis on our measures. Principal components analysis is a numerical method used to analyze multivariate data (Legendre and Legendre 1998). It is an ordination technique that is used to summarize trends and patterns among samples (urbanized areas, in our case), given a number of characteristics for each sample. The output of a principal components analysis is a score that combines the characteristics that explain most of the variance among samples. The principal components analysis was performed using PC-ORD (MjM Software Design 2000).

Both cluster and principal component analyses were performed on Z-transformed indices, or Z-scores. A Z-score is the number of standard deviations an observation is from the mean of the distribution. We used Z-scores instead of the raw index values, because the index values were of very different magnitudes. Cluster and principal component analysis are sensitive to large differences in magnitudes and will return spurious results if data are not transformed.

We used cluster and principal components analyses to group cities with similar characteristics of land consumption (LAND), fringe-to-center land consumption ratio (FCLAND), and daily vehicle miles traveled per person. We used the observed daily vehicle miles traveled per person rather than our density-adjusted DRIVE index, because density was incorporated into the analyses (through LAND) and both methods therefore account for differences in density.

According to our cluster analysis, most of the difference between groups of cities was explained by overall land consumption (LAND), followed by the fringe-to-center land consumption ratios (FCLAND), followed by daily vehicle miles traveled per person (Figure 3). Principal components analysis of the same variables yielded similar results (Table 4). The first principal axis captured 57% of the variance in the data, and was most closely associated with land consumption (LAND) and daily vehicle miles traveled per person. The second axis captured an additional 24% of the variance, and was most closely associated with the fringe-to-center land consumption ratio (FCLAND).

The larger, older cities all had relatively low levels of land consumption and relatively low levels of daily driving per capita. Among cities with low levels of land consumption, daily driving per capita was relatively low, regardless of the fringe-to-center consumption ratio. No cities had both high levels of land consumption and a high ratio of fringe-to-center land consumption. In essence, both the core and fringe of cities with high rates of land consumption were developed at similar densities. Cities with high land consumption levels were further differentiated by the relative amounts of driving per capita. Many of the cities with high levels of daily driving per capita have recently experienced periods of high growth and economic prosperity.

4.3. Correlates of Sprawl

4.3.1. Forest Fragmentation

Background

Widespread concern about environmental degradation as a result of regional development patterns emerged in the 1960's and 1970's (Burgess 1998). Land transformation has been cited as the major force driving losses in biological diversity (e.g., Vitousek et al. 1997). Habitat fragmentation, in particular, has been documented as having negative effects on biodiversity by increasing "edge effects," and isolating animal populations at a variety of spatial scales (Lovejoy et al. 1986, Laurance et al. 1997). Though rarely mentioned directly, issues related to fragmentation, such as loss of and limited access to open space, are often cited as negative effects of "leapfrogging" development (Downs 1998; Ewing 1994, 1997). Sprawling development is said to result in small, isolated patches of habitat surrounded by land in residential, commercial, or industrial uses. In the mid-Atlantic region, concern about habitat fragmentation is focused on forested habitat, largely because forest is the climax vegetative community in the region.

Methods

We tested the hypothesis that the degree of forest fragmentation in and around an urbanized area is directly related to the degree of sprawl. We used forest fragmentation maps developed by Riitters, et al. (2000) from Multi-Resolution Land Characteristics (MRLC) land-cover maps derived from 1992 Landsat Thematic Mapper (TM) data, at 30 meter by 30 meter resolution. Riitters et al. (2000) assigned one of six fragmentation categories to each forest pixel based on the land cover in three fixed-area windows surrounding the pixel (9x9, 27x27, 81x81). Fragmentation categories are: interior, perforated, undetermined, transitional, edge, and patch. We used data from the smallest scale (highest resolution) window (9x9) for our analysis.

We considered all but the forest interior category to be fragmented and calculated the proportion of all forest pixels that were interior forest in each urbanized area. Because sprawl is said to affect habitat near urbanized areas, we also calculated the percent interior forest in a five-kilometer buffer around the urbanized areas.

Findings

Neither the proportion of interior forest within the urbanized area nor the proportion in the five kilometer region around the urbanized area were correlated strongly with any of our measures of sprawl (Table 6).

4.3.2. Socioeconomic Measures

Background

Because sprawl has been blamed for a variety of social ills, we set out to determine if any of our measures were correlated with easily measured socioeconomic indicators. In *Sprawl City: Race, Politics, and Planning in Atlanta*, Bullard et al. (2000) presented arguments that typify the discussion of socioeconomic issues related to sprawl. Bullard et al. (2000) theorized that government policy, including housing, education, and transportation policies, have subsidized separate but unequal economic development, segregated neighborhoods, and affected the spatial layout of central cities and suburbs. They offer an environmental justice framework with which to investigate the social effects of sprawl on minority and low-income individuals. Environmental justice encompasses environmental racism — discrimination that targets people of color and certain socioeconomic backgrounds and excludes them from planning decisions — and environmental inequity, which denies ethnic and low-income individuals access to employment centers.

