The University of Texas at Austin

Department of Environmental and Water Resources Engineering

Changes in Land Cover in US Cities over Time

CE 394K.3 GIS in Water Resources

Author:
Maarten Kroll (mk38583)
maarten.kroll@utexas.edu

Course Instructors:
Dr. David R. Maidment (UT Austin)
Dr. David G. Tarboton (USU Logan)

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1 Introduction

Cities all around the world expand and decrease over time. Most often this is due to economic prosperity or loss that people come and leave. However, over the last couple of decades, urbanization has increased rapidly and in the meantime, 55 % of the world population lives in cities and the expectations are that this will increase even more in the near future [1].

With that, changes in land use are inevitable as cities expand. Although the largest growth is expected to take place in east Asia, the African continent and countries in South America, growth in cities across the (continental) United States is a given fact.

The financial crisis back in 2008 had a massive impact on the US economy and cities like Detroit started to see a decrease in population. Nevertheless, cities across the country saw increases in population.

This report provides the results of a research that has been done to changes in population and land cover of ten cities across the country:

- Austin
- Chicago
- Dallas
- Detroit
- Houston
- Los Angeles
- Miami
- New York
- San Francisco
- Seattle

This selection is based on the fact to investigate land cover in cities divided into four categories: the Atlantic coast, the midwest, Texas and the Pacific coast. These can possibly give a good idea about how these places have developed over time.

Section 2 provides an overview of all the data that has been used, whereas section 3 shows the procedures that need to be executed in order to get the results. Section 4 provides the results for all 10 cities and divides them into subcategories as well. Section 5 comes with a couple of conclusions and recommendations.

Within the report, all steps will be based on San Francisco. Data for all other cities can be found in appendices A and B.

2 Getting the Required Data

The following data is necessary for this research:

- Map of US Counties
- NLCD Database of 2001, 2006, 2011
- Imperviousness Developed Area Maps

[1] `https://www.un.org/development/desa/publications/2018-revision-of-world-urbanization-prospects.html`

2.1 US Counties

The map of the US counties can be seen in figure 1. Its corresponding coordinate system is the NAD 1983 Contiguous USA Albers projection. It has been decided to use this coordinate system for all other data that needs to be used.

Figure 2 presents the counties in which the cities, mentioned in section 1 are located. Table 1 presents the corresponding counties.

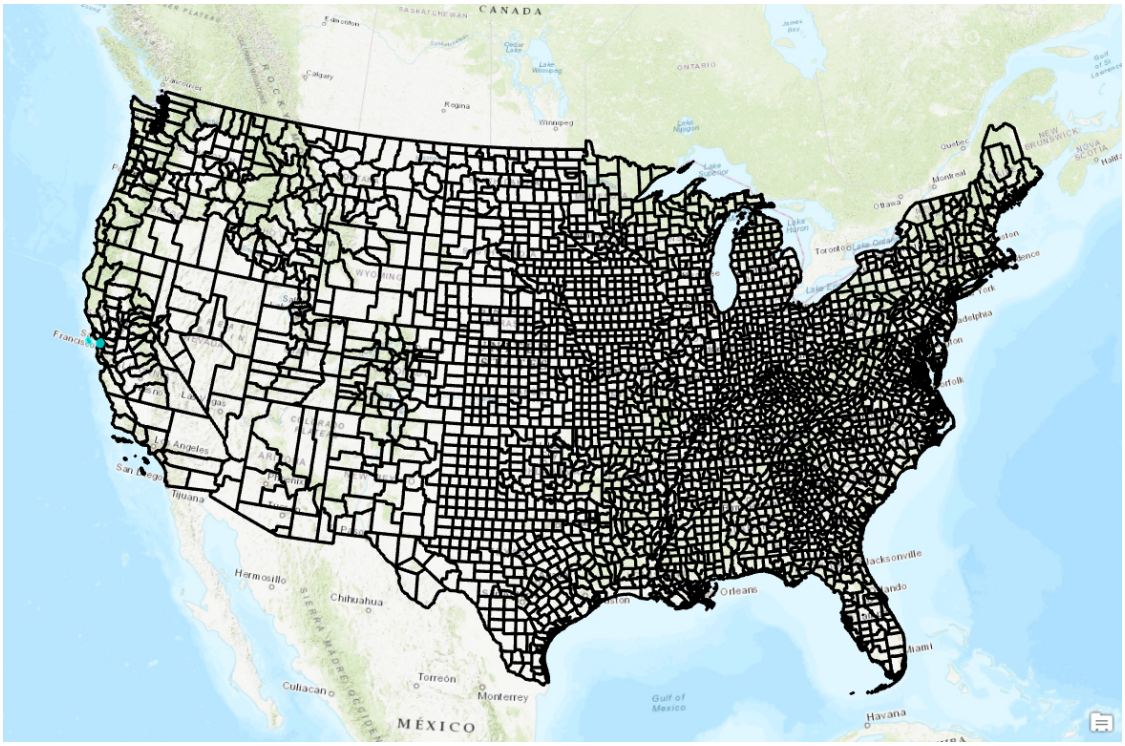

Figure 1: US County Map

2.2 NLCD Database

The NLCD Data of 2006 and 2011 can be obtained from the Living Atlas. The data of 2001 can be obtained from the NLCD website [2].

The land cover of 2011 is presented in figure 3. Note that the corresponding counties of figure 2 are presented as well.

2.3 Imperviousness Data

This data provides density of developed area. Figure 4 presents the imperviousness map as of 2011.

[2] https://www.mrlc.gov/finddata.php

Figure 2: Chosen Counties

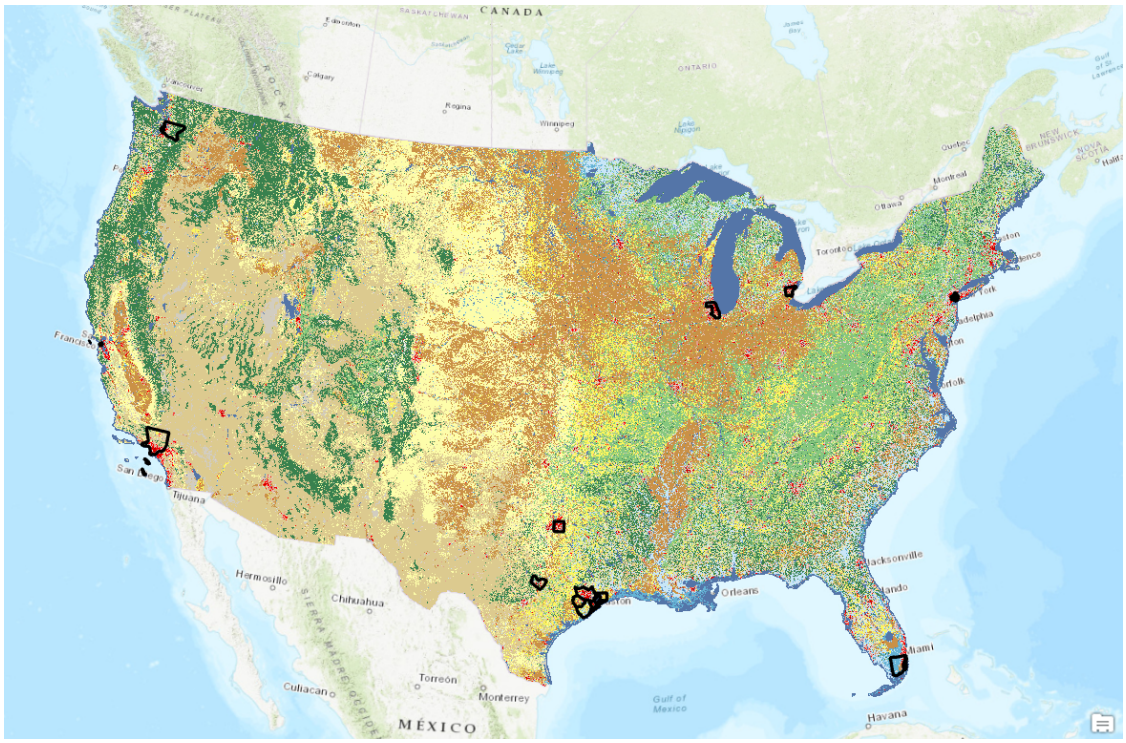

Figure 3: US Land Cover of 2011

City	County/Counties
Austin	Travis
Chicago	Cook
Dallas	Dallas
Detroit	Wayne
Houston	Brazoria, Chambers, Fort Bend, Galveston, Harris
Los Angeles	Los Angeles
Miami	Miami Dade
New York	The Bronx, Brooklyn, Hudson (NJ), Manhattan, Queens
San Francisco	San Francisco
Seattle	King

Table 1: Corresponding Counties

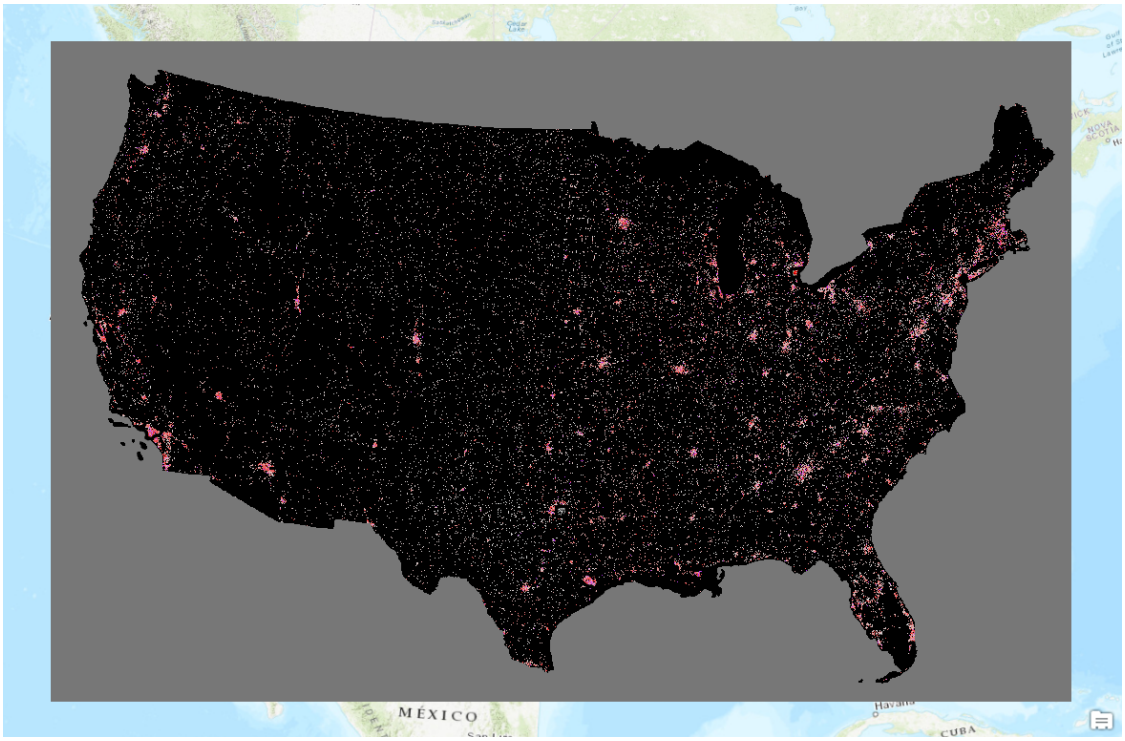

Figure 4: US Imperviousness map of 2011

3 Procedure

This section is all about how data for the various cities mentioned in section 1 and 2 is used and implemented. All calculations and conclusions in this section will only be done for San Francisco. For all other cities, please refer to the appendices starting on page 16 (however for conclusions and interesting remarks for other cities, please refer to section 5 as well).

