Mapping "Exurbia" in the Conterminous United States Using Nighttime Satellite Imagery

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Abstract

A quick search of "exurbia" on the internet yields various definitions: 'the region outside the suburbs of a city, consisting of residential areas (exurbs) that are occupied predominantly by rich commuters (exurbanites) (www.wordreference.com/English); and the cryptically self-referential 'a typically exurban area' (www.bartleby.com). Nighttime satellite imagery provided by the Defense Meteorological Satellite Program's Operational Linescan System (DMSP OLS) shows expansive areas of low light surrounding all major metropolitan areas. These areas would be characterized as pure vegetation by 30 meter resolution Landsat imagery yet they contain large numbers of people who have significant social, economic, and ecological impacts (e.g. traffic congestion and problems associated with the urban-wildlands interface). Questions explored in this paper are: 1) How big are 'exurban' areas in the United States?; 2) What cities have relatively large exurban areas and what cities have relatively small exurban areas?; How many people live in exurban areas?; 4) What are the costs and benefits of exurban areas and who pays for and/or receives them?; and finally, 5)Who lives in exurban areas? Conventional wisdom suggests that these 'exurbanites' are rich commuters who choose to live in natural settings beyond the city and suburbia; however, astronomic increases in real estate prices in places like Boston, New York, San Francisco, and Los Angeles suggest that many 'exurbanites' may be middle income teachers, police officers, and nurses trying to find affordable real estate. Our initial results suggest that 37% of the U.S. population lives in exurban areas that account for 14% of the land area. Purely urban areas account for 1.7% of the land area and house 55% of the population; and, rural areas (84% of the land area) contain only 8% of the population.

Introduction

Providing a non-controversial definition of "exurbia" is a daunting if not impossible task. Spectorsky is generally credited with coining the phrase "Exurbia" in his book 'The Exurbanites' which describes commuter settlements in areas outside of New York city inhabited by a wealthier class of people seeking a closer relationship with nature (Spectorsky 1955). Since 1955 the concept of exurbia has evolved and its spatial extent has grown. Recently David Brooks has characterized the Exurbans as providing the winning margin for George W. Bush in the 2000 presidential election (Brooks 2002). Daniels argues in his book 'When City and Country Collide' that the urban-rural fringe is developing in a haphazard manner and argues for higher density development patterns (Daniels 1999). Growth in exurban areas presents many social, economic, and environmental challenges; and, the costs of facing these challenges are often not paid for by the exurbanites themselves (Burchell 1998).

One problem associated with characterizing "exurbia" is whether to define it by the socio-economic and demographic characteristics of the people who live in it or to define it by the spatial patterns of development on the landscape. Daniels describes exurban areas as having the following characteristics:

- Located 10-50 miles from urban centers of 500,000 people or 5-30 miles from cities of at least 50,000
- Commute time is at least 25 minutes each way to work
- Communities have a mix of long-term and newer residents
- Agriculture and forestry are active, but declining, industries in the community

Researchers at The Exurban Change Project at Ohio State University describe exurbs as having a distinct spatial pattern of settlement that differs from their suburban counterparts. Among these differences are greater distances from the urban centers, different mixes of land uses and population density, and likelihood of transition to actual suburbs or edge cities within 10-20 years. The Exurban Change Project has mapped several representations of exurban Ohio based on population density thresholds and on distance from urban centers (http://www-agecon.ag.ohio-state.edu/programs/exurbs).

During the 1970's and 1990's the United States experienced counter-urbanization in which more people moved into non-metropolitan counties than moved into metropolitan counties (Nelson and Sanchez 1999) (Berry and Gillard 1977; Long and DeAre 1988; Long and Nucci 1997). Interesting theoretical debates have arisen regarding Alonso's theory of urban form and the fundamental nature of exurbanization (Alonso 1964). Long and Nucci have argued that exurbanization is a unique and unprecedented pattern of development in the United States (Long and Nucci 1997). However, Nelson and Sanchez make the argument that there is no significant difference between the suburbs and exurbs (Nelson and Sanchez 1999) (Nelson and Sanchez 1997). Nelson and Sanchez's study compared household characteristics, occupations of workers, employment accessibility, residence characteristics, and clustering of urban and exurban areas and found no significant differences between them. Their conclusion was that metropolitan areas are not reliably delineated into distinct rings of suburban and exurban development. To some extent it could be argued that exurbs are merely proto-suburbs which will evolve into suburbs in the fullness of time. However, the spatial extent of exurbs, environmental constraints, zoning patterns, and the water, sewage, and transportation infrastructure which support exurban areas suggest that the evolution of exurban landscapes to suburban landscapes may not take place in the same way these transitions have occurred historically. Most of these previous studies and characterizations of exurban areas rely primarily on census data. This study provides an alternative perspective on exurbia by focusing primarily on remotely sensed satellite imagery.