Methods and Findings

We selected a number of socioeconomic attributes available from 1990 US Census data and examined their correlation with our measures of sprawl (Table 7). None of the attributes were correlated strongly with our sprawl measures (Table 6). We examined scatterplots of the moderately correlated (>0.4) pairs and found that they were dominated by one or two outlying values, making any generalizations suspect. Although the relationship is weak (r=0.43), our index of land use separation and accessibility (DRIVE) does appear to increase as the median age of housing (MEDAGE) decreases. The implication is that urbanized areas with new housing stock have a larger separation of land uses and poorer accessibility, resulting in more driving.

4.4. Future Work

Our sample size was relatively small in terms of performing cluster and principal components analyses, and New York was an outlier in several respects (e.g., area, density). Applying our measures to all the urbanized areas in the US, increasing our sample size from 49 to nearly 400, might reveal additional trends.

Conceptually, we agree with Ewing (1994) that accessibility and lack of functional open space are key characteristics of sprawl. We do not agree with his assessment of the ease with which these characteristics can be measured. The daily vehicle miles data we used are an imperfect measure of accessibility, because they are aggregated data that provide no information about what individual drivers are doing or where they are going. Personal transportation surveys (e.g., US-FHA 2001) are a better approach to measuring accessibility, because they provide information about where people are going, and how they are getting there. Unfortunately, they are costly to implement and available for only a limited number of Metropolitan Statistical Areas. Further exploration of accessibility measures that can be calculated easily for all urbanized areas would be an important contribution to the sprawl literature.

We did not develop any measures of functional, public open space. These data are difficult to develop on a national scale, because no agency collects them consistently. It is also unclear how privately owned, undeveloped lands would be accounted for in a measure of open space. While it is possible to delineate undeveloped lands using aerial photography or satellite imagery, determining if they are functioning as desired (e.g., as wildlife habitat) is a more difficult task. Data on public parks might be available in a fairly consistent form nationally, and might provide an additional measure of sprawl.

Shannon’s entropy measure of spatial dispersion merits further investigation (Yeh and Li 2001). In a small pilot study, we analyzed census population data at the block level using a geographic information system to calculate the degree of entropy for 14 North Carolina urbanized areas. Entropy was calculated using four concentric rings of equal area around an urbanized area's center of population mass. The largest ring had a radius equal to the longest span from the center of population to the urbanized area boundary. The urbanized areas were differentiated by entropy, which was not well correlated with any of our other sprawl measures. A combination of entropy and population moments (e.g., Malpezzi 1999) might allow one to refine the spatial resolution of our density measures.

5.0. CONCLUSION

The essential issue being addressed in the sprawl debate is the evolution of urban form through time. Cities grow, with or without planning, and develop landscape characteristics that persist through time and determine how they will function. The word "sprawl" is being used to describe a contemporary urban growth form, as well as the effects of that form. Galster et al. (2000) suggested that sprawl can have a number of dimensions, and that cities might sprawl differently along these dimensions. Our analyses support this notion. We calculated seven sprawl measures and found little correlation among them, indicating that they each measure a different dimension of sprawl. Further, few of our measures correlated well with Galster et al.'s (2000); nor did they correlate with the measures presented in *USA Today* (El Nasser and Overberg 2001).

With so many possible measures — none correlated strongly with the measures of environmental and socioeconomic issues we examined — we found ourselves wondering, "Just what is sprawl, anyway?" Clearly, sprawl is multi-faceted. How sprawl is defined may indeed be in the eye of the beholder, because different dimensions of sprawl may be important for different environmental and socioeconomic issues. Conceptual models relating the characteristics of sprawl to purported effects of sprawl are needed to select appropriate sprawl measures. For example, people concerned about loss of wildlife habitat and farmland may be most interested in land consumption and the rate at which it is increasing (LAND and LAND9080). Those concerned with air pollution may be more interested in the sheer size of an urbanized area (AREA) and the separation of land uses, as reflected by our DRIVE measure. If traffic congestion is the major concern, accessibility and separation of land uses are likely to be of paramount concern (DRIVE). In this case, density is only important insofar as it contributes to separation of land uses. People who agree with Harvey and Clark (1965) that sprawl is best measured by trends in density will be most interested in our temporal indices (LAND9080 and FCAREA9080).

