Land Use Change Patterns

In

Massachusetts 2001-2011:

A Case Study using NLCD land cover data

A thesis submitted by

Jiao Liu

In partial fulfillment of the requirements for the degree of

Master of Arts

in

Urban and Environmental Policy and Planning

Tufts University

August 2018

Advisor: Sumeeta Srinivasan

Reader: Barbara Parmenter

Abstract

This thesis will explore the utility of publicly available datasets specifically the National Land Cover Database (NLCD), Smart Location Database and MassGIS data to show ways in which urban planners and policy-makers in Massachusetts could better understand spatial land use change patterns and the correlation between land use change and built environment characteristics. In addition, the literature review provides an assessment of the use of NLCD data, and a survey of existing research on how land use change is related to the built environment. The results suggest that a significantly large area changed to lower intensity developed urban area from forest in Massachusetts between 2001 and 2011. Land use change patterns were also significantly affected by the built environment of the location. Specifically, the regression models suggest that proximity to transit and transit based accessibility to jobs were significant in making low intensity land use change less likely and automobile based access to jobs led to significantly higher low intensity land use change. This thesis finds that NLCD, Smart Location and local GIS data like the data obtained from MassGIS, could be used to better understand the land use change patterns. Finally, it concludes with some limitations in data and methodology and suggestions for future research as well as some recommendations for planners and policy makers.

Acknowledgment

First, it is the great honor to have Sumeeta as my advisor. During the long time period of incubation of this thesis, Sumeeta helps me a lot in topic selection, finding data, methods guidance and writing suggestion. Thanks also go to Barbara as my reader of this thesis. Barbara provided me with many wonderful ideas on the land use change pattern part and also helps me a lot to realize them. Thank you both in instructing me in the GIS field, from your GIS courses to the thesis.

Then a big thank to my parents, thank you for providing me the great chance to across thousands of miles to the United States. Also thank to my classmates Wencong, Nova, Situ and Ruby. I will never forget the time we spent in the Data Lab struggling together. Thank you my friends, Jeff, Cindy and Wenhan, your encouragement was a great support to me. Thank you all for helping me. I really appreciate it.

Table of Contents

List of Figures

List of Tables

Chapter 1: Introduction

Land use type change can happen during natural evolution, due to human activities, and because of natural disasters. Land use change has dramatically altered the Earth's landscape and climate in the long-term. In the short time, it is important to monitor land use change, since these changes are associated with critical issues of food security, energy supply, and biology diversity. (Colette, 2015).

Land use change science is an essential element of global environmental change and sustainability research (Gutman, 2004). Land use changes in urban areas, especially the conversion of crop field and forest to urban areas, is one of the most important forms of global environmental changes (Briassoulis, 2000). Monitoring land changes in urban areas can support decision making in urban planning and resource management (Lambin 2001). The advanced techniques in remote sensing and GIS offer great help in monitoring land changes in urban areas (Elvidge, 2004).

Smart Growth America mentions, *"Expansion is defined as the process in which the spread of development across the landscape far outpaces population growth." (Smart Growth America, 2014).* Urban expansion is a major driver of land use change.

Urban expansion can have negative impacts. It has been criticized for causing environmental degradation, intensifying segregation of the land cover type and undermining the vitality of existing urban areas, especially the commercial vitality of downtown. Monitoring land use change is a one way to assess urban expansion. By monitoring and analyzing patterns of land use change planners can mitigate the effects of the expansion as well as manage the negative effects. (Kates et al. 2001).

In addition, understanding land use change can help planners balance fundamental human needs while maintaining ecosystem services which is the core challenge of sustainable development. (Kates et al. 2001). Today data sets and tools are available to help professional planers and policy makers monitor land use change. This thesis will demonstrate how to use public available data sets to explore land use change and urban expansion in Massachusetts. Similar analyses could be replicated anywhere in the contiguous United States.

In this thesis, I will examine land use change in Massachusetts between 2000 and 2010. First I will examine the spatial patterns of land use change to low intensity use, especially those that changed from forests and agricultural areas to low density urban areas, using land cover and land use change data from National land Cover dataset (NLCD) between 2001 and 2011. I will then identify built environment and socioeconomic factors that are correlated with low-intensity land use change, including low income, a lack of job access diversity, low population density, low road network density, and intersection density.

The purposes of this thesis are as follows:

i) Find previous literature on how researchers use NLCD to monitor land use change.

ii) Using NLCD land cover data in 2001 and 2011 to identify the land use change pattern in Massachusetts.

iii) Using NLCD land use change from 2001 to 2011 and built environment data from the `Smart Location Database to identify the possible correlation of land use change and built environment.

iv) Compare the results of analysis and the previous case study in literature review to better understand and utilize those NLCD and Smart Location Database and test the accuracy of those datasets.

The literature review in the next chapter provides a brief background of land use change, existing research in land use change using NLCD data, as well as some factors which are known to affect land use change. The methods chapter describes the GIS methods to address my research questions, identifying the types of land use changes from previous land cover to developed land and finally discussing the relationship between land use change and built environment.

Chapter 2: Literature Review

2.1: Land use change.

Since the mid-20th century, many American metropolises have undergone dramatic growth, with new metropolitan development patterns that shifted from more dense urban land uses to more expansive suburban land uses. This phenomena has been referred to as suburbanization. (Mieszkowski, P., & Mills, E. S., 1993). While urban development has always been regarded as a signal of the regional economic prosperity, the low density built-up land use patterns that emerged in suburban areas results from urban expansion, have begun to undermine environmental sustainability. (Lambin, 2001).

Globally, the conversion of grasslands, forests, and wetlands into developed areas has led to increases in production of food, timber, housing, and other commodities for human activities, but at the cost of reductions in many ecosystem services and biodiversity. (Lawler, J. J.et al, 2014).

In general, large scale land use change, which mostly results from human activities, have profound consequences for nature, including carbon and hydrologic cycles. (Blumstein & Thompson, 2015). Nowadays, over 60% of the nature ecosystems, such as forests and grassland have been destroyed and concerted to human-dominated uses with the rapid increasing rates and high intensity. (Foley, 2005). As more and more human influences on ecosystem have happened, keeping a balance between protecting the environment and gaining benefits is the priority things to be considered. (Daily, 2001).

2.2. Case study of using land use data from NLCD

Blumstein and Thompson (2015) found that in Massachusetts, the greatest single land cover transition during the decade between 2001 and 2011 was from forest to developed land. They found that developed urban areas increased by 6.3% and agricultural land uses declined by 5.3%. (Blumstein & Thompson, 2015). They also note that residential and commercial development increased along the western edge of the Greater Boston metropolitan area, replacing agricultural field and forestlands. Forest cover declined 1.9% during the same time period. Their study was based on NLCD (National Land Cover Datasets) for years of 2001, 2006 and 2011.

The NLCD is the primary source of land cover data in the USA, has been used extensively in studies of habitat change and environmental monitoring. (Konarska, 2002). However, the NLCD was created with the classification of Landsat-TM data. The classification tool has many limitations, such as the selection bias of training area, misclassification, the algorithms of different methods, supervised or unsupervised, minimum distance or maximum likelihood. These errors may affect the accuracy of the data. An overall accuracy assessment calculated with the confusion matrix of the 2001 and 2006 NLCD are 79% and 78% respectively, which means that 78% of the 2001 data and 79% of the 2006 data have the accurate classification results. The NLCD land use change map was created with the change detection method with an overall accuracy of 82%. (Wickham, 2013). However, recent efforts by the developers to improve comparability of the data provide confidence that the data is reliable and appropriate for land use change analyses. (Jeon, 2014).

2.3: Land use change and built environment

2.3.1 Transportation infrastructure: proximity to transit, highways

Transportation infrastructure is one important factor known to result in land use change. (Chomitz, K. M., & Gray, D. A., 1996). Furthermore, changes in land use and the associated building environment have been associated with the growth in travel demand. (Hansen, M., & Huang, Y., 1997). Kasraian, et al, (2016) reviewed the long-term influence of transport infrastructure networks including rail and road. Rail has resulted in the conversion of residential land use and higher density residential area. Some studies suggest that road network construction is associated with urban expansion, increases in employment densities in downtown area as well as commercial and industrial development. (Kasraian, et al, 2016).

Recently, there have been a lot of interest in examining the relationship between transportation and land use change due to the improvement in the quality and availability of fine grained transportation and land use data. (Handy, S., 2005). In addition, new methods and tools have become available such as remote sensing and GIS to better to investigate those links. (Kasraianet al, 2016). The figure below summarizes the transport land use feedback cycle, proposed by Wegener in 1999 and adapted by Bertolini in 2012. This shows the cycle of impacts of transportation networks and land use have for each other with other two elements, activities and accessibility. Besides, this the figure also illustrates external factors such as policy. The interaction between the two explain the trend of urban land use change in the U.S. and could help people better understand the relationship between transportation networks and land use. (Kasraian, et al, 2016). As seen in Figure 1, increase of accessibility results from the low-intensity land use changes in suburban area, along with improvement of transportation network. With increasing new transportation capacity there is increased destination accessibility, which in turn brings more people to the suburban areas resulting in urban expansion which leads to land use change. Thus transportation and land use change are closely linked. (Kasraian, et al, 2016). The loop is dynamic, which means those two elements, land use and transportation should be considered simultaneously. However, external factors also play an important role, such as zoning and other policies which favor low density, regional demand, economic development, technological innovations and infrastructure investment. (Kasraian, et al, 2016).

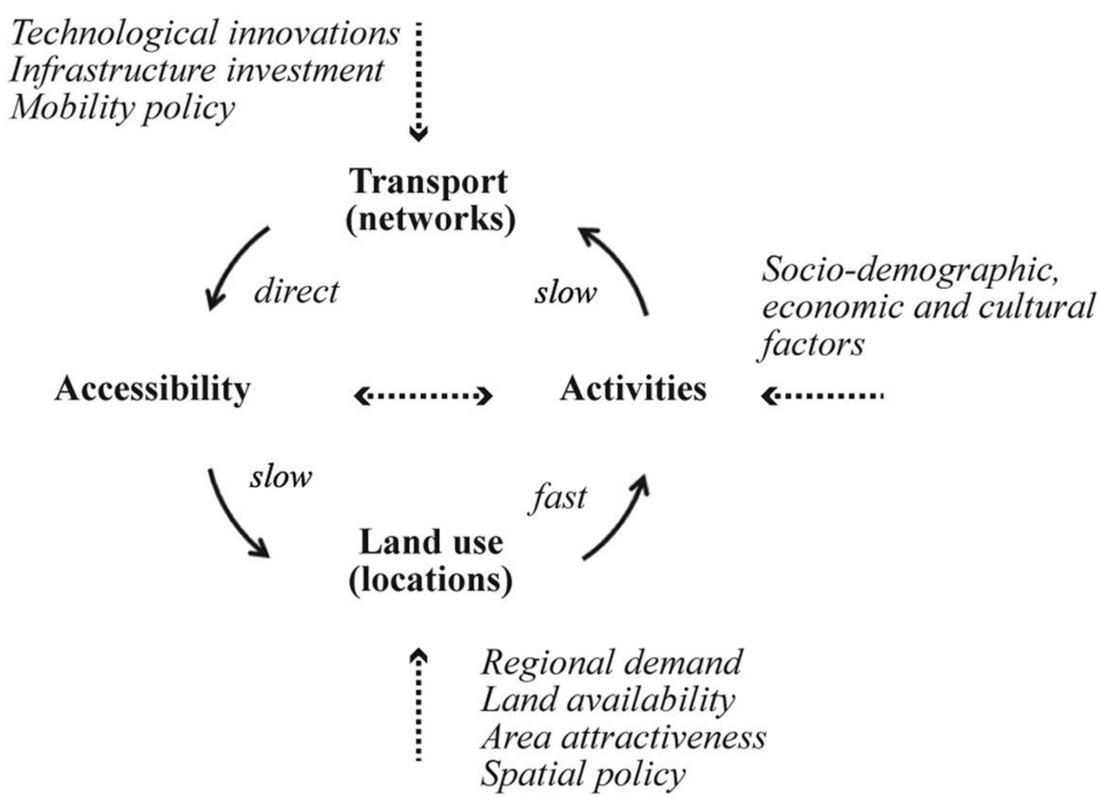

Figure 1. Transport Land Use Feedback Cycle (Wegener, 1999; adapted by Bertolini, 2012)

Transportation technology has been suggested as a major factor leading to land use change. (Xie & Levinson, 2010). Infrastructure investments and transport policies influence the supply, but also the usage of transportation networks. Land use can depend on exogenous factors influencing its supply. Without regional demand, new transportation networks are unlikely to stimulate land use change. Surprisingly, other measures of the built environment of a location have been not been well studied. Bollinger and Ihlanfeldt, (1997) suggest that high crime rates are a factor which could reduce the attractiveness of a location and found that it can neutralize the positive impact of transit infrastructure such as rail stations or accessibility factors such as employment. (Kasraianet al, 2016).

2.3.2 Accessibility to jobs: using transit and highway

Accessibility to jobs is associated with employment and residential distribution, as well as the highway and transit proximity to employment centers. The employment and residential distribution is mostly determined by the land use patterns. The urban land use model has often originated from the classic monocentric city model with most resources concentrating in the city's downtown. This model results in concentric rings of different land use types around the city, with business and commercial at the core, residential around and agricultural and forestry area at the margin. In this case, most of the employment is more concentrated in the inner city and some agricultural employment at the periphery. (Fragkias & Geoghegan, 2010).

With the rapid urban expansion and population growth, the land use model changed from monocentric city model to polycentric city model, with multiple CBDs around the caused by government policies such as zoning restrictions, attempting to create new employment opportunities and decentralizing the employment patterns. (Fragkias & Geoghegan, 2009). Firm locations were also affected by the suburban development (Kneebone, 2009) and there is considerable evidence showing that increases in job sprawl result in suburban populations that were more racially and economically homogeneous (Martin, 2001). Because the concentration of industrial and technology firms in a particular region makes those firms benefit from an innovation in a competitive local market and it is easier to regulate their pollution. Besides, zoning laws that strictly separate land use also results concentration of industrial and commercial development (Martin, 2001).

The current built environment was shaped by a polycentric spatial land use pattern and is known to affect the trip distance as well as the vehicle trip frequency.

(Cervero, R., & Kockelman, K., 1997). “Urban sprawl” as the dominant urban growth pattern in the US for over last few decades, has been associated with transportation (Southworth, 2001). For instance low density zoning, encourages more and more low-intensity land use changes take place in suburban areas which has resulted in increased highway traffic. (Southworth, 2001).

One major cause for the increasing highway traffic is increasing demand for car based travel. Increasing automobile based travel is a byproduct of suburbanization that resulted from land use change. If there is more sprawl and more low-intensity land use change, the different types of land use, such as residential, industrial, commercial, business and open space, are far apart and thus the vehicle travel distance is likely to increase. On the other hand, higher density with mixed land use is likely to not only reduce vehicle travel distance, but also encourage people to choose walk, cycle or take public transportation instead. (Southworth, 2001).

The first part of literature review illustrated the importance of studying land use change in order to better conserve forests. The second part discussed the use of the NLCD land cover data in understanding land use change.. In the last section the existing research linking land use change and built environment was discussed. The land use change and transportation combine a feedback loop, which means that they have impacts on each other.

While there has been some research on using NLCD data to understand the effects on loss of plant and animal habitat the data has not been used as a tool for planners. As planners in the US confront land use change in different ways across the country they need to understand how such data can be used to plan for the future. In this thesis I will use this data to understand land use change patterns in Massachusetts and how transportation infrastructure and accessibility to jobs can be used to understand low-intensity land use change in Massachusetts from 2001 to 2011

Chapter 3: Research Questions, Data and Methodology

3.1 Research Questions

Based on the literature review, the research questions that I am going to discuss more in this thesis include:

1) What is the NLCD data and how it could help in analyzing land use change pattern?

