Sam Shuster

GEOG 4450

5/2/2021

Final Project

Time-Series Analysis of the Urban Growth of Denver

Background:

According to U.S. Census Bureau, Population Estimates Program (PEP), the city was estimated to have a population of 599,825 people as of 2010. As of 2019, those estimates grew to 727,211 people. The actual recorded population of the city from the 2019 ACS was 600.158. Based on the calculations performed using the PEP figures, that is a 21.2% increase in population in just ten years. The rapid increase in population is likely due in large part to the implementation of Amendment 24 to the Colorado State Constitution which effectively legalized the use of cannabis for recreational purposes in 2012.

Objective:

The primary objective of the study was to produce a series of classified maps using Google Earth Engine to document the growth of the urban center of Denver. Using those maps, change detection was performed to quantify landcover changes over time and then corroborated Census population estimate data.

Methods:

Using Google Earth engine, supervised classification was performed on Landsat imagery to develop a classification scheme using a machine learning algorithm and classified maps previously created by the NLCD. Landsat 5 Thematic Mapper (TM) data was used for all years from 1986 to 2011 at 30 x 30m resolution. Images from 2016 and 2021 were collected from Landsat 8's OLI sensor, sampled at 30 x 30m resolution. All images classified were done so using false-color imagery. The first figure pictured shows one of the original Landsat images used and the associated study site in question.

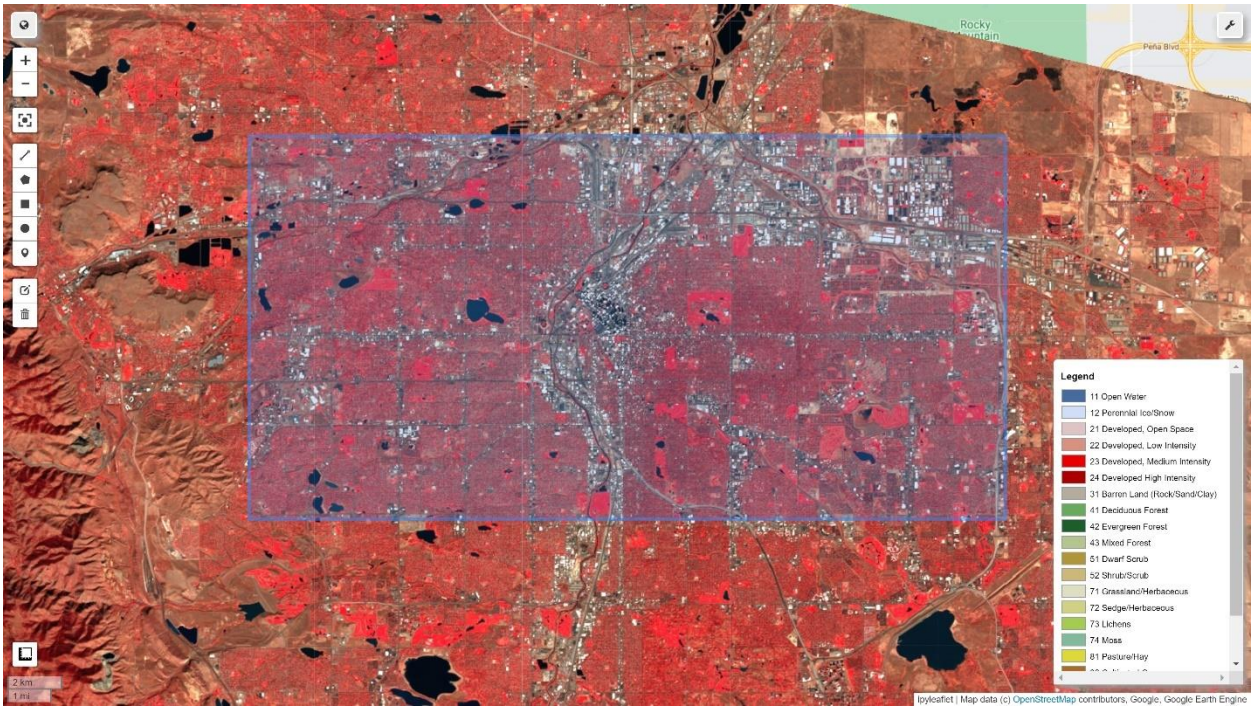

Figure 1. Landsat 8 (2016)

After collecting a Landsat image for a given year, the 2016 NLCD landcover map was overlayed.