Rather than attempting to develop composite indices of sprawl (e.g., Sierra Club 1998; El Nasser and Overberg 2001), it may be more useful to examine urban development patterns along a number of gradients. For example, our cluster and principal components analyses demonstrated that cities can be grouped based on a number of different measures. These analyses reflected the ability of spatial configuration to differentiate groups of cities, even with the relatively coarse data we used. Overall land consumption rates and the relative densities at which the urban center and fringe are populated explained much of the differences among groups of cities. Daily vehicle miles traveled per person differentiated patterns at finer scales. Although we found no strong correlation between our individual measures of sprawl and our measures of environmental and socioeconomic condition, further examination of these issues is warranted with respect to the clusters of cities we identified.

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Table 1. Some early uses of the word "sprawl" to describe urban growth patterns.

“The folly of allowing further unrestricted expansion and disorderly ***sprawling*** of cities into rural areas, turning green fields and forests into dreary city streets and making the countryside inaccessible to the poorer inhabitants of the interior districts, is gaining increasing recognition both in America and Europe.” (Buttenheim & Cornick 1938)

“Among the chief problems facing London, according to the County Plan, were congestion, slums, inadequate and maldistributed open spaces, indeterminate zoning, and ***sprawl***, if one includes the London region." (Rodwin 1945)

“The Association poses the alternative of ‘self-contained towns’ versus ‘***suburban sprawl***.’ It accuses the latter of two basic faults: first excessive demand for transportation and, second, lack of open space for recreation and also expansion .." (Blumenfeld 1949)

" … in the suburbs that have been growing so rapidly around the great centers the buildings exist, ideally, as free-standing structures in a parklike landscape. Too often the trees and gardens vanish under further pressure of population, yet the ***sprawling***, open individualistic structure, almost anti-social in its dispersal and its random pattern, remains." (Mumford 1953: 223)

“ … the aimless ***sprawl of suburbia*** is destroying a precious asset (open land).” (Haskell 1958)

“Great size has another feature that isn’t quite so beneficent. With very great population size comes very great area (as well as high density); and, with the increasing use of the automobile, we get ‘***sprawl***,’ all of which leads to intra-area spatial patterns characterized by very considerable social separation.” (Thompson 1966)

Table 2. Spatial characteristics of sprawl found in the literature.

Characteristic (our measures)*	**Description**	**Selected Citations**
High / inefficient land consumption; low population density (LAND, LAND9080, FCLAND)	Low population density; high levels of urbanized land per person; rate of land urbanization greater than rate of population growth, especially in fringe areas.	Black 1996; Downs 1998, Freeman 2001; Galster et al. 2000; Harvey and Clark 1965; STPP 2000; Montaigne 2000
Fringe Development (FCAREA1990, LAND9080, FCAREA9080)	Development away from city center; rapid development of open spaces on city boundary.	Besl 2000; Downs 1998; Galster et al. 2000; Katz and Bradley 1999
Lack of connectivity (DRIVE)	Arterial street systems; lack of grid; lots of dead ends.	Duany and Plater-Zyberk 1998; NRDC 1996
Leapfrogging; scattered development (DRIVE)	Development that skips over empty parcels.	Clawson 1962; Mills 1981; Downs 1998; Gordon and Richardson 1997b, Yeh and Li 2001
Separation of uses (DRIVE)	Different land uses (employment, retail, residential) are far apart; residential development beyond edge of employment and retail services; lack of residential development in city center.	Brown et al. 1998; Downs 1998; Duany and Plater-Zyberk 1998; Ewing 1994,1997; Galster et al. 2000
Lack of functional open space	Lack of open space that performs a useful public function; ill-defined residual space.	Anonymous 1999; Ewing 1997, 1994
Aesthetics and architecture	You know it when you see it. Big-box retail; strip malls; no sidewalks; excessively wide roads. Large, disjointed buildings set back from street, highly articulated, rotated on lots.	Duany and Plater-Zyberk 1998; Gore 1998; Koffman 1999; Kunstler 1996; NRDC 1996

* Our measures are defined fully in Table 3.

Table 3. Quantitative measures of sprawl that we calculated. For all measures, higher values indicate more sprawl.