2) What is the spatial pattern of land use change in Massachusetts from 2001 to 2011 with NLCD data based on the case study?

3) How can Smart Location Data on transportation infrastructure and accessibility to jobs be used to understand low-intensity land use change in Massachusetts from 2001 to 2011?

For this I will use data from NLCD, EPA and MassGIS. NLCD is the land cover type data and land use change data from Multi-Resolution Land Characteristics Consortium (MRLC), which are created by GIS and remote sensing methods. Smart Location Database is provided by EPA, which is about the built environment. MassGIS provides several vector data in Massachusetts, which improves visual interpretation.

3.2 Study Area

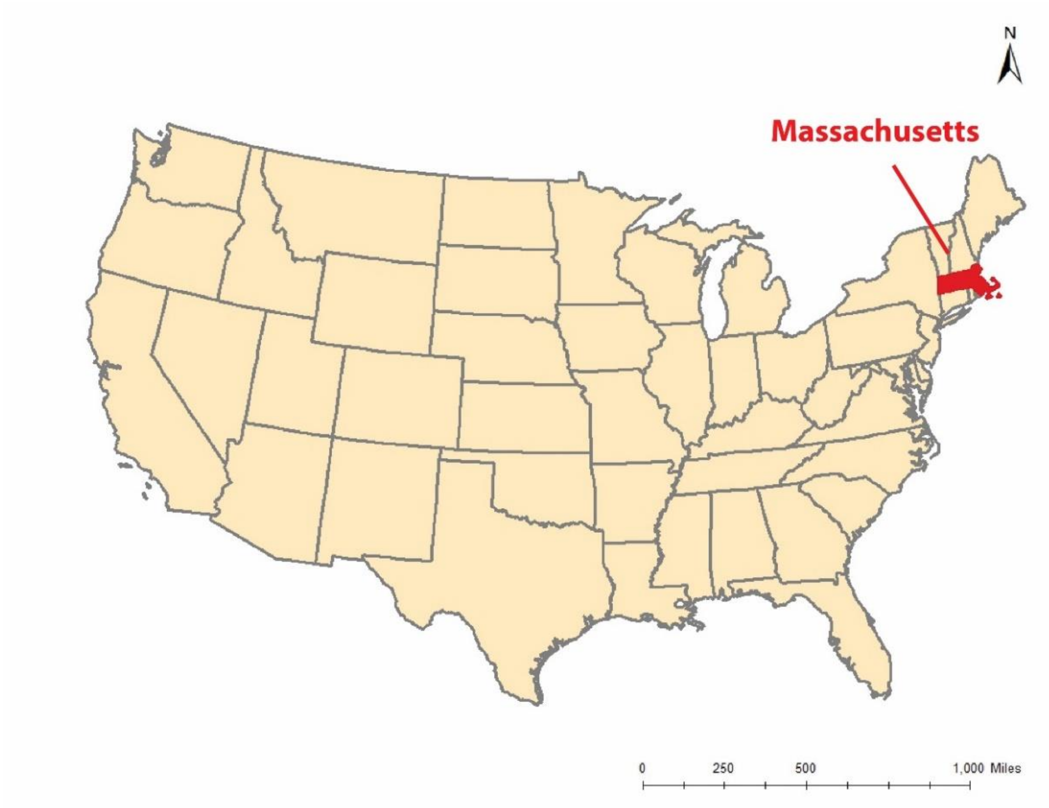

Figure 2. The Location of Massachusetts

Massachusetts (69.9-73.5°E, 41.3-42.9°N) is approximately 10,565 mi² and is predominately forested of 63%. The state contains 351 towns. The capital of Massachusetts and the most populous city in New England is Boston. In 2013, the population of Massachusetts was 6.7 million, with over 80% of Massachusetts's population lives in the Greater Boston metropolitan area (U.S. Census Bureau 2014).

3.3 Data Description

3.3.1 National Land Cover Dataset (NLCD)

The NLCD official websites provide information about the National Land Cover Dataset (NLCD). The NLCD is the primary source of land-cover data in the whole USA and has been used extensively in researcher of animal habitat loss, forest fragmentation and ecosystem service valuation (Konarska, et al, 2002).

National Land Cover Database 2011 (NLCD) is from Multi-Resolution Land Characteristics Consortium (MRLC) websites, which is a partnership of federal agencies. NLCD is the most recent national land cover product. NLCD 2011 provides four new data sets, the capability to assess wall-to-wall, spatially explicit, national land cover changes and trends across the United States from 2001 to 2011. The fundamental concept behind NLCD products is that the Earth's surface is constantly changing as is the land cover. (Torge, 2001). So it is necessary to routinely measure and understand the causes and results of land cover change. (Homer, 2015).

Based on its metadata, land cover change is measured with remote sensing technology. As with two previous NLCD land cover products (NLCD 2001 and NLCD 2006), NLCD 2011 keeps the same 16-class land cover classification scheme that has been applied consistently across the United States at a spatial resolution of 30 meters. NLCD 2011 is based primarily on a decision-tree classification of circa 2011 Landsat satellite data.

The methods and algorithms of NLCD are based on scientific research, which are reproducible. Product generation followed identical protocols nationally to ensure the consistency and accuracy both in space and time. Production protocols include source data preparation, spectral change detection, land cover change modeling and mapping, impervious and canopy generation, post-processing and product description. (Homer, 2015).

NLCD 2001 to 2011 Land Cover Change layer only contains those pixels identified as changed between NLCD 2001 and NLCD 2011 across the conterminous United States. In this data set, it uses raster data to show the land use change from the 2001 to 2011. Besides, NLCD 2001 land cover and NLCD 2001 to 2011 land cover from to change index are also useful. The 2001 land cover data shows the land cover type of Massachusetts in 2001 and the change index is a very detailed data showing the land use type in 2001 and 2011 respectively. (NLCD website).

Table 1. NLCD Data Description

Data set	Description	How I will use it
NLCD 2001 land cover	The 2001 land cover layer.	The original base data, with which to compare changed areas.
NLCD 2011 land cover	The 2011 land cover layer	Identify the land cover type of Massachusetts in 2011 and compare to 2001 land cover type.
NLCD 2001 to 2011 land cover change	Land cover layer containing those only changed pixels from 2001 to 2011.	Find areas that changed to developed urban areas.
NLCD 2001 to 2011 land cover from to change index	Raster layer containing the "from" and "to" land cover classes between 2001 and 2011.	Determine those unchanged areas as well as what land cover types had changed to developed urban areas and their surroundings.

3.3.2 Smart Location Database

I will use a data set called Smart Location Database to address my research question that correlates the built environment and land use change. It was produced by EPA (Environment Protection Agency), and has estimated several variables measuring accessibility to jobs and other characteristics of the built environment. The EPA has developed three data products to measure the relationship between building environment and transit accessibility among United States. Smart Location Database is one of them, which is a geographic data resource to measure location efficiency and summarizes more than 90 different indicators associated with the built environment by block Groups (Ramsey, K., & Bell, A., 2014).

In terms of transit, the EPA provides its own criteria to classify all street links as either auto-oriented, multi-modal, or pedestrian-oriented. Total road network density is calculated by summing links from all three categories above and dividing by land acre. (Ramsey, K., & Bell, A., 2014).

EPA calculated total intersection density by creating a weighted intersection density metrics. In particular, auto-oriented intersections were weighted zero, because in many instances, auto-oriented intersections are unfriendly to pedestrian and bicycle mobility. Furthermore, since three-way intersections do not promote street connectivity as effectively as four-way intersections, their relative weight was reduced accordingly. (Ramsey, K., & Bell, A., 2014).

3.3.3 MassGIS

I also selected some vector data from MassGIS, such as highway, MBTA Commuter Rail and New Dun and Bradstreet Business Data (A 2007 dataset), which help improving the visual interpretation of my analysis results.

Table 2 Data from MassGIS

Data Set	Description	Source
Highway	Interstate highways and highways in Massachusetts	MassGIS
MBTA Commuter Rail	The purple line	MassGIS
New Dun and Bradstreet Business Data	contains point locations of businesses created in 2007 from the commercial Dun and Bradstreet database	MassGIS
OpenSpace	protected and recreational open space	MassGIS
Towns_Poly	Public boundary of towns in Massachusetts	MassGIS

The protected and recreational open space data set is collected from MassGIS. They represent parklands, forests, golf courses, playgrounds, wildlife sanctuaries, conservation lands, water supply areas, cemeteries, school ball fields, and other open land that may be classified as protected or recreational in use.

3.4 Methods

3.4.1 Identify spatial land use change pattern in Massachusetts

To answer the question 2: identifying land use change patterns in Massachusetts, especially the developed urban areas and their surroundings, the three versions of NLCD are combined for analysis. These were my major steps:

1) Use the Clip tool in ArcGIS to extract those versions of NLCD to only focus on the area of Massachusetts.

2) Use the NLCD 2001-2011 change file and Reclassify tool in ArcGIS to identify those areas that have changed to some form of development since 2001 and identify what land cover type they were in 2001. This is useful to identify what those changing area was before and which land cover type have changed the most.

3) For each town, use the Tabulate Area tool in ArcGIS to join reclassified shapefile to towns' shapefile, then calculate percentage of the acres of change into each of the developed urban types for each town. Focus on the top ten towns in each category and determine their spatial pattern and using Local Moran's I to determine the cluster pattern. The cluster maps are good for determine the distribution of each types of developed land use change visually.

4) Calculate the acres of previous land cover in 2001 with the NLCD 2001 data set and calculate the acres of land cover in 2011 with the NLCD 2011. Then make

a comparison of those two datasets to determine which kind of land cover type have changed the most and make further analysis.

5) For each cluster of change to developed urban areas, identify the land cover of surrounding area and predominant land cover type in 2001 with the Reclassify, Raster Calculator and Euclidean Distance tools in ArcGIS (define the surrounding area to be analyzed at 15 cells which would be 450 meters, 450 meters is an estimate of the threshold that people prefer walking and good for human activities).

6) Use the Kernel Density tool in ArcGIS with the DNBBUSINESS_PUBLIC dataset to make the business density map in the 100-meter output cell size, which is helpful to make a visual analysis on the relationship between employment and transit and highway construction.

3.4.2 Determine the correlation between built environment and low-intensity land use change.

Because Ewing (2014), defined land use change as an obvious characteristic of urban expansion, and the low value in spatial heterogeneity is related to urban expansion. Therefore I examine "Low-intensity land use change", in particular. This is the combination of low and very low intensity developed urban area land use change from NLCD data, to the total developed urban area land use change in a spatial unit. To better address the question 3, to determine the correlation between built environment and low-intensity land use change, the variable, “low-intensity land use change” is calculated with the NLCD land use change 2001 to 2011 data. “Low-intensity land use change” is shown in the equation below:

$$\boldsymbol{L = \frac{Dv+Dl}{Dv+Dl+Dm+Dh} \times 100\%} \qquad \textbf{\textit{Equation 1}}$$

Where

L: low-intensity land use change

$\mathbf{D_o}$: very low in developed area

$\mathbf{D_l}$: low intensity in developed area

$\mathbf{D_m}$: medium intensity in developed area

$\mathbf{D_h}$: high intensity in developed area

These variables can be found in the attribute called “Land Cover Class Code Value” in NLCD 2001 to 2011 land cover change, which is used to represent land use change. The value calculated using Equation 1 is a number that ranges from 0 to 100, which indicates the percentage of low intensity land use change in developed area to the total land use change in developed area in a spatial unit. I have used two spatial units in this analysis: town and census block group.

Table 3. Variables Description

Independent Variable	Description	Data Set
Low-intensity land use change	Low intensity developed urban area land use change to the total developed urban area land use change.	NLCD 2001 to 2011 land cover change
Dependent Variable	**Description**	**Data Set**
Gross employment density	Jobs/acre, on unprotected land	Smart Location Database
Gross population density	Population/acre, on unprotected land	Smart Location Database
Total road network density	Summing links from auto-oriented, multi-modal, and pedestrian-oriented road network and dividing by land acre.	Smart location Database
Job density	Job per household	Smart location Database
Employment diversity	Employment entropy, including retail, office, industry, service and entertainment	Smart location Database
Intersection density	Intersection density in terms of pedestrian-oriented intersections having four or more legs per square mile	Smart location Database
Transit accessibility	Distance from population weighted centroid to nearest transit stop (meters)	Smart location Database
Destination accessibility by auto	Jobs within 45 minutes auto travel time	Smart location Database
Destination accessibility by transit commute	Jobs within 45 minutes transit commute	Smart location Database
Working-age population	Working-age population within 45-minute transit commute	Smart location Database

Proportional Accessibility to Regional Destinations	Working-age population accessibility by auto expressed as a ratio of total core based statistical areas accessibility	Smart location Database
Income	Median income in towns in 2010.	Census 2010

Based on the report by Smart Growth America, (2014), development density is a significant factor correlated with low-intensity land use change, which including population density and employment density. (Smart Growth America, 2014). I will use income, population density and employment diversity as potential development density factors based on Ewing's study in development density and activities centering. Besides, Ewing also mentions that the balance of jobs to total population and mix of job types are necessary to avoid sprawl (Smart Growth America, 2014). Therefore job accessibility by transit and by auto are other possible factors, in addition to destination accessibility. Ewing suggests that highway construction, road network and intersection design are important. (Smart Growth America, 2014). Those aspects could be considered as independent variables which are possible correlated with low-intensity land use change.

I use GeoDa for Exploratory Spatial Data Analysis and to calculate spatial statistics (Anselin, L., 1995), such as Univariate Local Moran's I, creating scatter plots and conditional maps to determine the spatial patterns of land use change, built environment and accessibility related variables in Massachusetts. Univariate Local Moran's I can for example map income clusters, which could tell us which areas are high income surrounded by high income. Scatter plots will be used for analysis of the correlation of these variables across the state. I will then use multivariate spatial regressions (Anselin, L., 2002) in GeoDa to find some potential spatial relationships between low-intensity land use change and accessibility and sociodemographic variables.

Chapter 4: Analysis of Land Use Change Pattern in Massachusetts

In this chapter I will use maps and tables to first summarize the land use patterns that emerged from the NLCD data at the pixel level. I will also summarize the patterns of change in tables by towns. I will then list some examples that are unique and surprising in the findings. Finally, I will provide discussion and limitations.

4.1 Results

As the two land cover maps and the table show (Figures 3 and 4, and Table 3), Massachusetts was mostly forested, shown in green color in the map. There were also large clusters of developed urban area, shown as red in the map. The urban development pattern is polycentric surrounding the city of Boston, and other cities including Springfield, Worcester, Lowell and Lawrence.

Table 3 shows the area in acres in 2011 subtracted from the area in acres in 2001 of each land cover type. The four types of developed urban area increased more than other land cover types. Along with a small increase of shrub and grassland, there was a large decrease of other natural land cover types, such as forests, wetlands and agriculture fields. High intensity developed urban land cover area had the highest percentage increase of 13.42%, while medium intensity developed urban area also increased to 9.94%. Those statistics suggest urban expansion, with increased urban development due to human activities from 2001 to 2011 with a loss of natural land cover.