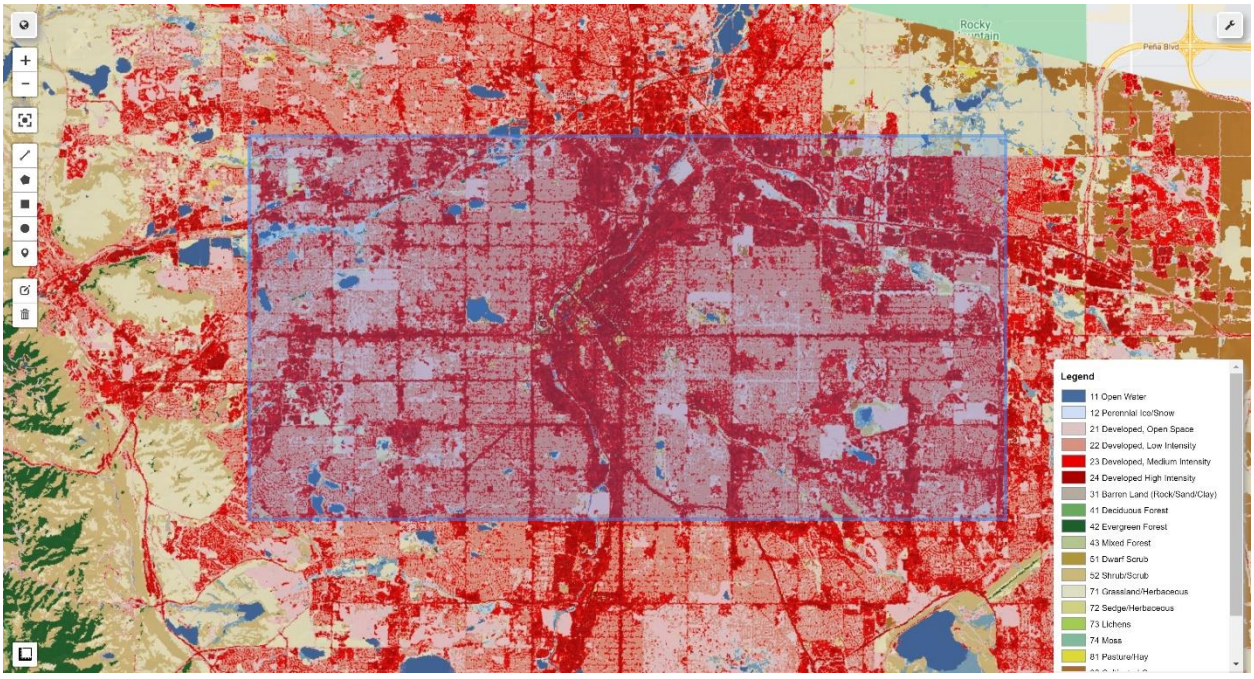

Figure 2. NLCD Landcover 2016

25,000 training points were then collected from the overlayed NLCD map to train the classifier. Above is the mentioned overlayed NLCD map and below is the result of training point collection.

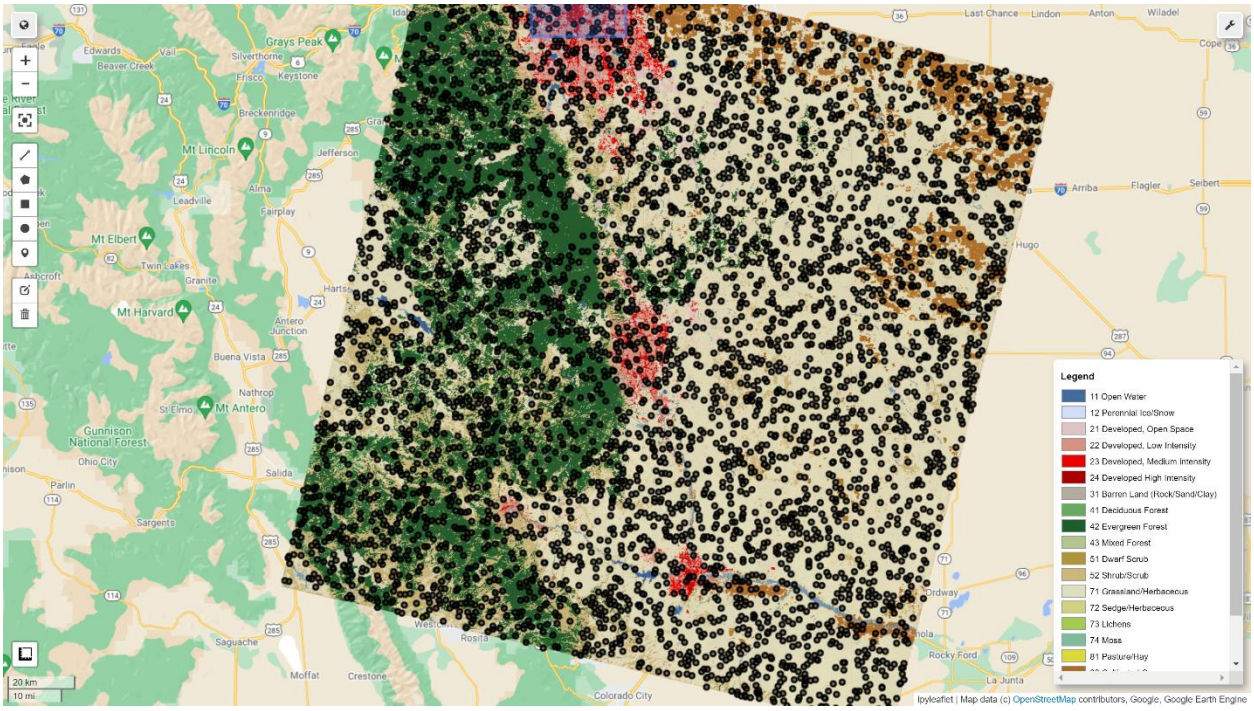

Figure 3. Training Points

The smileCart machine learning supervised classification algorithm was used in all instances. Using the trained classifier, I was able to classify eight false-color Landsat images spanning from 1986-2021, spaced out every 5 years. Pictured below is the classified map of the area of interest from 2016, which was created using this process.

