Urban Sprawl GIS Analysis

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Created for GEOL 340: Images of the Earth at Guilford College.

Urban Sprawl is an increasingly complex and relevant issue to governments and citizens in the U.S. It is also, at it's core, a spatially-oriented issue, and visual representation has played a key role in raising awareness of the severity of the problem. When most people think of sprawl, they are reminded of the striking images of suburbs stretching out as far as the eye can see—not necessarily of the environmental and social impacts. As such, data visualization through a Geographic Information System can be a powerful tool for demonstrating the extent and effects of sprawl.

Furthermore, as sprawl is a spatial issue, representation of spatial data is important for determining the effectiveness of solutions. I explored the way smart growth solutions such as the urban growth boundary alter the look of the landscape, and quantified this using the Normalized Difference Vegetation Index (NDVI).

Background

Urban sprawl is an issue close to home for many Americans. Cities in the U.S. have been consistently expanding into the suburbs through the last century, requiring more expansive road and infrastructure systems, loss of agricultural land and open space, and construction of new homes rather than re-use of old buildings. Furthermore, expansion away from the city center into the suburbs facilitates an increased reliance on cars for transportation and economic segregation between different living communities. Figure 1 shows examples of these problems in Los Angeles, CA and Phoenix, AZ, cities known for massive sprawl, reliance on cars, and a lack of open, "green" space.[1,2]

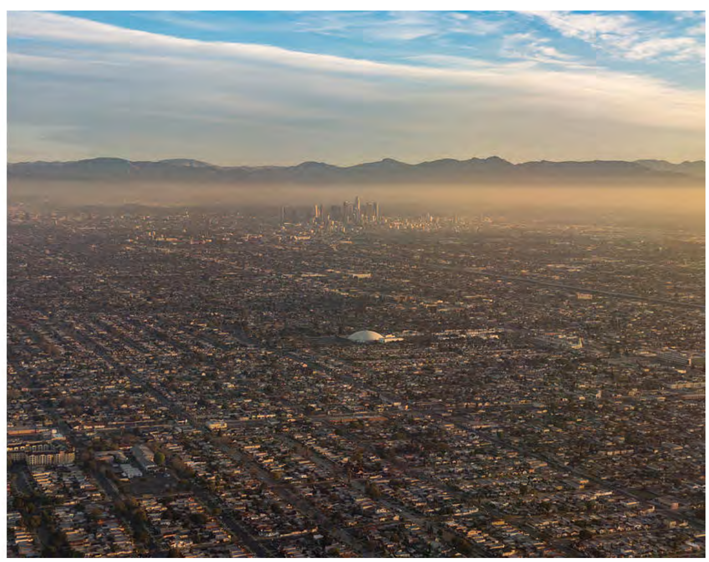

Figure 1: Aerial photos of Phoenix, AZ (left) and Los Angeles, CA (right)

In researching solutions, I looked particularly at smart growth—a set of guidelines published and maintained by the EPA to facilitate environmentally sustainable, safe, and cost effective urban development.[3] The goal of smart growth policies are numerous, but are primarily centered around concentrating development in the existing urban center, mixing land uses, and allowing for easy transportation by bike or foot. Smart growth policies emphasize building neighborhoods with walkable destinations, public spaces, and a feeling of community. They also typically attempt to address the environmental and public health issues associated with sprawl, such as the lack of green space and reliance on cars.[1]

[1] Reliance on cars is a direct result of sprawl—the further away the suburbs get, the longer commute times people have. In working to develop mixed-use communities within the urban center, smart growth developers are simultaneously working to build a sense of place in their town and reduce pollution and its associated public health issues.

I looked particularly at one of the many smart growth tools used by governments: urban growth boundaries, or UGBs, first implemented in Europe in the 1930's and in the United States in the 1950's. The idea behind a UGB is fairly simple—the regional planning government determines and regularly re-evaluates a boundary that defines what land can be used for urban development and what is protected from it. This allows a city to control where and how the city develops, as well as plan ahead and define certain areas as areas of potential development in the decades to come. However, UGBs have been criticized for increasing housing prices within the city, forcing people to live in a nearby city and commute through the rural areas surrounding the main city.