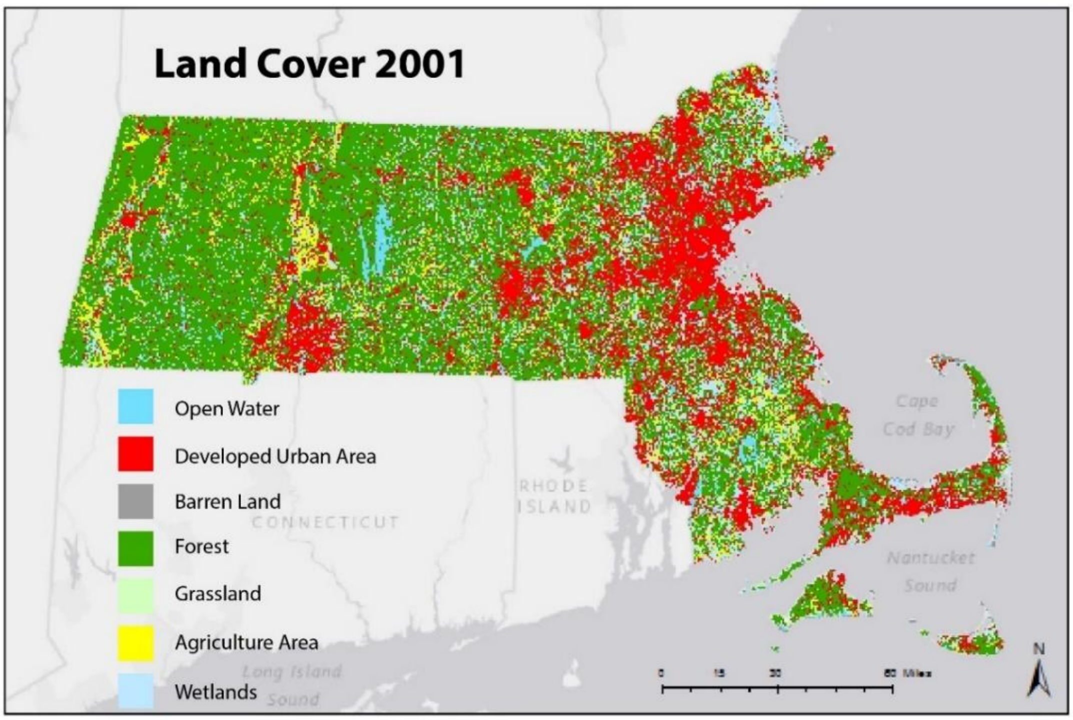

Figure 3. Land Cover Type in 2001

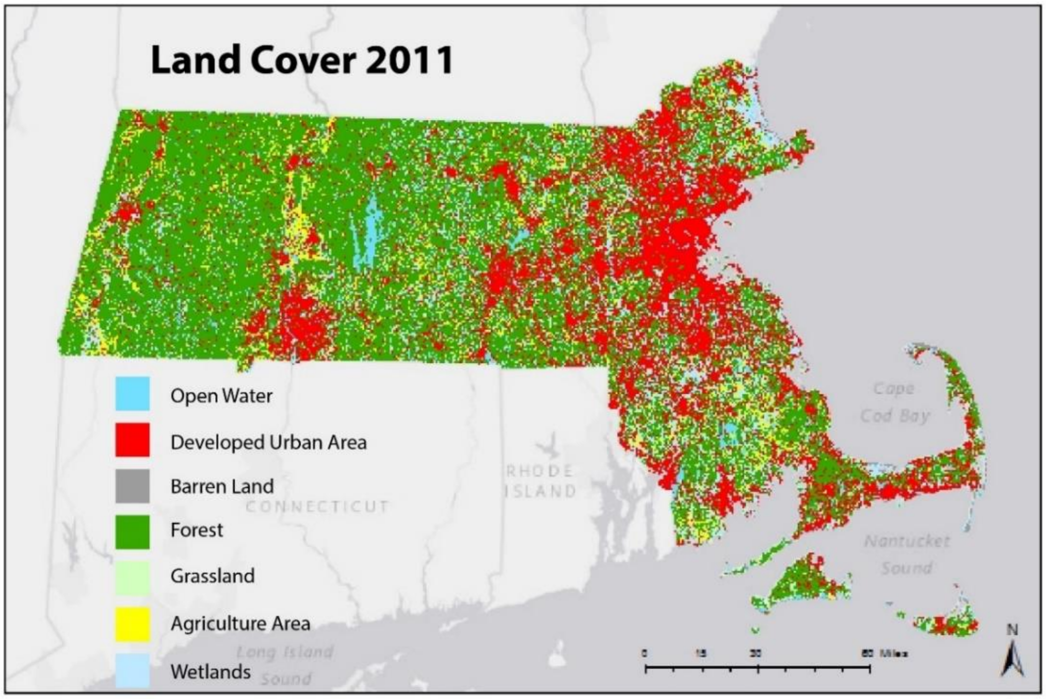

Figure 4. Land Cover Type in 2011

Table 4. Land Cover Type in 2001 and 2011

Land Cover Type	**Acres in 2001**	**Acres in 2011**	**Change**	**Percentage (%)**
Developed, High Intensity	99,738	113,126	13,388	13.42
Shrub	61,598	67,878	6,280	10.2
Developed, Medium Intensity	318,544	350,213	31,669	9.94
Barren Land (Rock/Sand/Clay)	44,903	46,837	1,934	4.31
Developed, Low Intensity	385,680	401,026	15,346	3.98
Developed, Very Low Intensity	425,527	442,095	16,568	3.89
Grassland	47,984	49,533	1,549	3.23

Emergent Herbaceous Wetlands	107,965	107,613	-352	-0.33
Open Water	180,025	178,810	-1,215	-0.67
Woody Wetlands	528,091	521,141	-6,950	-1.32
Mixed Forest	413,694	406,151	-7,543	-1.82
Deciduous Forest	1,682,472	1,646,826	-35,646	-2.12
Evergreen Forest	563,462	545,906	-17,556	-3.16
Cultivated Crops	70,208	66,535	-3,673	-5.23
Hay	248,887	235,562	-13,325	-5.35
Total	5,178,778	5,179,252	474	

I set a buffer of 450 meters around pixels that changed to developed urban area, but excluded those pixels themselves, and the buffers are referred to as “surrounding” areas (Figure 5 and Table 5). The map of surrounding land cover types in 2001 as well as a table identifying the surrounding land cover types in 2001 of those areas that changed to developed urban area are shown in Figure 5 and Table 5. As seen in Figure 5 there are a large number of developed urban area. Forests and wetlands are also dominant in the surrounding area.

Table 5. Land Cover Type in 2001 and 2011 for Areas Surrounding Urbanizing Pixels (A Buffer of 450-meter Surrounding Area)

Land Cover Type	Acres
Deciduous Forest	372,805
Developed, Low Intensity	317,495
Developed, Medium Intensity	302,522
Developed, Very Low intensity	275,925
Woody Wetlands	199,045
Evergreen Forest	141,487
Developed, High Intensity	98,539
Hay	63,339
Open Water	57,687
Mixed Forest	53,110
Emergent Herbaceous Wetlands	38,415
Grassland	21,073
Cultivated Crops	20,217
Shrub	17,626
Barren Land (Rock/Sand/Clay)	12,725
Total	1,992,010

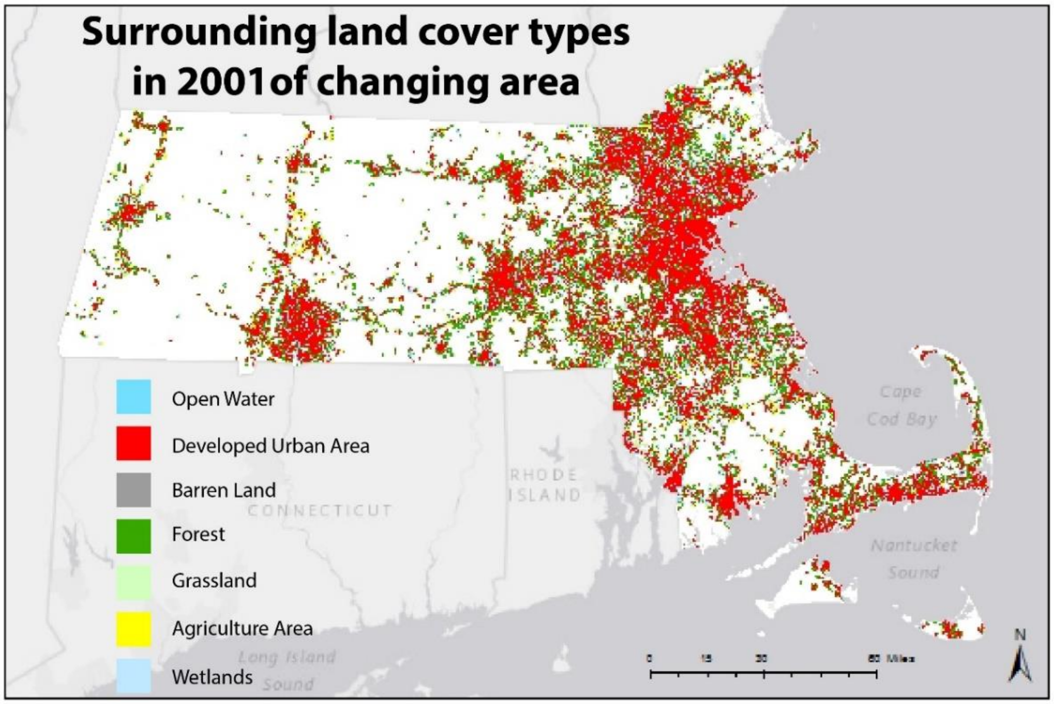

Figure 5. Land Cover Type in 2001 and 2011 for Areas Surrounding Urbanizing Pixels (A Buffer of 450-meter Surrounding Area)

The map as well as table of changing area land use type in 2001 (Figure 6 and Table 6) shows what the land cover of the changed pixel was like in 2001, showing locations that have changed to developed urban area. The area of the forests were relatively large and there were also some urban areas changing to other types of urban area. The area of high-intensity developed urban area in table 6 is 0, which means that there is no developed area have changed from higher intensity to lower intensity.

Based on these findings, we see that the changing land use patterns in the decade of 2001 to 2011 suggest that most of the changes are surrounded by existing urban areas and they have changed from lower intensity developed area to higher intensity developed area. In addition, there were large area of forests that changed to developed urban area suggesting a pattern of urban expansion.

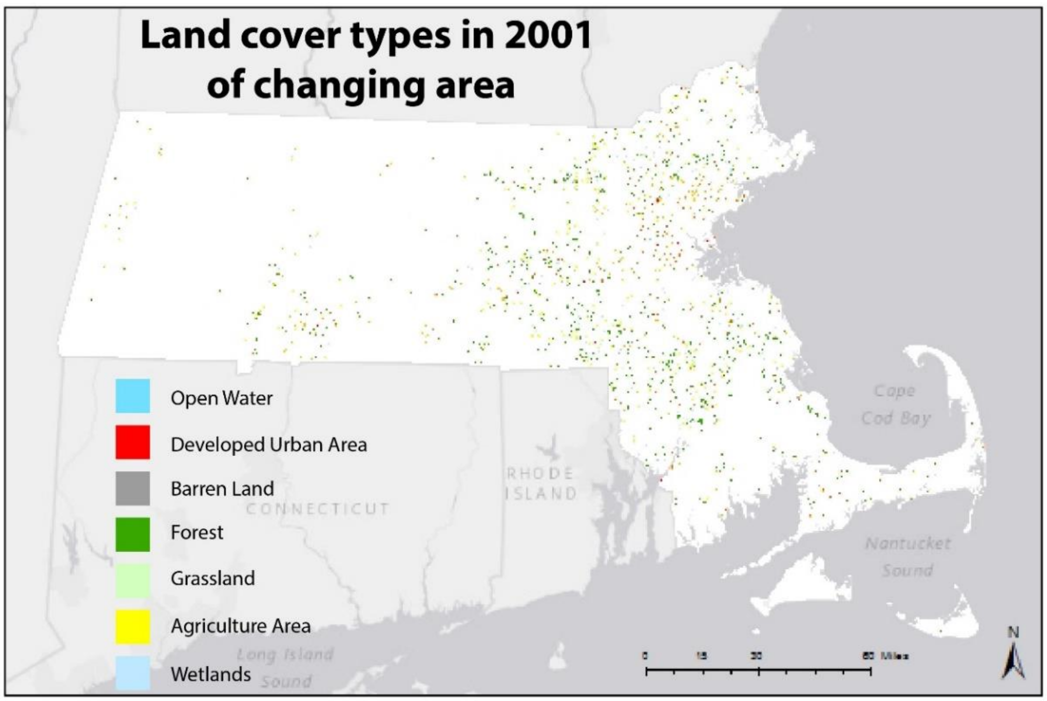

Figure 6. Original Land Cover Types for Urbanizing Pixels

Table 6. Original Land Cover Types for Urbanizing Pixels (What Were the Land Cover Types of changing pixels like in 2001)

Land Cover Type	Acres
Deciduous Forest	28,042
Developed, Very Low Intensity	17,822
Developed, Low Intensity	13,124
Evergreen Forest	12,451
Hay	12,395
Woody Wetlands	6,346
Mixed Forest	4,496
Shrub	3,760
Cultivated Crops	2,948
Barren Land (Rock/Sand/Clay)	2,849
Grassland	1,690
Emergent Herbaceous Wetlands	1,592
Developed, Medium Intensity	1,120
Open Water	383
Developed, High Intensity	0
Total	109,018

Figure 7 shows a business density Map created with the DNBBUSINESS dataset and it shows the density of the business locations in 2007, with each pixel set to a size of 100 m2. The higher densities area appears to follow the pattern of highways and commuter rail lines. This suggests a correlation between employment and accessibility to jobs as noted in the literature review.

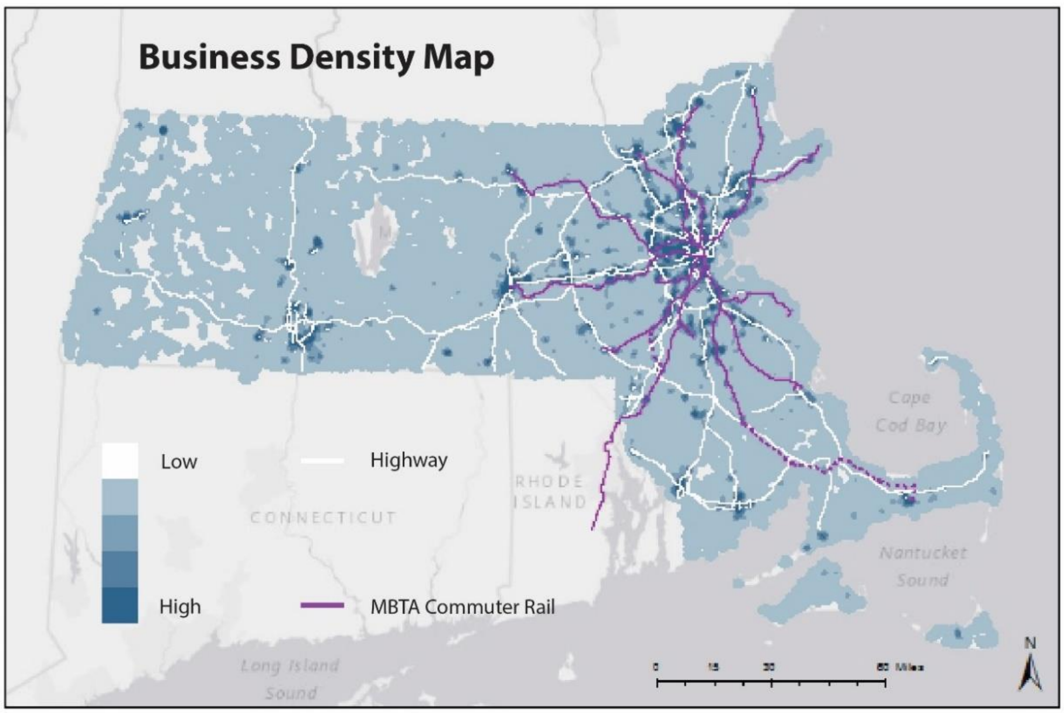

Figure 7. Business Density Map

Based on the tables and figures the very low intensity and low intensity land use change (Figure 8, 9, 10, 11 and Table 7, 8), it is obvious that towns with low or very low intensity land use change, are clustering in suburban areas and also following the pattern of highway construction. Figure 11 shows this using Local

Moran's I. Here the low-low clusters are in the western parts of the state where there are more forests. The top 10 towns, are highlighted red in the percentage map and listed in Tables 7and 8. Those towns appear to have more low-intensity land use change, which could be a signal of urban expansion.