3.1 NLCD Data

First, the land cover datasets for 2001, 2006 and 2011 have been extracted for the corresponding counties. Figures 5, 6 and 7 show the land cover of 2001, 2006 and 2011 for San Francisco respectively.

By downloading the Attribute Tables of the datasets and combining the various parts that are developed, a graph can be made that shows how the percentage of developed area relates to the changes in population.

The Attribute Table for 2001 is shown in table 2 (more information about the yellow marked numbers can be found in section 3.1.1) and the sorted categories can be found in table 3. The corresponding graph for the percentage of developed area versus population can be seen in figure 8. For land cover of all other cities, please refer to Appendix A.

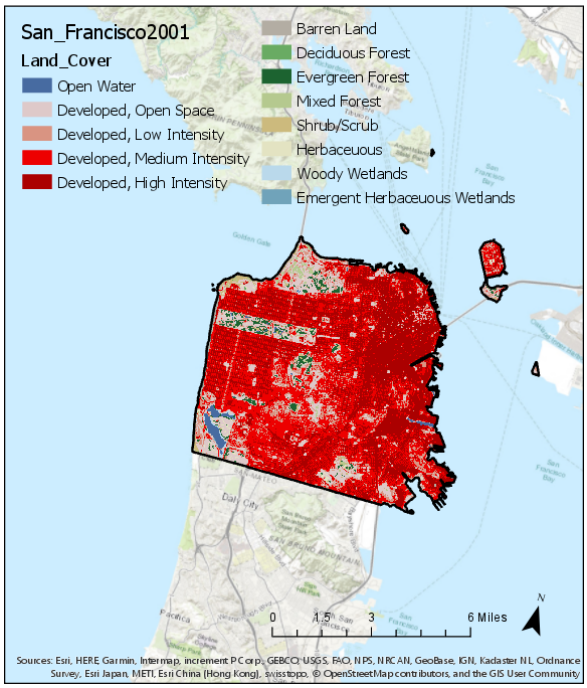

Figure 5: San Francisco Land Cover 2001

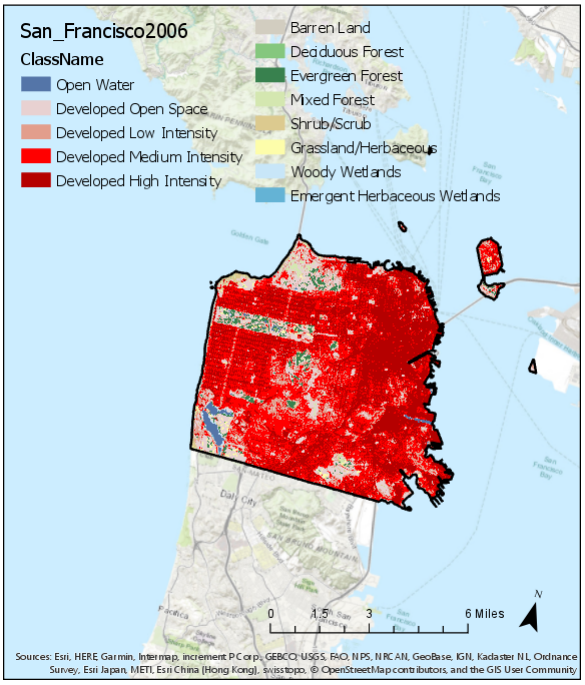

Figure 6: San Francisco Land Cover 2006

3.1.1 Some Notable Issues

Something striking that has been observed is the fact that the surface areas for de NLCD databases of 2001 are different compared to those of 2006 and 2011. This can be seen when having a look at the total counts of cells and surface areas of tables 2, 4 and 5 (the yellow marked numbers), showing the data for 2001, 2006 and 2011 respectively. The surface area somehow increased massively between 2001 and 2006, and then remained about equal through 2011.

This of course does not make sense at all. According to the US census bureau, the surface of San Francisco County is equal to 122.70 km^2 [3]. This holds for all investigated counties in this research. It is unclear why the NLCD data for 2006 and 2011 provides different numbers.

[3] `https://www.census.gov/support/USACdata.html`

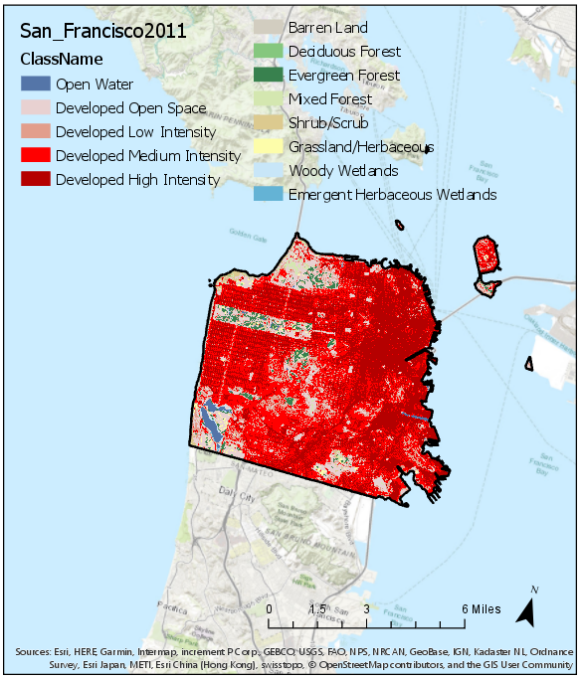

Figure 7: San Francisco Land Cover 2011

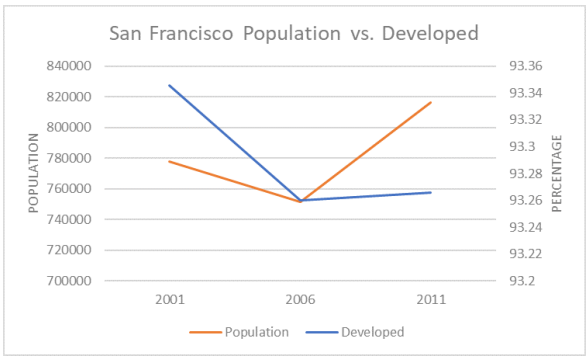

Figure 8: San Francisco

Cell size (m^2)	Land Cover	Count	Surface (m^2)	Surface (km^2)	Percentage
900	Open Water	1993	1793700	1.7937	1.46
900	Perennial Snow/Ice	0	0	0	0
900	Developed, Open Space	14983	13403700	13.4037	10.92
900	Developed, Low Intensity	15887	14298300	14.2983	11.65
900	Developed, Medium Intensity	48479	43631100	43.6311	35.55
900	Developed, High Intensity	48034	43230600	43.2306	35.22
900	Barren Land	721	648900	0.6486	0.53
900	Deciduous Forest	15	13500	0.0135	0.01
900	Evergreen Forest	2929	2636100	2.6361	2.15
900	Mixed Forest	918	826200	0.8262	0.67
900	Shrub/Srub	1245	1120500	1.1205	0.91
900	Herbaceous	964	867600	0.8676	0.71
900	Hay/Pasture	0	0	0	0
900	Cultivated Crops	0	0	0	0
900	Woody Wetlands	266	239400	0.2394	0.19
900	Emergent Herbaceous Wetlands	23	20700	0.0207	0.02
		136367	122730300	122.7303	100

Table 2: San Francisco Land Cover 2001

Land Cover	Percentage
Water	1.46
Developed	93.34
Barren	0.53
Forest	2.83
Shrubland	0.91
Herbaceous	0.71
Cultivated	0
Wetland	0.21

Table 3: San Francisco Land Cover 2001 Sorted

This is why it has been decided to make use of the percentage values of the various land cover parameters. These numbers seem to make more sense, however they unfortunately do not present the exact right numbers. There is a chance that this data eventually might be contradictory with the imperviousness data (section 3.2 and Appendix B).

Cell size (m^2)	Land Cover	Count	Surface (m^2)	Surface (km^2)	Percentage
900	Open Water	3384	3045600	3.0456	1.55
900	Perennial Snow/Ice	0	0	0	0
900	Developed, Open Space	22622	20359800	20.3598	10.36
900	Developed, Low Intensity	23804	21423600	21.4236	10.90
900	Developed, Medium Intensity	78699	70829100	70.8291	36.03
900	Developed, High Intensity	78591	70731900	70.7319	35.98
900	Barren Land	1321	1188900	1.1889	0.60
900	Deciduous Forest	22	19800	0.0198	0.01
900	Evergreen Forest	4725	4252500	4.2525	2.16
900	Mixed Forest	1472	1324800	1.2348	0.67
900	Shrub/Srub	1965	1768500	1.7865	0.90
900	Herbaceous	1352	1216800	1.2168	0.62
900	Hay/Pasture	0	0	0	0
900	Cultivated Crops	0	0	0	0
900	Woody Wetlands	412	370800	0.3708	0.19
900	Emergent Herbaceous Wetlands	69	62100	0.0621	0.03
		218438	196594200	196.5942	100

Table 4: San Francisco Land Cover 2006

Cell size (m^2)	Land Cover	Count	Surface (m^2)	Surface (km^2)	Percentage
900	Open Water	3402	3061800	3.0618	1.56
900	Perennial Snow/Ice	0	0	0	0
900	Developed, Open Space	22038	19834200	19.8342	10.08
900	Developed, Low Intensity	23122	20809800	20.8098	10.58
900	Developed, Medium Intensity	79346	71411400	71.4114	36.20
900	Developed, High Intensity	79342	71407800	71.4078	36.30
900	Barren Land	1301	1170900	1.1709	0.60
900	Deciduous Forest	25	22500	0.0225	0.01
900	Evergreen Forest	4751	4275900	4.2759	2.17
900	Mixed Forest	1465	1318500	1.3185	0.67
900	Shrub/Srub	1967	1770300	1.7703	0.90
900	Herbaceous	1332	1198800	1.1988	0.61
900	Hay/Pasture	0	0	0	0
900	Cultivated Crops	0	0	0	0
900	Woody Wetlands	408	367200	0.3672	0.19
900	Emergent Herbaceous Wetlands	67	60300	0.0603	0.03
		218566	196709400	196.7094	100

Table 5: San Francisco Land Cover 2011

3.2 Imperviousness Data

The land cover data gives a good first impression of how developed a city is. However, since the data is extracted over counties, the percentage developed area is lower in counties like Travis County, Austin (figures 14 to 16), King County, Seattle (figures 46 to 49) and Miami Dade County, Miami (figures 38 to 41), compared to San Francisco County or Wayne County, Detroit (figures 26 to 29).

By downloading the imperviousness data, the density of developed area can be viewed better. Also for counties where its biggest part is not the corresponding city itself. The results for San Francisco can be seen in figures 9 to 11. The lighter the color, the more intense the developed area is.

The maps for all other cities however, are not provided in this report. It turns out that it is even better to use maps in which the change in imperviousness is projected. More details about these maps can be found in section 3.2.1.

3.2.1 Imperviousness Change

Another way to look how this has changed over time is by using maps that show the change of imperviousness over time. This data is available. The results for San Francisco can be seen in figures 12 and 13.

The data should be implemented as follows: the lighter the color, the larger the change (i.e. increase) in percentage developed area has occurred over time. When the area has a dark color, it indicates the area hardly hasn't changed over time.

These maps are a good indicator of how San Francisco develops over time. Besides it is easier to see which areas within the city boundaries keep on developing and which areas don't.

It has been difficult to get exact details about the changes in imperviousness for all cities.