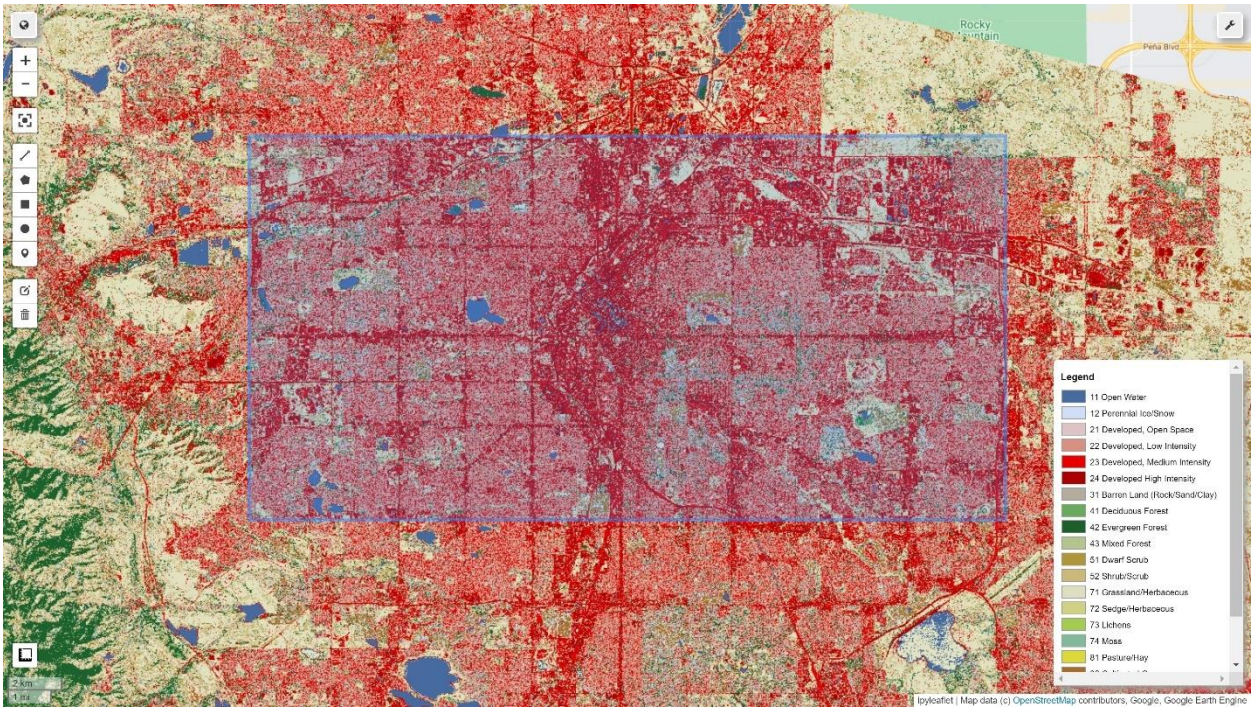

Figure 4. Final Resultant Classified Map (2016)

A side-by-side comparison of the original NLCD map and the classified map created shows an increase in detail and classification resolution. The NLCD land cover data set is created using Landsat 30 x 30m data but it appears the classification performed has a lower resolution than the method performed in this study despite using the same resolution images. Using the eight Landsat images collected, change detection was conducted and reported in conjunction with Census data to corroborate claims of city growth over time. The following collection of figures are the series of classified maps created.

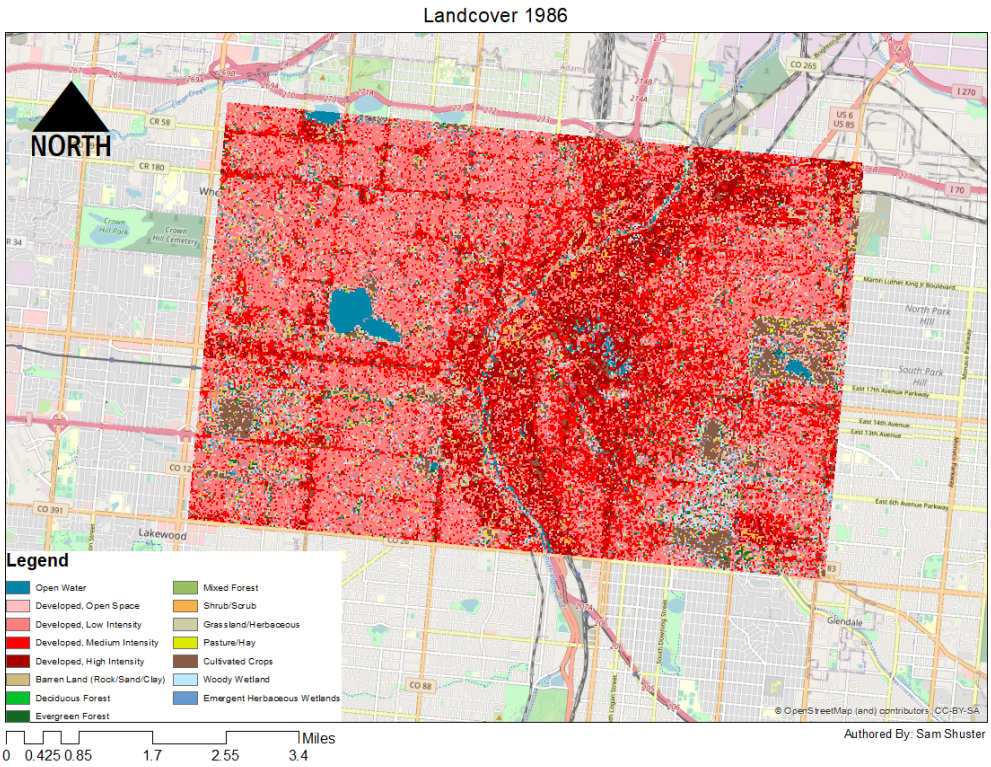

Figure 5.