This research uses remotely sensed imagery to make simple empirical definitions of "exurbia". Delimiting exurban area with census data is limited in its usefulness because of the somewhat arbitrary boundaries of the administrative units (particularly in less densely populated areas) (Nelson and Sanchez 1999). An unusual advantage of the nighttime satellite imagery for this purpose is its relatively coarse spatial resolution (1 km x 1 km pixels). The nighttime imagery can "see" low levels of light from sparsely scattered development that appears to be vegetation, rock, or dirt in classifications of moderate spatial resolution Landsat images (30m x 30m pixels). This scattered development is not discernible in daytime imagery until relatively fine spatial resolution imagery is used (less than

10 m x 10 m pixels). The 'leap-frogging' of spatial scale enabled by the nighttime imagery allows for relatively easy explorations of areas as large as the United States.

Data and Methods

The data used in this analysis were: 1) A 1998 radiance calibrated nighttime satellite image of the conterminous United States; 2) Census 2000 Urbanized Areas Cartographic Boundary Files (http://www.census.gov/geo/www/cob/ua2000.html); 3) Landscan 2000 population density data produced at Oak Ridge National Laboratory; and 4) National Land Cover Data derived from Landsat imagery and ancillary data. A brief description of these datasets follows.

The nighttime lights product is a hyper-temporal mosaic of many orbits of the Defense Meteorological Satellite Program's Operational Linescan System (DMSP OLS) in which clouds, gas flares, lightning, and other ephemeral and extraneous signals have been screened out leaving only "city lights" (Elvidge, Baugh *et al*. 1998). The Census 2000 Urbanized Areas dataset was used primarily for comparison purposes only. This vector dataset consisted of the polygons that were classified as Urban Areas (UA) or Urban Clusters (UC) by the census bureau.

> For Census 2000, an urbanized area (UA) will consist of a densely settled core of census block groups (BGs) and census blocks that meet minimum population density requirements, along with adjacent densely settled surrounding census blocks that together encompass a population of at least 50,000, at least 35,000 of whom live in an area that is not part of a military installation. For Census 2000, an urban cluster (UC) will consist of a densely settled core of census BGs and census blocks that meet minimum population density requirements, along with adjacent densely settled surrounding census blocks that together encompass a population of at least 2,500 people, but fewer than 50,000 people, or greater than 50, 000 people if fewer than 35,000 of them live in an area that is not part of a military installation. (http://www.census.gov/geo/www/ua/ua_2k.html)

The Landscan 2000 population density dataset was used in lieu of actual census data because of its raster format which simplifies the analyses conducted with the nighttime imagery. The Landscan 2000 data are a representation of population density at 1 km spatial resolution derived from census data (Dobson, Bright *et al*. 2000). The fine resolution land-cover dataset that was used in this study was created as part of a

cooperative project between the U.S. Geological Survey and the U.S. Environmental Protection Agency. This joint effort classified Landsat Thematic Mapper (TM) imagery, which has a resolution of 30m, to produce a land-cover map for each state using a consistent land-use/land-cover classification scheme. The National Land Cover Dataset (NLCD) is a continuous land-cover dataset for the conterminous United States that includes 21 land-cover classes (Vogelmann, Sohl *et al*. 1998; Vogelmann and Howard 2001).