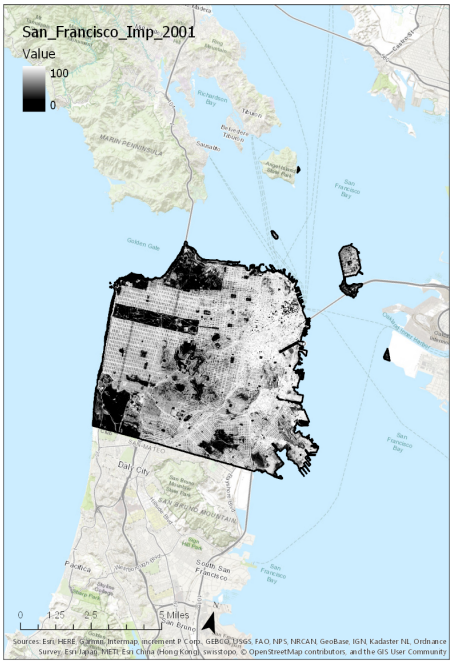

Figure 9: San Francisco Imperviousness 2001

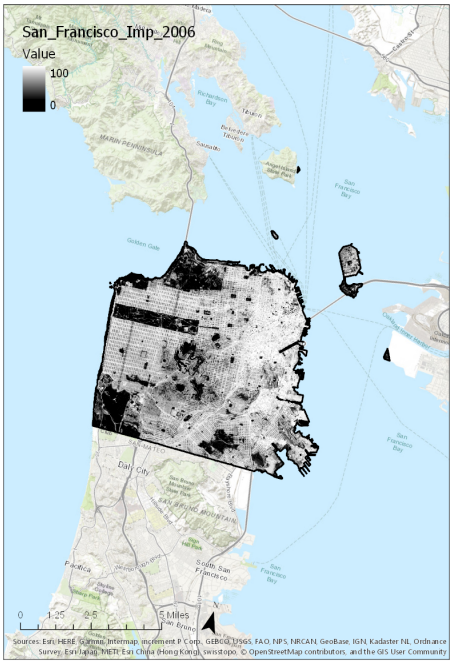

Figure 10: San Francisco Imperviousness 2006

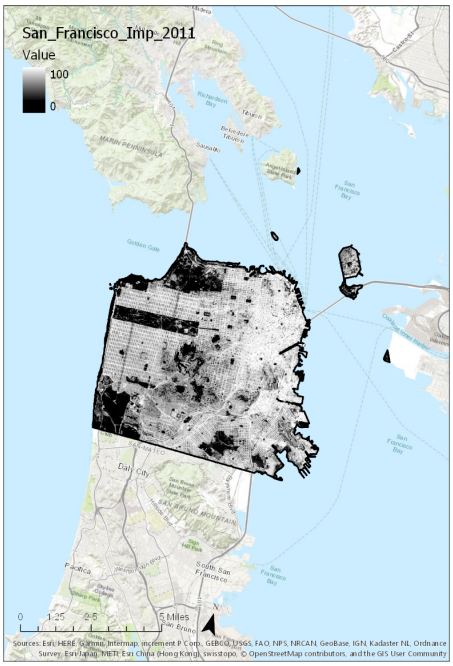

Figure 11: San Francisco Imperviousness 2011

This is because only values from 0 to 100 (these indicate how impervious the area is, 0 means no change, 100 means a maximum change) are provided. And this is not even the same for all places. Therefore it has been decided to determine the cities' changes based on the provided maps.

Even though this is less exact than determining the changes via numbers, it is still possible to make some conclusions on these maps. For all cities other than San Francisco, the maps of the imperviousness changes for the periods of 2001-2006 and 2006-2011 can be found in Appendix B.

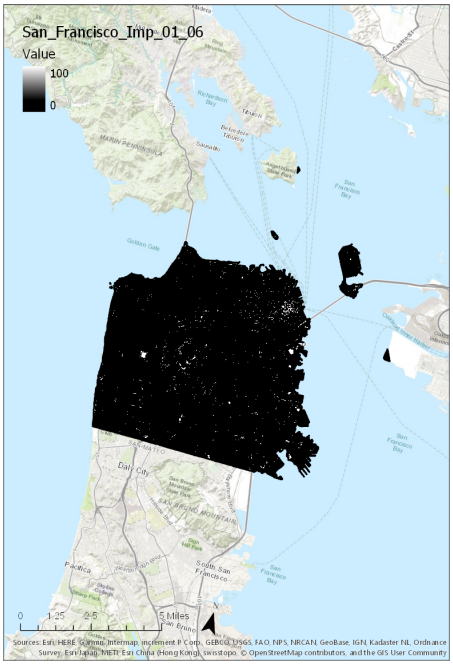

Figure 12: San Francisco Imperviousness Change '01/'06

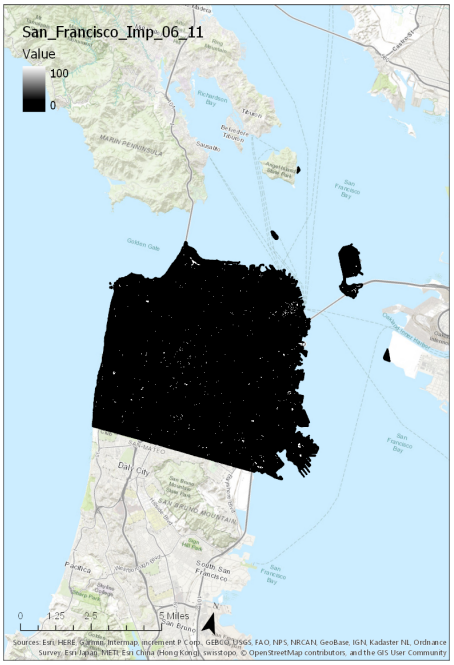

Figure 13: San Francisco Imperviousness Change '06/'11

4 Results

This section will be divided into two analysis. First each city will be analyzed individually (section 4.1). The evaluation will be done in alphabetical order, apart from San Francisco. This city will be analyzed first, because it is used as an example in this report. Other than that every other city will be analyzed in alphabetical order.

In the second analysis (section 4.2), the cities will be grouped in the following regions:

1. Atlantic Coast
2. Midwest
1. Texas
2. Pacific Coast

For all other cities other than San Francisco, the analyzed figures can be found in appendices A and B.

4.1 Individual Analysis

4.1.1 San Francisco

Since San Francisco is located on a peninsula, there is very little growth possible within the city boundaries. Within the city boundaries itself nearly everything is developed, apart from Golden Gate Park, areas close to the Golden Gate Bridge and Lake Merced Park. From figures 5 to 7 it is difficult to give a conclusion about increase or decrease in developed area. When one however has a look at the graph in figure 8, remarkably a decrease in percentage developed area can observed between 2001 and 2006.

This however, seems contradictory with figure 12. Since there are white dots all over the city, this should mean an increase in percentage developed area. A possible reason could be because of the fact that the NLCD data of 2006 and 2011 give different values for the total surface of all analyzed counties (section 3.1.1). It is very likely that more of these contradictory results will be observed for all other cities.

4.1.2 Austin

Austin is located in Travis County. Travis exceeds the Austin city limits and therefore shows more green within the maps presented in figures 14 to 16. The city and major roads are clearly visible. Other than San Francisco, these figures clearly show an increase in developed area, which is also confirmed in figure 17. The maps also show how the old Austin Robert Mueller Municipal Airport has transformed in the residential area Mueller.

Figures 50 and 51 show that the percentage of developed area has increased almost everywhere. Interesting to mention is the construction of the north part of highway 130 between 2001 and 2006 and the south part between 2006 and 2011.

4.1.3 Chicago

For this research, only Cook County has been analyzed. However, other than San Francisco, Chicago is not bounded by its county limits, nor it is located on a peninsula. Figures 18 to 20 show that almost everything of the county is developed, either high intensity or another category. It's striking however to see that its population has decreased over time, whereas the percentage of developed area started to see an increase after 2006, according to figure 21.

This however seems to be in accordance with figures 52 and 53, which show minor increases in imperviousness over the time range 2001-2006 and 2006-2011.

4.1.4 Dallas

The maps in figures 22 to 24 are very interesting and colorful. Just as Austin, developed areas can be observed easily around major roads. It is even clear enough to loop roads along the city.

Different from Chicago is that the developed area only counts for about 60 %, even though most of the county seems to be developed. Figures 54 and 55 clearly show increases in imperviousness, which is in accordance with figure 25.

4.1.5 Detroit

Detroit is another city which seems to be bounded by its county limits. Most areas close to the Canadian border seem most developed. Please refer to figures 26 to 28. It is striking to see that the percentage of developed area has decreased, whereas the Detroit population decreased, as can be observed in figure 29.

When having a look at figures 56 and 57 it is interesting to see that the imperviousness has increased more in the time range 2001-2006 than in the time range 2006-2011. It is very likely that this is due to the economic crisis that hit the city severely.

4.1.6 Houston

For this research it has been decided to use multiple counties rather than just one (see section 2.1, table 1). Houston mostly consists of developed areas, wetlands and grass lands. This can be concluded from figures 30 to 32. This seems to be in accordance with figure 33. The percentage of developed area is about 30 %, which seems reasonable when looking at the provided maps. However a clear increase in both population and developed area can be noticed. This can also be concluded when observing figures 58 and 59. Mostly Harris County shows increases in imperviousness.

4.1.7 Los Angeles

Los Angeles County shows a clear line between what is developed and what is not developed (see figures 34 to 36). This is because the city is situated between the Pacific Ocean and the Angeles National Forest, a mountain range about 30 miles inland. So even though LA County is much larger than the LA city limits, the city is still somehow bounded, just as San Francisco.

Nevertheless figure 37 shows a steady increase in both population and percentage of developed area. This is in accordance with figures 60 and 61. Interestingly enough, most of this increase increase in imperviousness seems to happen behind the Angeles National Forest mountain range. This could be a sign that the LA metropolitan area is likely to increase even more in the future.

4.1.8 Miami

The city of Miami is located (mostly) within Miami Dade County (section 2.1, table 1), which is much larger than the city itself. When looking at figures 38 to 40 the majority of the county

consists of wetlands. These wetlands are Everglades National Park. According to figure 41 Miami Dade County is developed for about 20 %. The maps seem to give a higher value for that however.

Figures 62 and 63 show that most of the increase in imperviousness seems to take place within the Miami city limits and its suburbs. Just as San Francisco and Los Angeles, Miami seems to be bounded by the wetlands. Different from Los Angeles County, is that it seems that Miami really is restricted to its current city limits and is not able to increase much further within its current boundaries.

4.1.9 New York

As mentioned in section 2.1, table 1, not all New York counties are analyzed in here. When looking at figures 42 to 44 the city looks bounded within its current county boundary limits. Nearly everything is colored red, indicating it is nearly all developed. A couple of exemptions are Central Park and wetlands around Jamaica Bay.

When just having a look at the three maps, it is difficult to conclude whether the developed areas have increased or decreased. According to figure 45, its percentage of developed area decreased between 2001 and 2006, but experienced an increase after that. Multiple explanations can be given for this trend. The same holds for its decrease in population between 2001 and 2006, but then again a sudden increase after that.

Figures 64 and 65 show that the imperviousness did increase during both time spans. Figure 64 seems contradictory with the graph in figure 45, because there are quite some white dots all over the city. Probably the same explanation could be used as is mentioned in section 4.1.1 (see section 3.1.1 for further clarification), where there is a discrepancy between the total surface areas of 2001 and 2006/2011.

4.1.10 Seattle

The maps provided in figures 46 to 48 are very colorful and show parts that are red (i.e. developed) and green (i.e. forest). King County is much larger than the Seattle city limits, so this means there should be plenty of room for further development. The graph in figure 49 confirms that. Within a span of 10 years, its percentage of developed area has increased from about 22.9 % to 23.55 % in 2011. Most of its developed area is around Puget Sound.

That's also the area where most of the increase in imperviousness has taken place, as can be observed from figures 66 and 67.

4.2 Categorical Analysis

Since the country is divided in a couple of regions when comparisons want to be made, it will be done for this research as well. As mentioned in the introduction in section 4, all cities will be divided over four regions in the country to see whether any links can be made between the cities in these regions and whether it can tell something about the general development in that area as well.