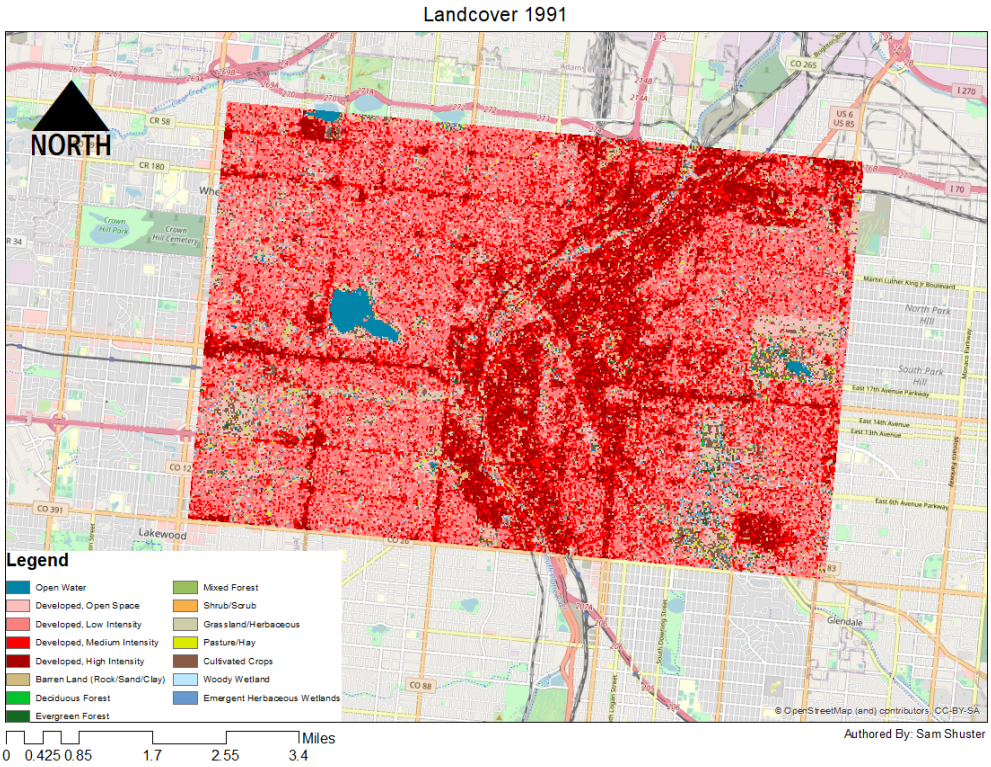

Figure 6.

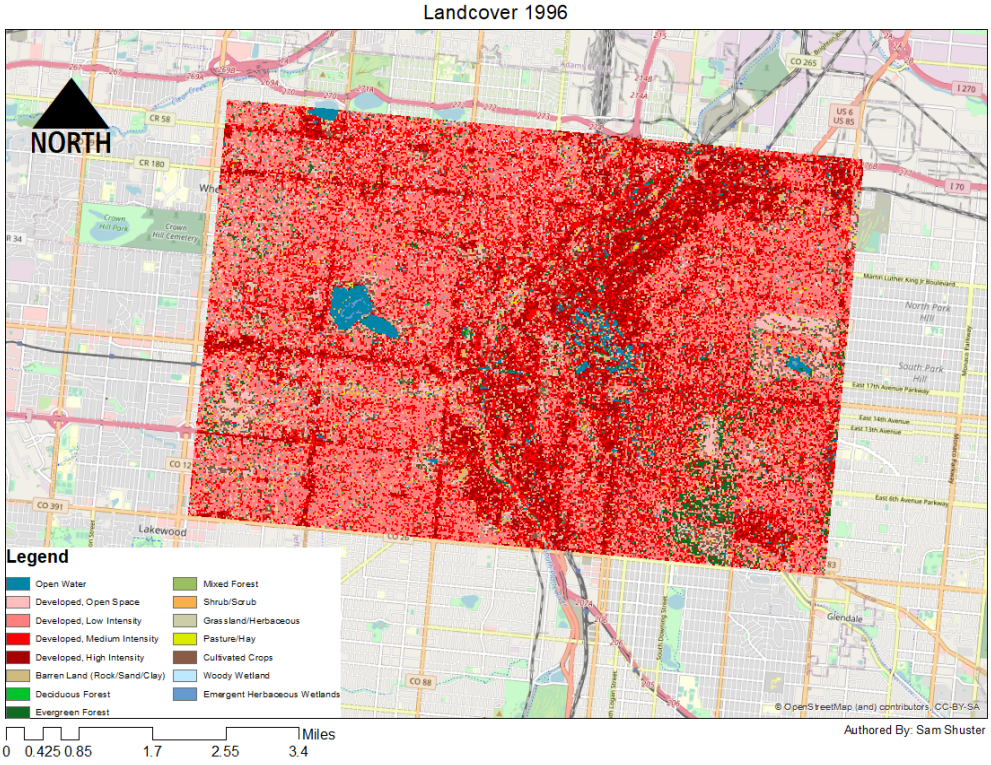

Figure 7.

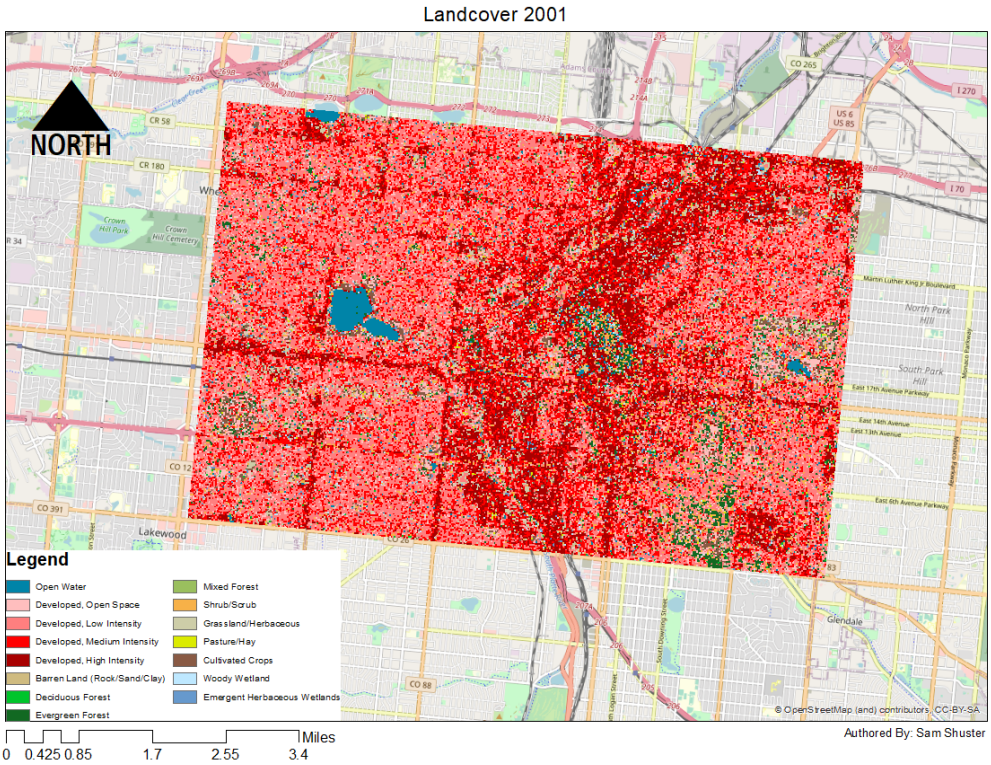

Figure 8.