The nighttime lights data products derived from the DMSP OLS have been used in many applications including delineating urban extent (Imhoff, Lawrence *et al*. 1997), estimating CO_2 emissions at the national level (Doll, Muller *et al*. 2000), estimating and mapping urban populations and densities (Sutton, Roberts *et al*. 2001; Sutton, Roberts *et al*. 2001), quantifying anthropogenic impervious surface area (Elvidge, Milesi *et al*. In Review), mapping economic activity (Sutton and Costanza 2002), measuring human impact on the environment (Sutton 2003), and characterizing urban sprawl (Sutton 2003). Many of these previous studies focused on the bright or saturated urban areas; however, surrounding almost all major and most minor urban areas there exist vast expanses of low levels of light intensity that we argue are the exurban areas of the United States.

This analysis began with a simple binary classification of the nighttime image of the conterminous United States into 'lit' and 'not-lit'. This image was classified into clusters based on contiguous 'lit' pixels and these clusters were classified on the basis of their size (Figure 1). The two largest clusters identified as the "Midwest Monster" and "Megalopolis" represent massive conurbations of urban and exurban areas. These large conurbations presented some difficulty with respect to attributing exurban areas to specific metropolitan areas. As a next step the nighttime imagery was overlaid on the finer resolution NLCD data to identify a threshold or light intensity level that distinguished urban from non-urban (Figure 2).

Figure 2 shows the southwest corner of the Denver metropolitan area and some of its hinterlands. The background image is the 30 m resolution NLCD data in which urban areas (low density residential, high density residential, and commercial/industrial/transportation) are displayed in red, burgundy, and gray. Most of these areas are enclosed by the solid black line which is light levels at or above the 'urban' threshold in the DMSP OLS nighttime imagery. Low light level boundaries are represented by the solid purple lines surrounding the Denver metro area. These low light levels contain primarily shrublands and evergreen and deciduous forests of the NLCD image. The yellow lines demarcate the UAs and UCs defined by the Census Bureau. Inset and expanded on this image is a 1 meter resolution IKONOS image of a low light or exurban area in which you can see roads and structures characteristic of an exurban environment.

Using the urban threshold (solid black line in Figure 2) the nighttime image was used to create urban, exurban, and rural (no light or dark) classified images. The urban image was clustered into metropolitan areas on the basis of