Table 7. Percentage of Very Low Intensity Land Use Change

Town	**Area of Very Low Intensity Land Use Change (m^2)**	**Total Area of the Town (m^2)**	**% of Very Low Intensity Land Use Change**
NORTH READING	1,697,400	34,957,834	4.86
RAYNHAM	2,397,600	53,739,375	4.46
NORFOLK	1,587,600	39,872,124	3.98
MIDDLETON	1,428,300	37,509,465	3.81
EASTON	2,823,300	75,713,032	3.73
HOPEDALE	510,300	13,779,880	3.70
AYER	909,900	24,611,460	3.70
BELLINGHAM	1,785,600	48,975,606	3.65
NORTH ATTLEBOROUGH	1,814,400	50,255,582	3.61
MEDWAY	1,066,500	30,205,798	3.53

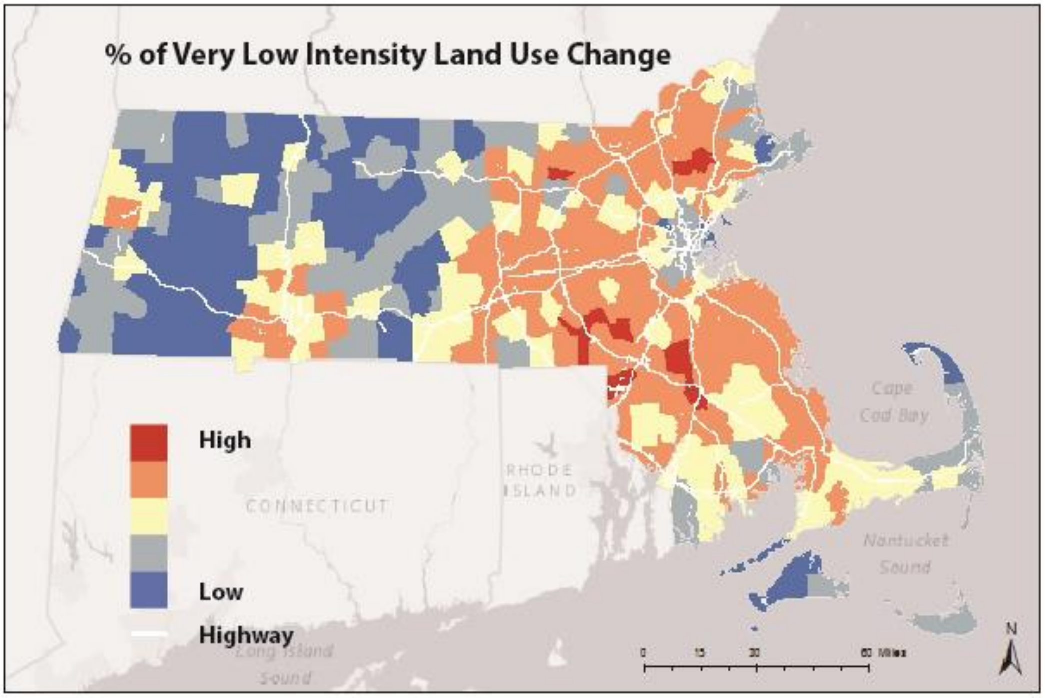

Figure 8. Percentage of Very Low Intensity Land Use Change by Town

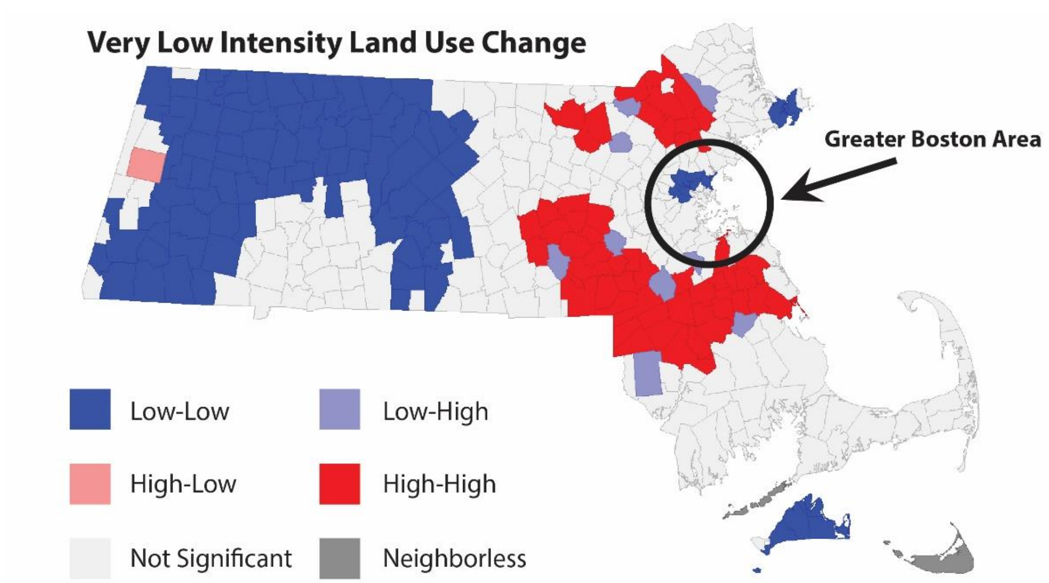

Figure 9. Very Low Intensity Land Use Change Cluster Map by Town

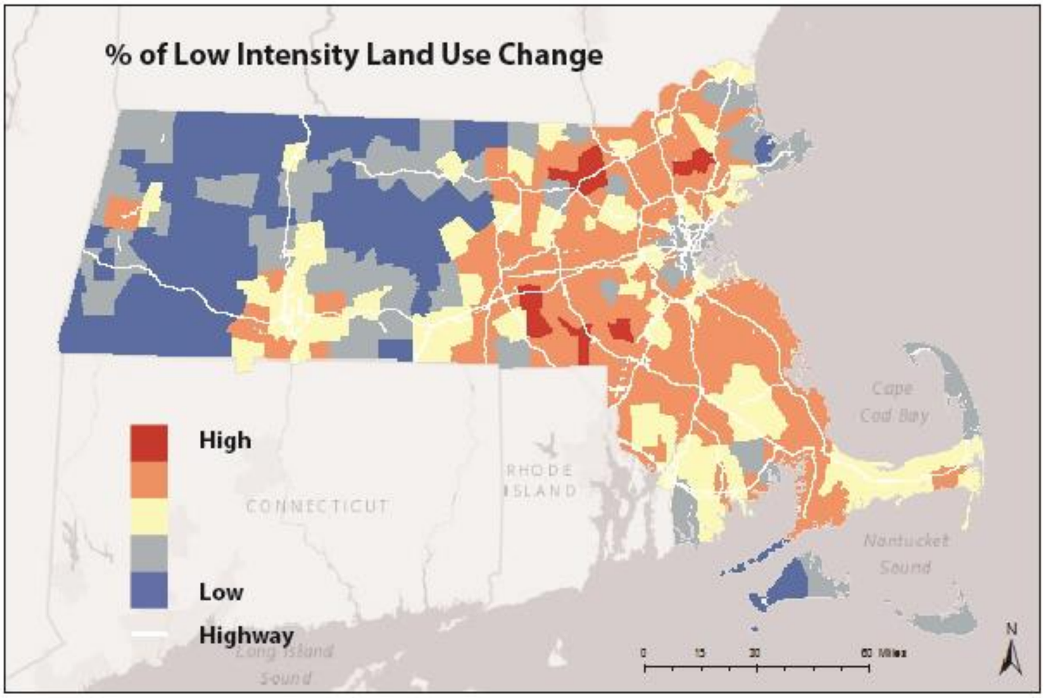

Figure 10. Percentage of Low Intensity Land Use Change by Town

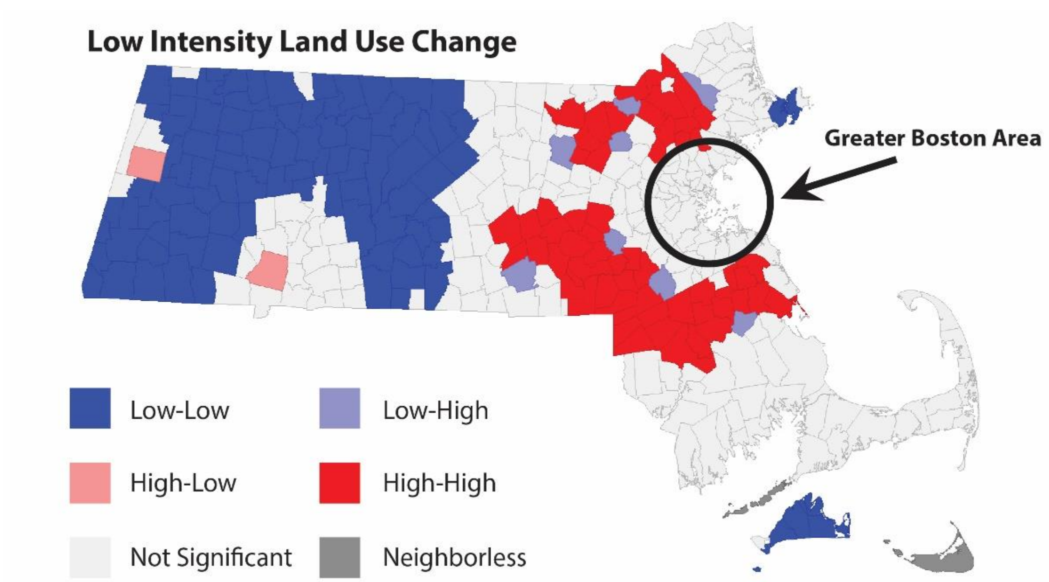

Figure 11. Low Intensity Land Use Change Cluster Map by Town

Table 8. Percentage of Low Intensity Land Use Change

Town	Area of Low Intensity Land Use Change (m^2)	Total Area of the Town (m^2)	% of Low Intensity Land Use Change
HOPEDALE	481,500	13,779,880	3.49
AYER	854,100	24,611,460	3.47
NORFOLK	1,350,000	39,872,124	3.39
NORTH READING	1,166,400	34,957,834	3.34
GRAFTON	2,010,600	60,432,510	3.33
MIDDLETON	1,115,100	37,509,465	2.98
LITTLETON	1,332,900	45,412,155	2.94
WESTFORD	2,313,000	81,208,951	2.85
NORTHBRIDGE	1,309,500	46,797,564	2.80
BELLINGHAM	1,350,900	48,975,606	2.76

Figures 12, 13, 14, 15 and Tables 9, 10 show towns that have higher percentage of medium and high intensity land use change, which seem to cluster close to the Greater Boston Area. As discussed previously most of the medium and high intensity land use change was from low intensity developed area, suggesting urbanization. As Table 10 shows some of the towns in the top 10 list of high intensity land use change, are close to Boston, which is the largest city in the region. Revere, Winthrop and Chelsea, are close to Boston or connected by highway or rail lines. Malden as well as Cambridge is also well connected to Boston and has many commercial and business area and in the case of Cambridge has large employment incubators like Harvard and MIT. These towns are among the most densely populated urban cities in Massachusetts and high intensity developed land use change have taken place there.

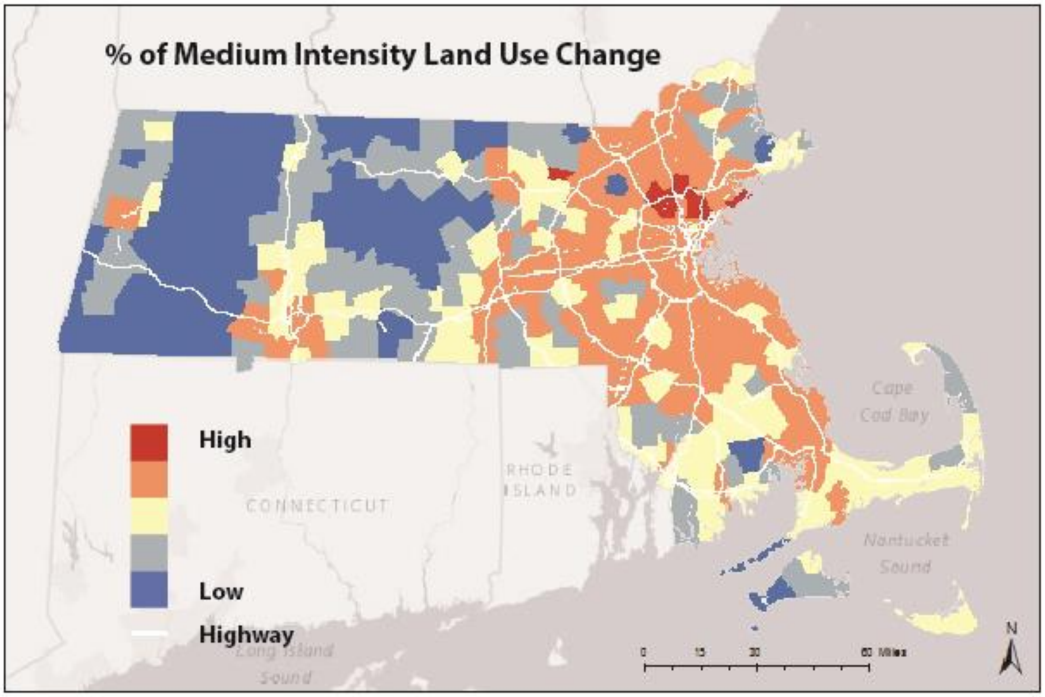

Figure 12. Percentage of Medium Intensity Land Use Change by Town

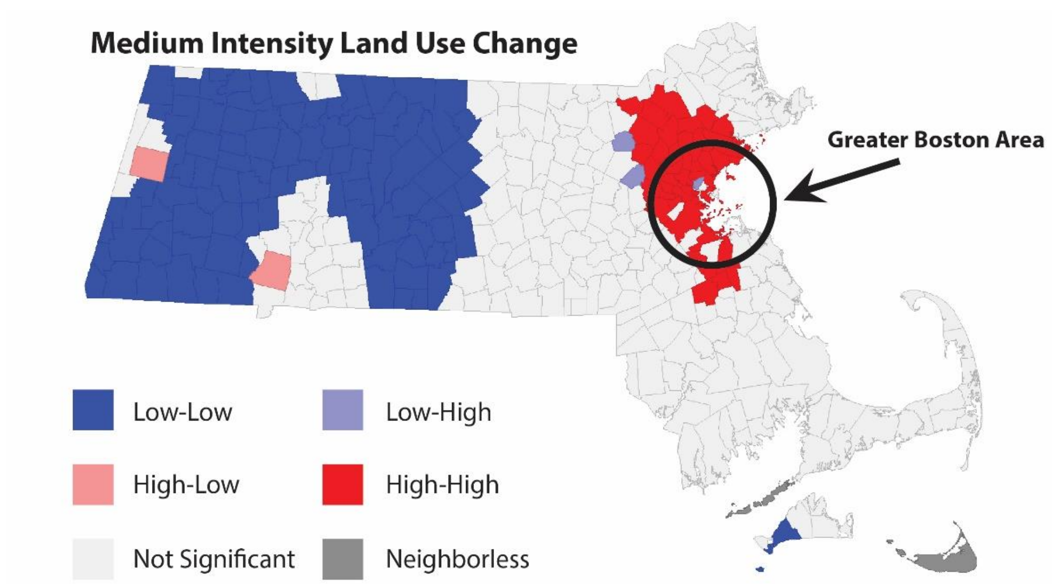

Figure 13. Medium Intensity Land Use Change Cluster Map by Town

Table 9. Percentage of Medium Intensity Land Use Change

Town	Area of Medium Intensity Land Use Change (m^2)	Total Area of the Town (m^2)	% of Medium Intensity Land Use Change
MELROSE	693,900	12,288,894	5.65
WAKEFIELD	1,075,500	20,661,492	5.21
SWAMPSCOTT	364,500	7,873,265	4.63
MARBLEHEAD	489,600	11,550,152	4.24
WINCHESTER	690,300	16,490,721	4.19
SAUGUS	1,208,700	29,570,458	4.09
AYER	999,000	24,611,460	4.06
WOBURN	1,354,500	33,567,689	4.04
BURLINGTON	1,212,300	30,712,459	3.95
READING	999,900	25,827,652	3.87