Measure	Description / Rationale (Data Source)	Formula
Land Consumption		
AREA	Area of urban area (square miles) in 1990. Larger urban areas consume more land, and are considered more sprawling. (US Census Bureau)	UA* Area
LAND	Urbanized land per capita in 1990. Size of urban area / population (acres per 1,000 people). A more sprawling city uses more land per person. (US Census Bureau)	UA Area (acres) / UA Population (1,000s
Population Concentration		
FCAREA	Fringe-to-center area ratio in 1990. Ratio of fringe area to area of city center. Sprawled cities are said to have more development away from their city centers. (US Census Bureau)	Area of UA Fringe / Area of UA Center
FCLAND	Fringe-to-center land per capita ratio in 1990. Ratio of land used per capita in the fringe to land used per capita in the city center. Sprawled cities are often said to have much higher land consumption per capita in the fringe than in the center. (US Census Bureau)	(Fringe Area / Fringe Population) / (Center Area / Center Population)
Separation of Land Uses / Accessibility		
DRIVE	Daily Vehicle Mileage per Capita in 1993. This measure reflects the average daily mileage per capita relative to cities of the same population density. >1 means more driving than average for cities of same density <1 means less driving than average for cities of same density We used this index as a surrogate for measuring several spatial characteristics of sprawl. Separation of land use, lack of connectivity, and poor accessibility are spatial characteristics of sprawl that result in increased driving and higher values of this index. (US Federal Highway Administration)	Observed Daily Mileage / Expected Daily Mileage (See text for details)
Temporal Development Patterns		
FCAREA9080	Ratio of fringe-to-center area ratio in 1990 to 1980 value. Cities are more sprawling when the size of their fringe areas increases faster than the size of their centers (i.e., FCAREA9080 > 1). (US Census Bureau)	FCAREA (1990) / FCAREA (1980)
LAND9080	Ratio of urbanized land per capita in 1990 to 1980 value. Cities are sprawling when their rate of land use per capita is increasing (i.e., LAND9080 > 1). (US Census Bureau)	LAND (1990) / LAND (1980)

*UA = US Census-defined urbanized area

Table 4. Sprawl rankings of 49 urbanized areas in the mid-Atlantic states from most sprawled (1) to least sprawled (49). The first column lists the urbanized areas from most to least sprawling as ranked by the first principal axis of a principal components analysis of overall land consumption (LAND), fringe-to-center land consumption ratio (FCLAND), and observed daily vehicle miles traveled. The remaining columns show the rank of each urbanized area for each of our seven sprawl indices, from the most sprawled (1) to the least sprawled (49).

	City (principal axis 1)	AREA	LAND	FC AREA	FC LAND	DRIVE	LAND 9080	FCAREA 9080
1.	Asheville NC	23	7	32	31	4	34	30
2.	Hickory NC	32	5	24	42	5	23	45
3.	Vineland-Millville NJ	15	1	48	49	44	48	35
4.	Kingsport VA	20	2	27	43	23	22	44
5.	Lynchburg VA	19	3	39	29	20	24	6
6.	Bristol TN/VA	38	4	44	24	22	37	33
7.	High Point NC	30	14	41	41	13	20	38
8.	Burlington NC	39	17	34	38	1	31	24
9.	Gastonia NC	27	13	30	37	11	27	36
10.	Raleigh NC	11	23	40	32	3	11	10
11.	Greensboro NC	25	32	47	22	2	25	41
12.	Winston-Salem NC	16	20	42	26	10	41	31
13.	Danville VA	42	8	49	19	24	3	49
14.	Wilmington NC	29	6	31	27	32	44	39
15.	Goldsboro NC	40	11	35	15	38	46	46
16.	Norfolk-Virginia Beach VA	3	9	43	13	37	2	48
17.	Durham NC	18	30	46	44	16	26	47
18.	Charleston WV	21	21	26	46	12	4	4
19.	Atlantic City NJ	17	16	13	40	14	8	29
20.	Charlotte NC	8	27	45	23	19	47	18
21.	Roanoke VA	26	31	38	45	17	42	20
22.	Petersburg VA	33	19	29	47	36	19	2
23.	Richmond VA	7	29	19	34	7	40	9
24.	Fayettville NC	14	24	25	48	39	43	32
25.	Hagestown MD	44	22	21	14	28	36	19
26.	Huntington-Ashland WV/KY	24	25	23	33	29	7	8
27.	Annapolis MD	37	18	11	5	31	5	11
28.	Jacksonville NC	31	12	16	30	48	49	40
29.	Parkersburg WV	48	36	37	39	40	6	7
30.	Allentown PA	13	42	22	28	30	35	15
31.	Charlottesville VA	47	39	33	25	33	14	5
32.	Altoona PA	46	40	28	8	41	21	25
33.	Scranton-Wilkes-Barre PA	9	28	14	20	42	30	22
34.	Harrisburg PA	12	26	2	16	8	28	34
35.	Sharon PA	43	10	5	3	49	1	1
36.	Erie PA	34	41	36	35	45	9	27
37.	Johnstown PA	45	34	17	17	43	15	26
38.	Baltimore MD	6	43	12	10	18	18	17
39.	Wilmington DE	10	37	7	36	15	39	43
40.	Reading PA	35	46	18	11	34	33	13
41.	State College PA	49	45	20	1	47	10	3
42.	Trenton NJ	22	44	4	4	9	38	23
43.	York PA	36	38	8	9	21	32	14
44.	Monessen PA	41	15	1	21	46	13	12