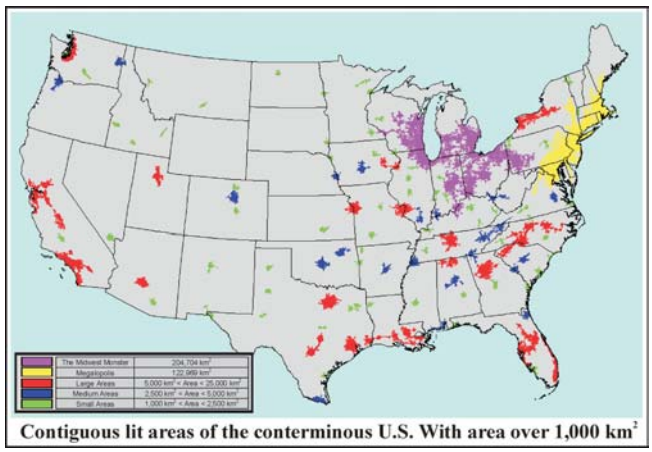


Figure 1 Contiguous lit areas of the conterminous U.S. with area over 1,000 km^2

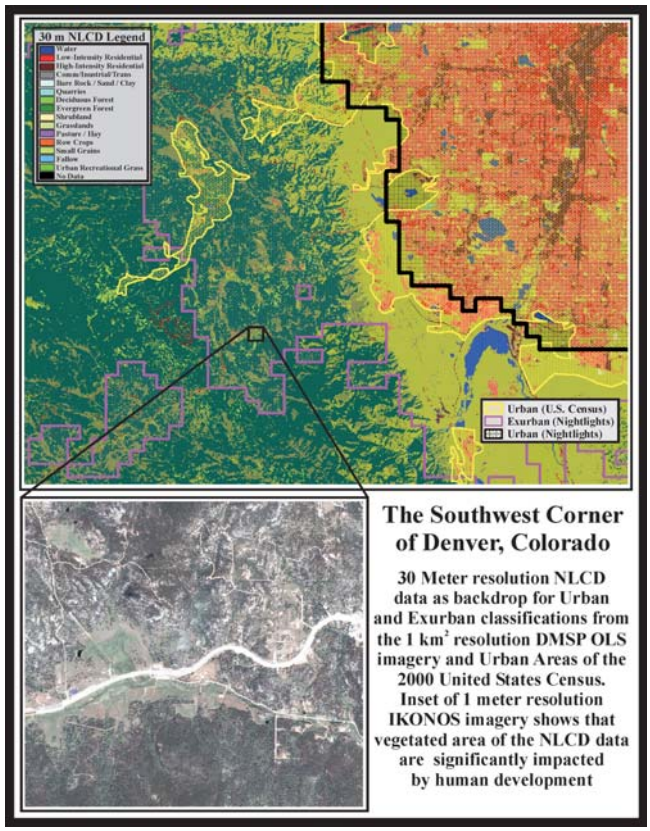


Figure 2 Exurban Area in Southwest Denver

contiguous urban pixels and those urban areas with area greater than 500 km2 were preserved. This produced an image with 48 urban metro areas containing populations ranging from 228,000 (Youngstown, OH) to 10,443,000 (New York, NY). (Youngstown seemed to be an unusual inclusion in this set while Pittsburgh, PA was a notable exclusion). The exurban image was classified in such a manner that the exurban areas were associated with these larger (greater than 500 km2) urban metro areas based on closest proximity and as long as they were within 100 km