Only a few major cities in the U.S. have implemented urban growth boundaries, including Seattle, WA, Honolulu, HI, Lexington, KY, and Portland, OR—the city that I have focused my analysis on. Portland's UGB has existed since 1970, although expanded several times since then. Portland is known by many for its radical planning policies, and residents know how quick the change from urban to rural is along the edge of the city. I chose to explore this concept more thoroughly, and quantify how Portland's landscape changes across the UGB. Furthermore, I chose to use Portland as a model and evaluate how (and if) other cities could implement similar boundaries.

Data

Beginning this project, I knew I wanted to demonstrate the extent of urban sprawl by showing change over time. One of the most obvious indicators of urban sprawl is the increasing population density in areas along the edge of the city. I used data from the National Historical Geographic Information System (NHGIS) to map population density at the census tract level, for individual states.[4] On the NHGIS site, I found compiled census data from 1970 to 2010, as well as census tract shapefiles that could be easily joined.

Additionally, I wanted to use satellite imagery to visualize and quantify the landscape across several cities. I used the USGS Earth Explorer tool to acquire images from Landsat, a long running, relatively high-resolution satellite network with publicly available data.[5] Most of the Landsat data I used were from Landsat 8, an 11-band satellite capturing light ranging from 433 to 1250 nm.

Analysis

Visualizing Sprawl

Using data from the NHGIS, I mapped demographic factors at the census tract level for Los Angeles, San Francisco, Houston, Dallas, and Phoenix, on 10-year intervals from 1970 to 2010. Not all of these maps are included here, as many of them show similar patterns; however, there are many other cities that might show indicators of extensive urban sprawl. These maps are intended to represent the scale and pace of urban sprawl in the U.S., as many cities have seen substantial growth in suburban areas in the past 40 years.[2]

[2] An interesting example of this: in 1970, there were so few people and such little development in much of Arizona that the NHGIS census tract shapefile does not include many regions of the state. These desert areas simply show up as empty, and a map of the Arizona census tracts only shows clusters around the cities. By 2010, the census showed significant suburban populations in these areas, as the city of Phoenix had expanded so rapidly.

Figure 2 shows the population density of Houston, TX and its surrounding area from 1970 to 2010. The map demonstrates a case of low-density sprawl, as the density of the city center appears to decrease as people move out into the suburbs. These suburban areas have low population density relative to the more concentrated Houston of 1970. The diminishing density of the inner city is most evident between 1980 and 90, and the movement out to the suburbs is most evident between 1970 and 80. The map yields insight into how much land has been turned into suburb in the past 40 years.

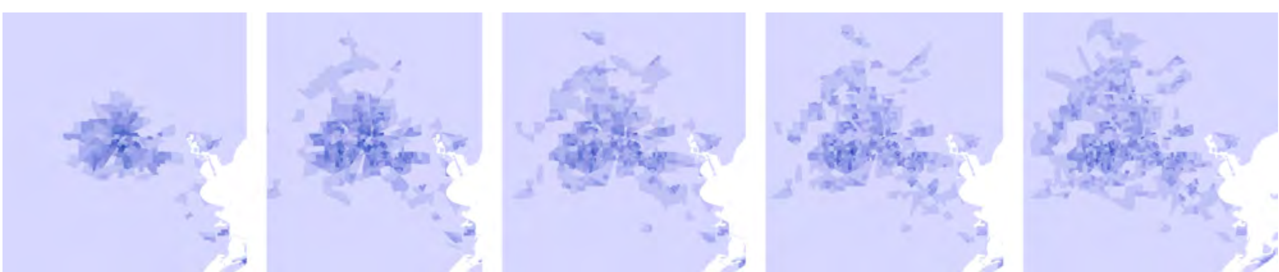

Figure 2: Population density of census tracts in Houston, TX, from 1970 (left) to 2010 (right), in ten year increments.