45.	Washington DC	4	47	9	18	6	45	37
46.	Pittsburgh PA	5	33	3	12	35	12	28
47.	Lancaster PA	28	35	6	7	27	29	16
48.	Philadephia PA	2	48	10	6	25	17	21
49.	New York NY	1	49	15	2	26	16	42

Table 5. Correlations among sprawl measures. Sprawl measures are defined in Table 3; PC1 is the score of the first principal components axis; negative numbers are shown in parentheses.

	AREA	LAND	FCLAND	FCAREA	LAND9080	FCAREA9080	DRIVE
AREA	1						
LAND	(0.31)	1					
FCLAND	0.38	(0.44)	1				
FCAREA	0.14	(0.32)	0.48	1			
LAND9080	0.03	0.07	0.31	0.13	1		
FCAREA9080	(0.2)	(0.17)	0.27	0.22	0.43	1	
DRIVE	0.02	(0.04)	(0.26)	(0.12)	(0.27)	(0.27)	1
PC 1	(0.30)	0.79	(0.60)	(0.68)	(0.11)	(0.30)	(0.41)

Table 6. Correlations between sprawl measures and measures of potential environmental and socioeconomic correlates. Sprawl measures and definitions are provided in Table 3; PC 1 is the score of the first principal components axis; fragmentation variables are described in the text; socioeconomic variables are described in Table 7. Negative numbers are shown in parenthases

	AREA	LAND	FC LAND	FC AREA	LAND 9080	FCAREA 9080	DRIVE	PC 1
Forest Fragmentation								
Inside UA*	0.17	0.34	(0.07)	(0.13)	(0.19)	(0.05)	(0.36)	(0.04)
UA Buffer**	0.01	(0.04)	0.02	(0.22)	(0.23)	0.06	(0.28)	(0.05)
Socioeconomic Measures								
HS%	(0.12)	0.09	(0.04)	0.33	0.10	0.06	(0.42)	(0.22)
GRAD%	0.20	(0.47)	0.27	0.06	0.00	0.13	0.20	(0.27)
PCINCOME	0.38	(0.45)	0.25	0.13	(0.12)	(0.06)	0.35	(0.25)
POVERTY	(0.28)	0.20	0.01	(0.29)	0.30	0.25	(0.43)	(0.12)
MEDAGE	0.03	(0.26)	0.30	0.38	0.20	0.21	(0.43)	(0.49)
MEDVALUE	0.56	(0.40)	0.34	0.22	(0.16)	(0.12)	0.28	(0.31)

* UA = US Census-defined urbanized area
** Within a 5-kilometer buffer around the urbanized area

Table 7. Description of socioeconomic variables we correlated against our measures of sprawl.