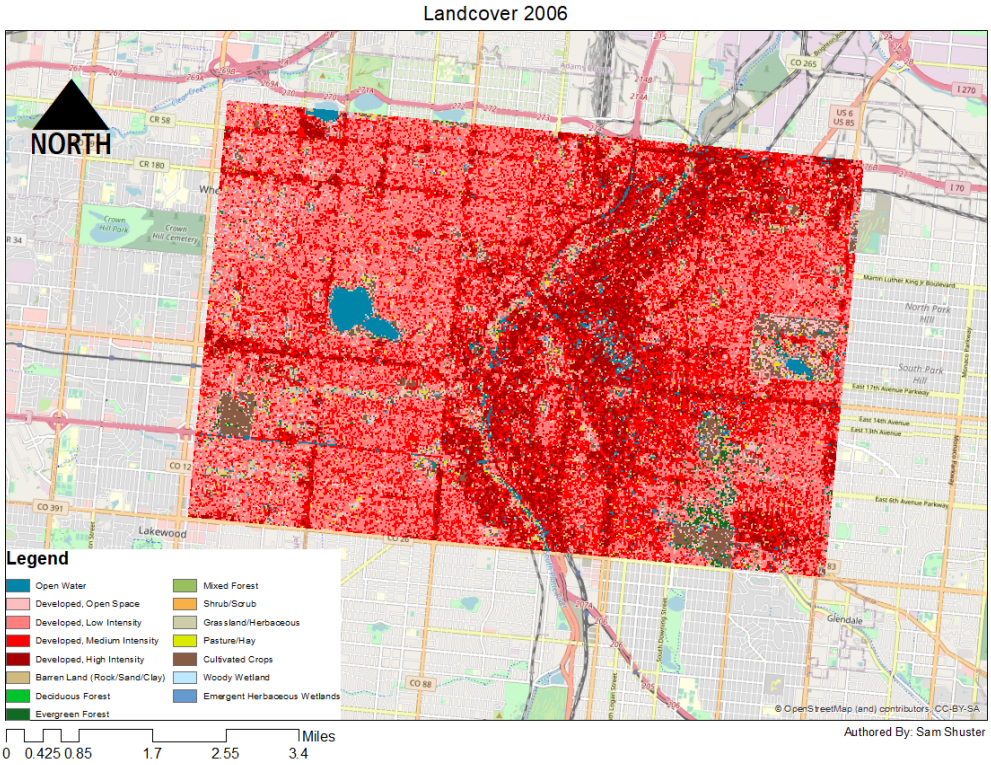

Figure 9.

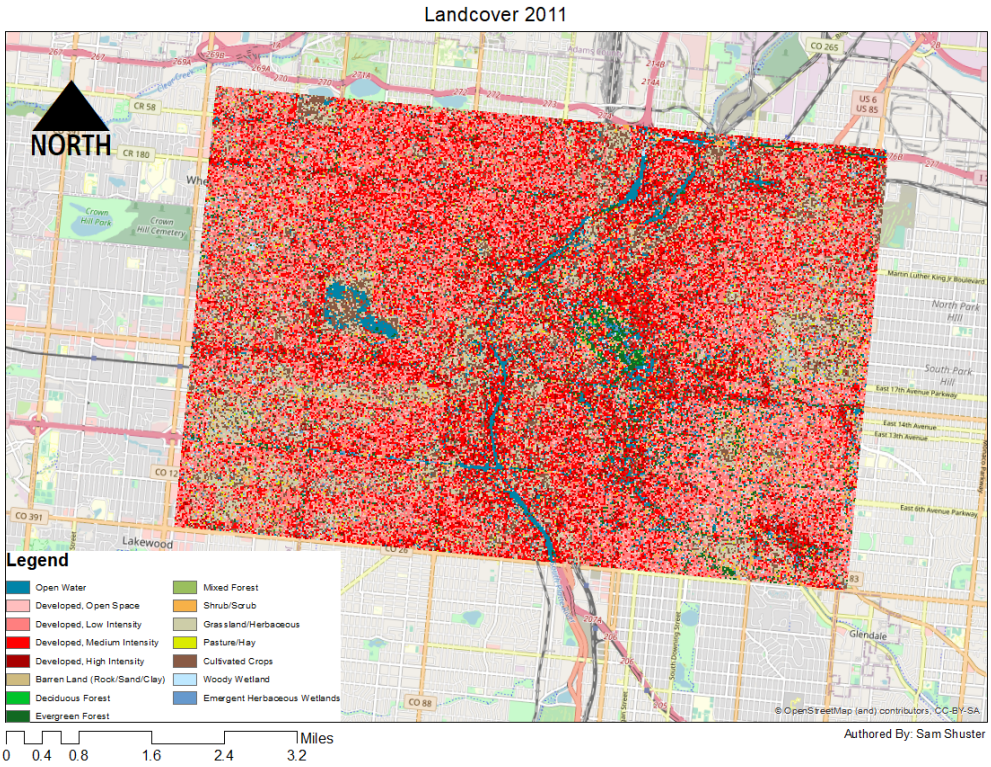

Figure 10.