Figure 3 shows true-color satellite imagery of Phoenix, AZ, in 1987 and 2017, acquired from Landsat 5 and 8, respectively. Phoenix is known for suburban sprawl, characteristic of desert cities with few geographic boundaries restricting growth. The cartesian grid of suburban roads in Phoenix has been expanding rapidly for decades, and Figure 3 shows exactly that. Almost all of the farmland that existed outside of Phoenix in 1987 is now gone, replaced with suburban areas almost as large as Greensboro.[3]

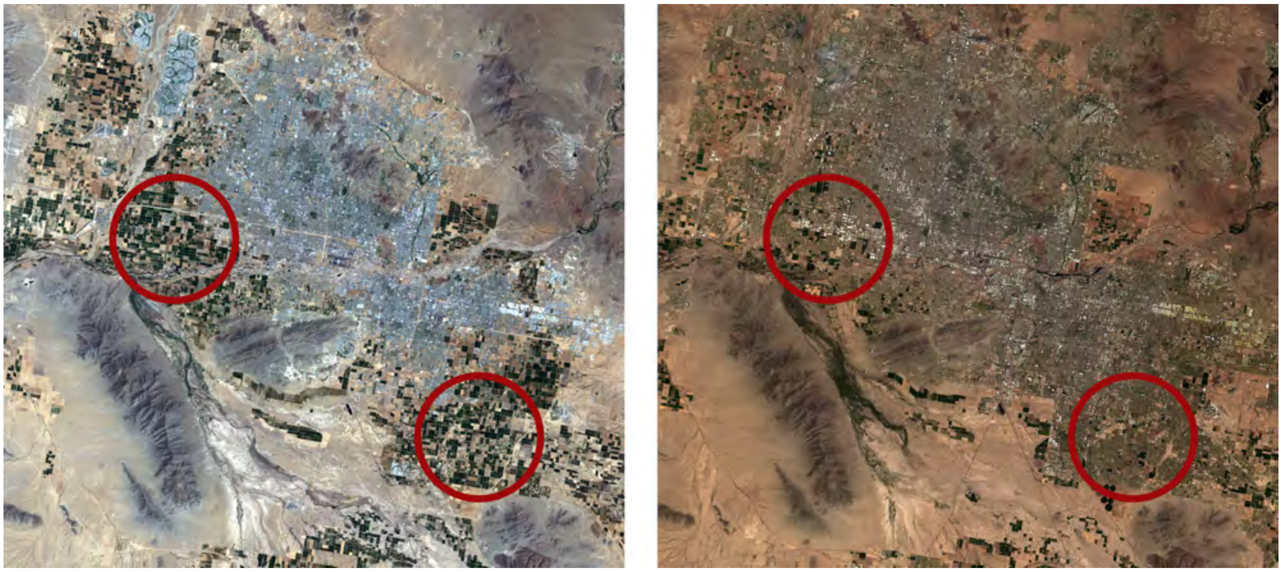

Figure 3: True-color satellite images of Phoenix, AZ, in 1987 (left) and 2017 (right). Specific areas that have undergone significant suburban development are circled in red. Data used to generate this image are from USGS Landsat 5 and 8.

Visualizing Smart Growth Solutions

In order to visualize the environmental and physical effectiveness of smart growth solutions such as UGBs, I returned census data and satellite imagery. Focusing my analysis on Portland, Oregon, I began by mapping population density at the census tract level, shown in Figure 4. Most of the population is contained within the urban growth boundary, as is to be expected.

Furthermore, Figure 5 shows a false-color infrared image of Portland, OR. The map reveals the border between urban and rural areas, as the landscape of the rural regions reflects more infrared light and thus appears brighter and redder.

Overlaid onto Figures 4 and 5 is a rough outline of Portland's UGB, last updated September 2016, which matches the infrared shading and population density closely.[6] Expanding on the insight, I used the Raster Calculator feature in Esri's ArcMap to generate Figure 7, the Normalized Difference Vegetation index for Portland, Oregon. The NDVI ranges from -1 to 1, with higher values representing healthier vegetation. I used the NDVI to quantify the "greenness" of the landscape, and in particular, how the "greenness" increased as I looked further away from the city. I did this by dividing the city region up into concentric, circular rings, centered on downtown, with equal distance between them. These rings for Portland are shown in

[3] In 2016, Greensboro, NC, had a population of 287k, and Chandler, AZ (the southeastern highlighted suburb of Phoenix) had a population of 247k.