4.2.1 Atlantic Coast

Both Miami and New York are located in this (big) region. Whereas Miami saw increases in both population and percentage developed area over the span 2001-2011, New York witnessed both a decline in its population as well as its percentage of developed area between 2001 and 2006. Various reasons could be given for this, among which an increase in housing prices might be a reason for its population decline.

In general, it is difficult to give predictions for other Atlantic cities based on these results. However, a lot of places show increases in its population.

4.2.2 Midwest

Chicago and Detroit are located in this area. Both places show some interesting and similar results. When having a look at the graphs in figures 21 and 29, both places show an increase in percentage of developed area whereas it saw a decline in its population (although both increases in percentage of developed area are minor). For Chicago, this phenomenon occurred between 2006 and 2011, whereas for Detroit, this occurred between 2001 and 2011.

The decreases in population could be because of the economic crisis of 2008 and the fact that a lot of (car) industry moved to other places. The question however still is, if these results are a good prediction for more places in the Midwest region.

4.2.3 Texas

Texas is the only of the four investigated regions in which all cities (Austin, Dallas, Houston) show steady growth rates. All three cities show increases in both population and percentage of developed area. Especially Dallas shows big increases in both parameters. According to figure 25 its population almost doubled (!) between 2006 and 2011, whereas its percentage of developed area increased from about 61 % to about 65 %. Austin (Travis County) and Houston both show a steeper increase in its percentage of developed area (figures 17, 33) than their increase in population.

Nevertheless, the results seem to make sense and seem to be in accordance with the fact that overall the Texas population has increased in this period [4].

4.2.4 Pacific Coast

For this research only three places are located on the Pacific coast: Los Angeles, San Francisco and Seattle. Even though there are many more places located near the coast, these probably can give a fair prediction for the rest of the coast.

Both LA and Seattle show increases in both population and percentage of developed areas (figures 37, 49), whereas strangely enough San Francisco shows decreases in both parameters over the period 2001-2006. As mentioned in section 4.1.1, a couple of reasons could apply for this. One of them could be the reason that the city is bounded by its city and county limits. The other one is, again, the fact that the NCLD data provides different surface areas for 2001 and 2006, 2011 (as is mentioned in sections 4.1.1 and 4.1.9).

[4] http://worldpopulationreview.com/states/texas-population/

5 Conclusions and Recommendations

Based on the provided results it is fair to say that it gives a good first impression of how land cover changes over time. The NLCD data of 2001, 2006 and 2011 information that is detailed enough. Moreover, the NLCD website even provides legends for all parameters [5].

All population vs. percentage developed area show some fair results. However, one should notice that the data is probably not completely right when it comes to surface areas unfortunately. As to what is explained in section 3.1.1, the results could have been better when the surface areas are equal to each other.

Nevertheless, it is interesting to plot the percentage of developed area against changes in population. Although most cities experienced increases both in population and percentage of developed area, it is interesting to see that this does not hold for all places.

The imperviousness maps provide interesting information as well. However, the maps that project the changes in imperviousness might be an even better indicator of development. Moreover, these maps support (most of) the graphs. They are very useful when one is interested in changes at a specific place. They proved to be a good tool for all 10 cities. They might have been even more useful for cities which are 'bounded' by either county limits or geographical ones (i.e. Miami, New York, San Francisco, Los Angeles) than those which have a lot of space to increase further (i.e. Austin, Seattle).

It proved to be difficult to give an overall prediction for specific regions based on the results of the cities themselves. New York showed different results comopared to Miami, making it almost impossible to give any growth rate predictions for other cities (Boston, Philadelphia, Washington D.C., Atlanta etc.) along the Atlantic. Besides, both places are located very far away from each other, so one can wonder whether this is a fair comparison at all.

The same holds for the Pacific coast. Although all three cities showed growth rates, it does not mean that more places along the coast might show the same trends.

From a geographical point of view, the Midwest and Texas might give better predictions for their corresponding regions. Especially the Texas cities, since these are located within the Dallas-Houston-San Antonio-triangle. However, one should be careful with overestimating predictions for the rest of the state. The same is true for the Midwest. Only Chicago and Detroit have been investigated, whereas there are many more places that might show completely different results (i.e. Pittsburgh, Columbus, Cincinnati, Indianapolis). However, Detroit showed interesting and contradictory results for its changes in population and percentage of developed area.

Therefore, it is recommended to analyze more cities in case one wants to give growth rate predictions for various regions throughout the country. Apart from that, more demographic data is necessary to draw any conclusions why cities witnessed either a growth or decline in population.

Last but not least, a solution must be found to make sure that the surface areas of the NLCD databases of 2001, 2006 and 2011 are equal to each other. Then, more reliable results can be extracted when looking at developed areas. By the end of December 2018, the NLCD database for 2016 will be available, which should make predictions and results more reliable.

[5] `https://www.mrlc.gov/data/legends/national-land-cover-database-2011-nlcd2011-legend`

Appendices

This section provides data and results from all other cities than San Francisco, which is widely discussed in section 3. The data for all other cities:

- Austin
- Chicago
- Dallas
- Detroit
- Houston
- Los Angeles
- Miami
- New York
- Seattle

is divided in a couple of categories. Appendix A provides the NLCD data from 2001, 2006 and 2011 in alphabetical order. Appendix B provides the imperviousness changes over the time spans of 2001-2006 and 2006-2011. Again, all remaining cities are mentioned in alphabetical order.

A Land Cover 2001, 2006, 2011

This subsection provides the NCLD data of 2001, All data for all cities is provided in alp 2006 and 2011 for all other cities in alphabetical order. Areas that are red indicate that the area is developed, whereas green parts (King County for example, figures 46 to 48) or blueish parts (Miami Dade County for example, figures 38 to 40) indicated forests or wetlands.

Cities that are located within counties that exceed the city boundaries (i.e. Travis County, Los Angeles County, Miami Dade County and King County) show much more forests and wetlands compared to those which barely exceeds the city boundaries (i.e. Cook County, Dallas County, New York and San Franciso).