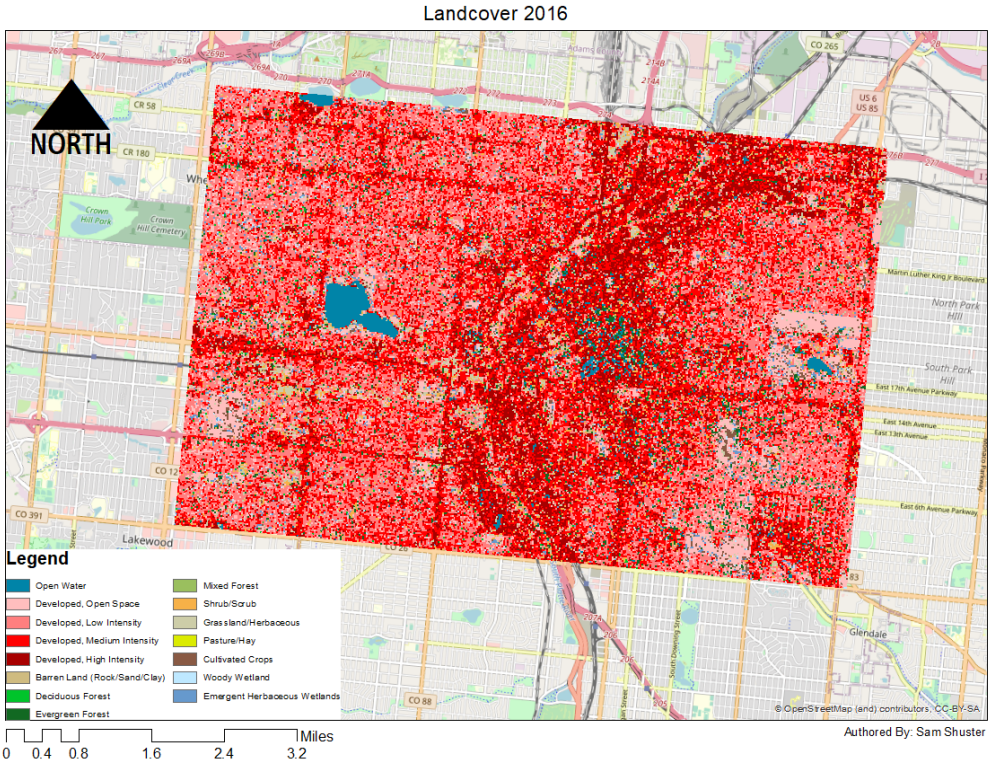

Figure 11.

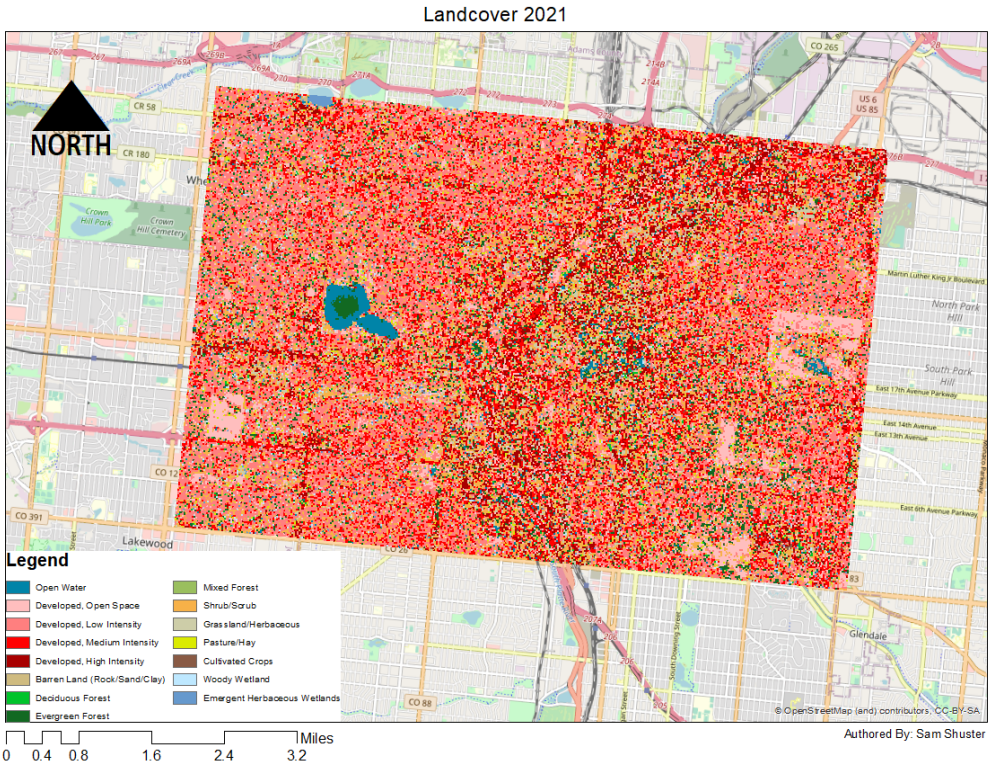

Figure 12.

The specific population figures used are sourced from the Population Estimates Program run by the Census Bureau. Using the figure estimates from the Census bureau from both 2010 and 2019, it is plain to see that there has been a very large and rapid increase in the population of the city since the time of the first Census estimation.

Geovisualization Method:

A variety of different visualization techniques were used to highlight the changes that have taken place in the urban area over time. ArcGIS was used to create a series of classified maps using data exports of the study area from Google Earth Engine (GEE). HTML links that navigate to classified interactive maps were also created within GEE. Animated images (.gif files) of the study area that accentuate the change and development over time and how the density of the city has increased following the passing of amendment 24.