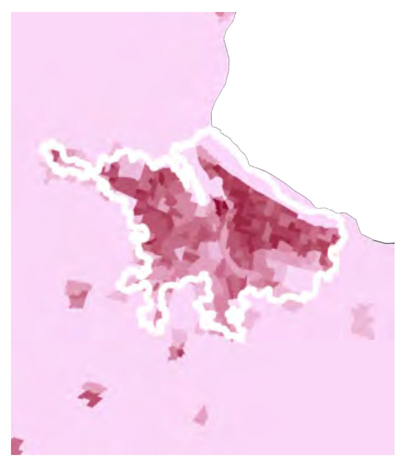

Figure 4: Population density in Portland, Oregon in 2010. The white boundary represents Portland's UGB, as of September 2016.

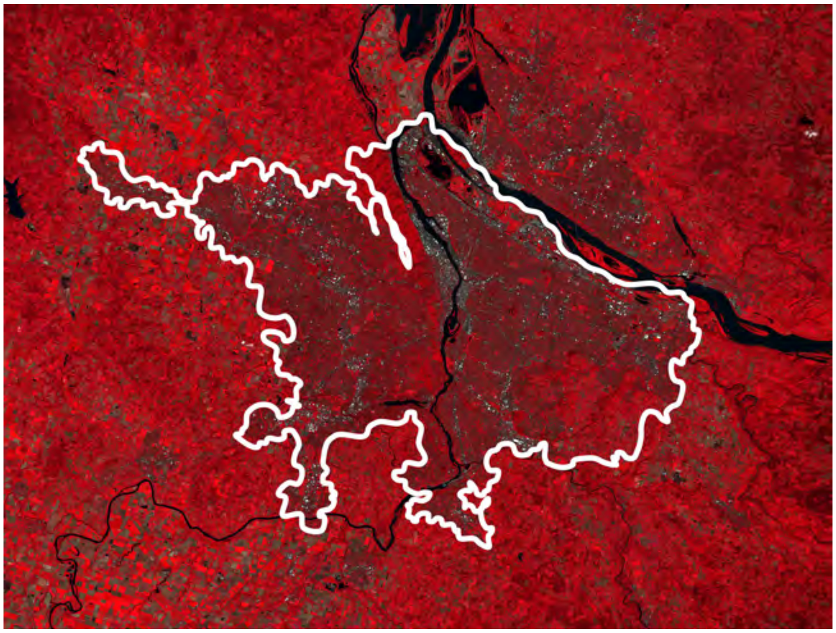

Figure 5: False-color infrared image of Portland, OR in 2017, overlaid with an outline of the city's UGB. The data used to generate this image are from USGS Landsat 8.

Figure 6: Portland, OR, divided into rings of equal thickness. These rings appear elliptical due to the conic projection used on the map; however, they in fact represent circular regions.

Figure 6, with each ring shaded a different color for ease of viewing. I was then able to calculate the mean NDVI value in each of these rings, to show the radial rate of change of the index. I plotted the mean NDVI in each ring in Figure 10 *a*.

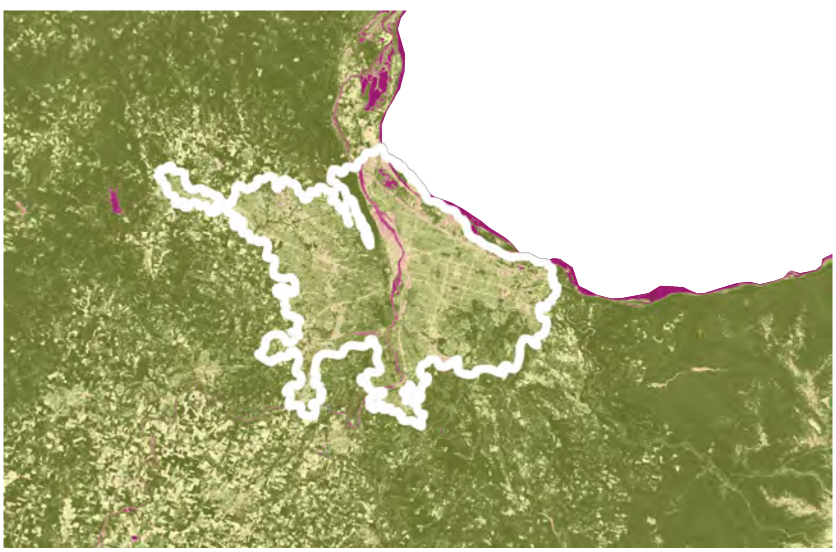

Figure 7: Normalized Difference Vegetation Index (NDVI) for Portland, OR in 2017. Higher index values are displayed as green, lower index values are displayed as purple.