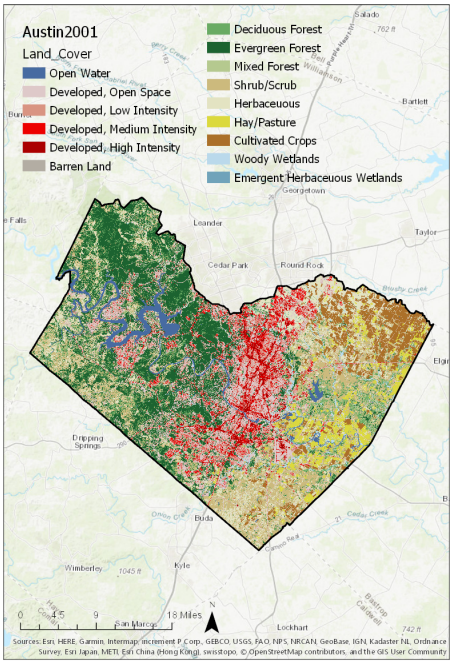

Figure 14: Austin Land Cover 2001

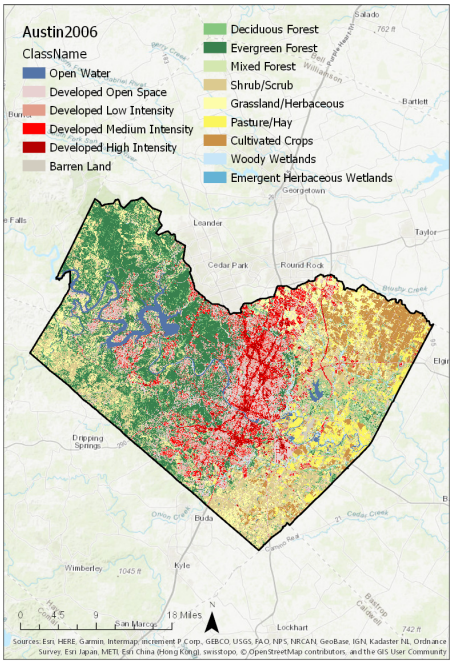

Figure 15: Austin Land Cover 2006

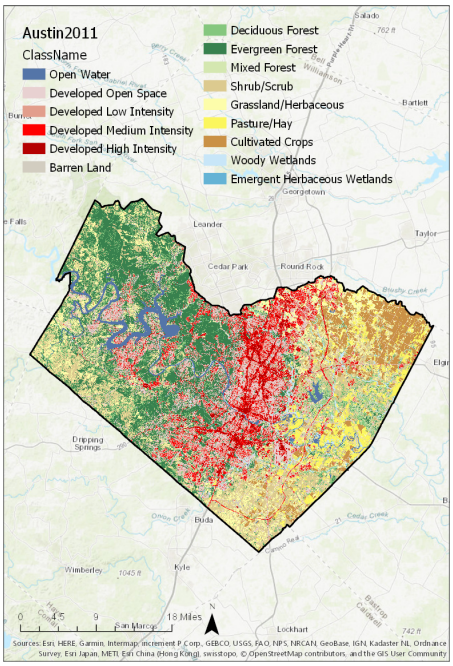

Figure 16: Austin Land Cover 2011

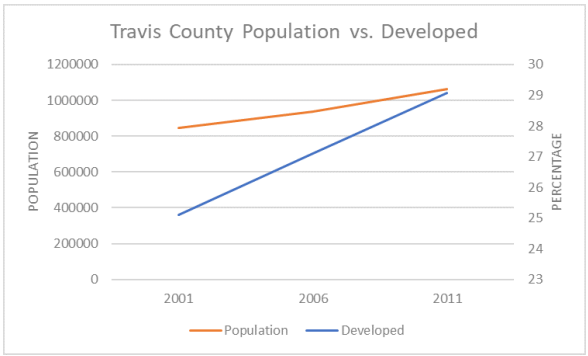

Figure 17: Austin

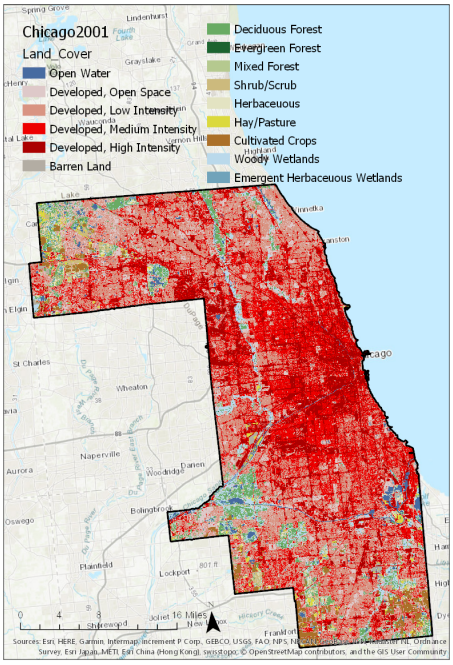

Figure 18: Chicago Land Cover 2001

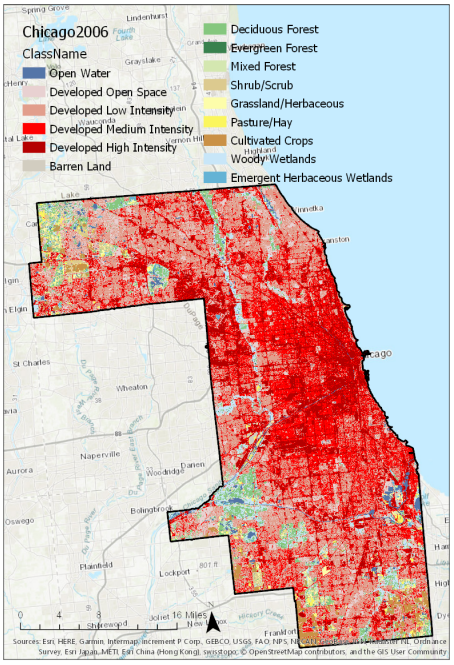

Figure 19: Chicago Land Cover 2006

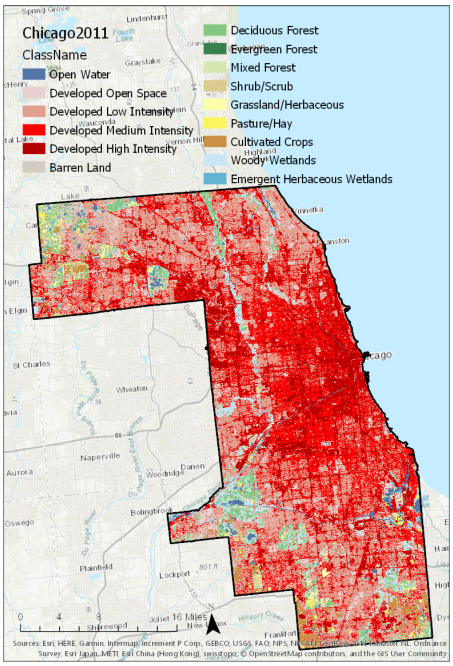

Figure 20: Chicago Land Cover 2011

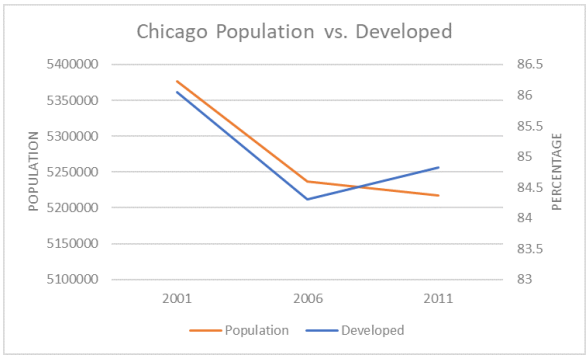

Figure 21: Chicago

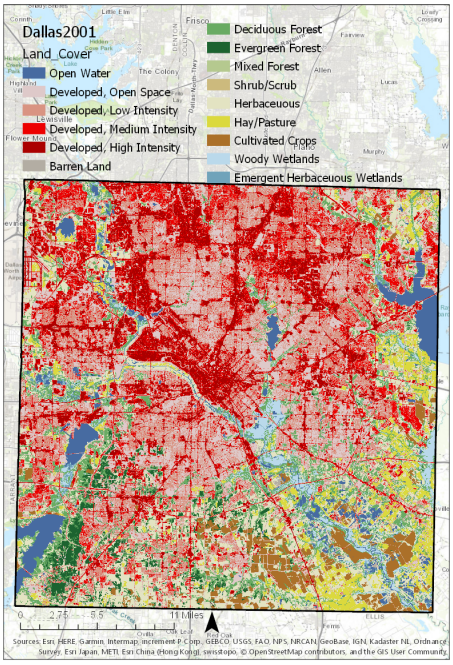

Figure 22: Dallas Land Cover 2001

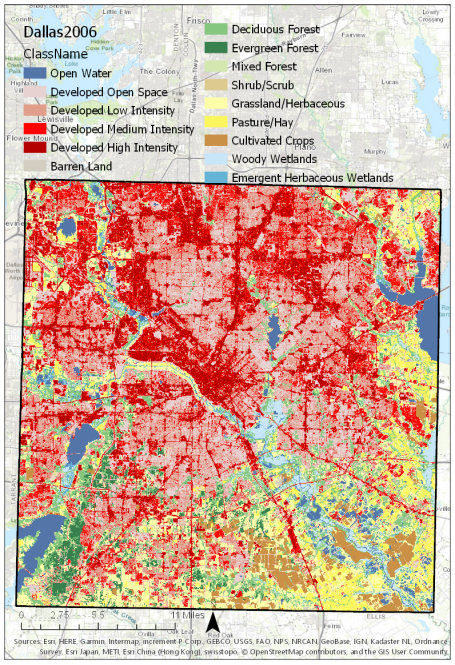

Figure 23: Dallas Land Cover 2006

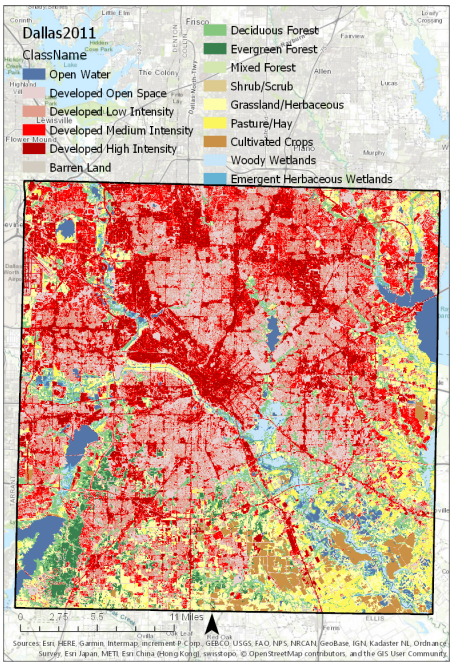

Figure 24: Dallas Land Cover 2011

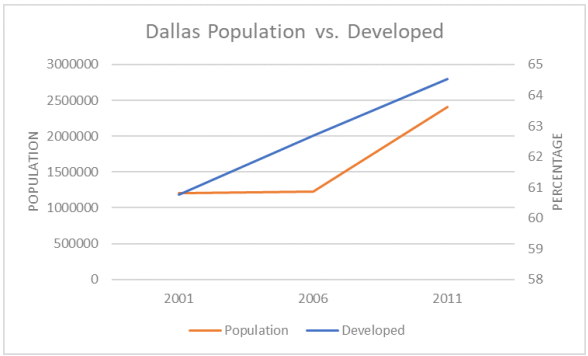

Figure 25: Dallas

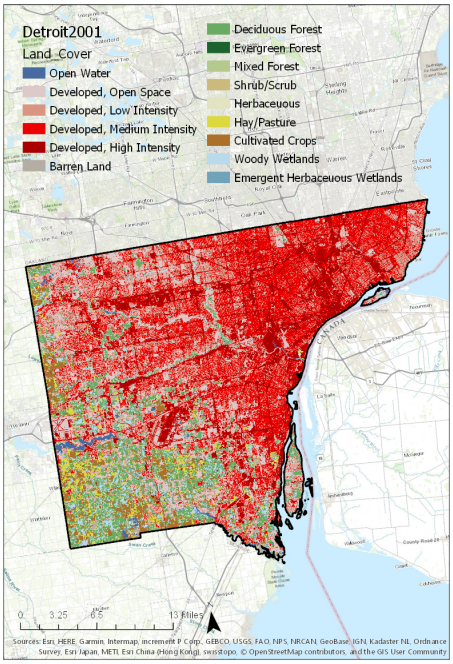

Figure 26: Detroit Land Cover 2001

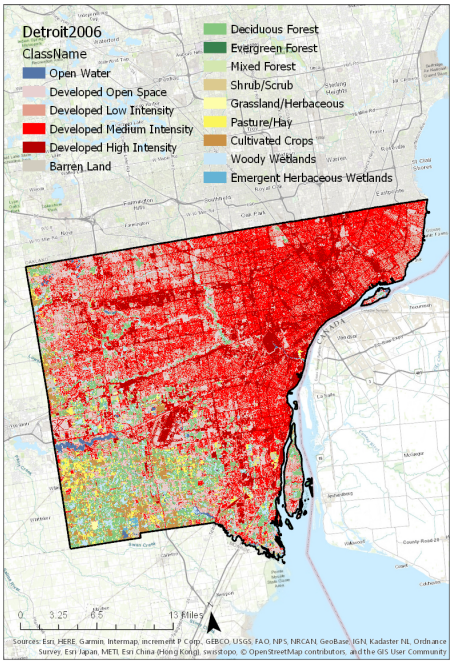

Figure 27: Detroit Land Cover 2006

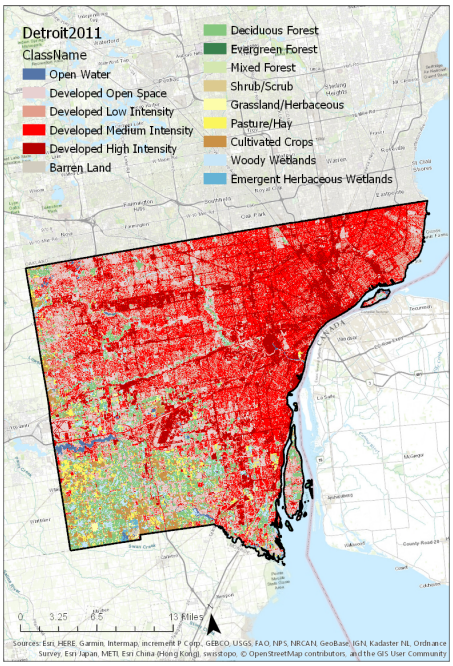