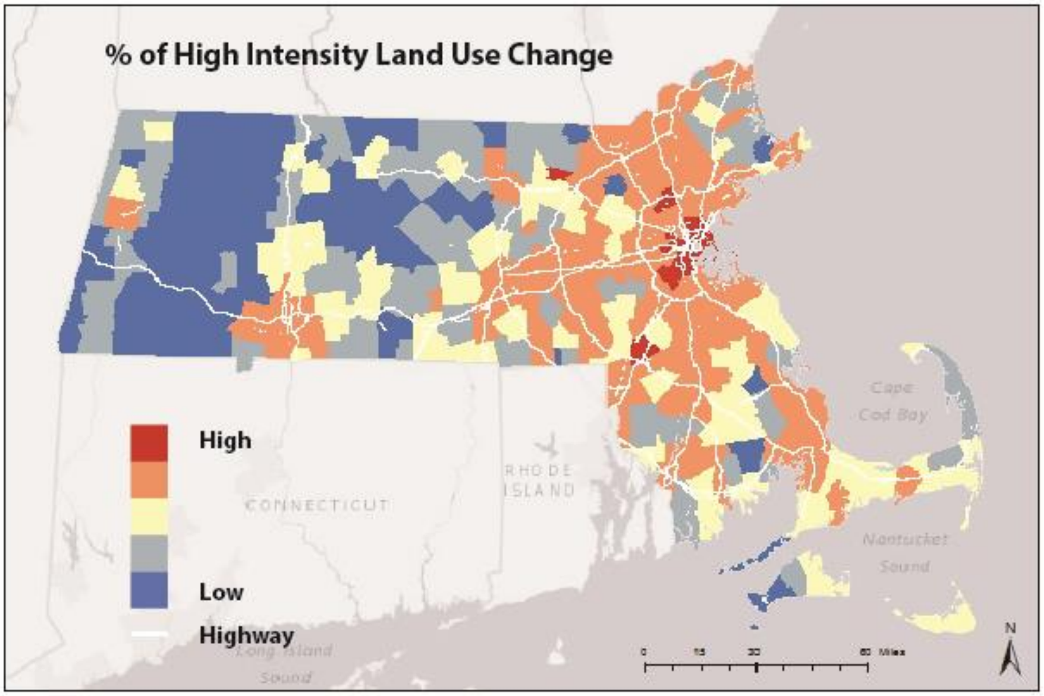

Figure 14. Percentage of High Intensity Land Use Change by Town

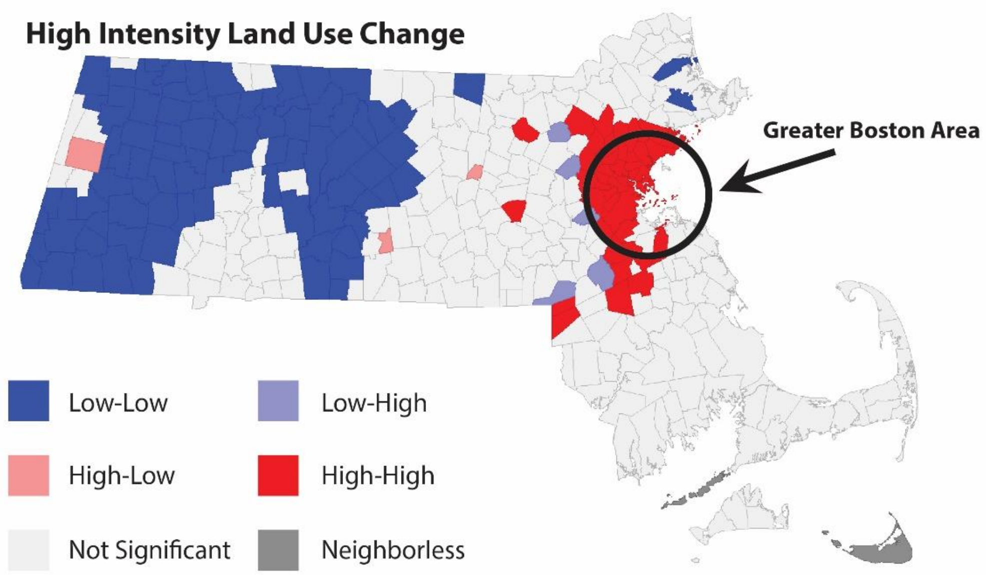

Figure 15. High Intensity Land Use Change Cluster Map by Town

Table 10. Percentage of High Intensity Land Use Change

Town	Area of High Intensity Land Use Change (m^2)	Total Area of the Town (m^2)	% of High Intensity Land Use Change
AYER	629,100	24,611,460	2.56
CHELSEA	111,600	5,720,708	1.95
BOSTON	2,468,700	128,251,223	1.92
REVERE	285,300	15,404,800	1.85
EVERETT	158,400	8,925,300	1.77
WINTHROP	94,500	5,345,616	1.77
WOBURN	585,900	33,567,689	1.75
CAMBRIDGE	306,000	18,557,078	1.65
FOXBOROUGH	844,200	53,994,232	1.56
MALDEN	202,500	13,130,619	1.54

One unusual city in the top 10 is "Ayer" which appeared in all four top 10 lists from very low intensity land use change to high intensity land use change. Ayer is a small town to the north-west of Boston. The land cover type map of Ayer in 2001 and 2011 respectively are shown in Figure 16 and 17. I use the graduated red colors to separate developed urban areas with different intensities. There was a large area of newly developed urban area in the east part of the city. The size of Ayer is relative small, so as a percentage of developed land use change was relatively high. Within its relatively small, but thriving and historical area, the town boasts numerous industries, and also benefits from commuter rail service to Boston and its proximity to towns like Acton, Littleton and Westford which are attractive for families looking for good school districts.

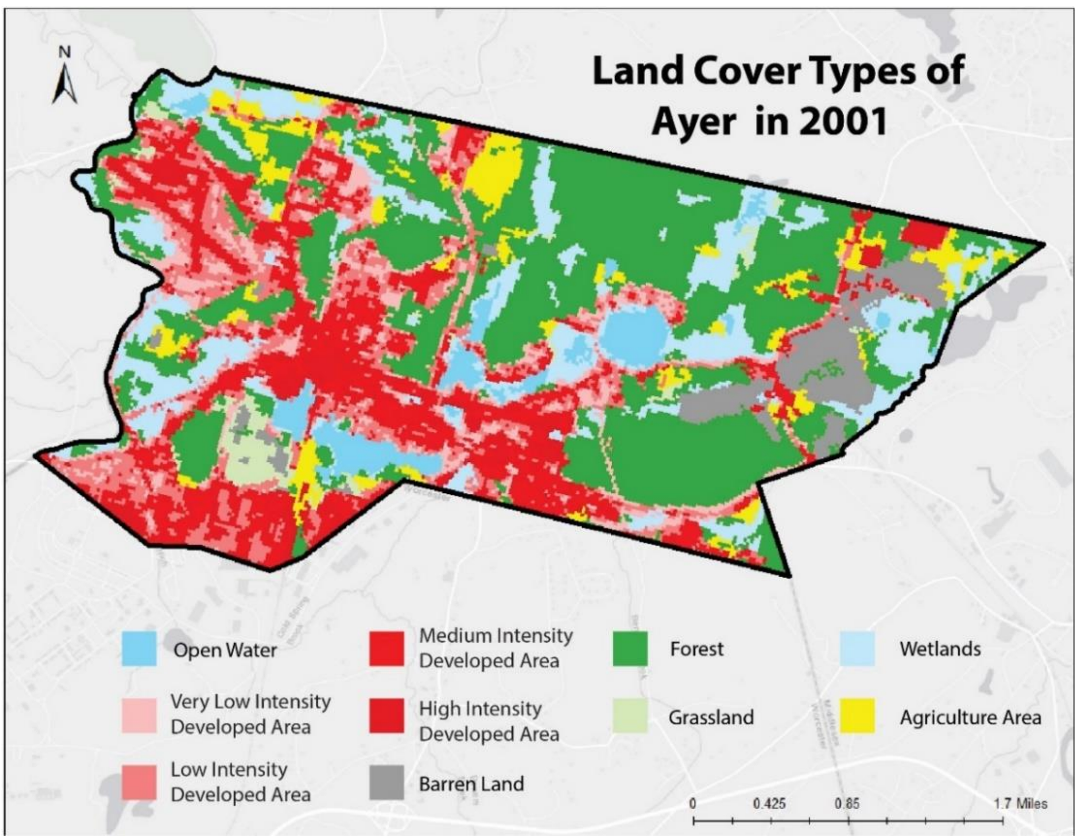

Figure 16. Land Cover Type of Ayer in 2001

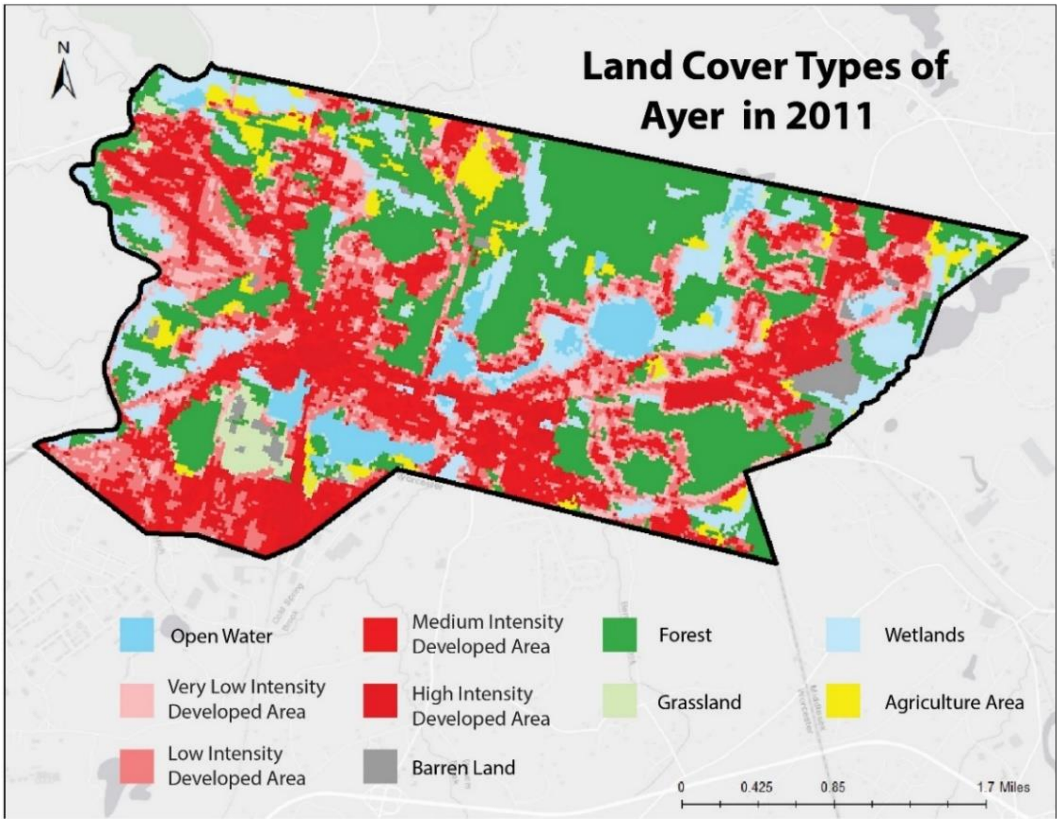

Figure 17. Land Cover Type of Ayer in 2011

Another interesting phenomenon is that some towns, like Carlisle, Concord and Lincoln, have very little land use change to developed urban area while their neighbors, like Westford, Littleton, Billerica and Burlington, have a lot of change, which is marked with red in the Figure 18. One possible reason for this is that there are more protected open spaces, which is shown green, in Carlisle, Concord and Lincoln than their neighbors. Based on zoning policy, those open space are unlikely to change in the short term.

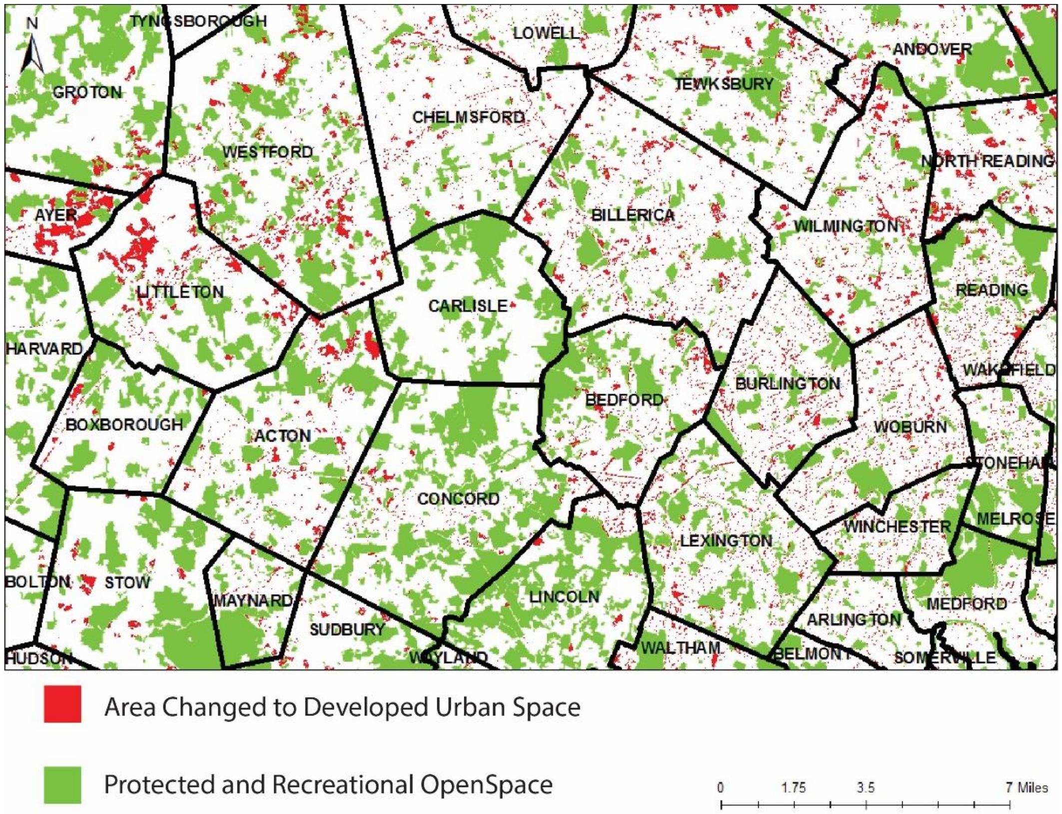

Figure 18. Developed Land Use Change and Open Space

4.2 Discussion and Limitations

Blumstein & Thompson (2015), provided a case study of analyzing land use change pattern in Massachusetts from 2001 to 2011 with the NLCD land cover data. I have followed some of their ideas to develop my analysis on land use change pattern in Massachusetts and my results confirm their findings about Massachusetts. My results suggest that many of the newly developed urban area are changing from existing low intensity developed urban area, which may be because of urban expansion. However, there are also large areas of deforestation, which may have resulted in loss of species habitat.