Next, I wanted to use Portland as a model to determine the ideal location for implementing a UGB in another city. I chose to test Greensboro, NC, by using the same process to graph the radial change in NDVI and determine how far from the city center the boundary should fall. I began by mapping the NDVI for Greensboro and the surrounding area, including nearby cities like Winston-Salem, High Point, and Burlington as well. This map is shown in Figure 9. I then repeated the process of dividing the region into rings, shown in Figure 8.

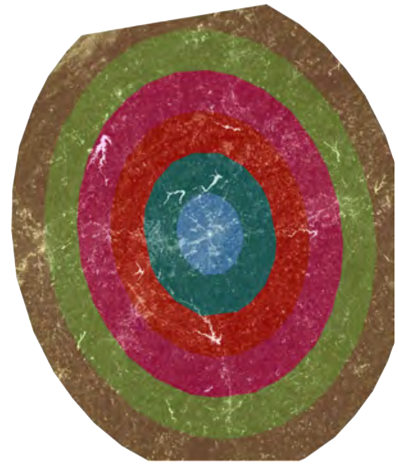

Figure 8: Greensboro, NC, divided into rings of equal thickness.

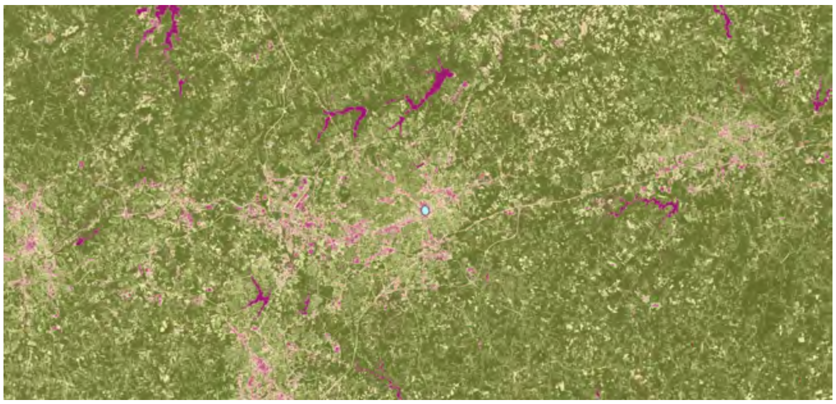

Figure 9: Normalized Difference Vegetation Index for Greensboro, NC in 2017.

A plot of the Mean NDVI for Greensboro, NC is shown in Figure 10 *b*.

Conclusions

The graph of Portland's NDVI shows the steepest increase in the vegetation index between rings 2 and 3. Figure 6 shows that most of the UGB falls roughly between these two rings, confirming that the fastest increase in "greenness" of the city would occur roughly at the boundary.

This method can be applied to other cities as well, to determine where an urban growth boundary should fall. Although this would work better for cities that are only beginning to grow and develop, it is interesting to apply it to already established cities. Extending this concept to Greensboro, I determined that if the city were to implement a UGB of some sort, it would likely need to be between rings 1 and 2 as defined in Figure 8, where the steepest increase in the NDVI occurs. It is also interesting to note the very small increase in NDVI between rings 2 and 3 for Greensboro, likely a result of the nearby cities in the region. Figure 11 shows an ultra-simplified UGB for Greensboro, based on the location of the steepest increase in NDVI. This boundary encompasses most of the developed parts of the city, but there are still substantial suburban communities outside of the boundary.