Figure 28: Detroit Land Cover 2011

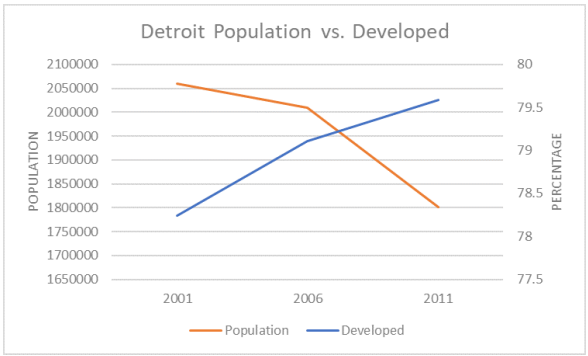

Figure 29: Detroit

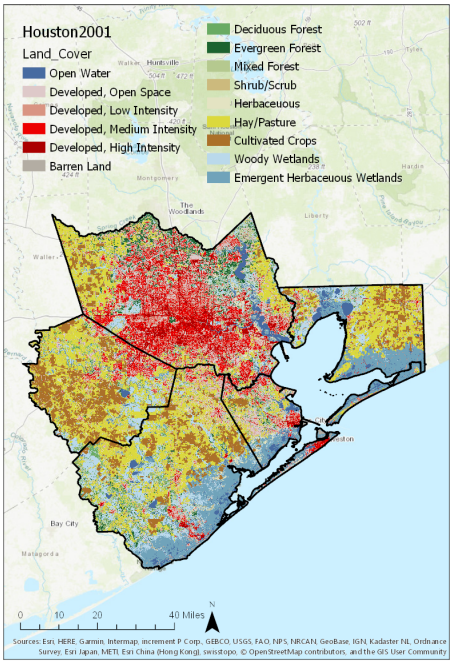

Figure 30: Houston Land Cover 2001

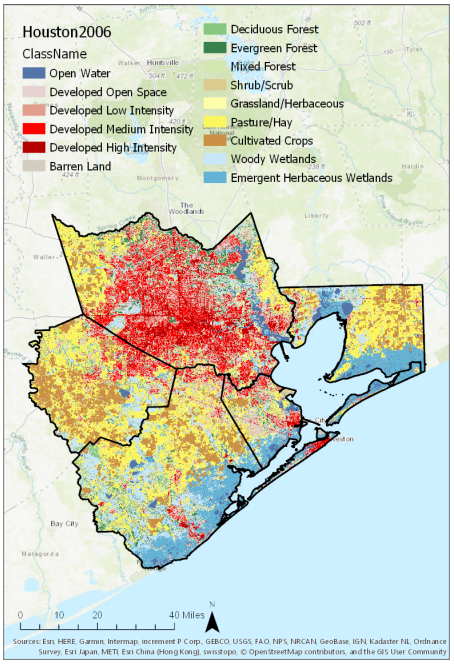

Figure 31: Houston Land Cover 2006

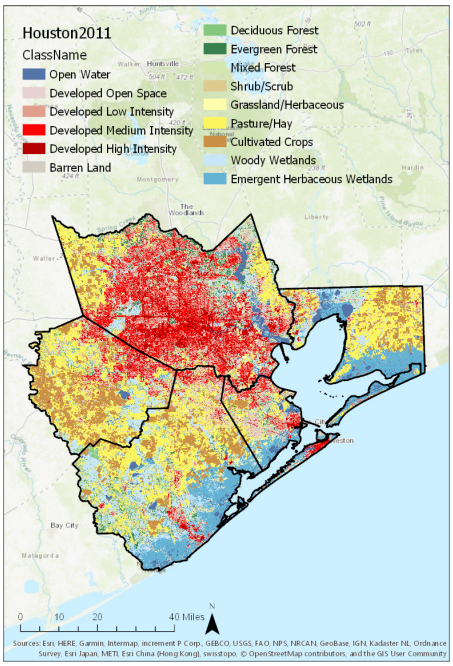

Figure 32: Houston Land Cover 2011

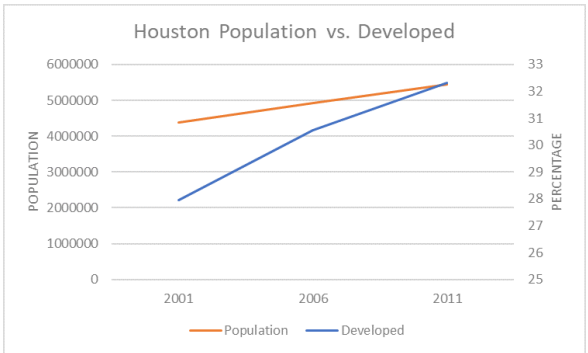

Figure 33: Houston

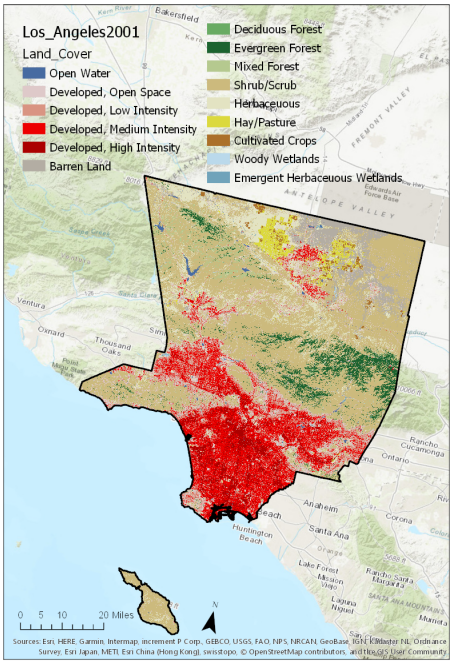

Figure 34: Los Angeles Land Cover 2001

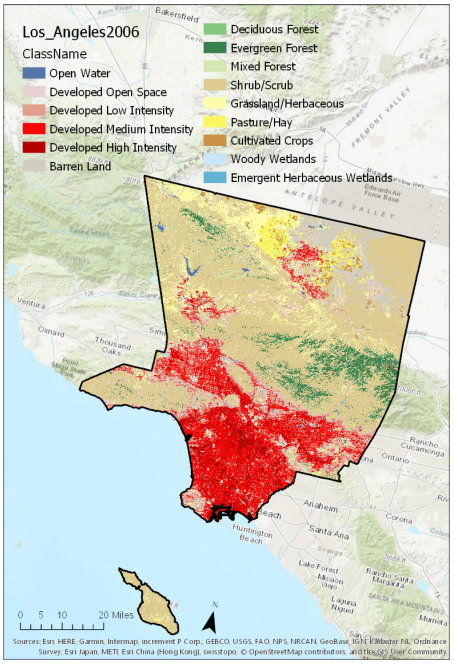

Figure 35: Los Angeles Land Cover 2006

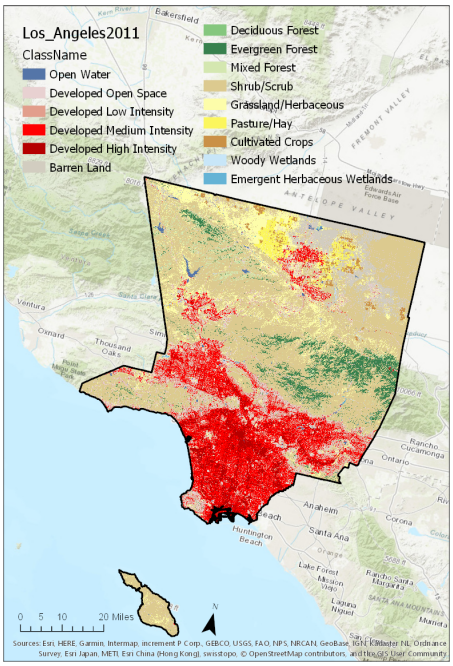

Figure 36: Los Angeles Land Cover 2011

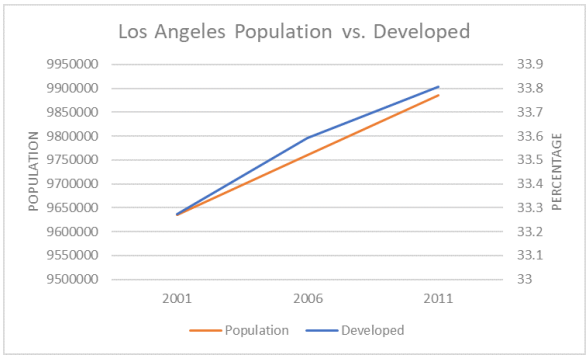

Figure 37: Los Angeles

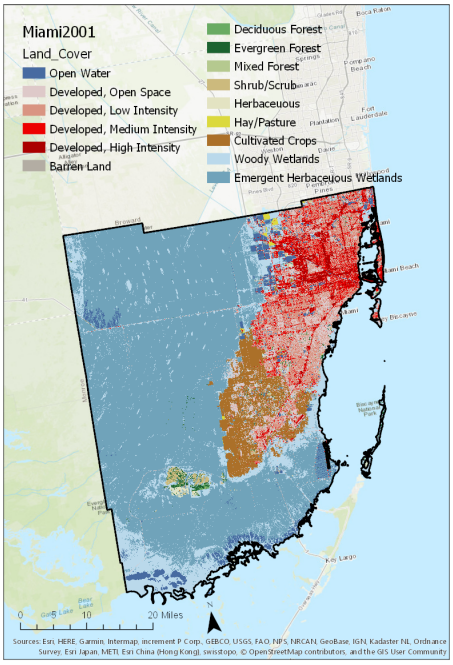

Figure 38: Miami Land Cover 2001

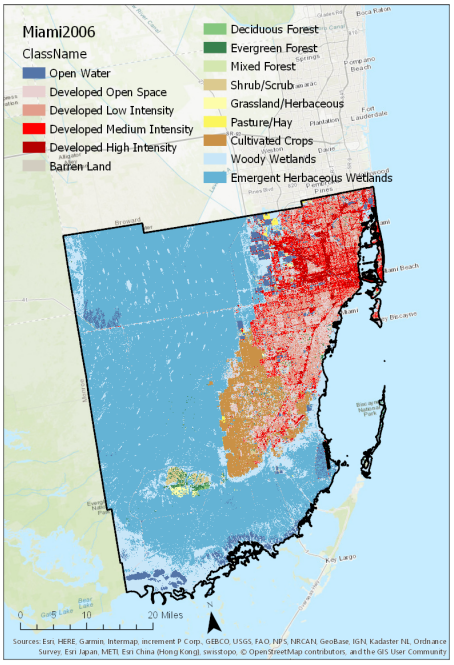

Figure 39: Miami Land Cover 2006

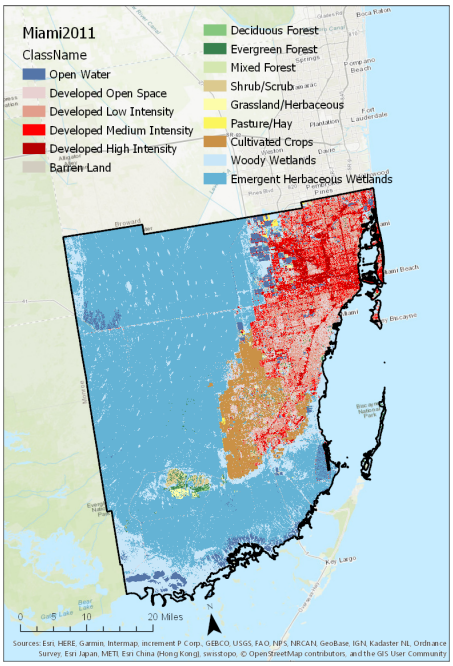

Figure 40: Miami Land Cover 2011

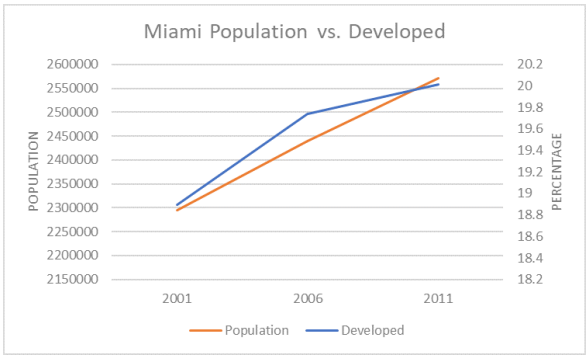

Figure 41: Miami

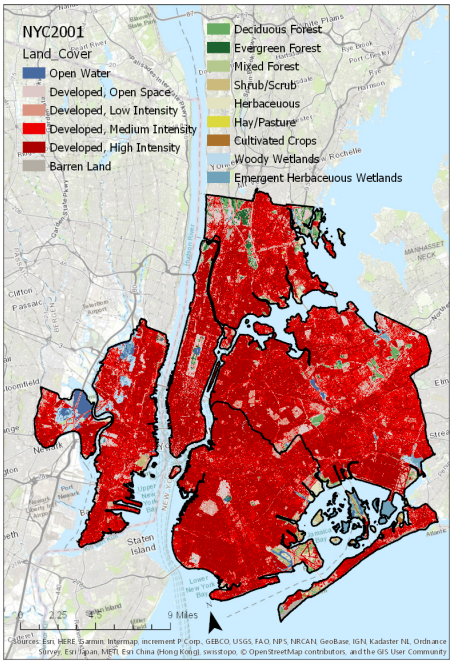

Figure 42: New York Land Cover 2001