4.2.1 Limitations

The NLCD official websites claimed that the overall accuracy for NLCD 2001 and 2006 are over 78%. In the field of remote sensing if the overall accuracy is more than 65%, the classification result is considered reliable. The core work of classification is matching each pixel's spectrum to the existing known spectrum of each land cover type in order to classify those pixels. But these images come from Landsat satellite, and the results could be affected by the weather, seasons and clouds. An accuracy of 78% is reasonable for a large area like the state of Massachusetts, at a resolution of 30 meters pixel. As Jeon (2014) mentioned, those data are reliable and appropriate for basic analyses. Despite the accuracy of NLCD data sets, there are still some limitations worth discussing.

Although the NLCD data has relatively high accuracy, there are still some errors in the data. For example there are some single pixels with a large area of surroundings unchanged, shown in Figure 19. This is in Medfield, which is a town south-west of Boston. Those red squares are pixels are shown as changed to developed urban areas. I checked those places with a satellite image and found that these pixels are existing residential areas, which are unlikely to have changed from 2001 to 2011. So this may be because the data error, or an error due to the classification method. Large clusters of changed pixels were found to be more reliable. So in future studies, it is better to only keep large clusters of pixels and eliminate single changed pixels.

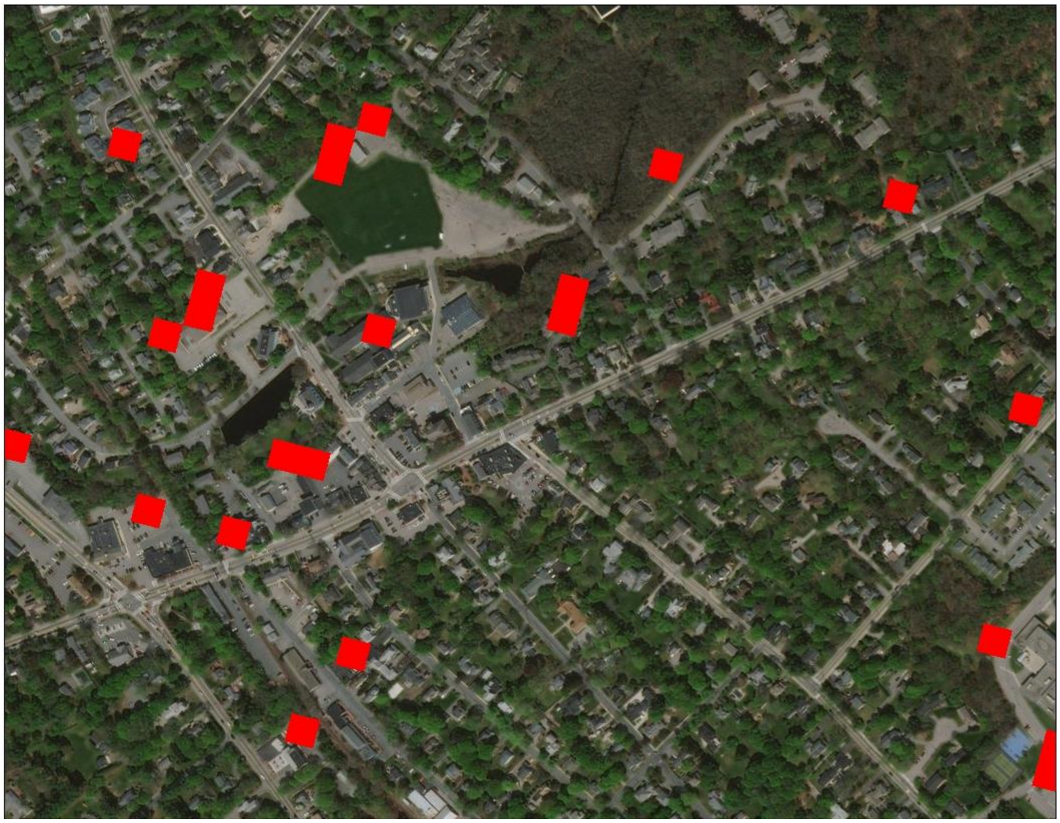

Figure 19. Small Scale Changing Pixels

This thesis uses the NLCD data set from 2001 to 2011. Ten years may be too short to witness land cover type changes. Furthermore the United States has been urbanizing for a long time. In recent years, urban development has been at a very slow pace in the United States. So for the further study, more data sets, such as the new one NLCD 2016, are necessary for an analysis of longer term land use changes.

Chapter 5: Analysis of Correlation between Low-intensity Land Use Change and Built Environment

In this Chapter, I will use GeoDa to conduct spatial statistics analysis. I will use univariate Local Moran's I to make cluster maps of the "low-intensity land use change" and other variables summarizing the built environment, transportation, income, employment and accessibility to jobs. Then I will use GeoDa to run an ordinary least squares (OLS) regression and spatial lag regression. Finally, I will discuss the results and limitations of this statistical analysis.

5.1 Results

The low-intensity land use change cluster maps shown in Figure 20 and 21 illustrate the pattern of low-intensity land use change in Massachusetts at the census block group scale. Figure 21 shows that in the Greater Boston Area, most of the clusters are low-low, which means those areas have a low percentage of low-intensity land use change and are surrounded by areas with low percentage of low-intensity land use change. The high-high clusters are in suburban areas between the I-95 and I-495 highways in a radial pattern. Ewing (2014), mentions that the urban expansion could be defined as low-density or single-use development. Low-intensity urban area land use change could be considered as low density development. It appears that low-intensity land use change is following the pattern of highway construction based on the map in Figure 20. Researchers have suggested that highway construction is one of the significant causes of low-density development, and this map supports this argument. Besides, the relative ease and low cost of automobiles and the low gasoline taxes enhance low-density development since it increases automobile based accessibility to suburban areas.

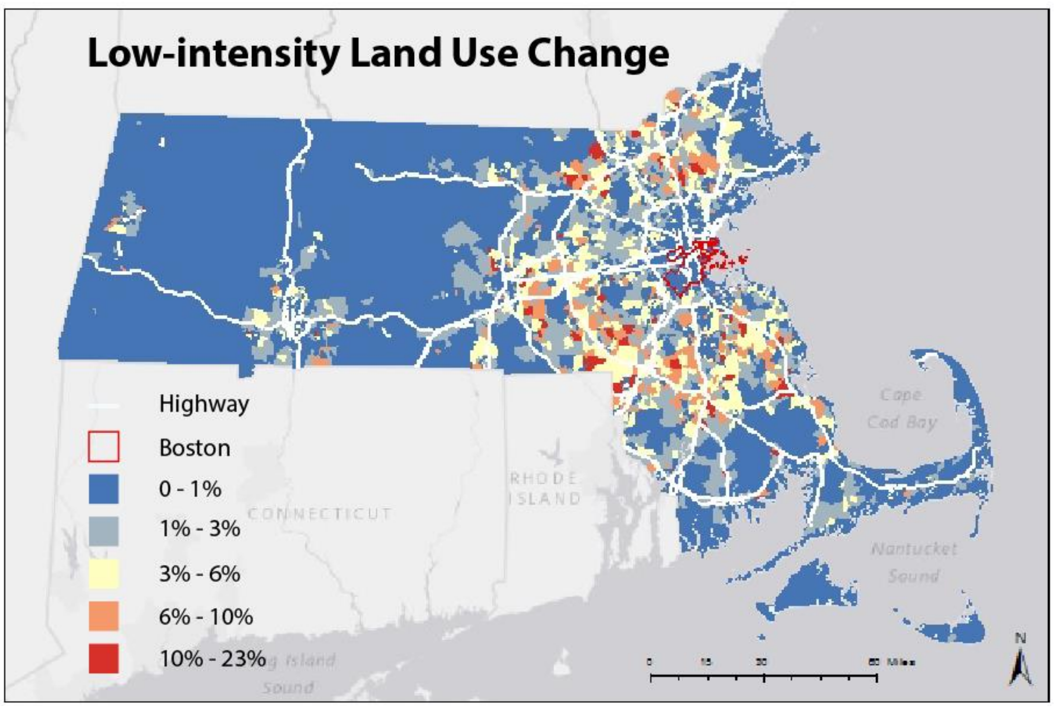

Figure 20. Low-Intensity Land Use Change Pattern by Block Group (The Percentage of Low-intensity Developed Land Use Change to The Total Developed Land Use Change)

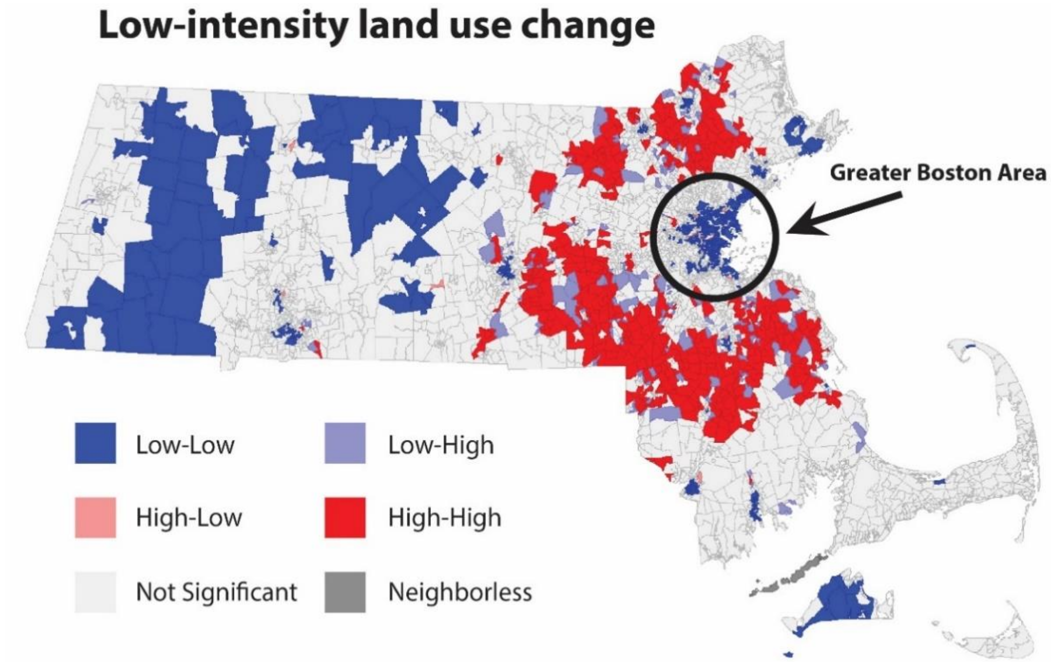

Figure 21. Low-Intensity Land Use Change Cluster Map by Block Group

The built environment variables from Smart Location Database, strongly illustrate the well-developed urban core of Massachusetts. The population density and employment density (Figure 22) are highly clustered in the Greater Boston area, the city of Springfield and the city of Pittsfield. Springfield and Pittsfield are two urban clusters on the west of Massachusetts. On the other hand, job density and employment diversity (Figure 22) don't have a very obvious pattern throughout the state. The difference between job and employment density is that job density is the jobs per household, while employment density is jobs per acres. The total road network density and intersection density (Figure 22) also have high values in the developed core urban areas, which makes sense because urban areas have more people, so that it is necessary to have more roads with more intersections.

Smart Location Database includes variables such as distance to nearest transit stop (Figure 23) that can be used to measure the transit accessibility of a location. These are mapped in Figure 23. Public transportation is very poor in non-urban areas in Massachusetts, and the red areas in the map are locations that are more than ¾ mile to the nearest transit stop.

Destination accessibility (Figure 23) shows the number of jobs within 45 minutes of the block group. For the destination accessibility by transit commute (Figure 23), because of the poor availability of public transportation in suburbs in Massachusetts, high values cluster close to the Greater Boston Area. But for the destination accessibility by auto (Figure 23), the clusters are bigger, but because of the concentration of the jobs close to the core urban areas they show a similar clustering pattern to the accessibility by transit.

The working-age population map (Figure 23) shows working-age population within 45 minutes transit commute. It also follows the pattern of MBTA public transportation. Those areas with high value are clustered in urban areas, which have better public transportation networks. The proportional accessibility to regional destination (Figure 23) is calculated by the value of working-age population within 45 minutes by auto to the total value of the same metropolitan area, which shows the relationship of working-age population within 45 minutes by auto value of each block group to its surroundings within the same metropolitan area. The red areas show that they are extremely high compared to their surroundings within the same metropolitan area. In this case the Great Boston area doesn't have large differences than its surrounding areas, so its value is relatively low.

The income map (Figure 23) also strongly suggests another reason for the urban expansion pattern in the state. The urban core is considered as a place for people working and entertaining, but people, especially those with high income, prefer to live in suburban areas to access better housing and low density. High income locations appear to be clustering in suburban areas surrounded the core employment centers in Boston.