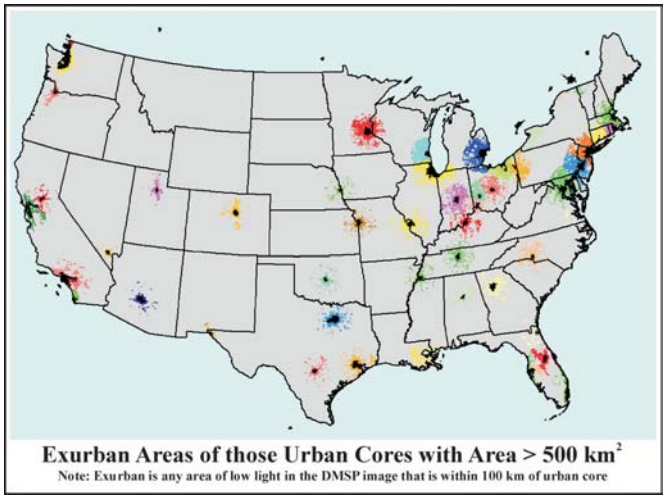


Figure 3 Exurban Areas of those Urban Cores with Area > 500 km2

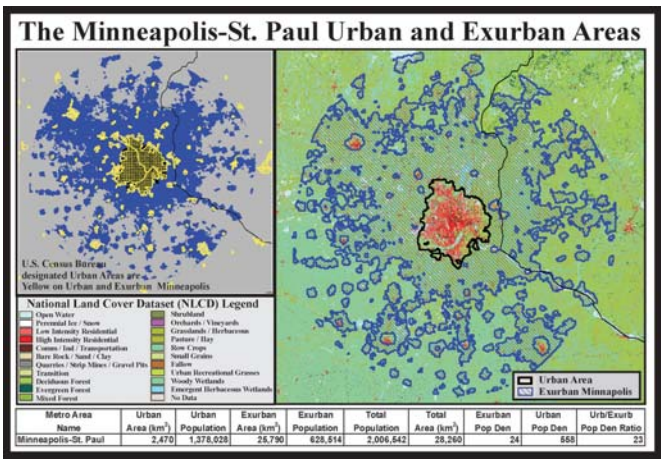


Figure 6 Urban and Exurban areas of Minneapolis-Saint Paul

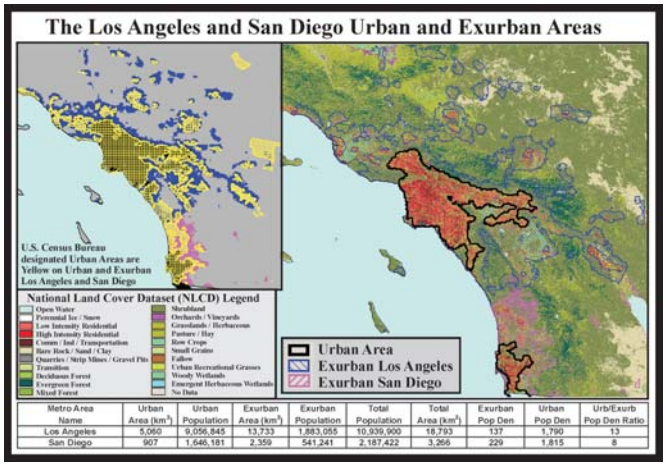


Figure 4 Urban and Exurban areas of Los Angeles and San Diego Metro Areas

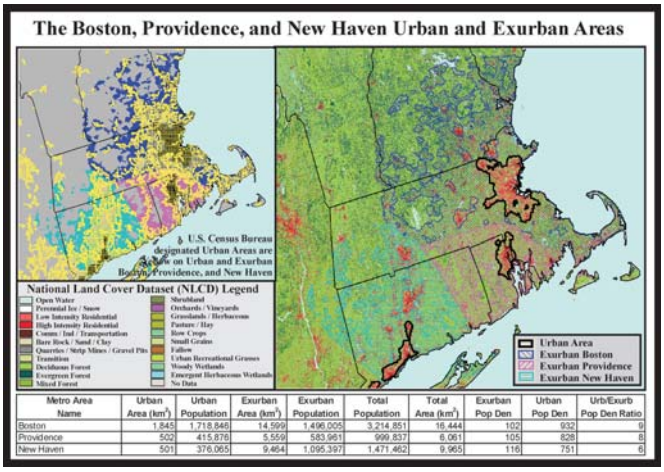


Figure 7 Urban and Exurban areas of Boston, Providence, and New Haven

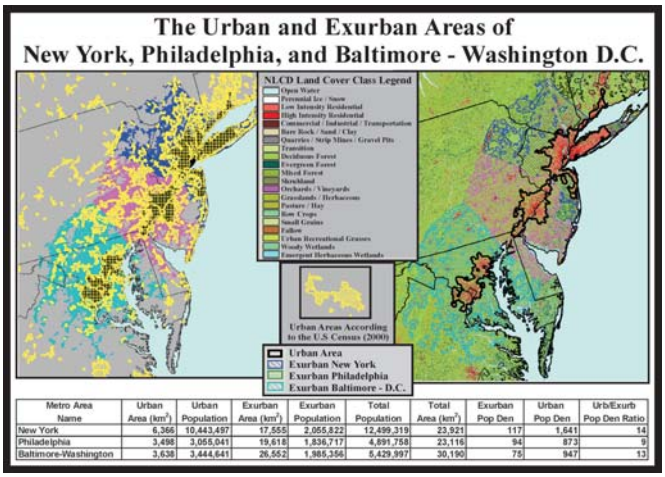


Figure 5 Urban and Exurban areas of New York, Philadelphia, and Baltimore-Washington D.C.