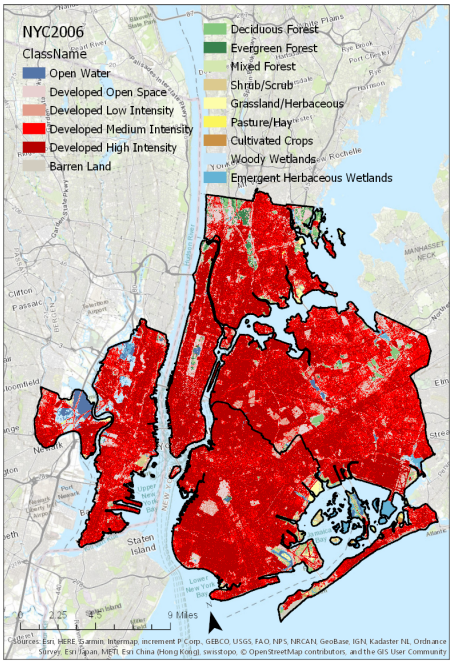

Figure 43: New York Land Cover 2006

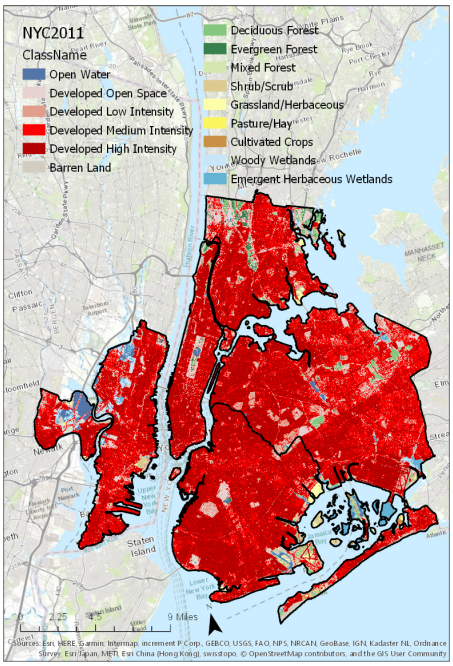

Figure 44: New York Land Cover 2011

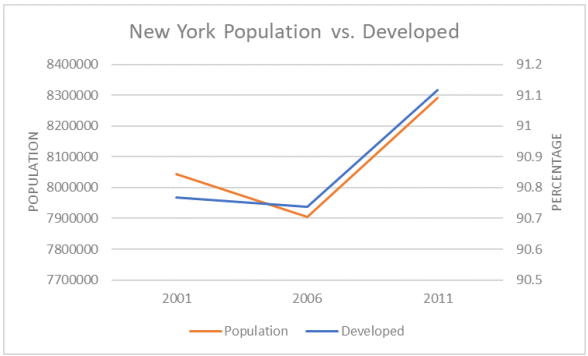

Figure 45: New York

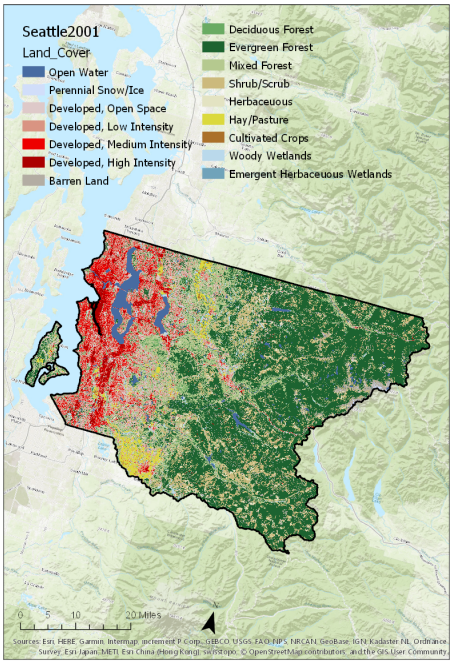

Figure 46: Seattle Land Cover 2001

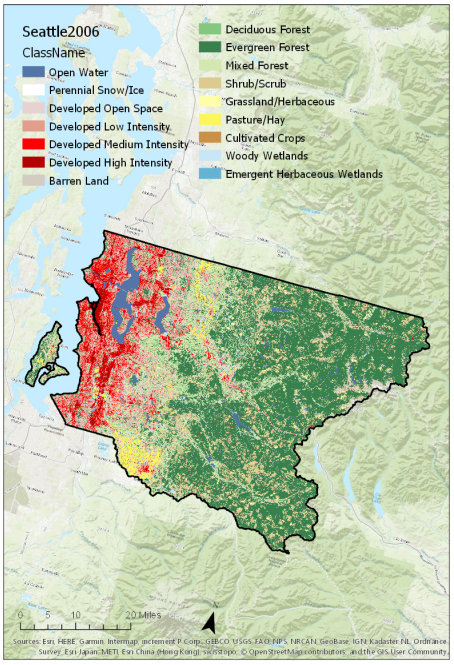

Figure 47: Seattle Land Cover 2006

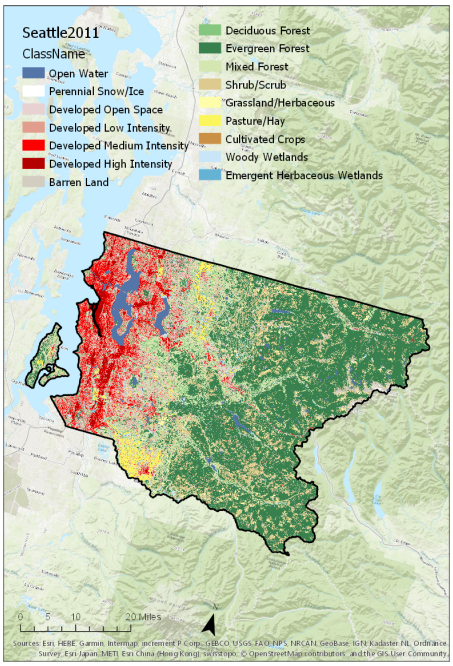

Figure 48: Seattle Land Cover 2011

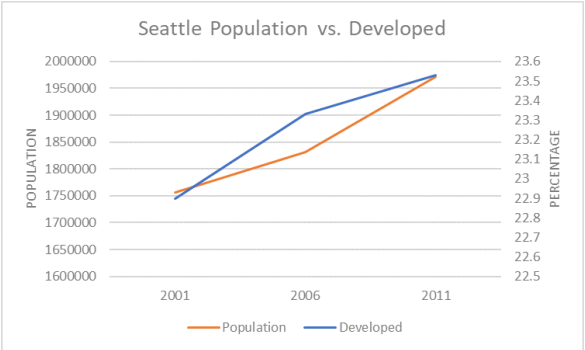

Figure 49: Seattle

B Imperviousness Change

This appendix presents the imperviousness change for all other cities. As explained in section 3.2, the maps show the change (increase) in percentage developed area over time. Each city has two maps, one for the change from 2001 to 2006 and from 2006 to 2011 respectively.

A light color means a high increase in percentage developed area, whereas a dark color means that the area has hardly changed over time. In other words, the lighter the color the larger the increase in percentage developed area over time.