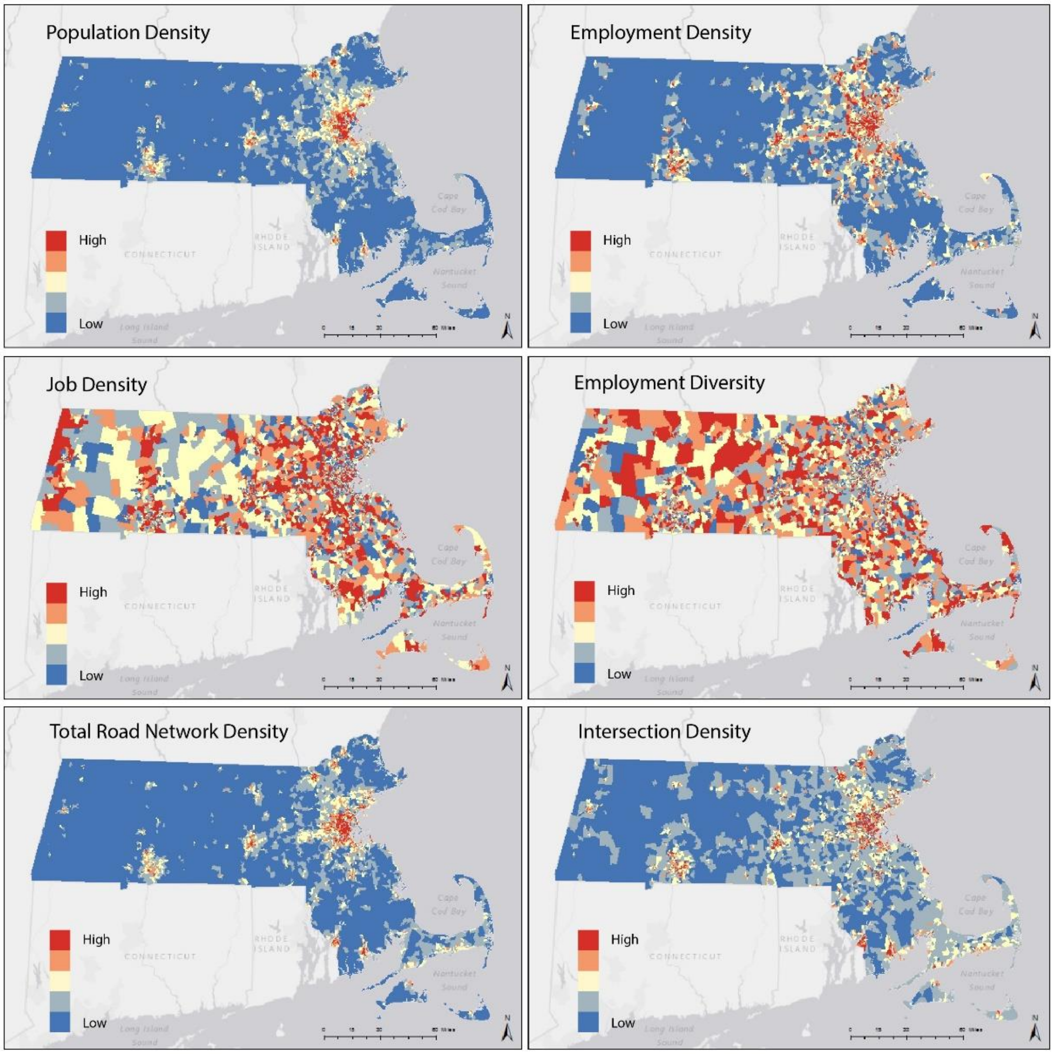

Figure 22. Spatial Factors Map by Block Group

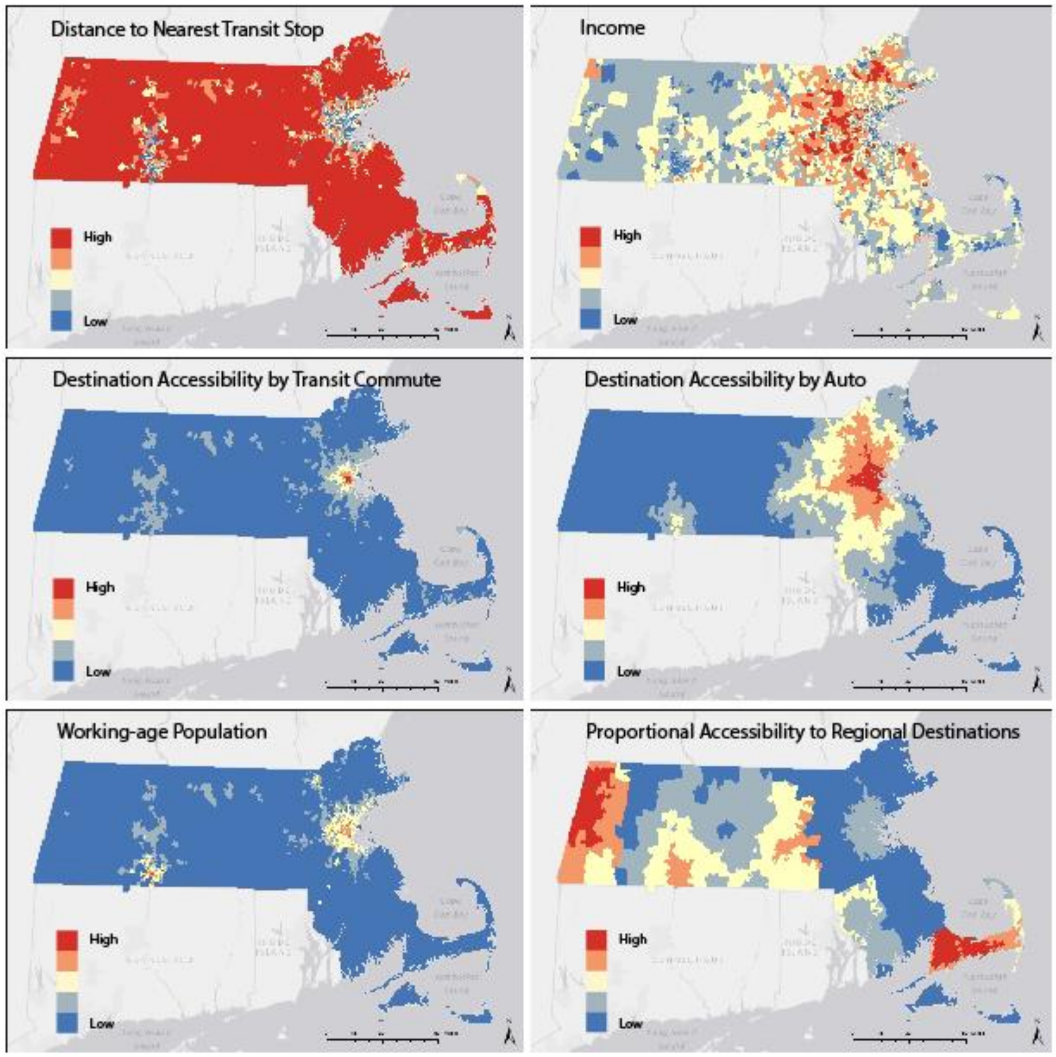

Figure 23. Spatial Factors Map by Block Group

The Local Moran's I cluster maps in Figure 24 and Figure 25 show high-high cluster in Boston, which is as expected. Some resources, like employment, education are concentrated in downtown, as is a better road network and public transportation system. High income households appear to prefer living in suburban area and the income cluster map strongly suggests this.

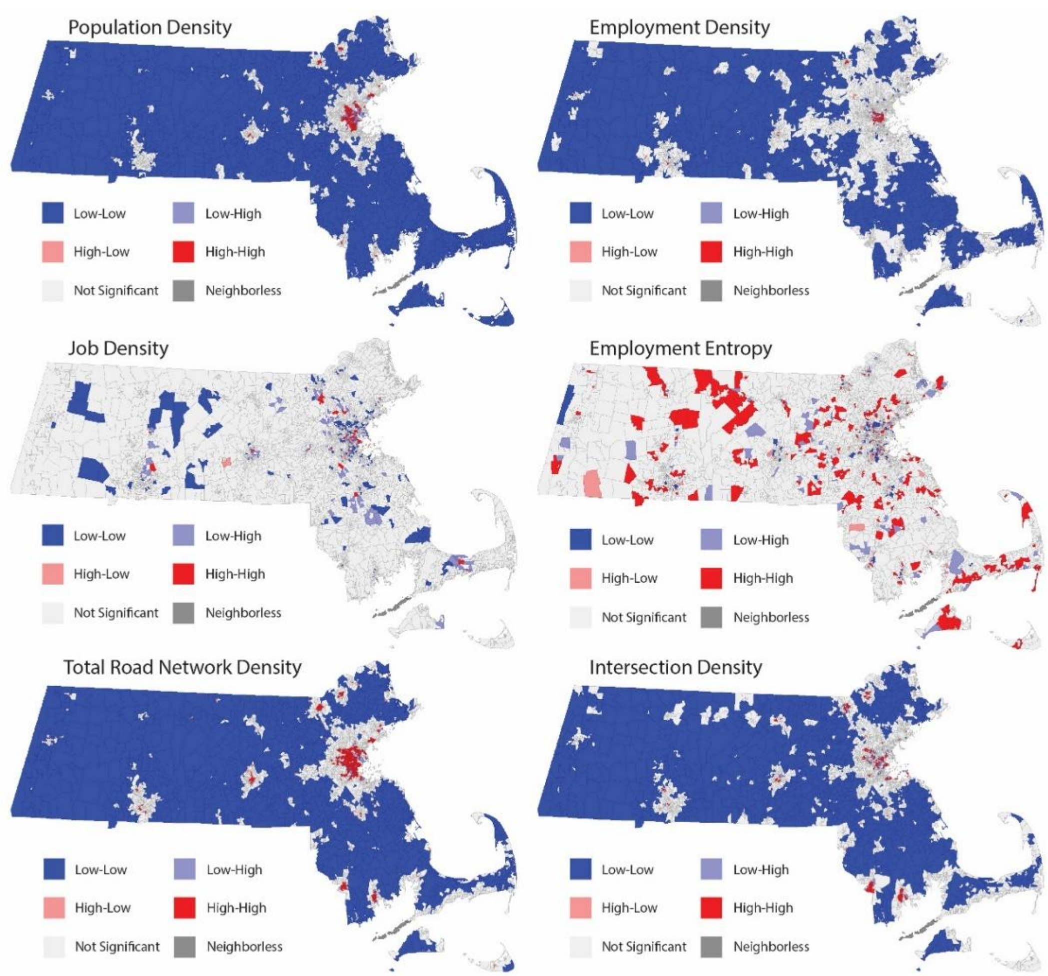

Figure 24. Cluster Map by Block Group

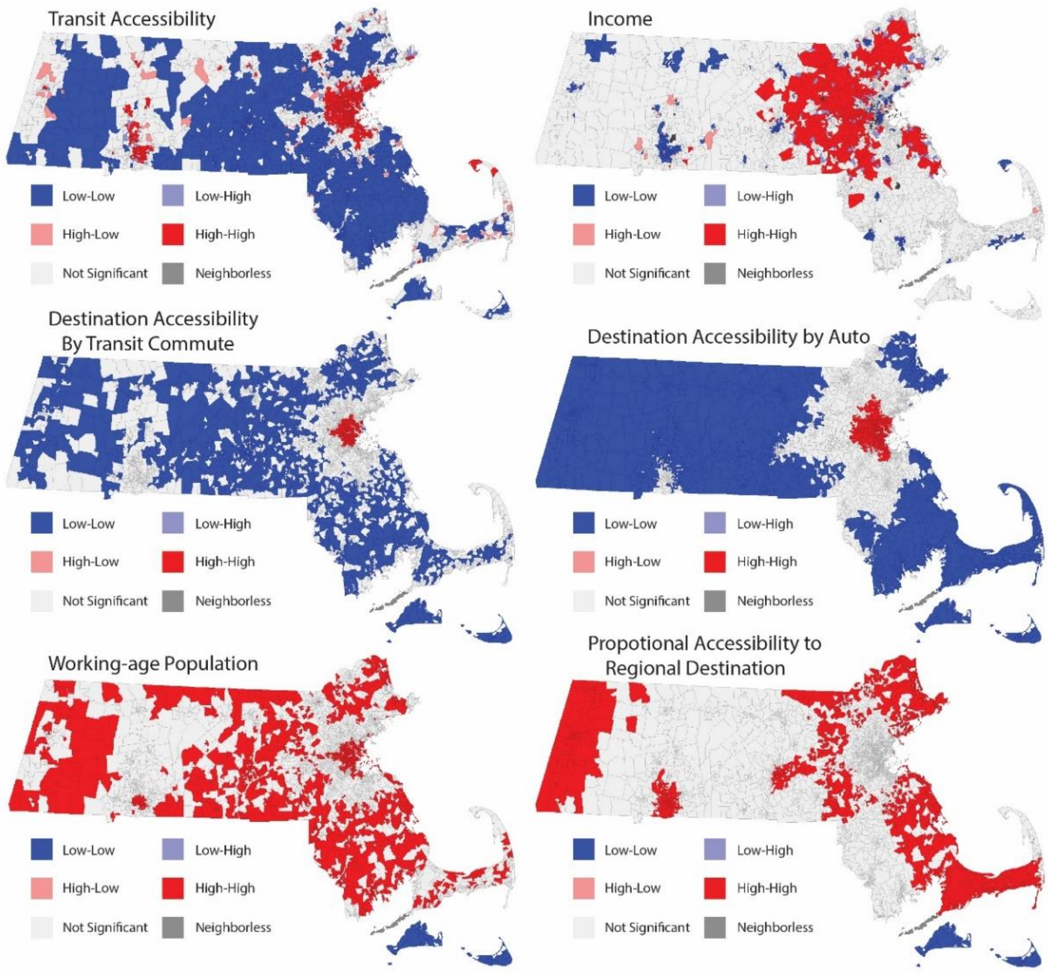

Figure 25. Cluster Map by Block Group

The city of Boston and its metropolitan area is the most urban area in Massachusetts. It has high density, high land use diversity, high population density, high employment density, better public transportation networks and road and intersection density. The cluster maps in Figure 24 and Figure 25 reflect this.

Table 11. Regression Table with dependent variable "low-intensity land use change" regressed on built environment and socioeconomic variables at the census block group level. Bolded variables are significant at 0.05 probability

Variable	OLS Coefficient	Probability of OLS	Spatial Lag Regression Coefficient	Probability of Spatial Lag
Constant	**$6.81*10^{-3}$**	0.00	$4.31*10^{-3}$	0.38
Gross employment density	$1.42*10^{-5}$	0.55	**$-2.11*10^{-6}$**	0.00
Gross population density	$6.98*10^{-6}$	0.37	$1.43*10^{-5}$	0.51
Total road network density	**$-5.86*10^{-4}$**	0.00	**$-4.15*10^{-4}$**	0.00
Job density	**$9.86*10^{-5}$**	0.01	$7.78*10^{-5}$	0.25
Employment diversity	**$2.03*10^{-3}$**	0.03	$8.95*10^{-4}$	0.29
Intersection density	$-5.08*10^{-6}$	0.70	$-6.04*10^{-7}$	0.96
Transit accessibility	**$-8.13*10^{-8}$**	0.00	**$-4.79*10^{-8}$**	0.00
Destination accessibility by auto	**$5.23*10^{-8}$**	0.00	**$3.21*10^{-8}$**	0.00
Destination accessibility by transit commute	**$-1.56*10^{-7}$**	0.00	**$-6.88*10^{-8}$**	0.03
Working-age population	$-1.05*10^{-7}$	0.43	$-4.04*10^{-7}$	0.74
Proportional Accessibility to Regional Destinations	$1.34*10^{-6}$	0.32	$5.42*10^{-7}$	0.66
Income	**$7.77*10^{-8}$**	0.00	**$4.35*10^{-8}$**	0.00
Spatial Lag			**0.45**	0.00
R-square	0.191		0.312	
Adjusted R-	0.189			

square		
N (total number of census block groups)	4945	4945

Firstly, I run the ordinary least squares (OLS) Regression with dependent or outcome variable "low-intensity land use change" and variables from the SLD as independent variables. The Robust LM (error) was not significant unlike the robust spatial lag. Table 11 shows the results of both the OLS and the spatial lag regression. Since the outcome (percentage low intensity land use change in a census block group) was highly spatially autocorrelated and the errors from the OLS model were also highly spatially autocorrelated I used a spatial lag correction.

I focus on factors which were significant, which I have highlighted in Table 11. The positive coefficient of income means high income is correlated with more low-intensity land use change. Urbanization would probably make people move from urban area to suburban area as they seek more housing at lower density, and this may especially be true for households with high income. This will likely result in low-intensity land use change.

For the employment density, the negative coefficient suggests that higher employment density is correlated with less low-intensity land use change. Since employment is clustered in urban areas, there is likely to be less low-intensity land use change in such locations.

Because public transportation system is available in urban areas, the negative coefficients suggests that block groups which are close to transit stops, or those with better transit accessibility to jobs, are correlated with significantly less low-intensity land use change. The pattern of public transportation system also illustrates the destination accessibility by transit commute. The jobs within 45 minutes by transit commute are clustered in urban areas, which is correlated with less low-intensity land use. However, the coefficient for destination accessibility by auto is quite different than the coefficient for transit accessibility, since jobs within 45 minutes by auto cluster in suburban areas. The positive coefficient suggests that such locations are more likely to have low intensity land use change.

5.2 Discussion

Most of the coefficient values are as expected and follow the literature review on the land use change and transportation and accessibility to jobs. Some limitations are described next.

5.2.1 Limitation

The R^2 for both models are relatively high for such models, 0.191 and 0.312 respectively. However some of the coefficients are not significant. The potential reasons for this lack of significance could be many. First, researchers in previous studies used a different scale such as the city or the region, unlike this study which was at the state level. Also Massachusetts is unique because Boston is among the oldest cities in the North American continent. Although the state has undergone great changes in the past 400 years, the early plans set the tone of the style of the whole state. The road network in cities within Massachusetts is very complex, unlike the regular blocks in Manhattan. So variables like intersection density may show different patterns in Massachusetts when compared to other American cities. Additionally data scale could be an issue. The Smart Location Database provides their data at the block group level and it may not accurately represent the level at which land use change is measured. Further error in the data from NLCD, could also affect the predictions of the model. Finally, many of these variables are correlated with each other. For example a location with high total road network density, is also likely to have high intersection density, transit accessibility and destination accessibility. In a regression, such multicollinearity could lead to insignificant coefficients.