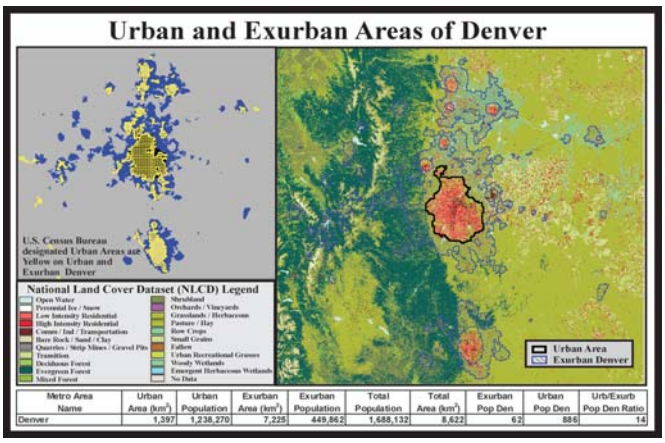
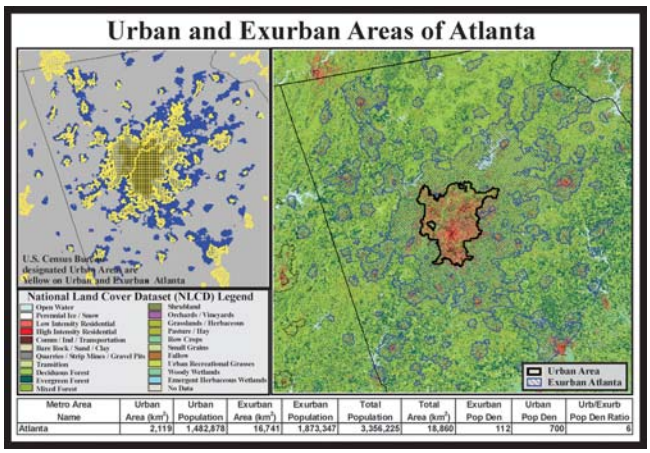
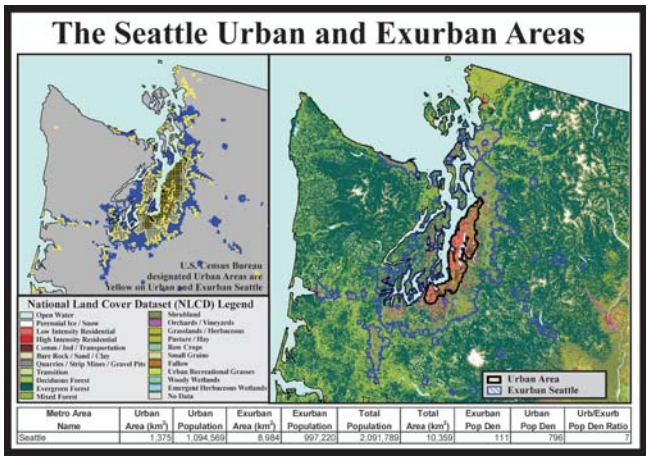


Figure 8 Urban and Exurban Denver



Metro Area Name	Urban Area (km²)	Urban Population	Exurban Area (km²)	Exurban Population	Total Population	Total Area (km²)	Exurban Pop Den	Urban Pop Den	Urb/Exurb Pop Den Ratio
Atlanta	2,119	1,482,878	16,741	1,873,347	3,356,225	18,860	112	700	6

Figure 9 Urban and Exurban Atlanta



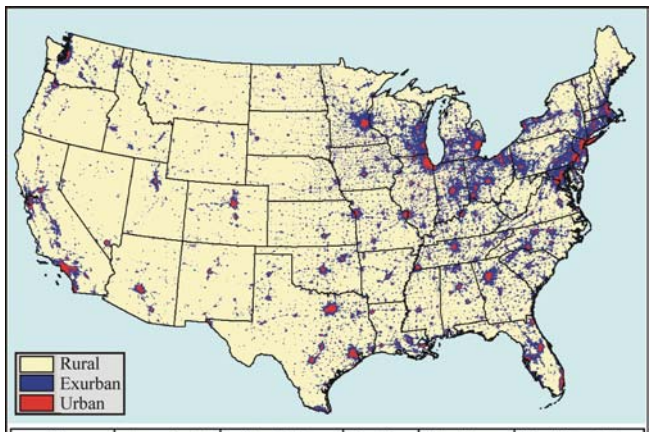
Metro Area Name	Urban Area (km²)	Urban Population	Exurban Area (km²)	Exurban Population	Total Population	Total Area (km²)	Exurban Pop Den	Urban Pop Den	Urb/Exurb Pop Den Ratio
Seattle	1,375	1,094,569	8,984	997,220	2,091,789	10,359	111	796	7

Figure 10 Urban and Exurban Seattle

(Figure 3). These 48 metropolitan urban areas and their associated exurban hinterlands were then examined according to the cartographic scheme of Figure 2 for coherence with this conception of exurban.

Results

The areas, populations, and population densities of the urban and associated exurban areas of these 48 metropolitan urban areas were determined and tabulated (Table 1). As expected New York, Los Angeles, and Chicago topped the list with populations of 10.4, 9.0, and 5.0 million 'urban' residents respectively. These numbers are smaller than the Census Bureau's reported population for these Metropolitan Statistical Areas (MSAs). However, this was to be expected because the classifications of urban, exurban, and rural from the DMSP OLS imagery do not correspond to the UA, UC, and MSA designations of the census bureau. For example, the Los Angeles PMSA (2000 population around 16 million) includes the city of Ventura, California. This analysis does not attribute the population of urban areas of Ventura to