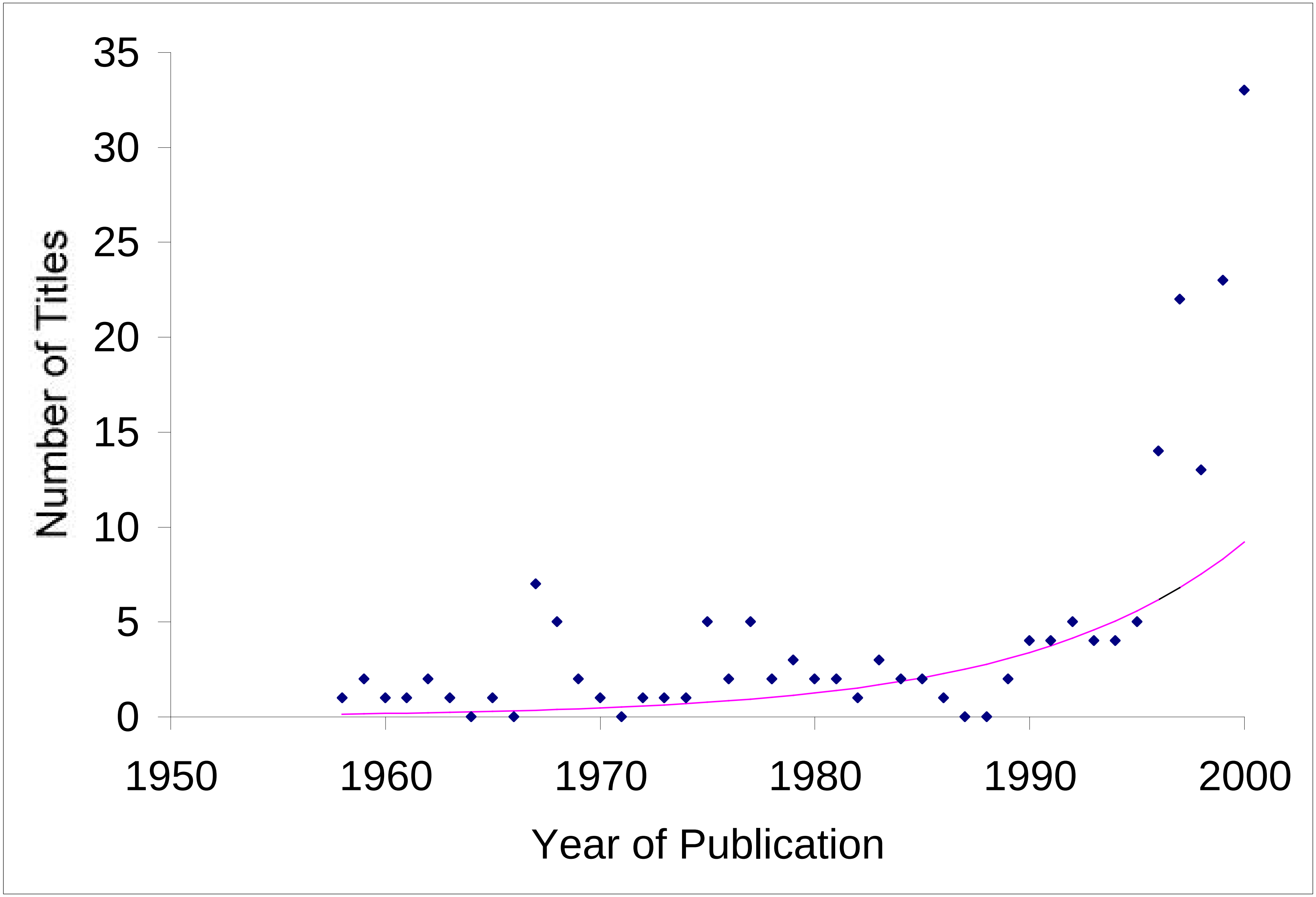
Variable	*Description / Rationale*
Educational Attainmant	
HS% GRAD%	Percent of people age 25 years and older for whom high school or graduate school is the highest level of education. Higher levels of education generally translate to higher income and increased ability to satisfy preference for low-density housing. Expect higher level of educational attainment to be correlated positively with sprawl. (Bullard et al. 2000)
Income	
PCINCOME	Per capita income for people age 5 years and older. In surveys, upper income individuals expressed a desire for low-density housing and the flexibility to be mobile. Expect sprawling cities to have a higher per-capita income. (Bullard et al. 2000)
POVERTY%	Percent of individuals age 5 years and older who fall below the 1989 poverty line. Sprawl leaves a decaying inner city with high rates of poverty. Expect sprawling cities to have higher poverty levels. (Bullard et al. 2000)
Housing	
MEDAGE	Median age of housing stock in 1989. During the 1950s-1970s, the influx of tract developments created affordable, low-density housing. Expect cities with newer homes to be more sprawling. (Dear and Elliot 2001)
MEDVALUE	Median home value in 1989. Real estate markets have a direct influence on cost and availability of housing in urbanized areas. High costs in the city center drive people into the fringe. Expect cities with higher median housing values to be more sprawling. (Dear and Elliot 2001)