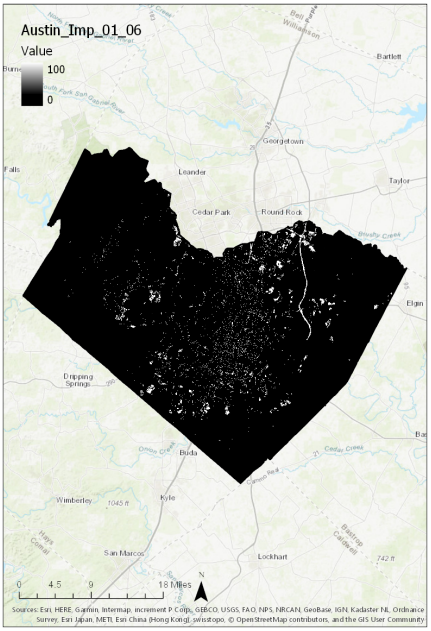

Figure 50: Austin Imperviousness Change '01/'06

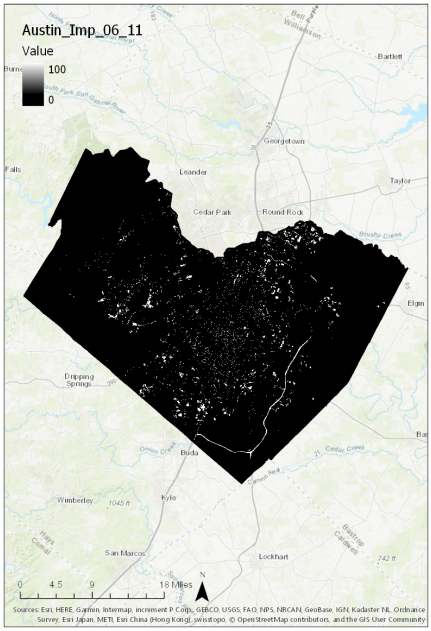

Figure 51: Austin Imperviousness Change '06/'11

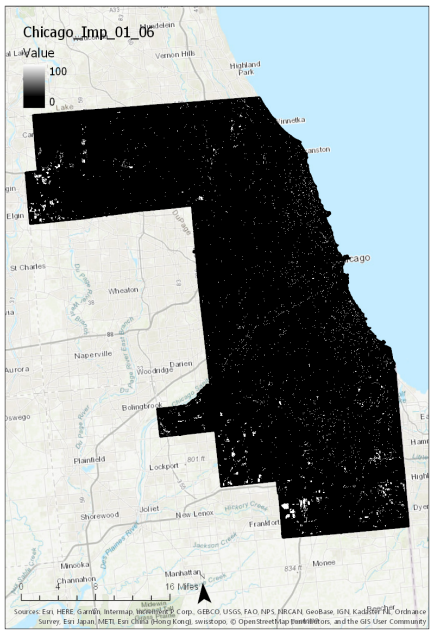

Figure 52: Chicago Imperviousness Change '01/'06

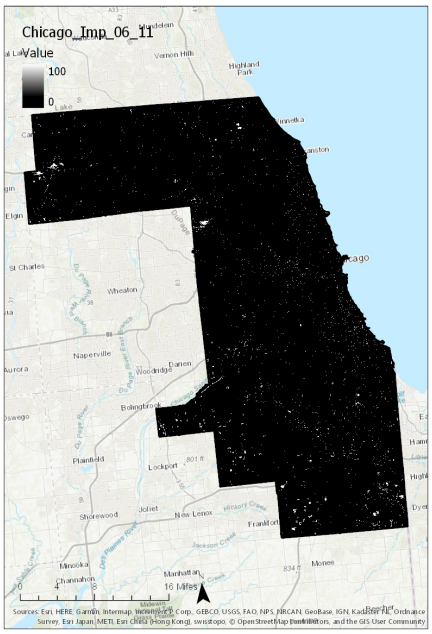

Figure 53: Chicago Imperviousness Change '06/'11

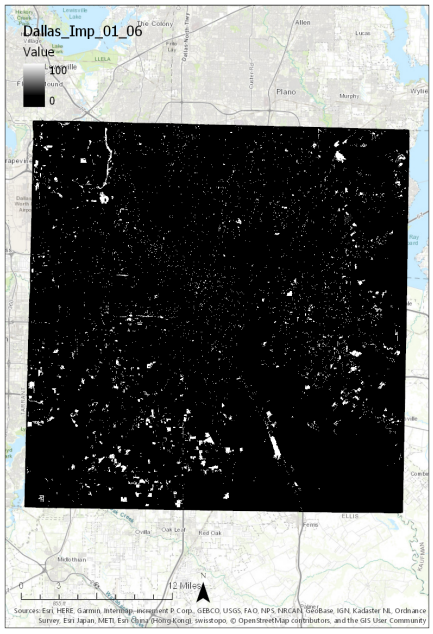

Figure 54: Dallas Imperviousness Change '01/'06

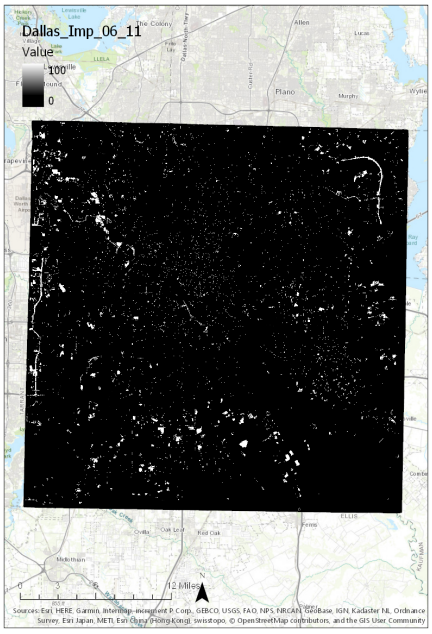

Figure 55: Dallas Imperviousness Change '06/'11

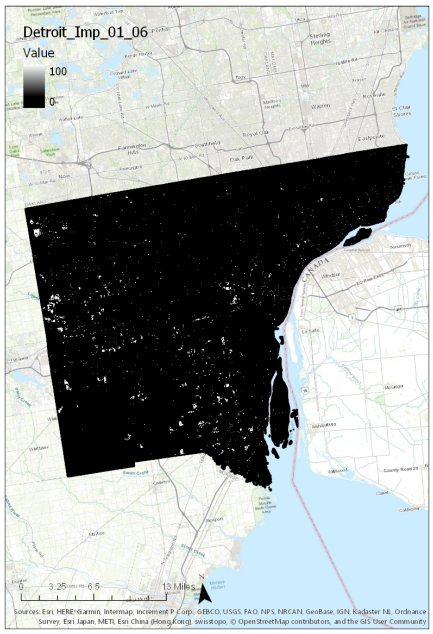

Figure 56: Detroit Imperviousness Change '01/'06

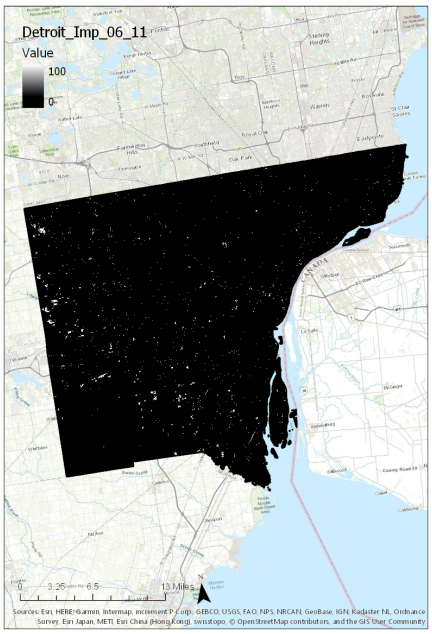

Figure 57: Detroit Imperviousness Change '06/'11

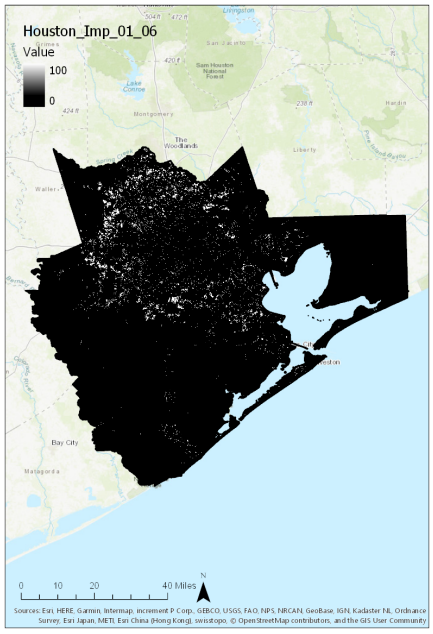

Figure 58: Houston Imperviousness Change '01/'06

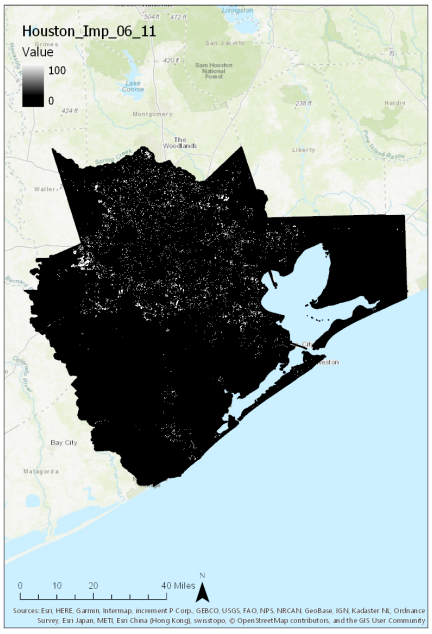

Figure 59: Houston Imperviousness Change '06/'11

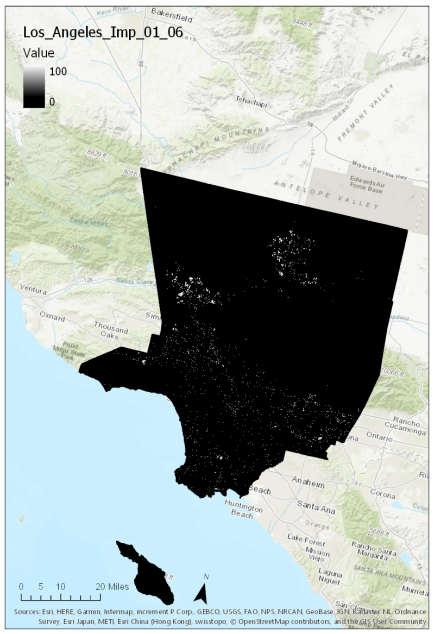

Figure 60: Los Angeles Imperviousness Change '01/'06

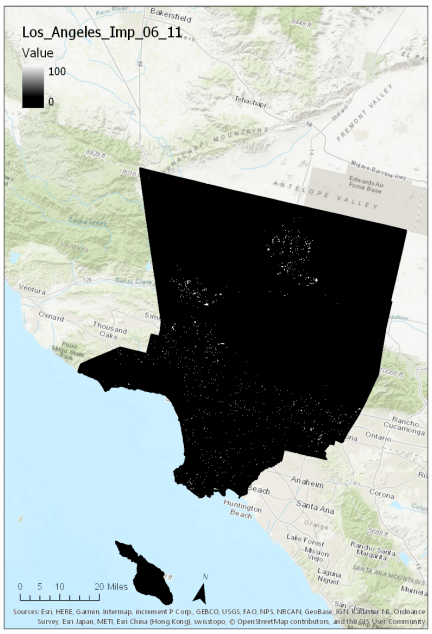

Figure 61: Los Angeles Imperviousness Change '06/'11

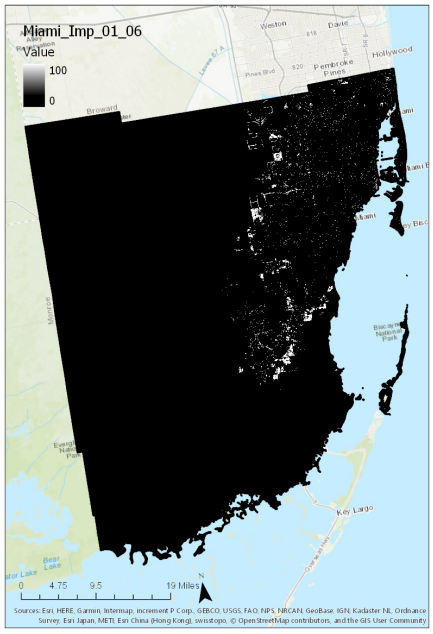

Figure 62: Miami Imperviousness Change '01/'06

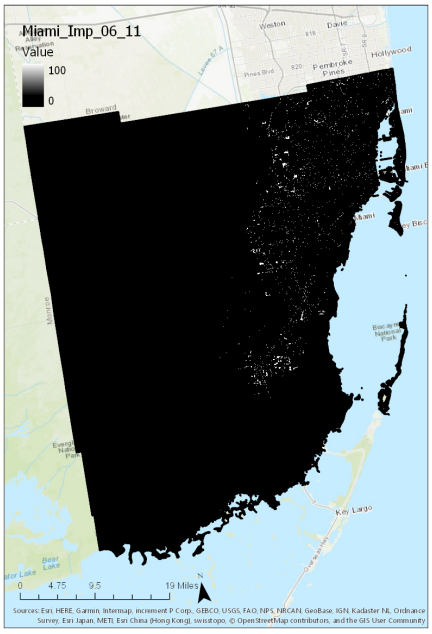

Figure 63: Miami Imperviousness Change '06/'11

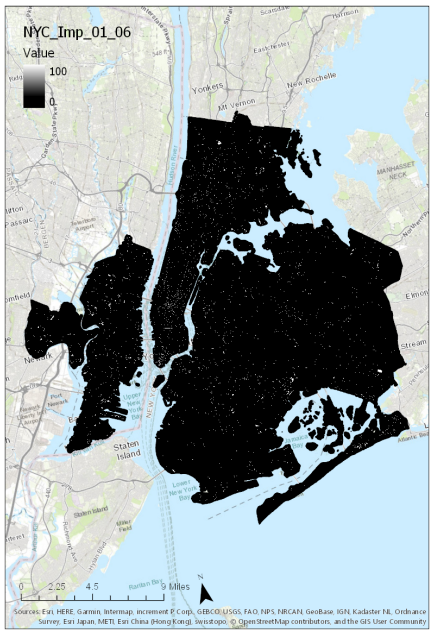

Figure 64: New York Imperviousness Change '01/'06

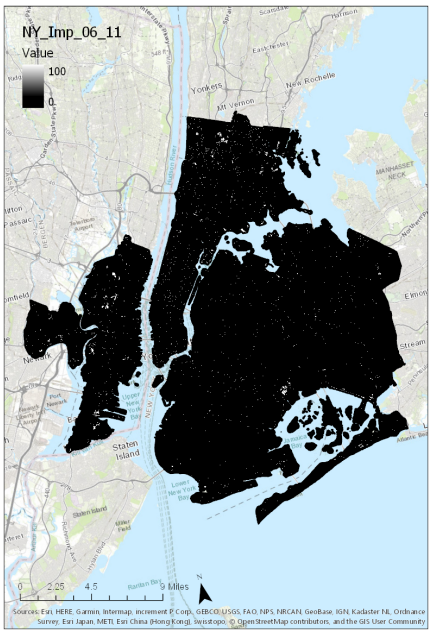

Figure 65: New York Imperviousness Change '06/'11

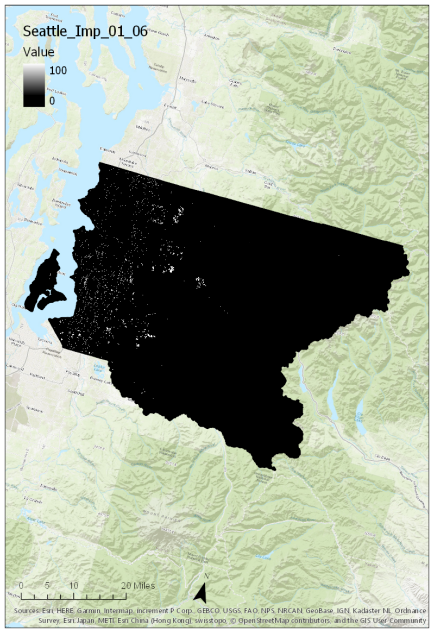

Figure 66: Seattle Imperviousness Change '01/'06

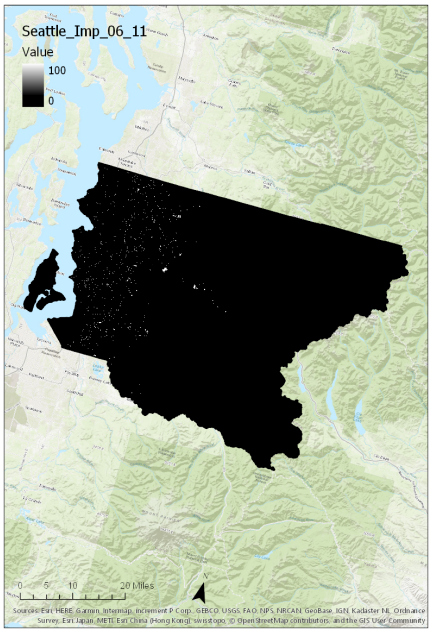

Figure 67: Seattle Imperviousness Change '06/'11