Class	Area (km2)	Population	Pop Den	% of Area	% of Population
Rural	6,528,385	23,115,941	4	84.0	8.3
Exurban	1,108,408	102,725,552	93	14.3	37.0
Urban	131,809	151,492,560	1,149	1.7	54.7

Figure 11 Urban, Exurban, and Rural areas for the conterminous U.S.

either the urban or exurban areas of the Los Angeles metropolitan area because Ventura constitutes urban area that is not contiguous to the urban area of Los Angeles (Figure 4). Urban areas defined by the DMSP OLS imagery that are less than 500 km2 in contiguous area are excluded from the definition of exurban area, consequently all of these measures of metropolitan population are lower than those of the Census. Figures 5-8 show the urban, exurban, and rural areas of New York - Philadelphia - Baltimore - Washington D.C., Minneapolis, Boston-Providence-New Haven, Denver, Atlanta, and Seattle, according to the cartographic scheme used in Figure 2. Figures 5-10 do not capture the full resolution of the 30 m NLCD data but do provide an accurate portrayal of how the DMSP OLS classifications correspond to the finer resolution imagery (for reference Figure 2 does capture the resolution of the NLCD imagery).

Inspection of Figures 5-10 clarifies how the DMSP OLS imagery can provide an alternative definition of urban, exurban, and rural than previously suggested methods based on census data. This DMSP OLS derived classification of urban, exurban, and rural is now applied to all of the conterminous United States (Figure 11). This shows 54.7% of the population in urban areas on 1.7% of the land, 37% of the population in exurban areas on 14.3% of the land, and 8. 3% of the population in rural areas on 84% of the land. For smaller urban areas this method most likely underestimates urban extent and over-estimates exurban extent; however, some of this is due to the coarse spatial resolution of the DMSP OLS imagery and warrants further research. Interestingly the respective population densities almost correspond to descending orders of magnitude (10^3 (Urban: 1,149 persons/km2); 10^2 (Exurban: 93 persons/km2); 10^1 (Rural: 4 persons/km2)). This suggests that almost 92% of the United States population lives in urban or exurban areas which is significantly higher than the 74.6% percent of population in urban areas reported by the census bureau.