Chapter 6: Conclusion

This thesis provided some suggestions for urban planners with some publicly available data sets such as NLCD, and SLD and basic GIS and remote sensing methods to better understand the land use change in Massachusetts. However, these results are applicable to the entire US or other countries where such data can be generated. The literature review provides the background of land use change and its relationship with built environment characteristics such as accessibility. The case study in Massachusetts using land cover data from NLCD and the correlation of land use change and built environment data at the town and block group level with SLD suggest that these data could be used to develop planning policy.

6.1 Recommendations

1) Valuable data sets, NLCD and Smart Location Database, are useful for urban planner.

Blumstein & Thompson (2015), have conducted research with the NLCD data. Based on their research, I have also conducted a basic analysis of land use change pattern in Massachusetts with NLCD land cover data. The NLCD data is useful for planners to better understand urban expansion. The three versions of NLCD data have their unique uses. The NLCD land cover in 2001 and 2011 are good for comparison of entire land cover types in 2001 and 2011. The NLCD 2001 to 2011 land cover change is used to find those areas changed to developed urban areas. And the NLCD 2001 to 2011 land cover from to change index provides detailed information about what has changed to what land cover type from 2001 to 2011. This thesis only focuses on those areas where developed urban changes have taken place. But for the further study, it is relatively easy for planners to identify other types of land use change, such as deforestation and agriculture increase with the change index data. The NLCD dataset updates every 5 years and a new data set will be available soon for NLCD 2016. Those could also be combined with built environment and Census data to make it relevant to planners and regional policy. The Smart Location Database provides detailed data about the built environment, density, diversity, transit and accessibility to jobs. In this thesis, I combined other data, such as highway, commuter rail, open space and business density from the local state agency for GIS data: MassGIS. Similar data as well as NLCD, and Smart Location Database are all easily access in 49 states in the mainland United State, free to use and with detailed metadata, which convenient for planners to conduct analysis at different spatial scales.

2) Urban planners should be familiar with some basic methods with GIS and remote sensing.

Along with these datasets, this thesis also provides some basic methods with GIS and remote sensing to deal with NLCD data. The NLCD data sets are made with the help of remote sensing methods, such as Classification and Change Detection. And since this is raster data, GIS tools like Reclassify and Raster Calculator are extremely useful. I have identified those areas that changed to developed urban areas, identify what was those places like in 2001 and the surrounding land cover types in 2001 with those two tools in GIS. In addition, the Tabulate Area tool in ArcGIS is also helpful to process these data into different spatial units such as the town level and block group' level. GeoDa which is a free open source software also performed an important role in generating cluster maps and spatial regressions. These tools are relatively simple for planners to use. Nowadays, planning not only refers to the policies that planners make, but also with the data analysis that they must conduct. GIS and remote sensing could provide valuable support in data visualization with maps and statistics, which helps planners to better understand places for which they must make policies.

3) Zoning code and transit accessibility are essential for planners to be make policies.

As the previous analysis shows that such towns like Carlisle, Concord and Lincoln, they have more protected open space. So that they have less area changed to developed open space. Different towns have their own zoning policies, which could have significant impacts of the land use change pattern. So planners should make policies based on different zoning policies of each town. Besides, Ayer is boasted from the commuter rail connected with Boston, and this could be useful for others. In additional, the situation of traffic congestion probably because I-93 is the only highway which connects the south to the north in New England and goes through downtown Boston. So there are heavy traffic in I-93. In conclusion, other cities could have their own development with the improvement of transit accessibility like highway and commuter rail. The government even could take building more north-south line highways into consideration to share the traffic of I-93 and more commuter rail lines.

4) Suggestions for further studies.

This thesis only focuses on the developed urban area land use change, but in future studies, NLCD and Smart Location Database are accessible in the country level. Others can perform similar analysis in other cities or other states, with other kind of land use types, like forests, agricultural fields and wetlands.

Besides, the idea of making an index of some variables in built environment is a good idea for further study since the results of each towns are not only the research for current situation, but also as a predictor of land use change pattern in the future. Those estimations could help those planners better making policies.

Finally, land use change as well as urban expansion also exit in other countries like China. It may have similar land use change pattern in China. But there are a few accessible datasets like NLCD and Smart Location Database, which could be used to make such analysis. So maybe it’s better to have more available data for analyzing land use change in China, which is helpful for preventing large scale urban expansion happen in the future.

Appendix

Table 12. Land Cover Class Code Value from NLCD

Value	Definition
11	Open Water - All areas of open water, generally with less than 25% cover or vegetation or soil
12	Perennial Ice/Snow - All areas characterized by a perennial cover of ice and/or snow, generally greater than 25% of total cover.
21	Developed, Open Space - Includes areas with a mixture of some constructed materials, but mostly vegetation in the form of lawn grasses. Impervious surfaces account for less than 20 percent of total cover. These areas most commonly include large-lot single-family housing units, parks, golf courses, and vegetation planted in developed settings for recreation, erosion control, or aesthetic purposes.
22	Developed, Low Intensity -Includes areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 20-49 percent of total cover. These areas most commonly include single-family housing units.
23	Developed, Medium Intensity - Includes areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 50-79 percent of the total cover. These areas most commonly include single-family housing units.
24	Developed, High Intensity - Includes highly developed areas where people reside or work in high numbers. Examples include apartment complexes, row houses and commercial/industrial. Impervious surfaces account for 80 to 100 percent of the total cover.
31	Barren Land (Rock/Sand/Clay) - Barren areas of bedrock, desert pavement, scarps, talus, slides, volcanic material, glacial debris, sand dunes, strip mines, gravel pits and other accumulations of earthen material. Generally, vegetation accounts for less than 15% of total cover.
41	Deciduous Forest - Areas dominated by trees generally greater than 5 meters

	tall, and greater than 20% of total vegetation cover. More than 75 percent of the tree species shed foliage simultaneously in response to seasonal change.
42	Evergreen Forest - Areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. More than 75 percent of the tree species maintain their leaves all year. Canopy is never without green foliage.
43	Mixed Forest - Areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. Neither deciduous nor evergreen species are greater than 75 percent of total tree cover.
51	Dwarf Scrub - Alaska only areas dominated by shrubs less than 20 centimeters tall with shrub canopy typically greater than 20% of total vegetation. This type is often co-associated with grasses, sedges, herbs, and non-vascular vegetation.
52	Shrub/Scrub - Areas dominated by shrubs; less than 5 meters tall with shrub canopy typically greater than 20% of total vegetation. This class includes true shrubs, young trees in an early successional stage or trees stunted from environmental conditions.
71	Grassland/Herbaceous - Areas dominated by grammanoid or herbaceous vegetation, generally greater than 80% of total vegetation. These areas are not subject to intensive management such as tilling, but can be utilized for grazing.
72	Sedge/Herbaceous - Alaska only areas dominated by sedges and forbs, generally greater than 80% of total vegetation. This type can occur with significant other grasses or other grass like plants, and includes sedge tundra, and sedge tussock tundra.
73	Lichens - Alaska only areas dominated by fruticose or foliose lichens generally greater than 80% of total vegetation.
74	Moss - Alaska only areas dominated by mosses, generally greater than 80% of total vegetation.

81	Pasture/Hay - Areas of grasses, legumes, or grass-legume mixtures planted for livestock grazing or the production of seed or hay crops, typically on a perennial cycle. Pasture/hay vegetation accounts for greater than 20 percent of total vegetation.
82	Cultivated Crops - Areas used for the production of annual crops, such as corn, soybeans, vegetables, tobacco, and cotton, and also perennial woody crops such as orchards and vineyards. Crop vegetation accounts for greater than 20 percent of total vegetation. This class also includes all land being actively tilled.
90	Woody Wetlands - Areas where forest or shrub land vegetation accounts for greater than 20 percent of vegetative cover and the soil or substrate is periodically saturated with or covered with water.
95	Emergent Herbaceous Wetlands - Areas where perennial herbaceous vegetation accounts for greater than 80 percent of vegetative cover and the soil or substrate is periodically saturated with or covered with water.

References

America, S. G. (2014). Measuring sprawl 2014. Washington, DC: Smart Growth America. Downloaded from http://www. smartgrowthamerica. org/documents/measuring-sprawl-2014. pdf on April, 8, 2014.

Anselin, L. (1995). Local indicators of spatial association—LISA. Geographical analysis, 27(2), 93-115.

Anselin, L. (2002). Under the hood: Issues in the specification and interpretation of spatial regression models. Agricultural economics, 27(3), 247-267.

Bertolini, L., Curtis, C., & Renne, J. (2012). Station area projects in Europe and beyond: Towards transit oriented development? Built Environment, 38(1), 31–50.

Blumstein, M., & Thompson, J. R. (2015). Land‐use impacts on the quantity and configuration of ecosystem service provisioning in Massachusetts, USA. Journal of Applied Ecology, 52(4), 1009-1019.

Bollinger, C. R., & Ihlanfeldt, K. R. (1997). The impact of rapid rail transit on economic development: the case of Atlanta's MARTA. Journal of Urban Economics, 42(2), 179-204.

Briassoulis, H. (2000). Analysis of land use change: theoretical and modeling approaches.

Cervero, R., & Kockelman, K. (1997). Travel demand and the 3Ds: density, diversity, and design. Transportation Research Part D: Transport and Environment, 2(3), 199-219.

Chomitz, K. M., & Gray, D. A. (1996). Roads, land use, and deforestation: a spatial model applied to Belize. The World Bank Economic Review, 10(3), 487-512.

Daily, B. F., & Huang, S. C. (2001). Achieving sustainability through attention to human resource factors in environmental management. International Journal of operations & production management, 21(12), 1539-1552.

DeNormandie, J. (2009) Losing Ground: Patterns of Development and Their Impacts on the Nature of Massachusetts. Mass Audubon, Lincoln, MA.

Elvidge, C. D., Dietz, J. B., Berkelmans, R., Andrefouet, S., Skirving, W., Strong, A. E., & Tuttle, B. T. (2004). Satellite observation of Keppel Islands (Great Barrier Reef) 2002 coral bleaching using IKONOS data. Coral Reefs, 23(1), 123-132.

Ewing, R., Meakins, G., Hamidi, S., & Nelson, A. C. (2014). Relationship between urban sprawl and physical activity, obesity, and morbidity–update and refinement. Health & place, 26, 118-126.

Foley, J. A., DeFries, R., Asner, G. P., Barford, C., Bonan, G., Carpenter, S. R., ... & Helkowski, J. H. (2005). Global consequences of land use. science, 309(5734), 570-574.

Fragkias, M., & Geoghegan, J. (2010). Commercial and industrial land use change, job decentralization and growth controls: a spatially explicit analysis. Journal of Land Use Science, 5(1), 45-66.

Gutman, G., Janetos, A. C., Justice, C. O., Moran, E. F., Mustard, J. F., Rindfuss, R. R., ... & Cochrane, M. A. (Eds.). (2004). Land change science: Observing, monitoring and understanding trajectories of change on the earth's surface (Vol. 6). Springer Science & Business Media.

Handy, S. (2005). Smart growth and the transportation-land use connection: What does the research tell us?. International Regional Science Review, 28(2), 146-167.

Hansen, M., & Huang, Y. (1997). Road supply and traffic in California urban areas. *Transportation Research Part A: Policy and Practice*, *31*(3), 205-218.

Homer, C., Dewitz, J., Yang, L., Jin, S., Danielson, P., Xian, G., ... & Megown, K. (2015). Completion of the 2011 National Land Cover Database for the conterminous United States–representing a decade of land cover change information. Photogrammetric Engineering & Remote Sensing, 81(5), 345-354.

Jeon, N. J., Noh, J. H., Kim, Y. C., Yang, W. S., Ryu, S., & Seok, S. I. (2014). Solvent engineering for high-performance inorganic–organic hybrid perovskite solar cells. Nature materials, 13(9), 897.

Kasraian, D., Maat, K., Stead, D., & van Wee, B. (2016). Long-term impacts of transport infrastructure networks on land-use change: an international review of empirical studies. Transport Reviews, 36(6), 772-792.

Kates, R. W., Clark, W. C., Corell, R., Hall, J. M., Jaeger, C. C., Lowe, I., ... & Faucheux, S. (2001). Sustainability science. Science, 292(5517), 641-642.

Kneebone, E. (2009). Job sprawl revisited: The changing geography of metropolitan employment. Metropolitan Policy Program, Brookings Institution.

Konarska, K. M., Sutton, P. C., & Castellon, M. (2002). Evaluating scale dependence of ecosystem service valuation: a comparison of NOAA-AVHRR and Landsat TM datasets. Ecological economics, 41(3), 491-507.

Lawler, J. J., Lewis, D. J., Nelson, E., Plantinga, A. J., Polasky, S., Withey, J. C., ... & Radeloff, V. C. (2014). Projected land-use change impacts on ecosystem services in the United States. Proceedings of the National Academy of Sciences, 111(20), 7492-7497.

Martin, D., Fowlkes, C., Tal, D., & Malik, J. (2001). A database of human segmented natural images and its application to evaluating segmentation algorithms and measuring ecological statistics. In Computer Vision, 2001. ICCV 2001. Proceedings. Eighth IEEE International Conference on (Vol. 2, pp. 416-423). IEEE.

Mieszkowski, P., & Mills, E. S. (1993). The causes of metropolitan suburbanization. Journal of Economic perspectives, 7(3), 135-147.

Monks, P. S., Archibald, A. T., Colette, A., Cooper, O., Coyle, M., Derwent, R., ... & Stevenson, D. S. (2015). Tropospheric ozone and its precursors from the urban to the global scale from air quality to short-lived climate forcer. Atmospheric Chemistry and Physics, 15(15), 8889-8973.

Multi-Resolution Land Characteristics Consortium (MRLC). (2011), National Land Cover Database (NLCD), received from https://www.mrlc.gov/nlcd2011.php.

Pfleging, W., Hanemann, T., Bernauer, W., & Torge, M. (2001, June). Laser micromachining of mold inserts for replication techniques: state of the art and applications. In Laser Applications in Microelectronic and Optoelectronic Manufacturing VI (Vol. 4274, pp. 331-346). International Society for Optics and Photonics.

Ramsey, K., & Bell, A. (2014). Smart location database. Washington, DC.

Rohde, R., Muller, R. A., Jacobsen, R., Muller, E., Perlmutter, S., Rosenfeld, A., ... & Wickham, C. (2013). A new estimate of the average Earth surface land temperature spanning 1753 to 2011. Geoinfor Geostat Overview 1: 1. of, 7, 2.

Smith, J. (2014). US Census Bureau.

Southworth, F. (2001). On the potential impacts of land use change policies on automobile vehicle miles of travel. Energy Policy, 29(14), 1271-1283.

Veldkamp, A., & Lambin, E. F. (2001). Predicting land-use change.

Wegener, M. (2004). Overview of land-use transport models. In D. A. Hensher & K. Button (Eds.), Transport geography and spatial systems (pp. 127–146). Kidlington: Pergamon/Elsevier Science.

Zhou, B., & Kockelman, K. M. (2008). Neighborhood impacts on land use change: a multinomial logit model of spatial relationships. The Annals of Regional Science, 42(2), 321-340.

Zhu, S., Xie, F., & Levinson, D. (2010). Enhancing transportation education through online simulation using an agent-based demand and assignment model. Journal of Professional Issues in Engineering Education and Practice, 137(1), 38-45.