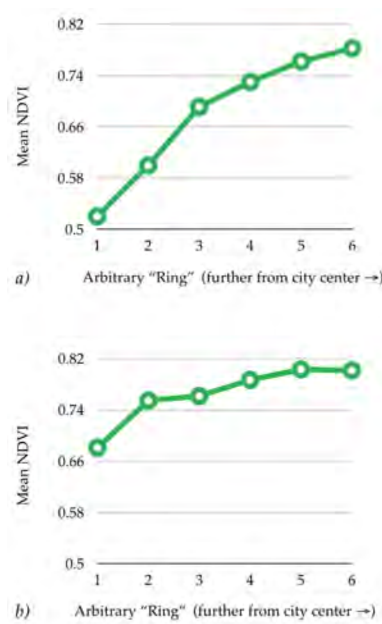

Figure 10: Plot of mean NDVI vs radial distance for *a)* Portland, OR and *b)* Greensboro, NC.

Future Work

Although this analysis reveals some interesting characteristics of smart growth cities, it could be expanded upon greatly by decreasing the thickness of the rings to get a more precise measurement, including direction in the measurement as well, and applying the method to cities that have not yet begun to grow. There are many cities that are likely to begin sprawling soon, and applying this method to determine the proper location for a UGB would be useful in implementing smart growth solutions before sprawl begins.

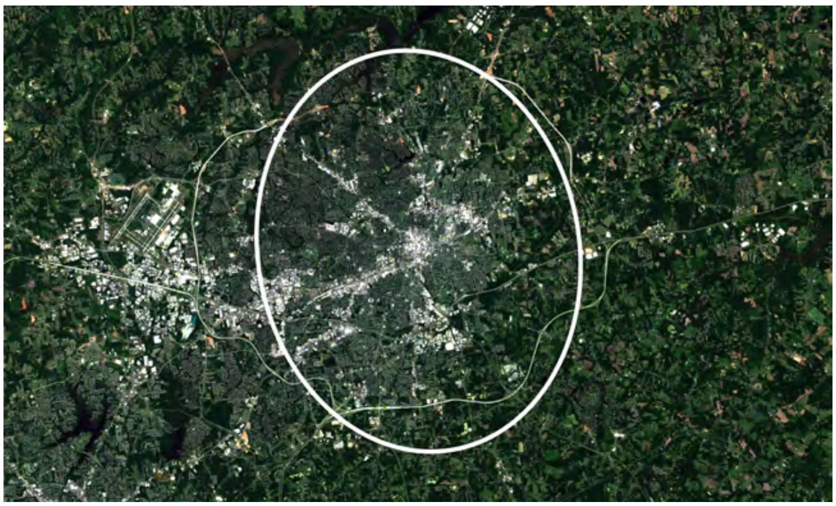

Figure 11: Simplified, potential UGB for Greensboro, NC based off the characteristics of Portland's UGB. Most of the core urban centers are within the boundary, although extensive suburban areas and the airport are outside the boundary.

Notes

[1]Mizuleva, Georgia. "The Impressive City Of Angels." *Fine Art America*, 25 Dec. 2015, fineartamerica.com/featured/the-impressive-city-of-angels-los-angeles-california-u-s-a-urban-sprawl-and-smog-georgia-mizuleva.html.

[2]O'Beirne, Greg. "Gallery of Urban Sprawl in the US." *ArchDaily*, www.archdaily.com/500409/urban-sprawl-in-the-us-the-10-worst-offenders/535a63a0c07a800482000073-urban-sprawl-in-the-us-the-10-worst-offenders-photo.

[3]"This is Smart Growth." *EPA.gov*, Smart Growth Network, April 2014, www.epa.gov/sites/production/files/2014-04/documents/this-is-smart-growth.pdf

[4]Steven Manson, Jonathan Schroeder, David Van Riper, and Steven Ruggles. *IPUMS National Historical Geographic Information System: Version 12.0* [Database]. Minneapolis: University of Minnesota. 2017. http://doi.org/10.18128/D050.V12.0

[5]"Earth Explorer." *US Geological Survey*, www.earthexplorer.usgs.gov/

[6]"Urban Growth Boundary." *Oregon Metro*, 2 September 2016. www.oregonmetro.gov/urban-growth-boundary