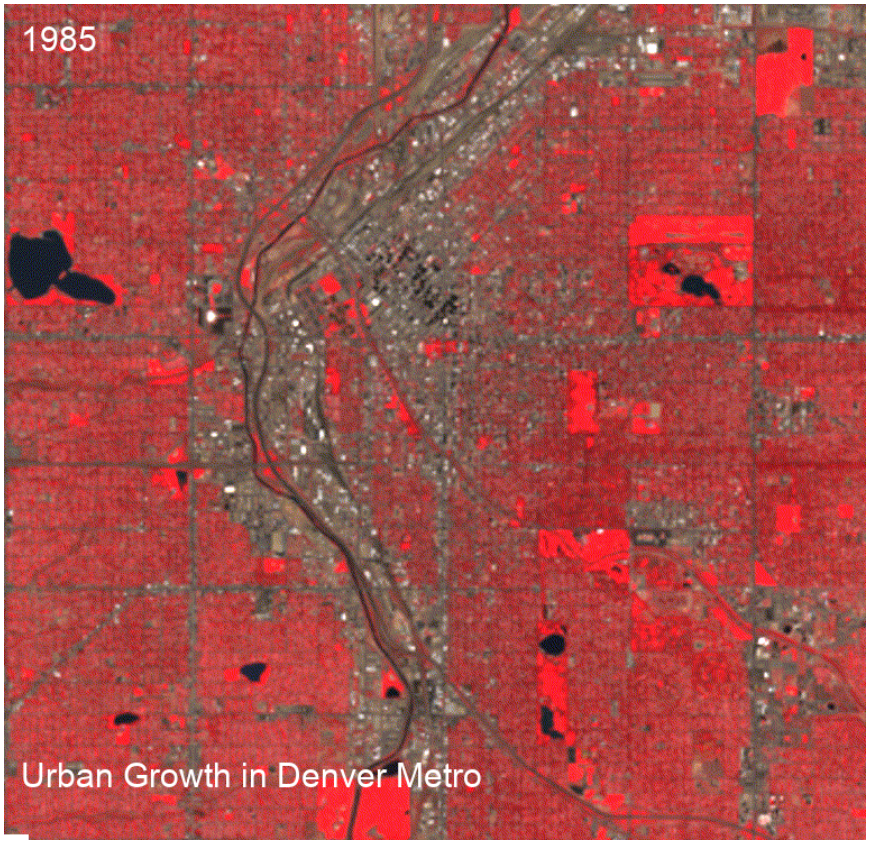

Figure 13. False-Color gif depicting development over time.

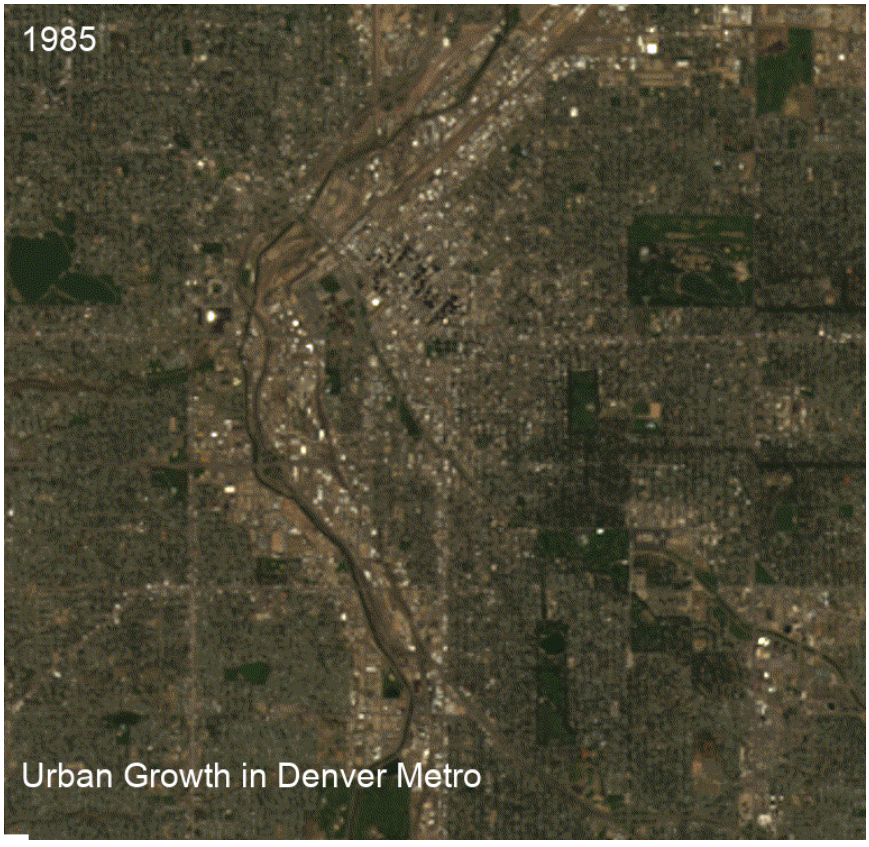

Figure 14. True-Color gif depicting development over time

The previously created series of classified maps (see figures 5-12) was created using ArcMap. I also used ArcMap and the Python script editor to create an interactive map that depicts where migrants are moving from and the volume of migrants coming from each state (see below).