FIGURE CAPTIONS

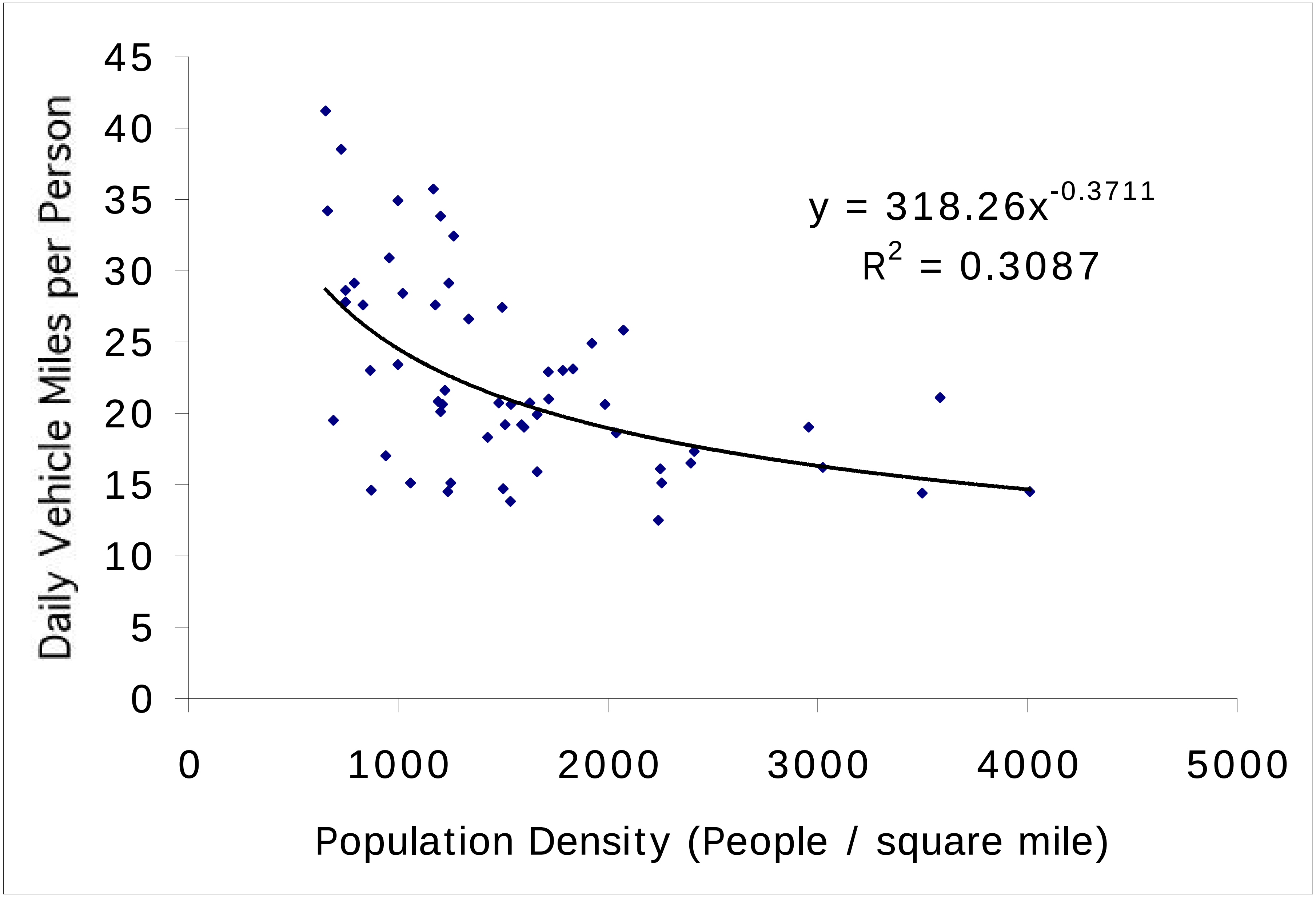
Figure 1. Number of journal articles including the word "sprawl" in the title. Search was performed on the Institute for Scientific Information's Science Citation database (URL=http://www.isinet.com/isi/products/citation/sci/, Feburary 2000). The curve shown is a best-fit exponential curve.

Figure 2. Daily vehicle miles traveled per person as a function of population density, using 1993 Federal Highway Administration data for the 49 urbanized areas examined in this study (Office of Highway Information Management 1994). We fit a power law curve to the data. The index of separation of land use and accessibility for an urbanized area is obtained by dividing the actual daily vehicle miles traveled per person for the urbanized area by the expected value (i.e., the value along the curve) for a hypothetical city of the same density. Observations above the curve are urbanized areas with higher than expected vehicle miles per person for a city of that density; observations below the curve have lower than expected vehicle miles per person for a city of that density.