Table 1 Urban and Exurban Areas, Populations, and Densities of 49 U.S. Cities

Metro Area Name	Urban Area (km^2)	Urban Population	Exurban Area (km^2)	Exurban Population	Total Population	Total Area (km^2)	Exurban Pop Den	Urban Pop Den	Urb/Exurb Pop Den Ratio
New York	6,366	10,443,497	17,555	2,055,822	12,499,319	23,921	117	1,641	14
Los Angeles	5,060	9,056,845	13,733	1,883,055	10,939,900	18,793	137	1,790	13
Chicago	5,313	4,970,777	22,321	1,131,023	6,101,800	27,634	51	936	18
Miami	2,987	3,708,042	4,619	452,270	4,160,312	7,606	98	1,241	13
Baltimore-Washington	3,638	3,444,641	26,552	1,985,356	5,429,997	30,190	75	947	13
Philadelphia	3,498	3,055,041	19,618	1,836,717	4,891,758	23,116	94	873	9
Dallas - Ft. Worth	3,320	2,800,483	11,433	1,003,921	3,804,404	14,753	88	844	10
San Francisco	1,639	2,739,945	10,997	1,606,460	4,346,405	12,636	146	1,672	11
Detroit	3,143	2,579,779	25,042	1,235,907	3,815,686	28,185	49	821	17
Houston	3,081	2,472,011	10,959	893,508	3,365,519	14,040	82	802	10
Phoenix	1,750	1,838,568	5,523	464,487	2,303,055	7,273	84	1,051	12
Boston	1,845	1,718,846	14,599	1,496,005	3,214,851	16,444	102	932	9
San Diego	907	1,646,181	2,359	541,241	2,187,422	3,266	229	1,815	8
Atlanta	2,119	1,482,878	16,741	1,873,347	3,356,225	18,860	112	700	6
Minneapolis-St. Paul	2,470	1,378,028	25,790	628,514	2,006,542	28,260	24	558	23
Denver	1,397	1,238,270	7,225	449,862	1,688,132	8,622	62	886	14
Cleveland	1,527	1,180,484	12,438	943,042	2,123,526	13,965	76	773	10
St. Louis	1,930	1,173,411	14,128	723,077	1,896,488	16,058	51	608	12
Seattle	1,375	1,094,569	8,984	997,220	2,091,789	10,359	111	796	7
El Paso	572	1,074,367	2,269	171,841	1,246,208	2,841	76	1,878	25
San Antonio	905	858,794	6,720	583,086	1,441,880	7,625	87	949	11
Las Vegas	744	855,447	2,669	111,235	966,682	3,413	42	1,150	28
Orlando	1,256	832,389	10,401	1,126,446	1,958,835	11,657	108	663	6
Sacramento	723	754,018	6,213	621,201	1,375,219	6,936	100	1,043	10
Kansas City	1,290	748,418	10,239	573,373	1,321,791	11,529	56	580	10
St. Petersburg	850	739,454	3,922	494,657	1,234,111	4,772	126	870	7
Milwaukee	1,130	737,248	16,435	484,727	1,221,975	17,565	29	652	22
Portland	874	718,111	5,850	624,159	1,342,270	6,724	107	822	8
New Orleans	624	706,159	9,679	709,583	1,415,742	10,303	73	1,132	15
Indianapolis	1,317	697,775	18,494	673,913	1,371,688	19,811	36	530	15
Columbus (OH)	859	669,368	13,458	648,093	1,317,461	14,317	48	779	16
Cincinnati	938	668,061	9,168	632,654	1,300,715	10,106	69	712	10
Memphis	869	549,916	8,166	444,341	994,257	9,035	54	633	12
Tampa	637	516,387	4,121	434,104	950,491	4,758	105	811	8
Norfolk	602	508,661	3,505	465,231	973,892	4,107	133	845	6
Salt Lake City	588	503,984	6,277	478,635	982,619	6,865	76	857	11
Buffalo	630	487,221	10,044	535,930	1,023,151	10,674	53	773	14
Louisville (KY)	729	471,376	11,267	619,255	1,090,631	11,996	55	647	12
Nashville	1,005	433,648	14,195	647,703	1,081,351	15,200	46	431	9
Providence	502	415,876	5,559	583,961	999,837	6,061	105	828	8
Oklahoma City	736	412,966	8,048	424,786	837,752	8,784	53	561	11
Omaha	573	384,682	6,584	225,102	609,784	7,157	34	671	20
New Haven	501	376,065	9,464	1,095,397	1,471,462	9,965	116	751	6
Jacksonville	577	373,287	6,751	642,031	1,015,318	7,328	95	647	7
Charlotte	620	357,651	15,533	1,457,915	1,815,566	16,153	94	577	6
Birmingham	675	352,683	10,055	668,578	1,021,261	10,730	66	522	8
Dayton	587	345,293	10,186	476,234	821,527	10,773	47	588	13
Youngstown	502	227,605	15,423	1,159,728	1,387,333	15,925	75	453	6

Conclusion

Historically populations have commonly been characterized as urban or rural. Changing urban form in the United States since World War Two has suggested that perhaps population should be characterized as urban, suburban, and rural. Changes in planning policy driven by concerns of urban sprawl have increased the density of recent suburban developments in many areas. This paper explores the idea of categorizing the lands and populations of the conterminous United States as urban, exurban, and rural. Nighttime satellite imagery provided by the DMSP OLS is used to classify the land of the conterminous United States as urban, exurban, and rural. Well lit areas are characterized as urban, areas of low light as exurban, and dark areas as rural. In the southwest corner of Denver this classification scheme separated housing with wells and septic tanks (exurban) from housing with municipal water and sewerage (urban). This urban classification includes most of the areas of Denver that would be classified as suburban. We feel that the distinction between urban and exurban is more pronounced than the distinction between urban and suburban and suggest the urban, exurban, rural classification scheme for characterizing the populations and land use of industrialized nations. For the conterminous United States 55% of the population lived in urban areas (1.7% of the land), 37% of the population lived in exurban areas (14% of the land), and 8% of the population lived in rural areas (84% of the land). The social, economic, environmental, and institutional challenges created by these exurban areas are significant and justify a this new classification scheme.

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