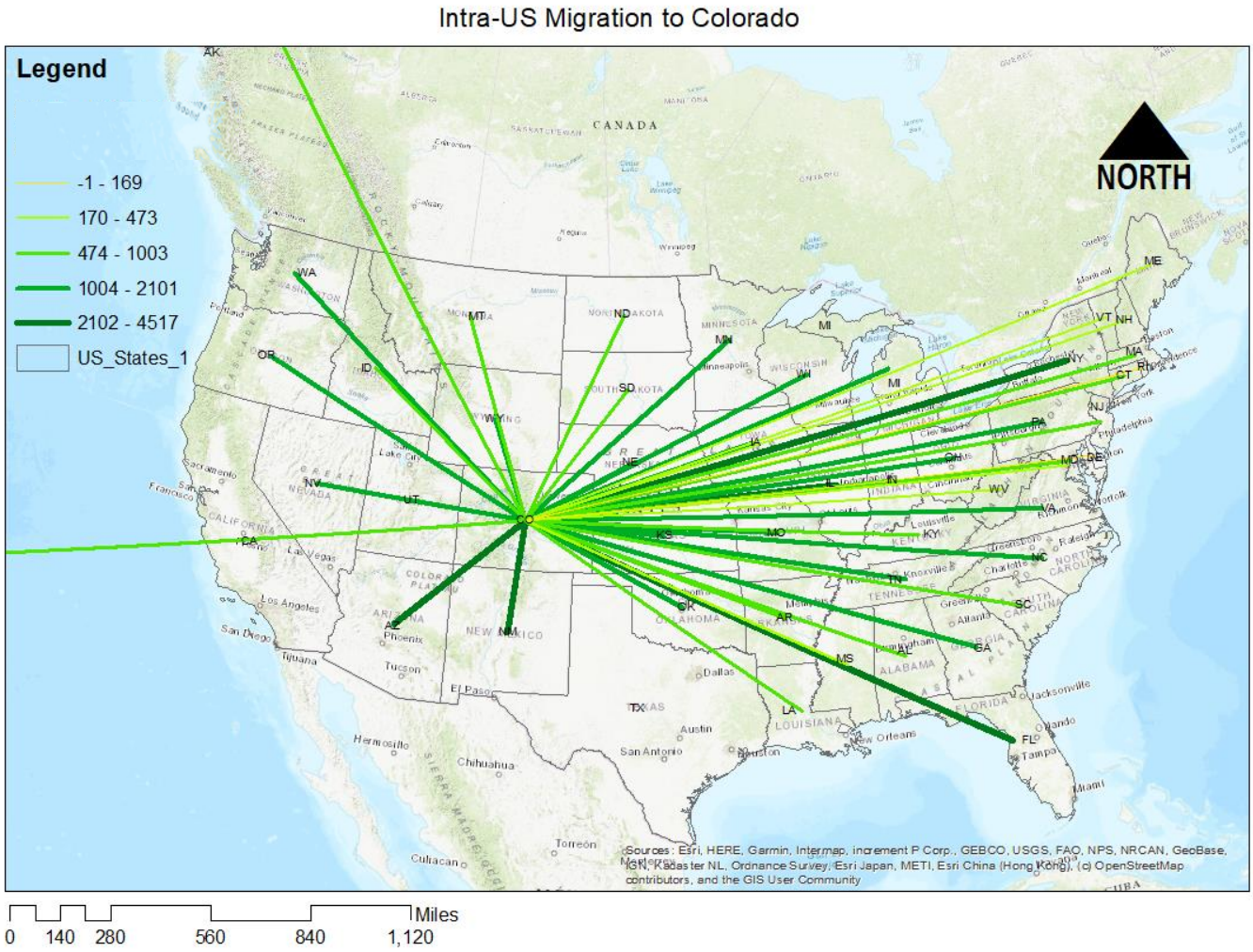

Figure 14. Population migration within the United States.

Change Detection:

Value	Landcover	Count 1986:	Count 2001:	Count 2016:	Change from 1986-2016:	% Change '86-'16:	Change from 2001-2016:	% Change '01-'16:	Average % Change:
11	Open Water	2329	1894	2015	314	-16%	-121	6%	-5%
21	Developed, Open Space	6441	8133	9520	-3079	32%	-1387	15%	23%
22	Developed, Low Intensity	40595	36218	31580	9015	-29%	4638	-15%	-22%
23	Developed, Medium Intensity	23945	26181	32326	-8381	26%	-6145	19%	22%
24	Developed, High Intensity	10592	14595	13870	-3278	24%	725	-5%	9%
31	Barren Land (Rock/Sand/Clay)	99	78	256	-157	61%	-178	70%	65%
41	Deciduous Forest	464	445	433	31	-7%	12	-3%	-5%
42	Evergreen Forest	1087	2298	3068	-1981	65%	-770	25%	45%
43	Mixed Forest	6	1	7	-1	14%	-6	86%	50%
52	Shrub/Scrub	2715	4485	3741	-1026	27%	744	-20%	4%
71	Grassland/Herbaceous	3812	4496	3549	263	-7%	947	-27%	-17%
81	Pasture/Hay	761	254	11	750	-6818%	243	-2209%	-4514%
82	Cultivated Crops	6282	2842	941	5341	-568%	1901	-202%	-385%
90	Woody Wetland	2667	729	822	1845	-224%	-93	11%	-107%
95	Emergent Herbaceous Wetlands	1916	1062	1572	344	-22%	-510	32%	5%

Increase in Landcover Type

Decrease in Landcover Type

Figure 15. Change Detection

Change detection yielded findings of a 22% average decrease in low-density urban development, a 22% increase in medium-density urban areas, and a 9% average increase in high-density urban areas from 1986 to 2016. The proportional decrease of low-density urban land and increase of medium-density urban land indicates a shift or an expansion in the types of buildings within the urban center. There were also significant increases in the amount of barren land, which includes areas of bare sand and soil. Land must be terraformed and manipulated in order to build quality structures during urban development so this is a reasonable finding. There were also large decreases in the amount of pasture/farmland present within the study area which is also reasonable when urban sprawl is considered. The associated average percent decrease in pastoral and cultivated lands are 4514% and 385%, respectively. The 45% increase of evergreen forests and the 50% increase in mixed forests indicates that despite urban development, attention is being paid to maintaining a healthy balance of green space/vegetation and other infrastructure.

Conclusions:

There has been a massive increase in the population of the city since the introduction of amendment 24. Since 2010 alone, there has been a population increase of 21% in Denver County. Change detection suggests that there have been significant physical developments of the urban space in conjunction with landcover changes that are indicators of landcover transformation. Given the rapid physical developments must therefore be a direct result of the intense population migration into the city. It should be noted that no accuracy assessment was performed on the classification model. Given the variation and the anomalous findings of the 2011 and

2021 classified maps, it would be wise to conduct an accuracy assessment of the model to better validate the claims made. Ultimately, however, the net average percent changes in landcover types and the associated interpretations largely seem reasonable, so for the purposes of answering the initial study questions put forth, it is determined that the findings are logical and likely fit the reality of events that have transpired.

References:

ArcGIS

Google Earth Engine

Jupyter Notebooks

USGS

United States Census Bureau