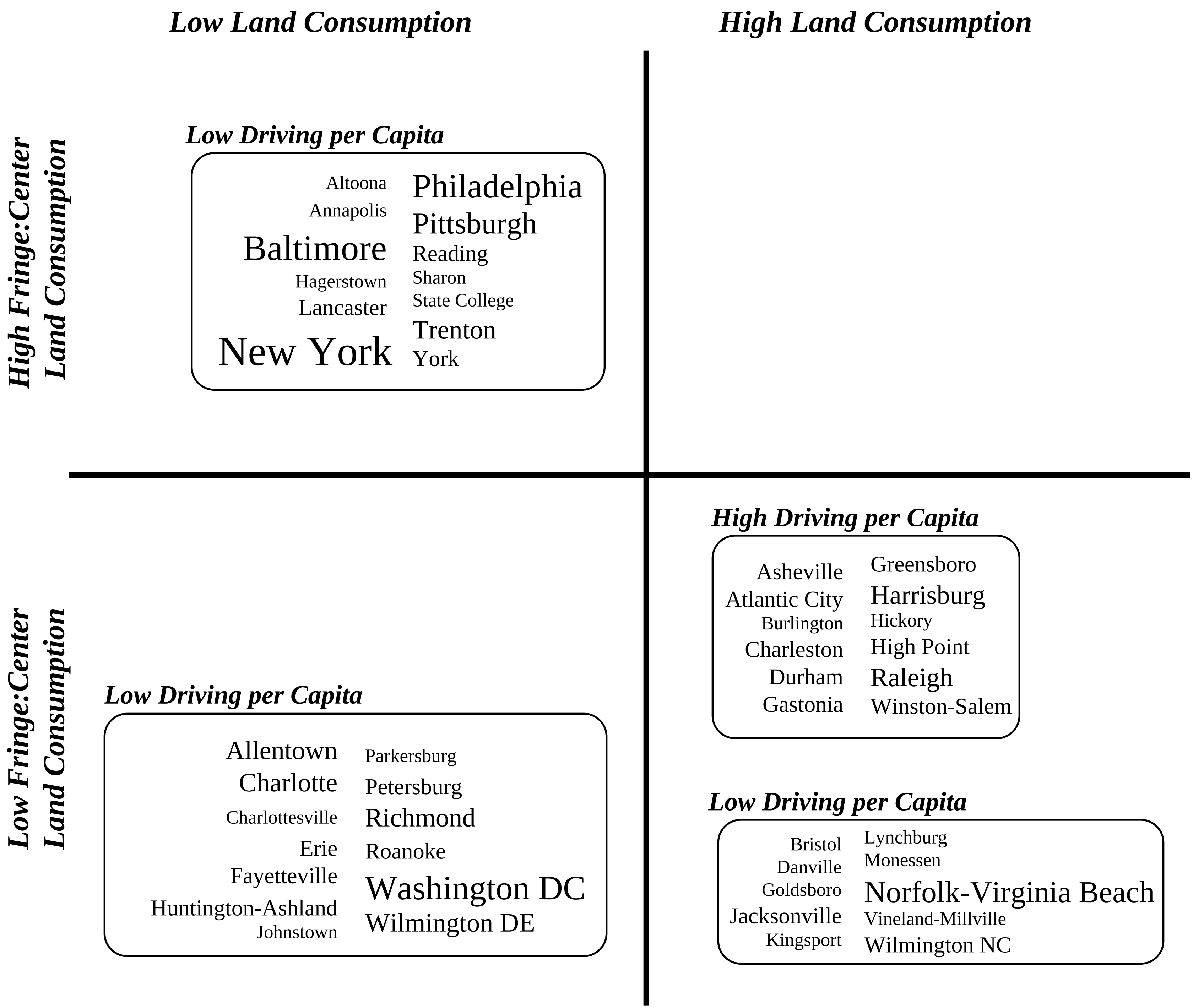
Figure 3. Results of a hierarchical cluster analysis on mid-Atlantic urbanized areas. The mid-Atlantic states are Delaware, Maryland, New Jersey, North Carolina, Pennsylvania, Virginia, and West Virginia. Font size is proportional to the natural log of the population.



35
30
25
20
15
10
5
0
Number of Titles
1950
1960
1970
1980
1990
2000
Year of Publication



Daily Vehicle Miles per Person
45
40
35
30
25
20
15
10
5
0
0
1000
2000
3000
4000
5000
Population Density (People / square mile)
y = 318.26x^-0.3711
R^2 = 0.3087


Low Land Consumption
High Land Consumption
High Fringe:Center Land Consumption
Low Driving per Capita
Altoona
Annapolis
Baltimore
Hagerstown
Lancaster
New York
Philadelphia
Pittsburgh
Reading
Sharon
State College
Trenton
York
Low Fringe:Center Land Consumption
High Driving per Capita
Asheville
Atlantic City
Burlington
Charleston
Durham
Gastonia
Greensboro
Harrisburg
Hickory
High Point
Raleigh
Winston-Salem
Low Driving per Capita
Allentown
Charlotte
Charlottesville
Erie
Fayetteville
Huntington-Ashland
Johnstown
Parkersburg
Petersburg
Richmond
Roanoke
Washington DC
Wilmington DE
Low Driving per Capita
Bristol
Danville
Goldsboro
Jacksonville
Kingsport
Lynchburg
Monessen
Norfolk-Virginia Beach
Vineland-Millville
Wilmington NC