Analyzing Land Cover Change to Predict Regulation Changes

Abstract

Throughout the late 2000s and early 2010s, the City of Mercer Island, WA experienced a building boom exemplified by the construction of large houses that included high roofs, tall walls, and the removal of most trees on development sites. As a result, the City of Mercer Island adopted a new set of development regulations for its single-family residential zones in 2017 intended to limit the impact of development on nearby trees and property owners. There is little research on whether property- or neighborhood-level changes can be identified using remote sensing; research has largely focused on large-scale, region wide analyses to demonstrate broad changes in land use and land coverage (for instance, from agricultural to urban uses) in response to changing demographics and governmental policies. Using the City of Mercer Island as a test case, this paper endeavors to show how remote sensing technology can be used to identify small-scale changes in land cover and, in contrast to the existing research, to analyze land use changes within a region to determine if the changes can predict changes to local land use regulations.

Introduction

Since 2010, the region surrounding Seattle, WA has experienced significant population growth (United States Census Bureau, 2021). In many areas around Seattle, property was redeveloped to accommodate the influx of new residents. The result was increased density in central neighborhoods and near future transit stops planned for the expansion of Sound Transit, the regional transportation authority. Other neighborhoods experienced redevelopment of single-family residential lots that resulted in an existing house being demolished and replaced by a new, larger house.

The City of Mercer Island, WA is a suburban city that falls into the latter category described above. Mercer Island experienced significant redevelopment within its single-family residential areas characterized by existing houses being demolished and replaced with new larger houses. The redevelopment was usually accompanied by increases to impervious surfaces and building height and the removal of many large trees. In an effort to reduce the impacts of new construction, the City of Mercer Island adopted two sets of new regulations in the mid-2010s:

- In 2015, a town center development ordinance was adopted adding restrictions to building form and requirements for affordable housing for residential projects.
- In 2017, a single-family residential development ordinance was adopted that increased impervious surface, building height, and setback restrictions. This ordinance also included new provisions requiring additional trees to be retained on development sites.

The case study of Mercer Island and its attempt to mitigate the impacts of redevelopment raises two several research questions. Firstly, did the regulations adopted by the City of Mercer Island have an effect on land cover within the city? If so, did the regulations have the desired effect for new development (reduction of impervious surface, retention of additional trees, etc.)? Next, can changes to land cover patterns be identified in other jurisdictions in the Seattle metropolitan area? Finally, can land cover changes identified through remote sensing analysis be used to predict where land use regulations have changed? This paper endeavors to answer this last question. In doing so, the other research questions listed above will also be answered.

Literature Review

For this project, I will explore the connections between land coverage changes and changes in governmental regulations. I will begin with a brief overview of the history of research in remote sensing and how it has evolved in the last several decades. I will then move on to show that some studies show that governmental regulations and policy have caused changes in land use cover, at least in part (Wu et al., 2006, Houet et al., 2010, Fichera et al., 2012, Li et al., 2020, Qacami et al., 2022). Finally, I will review research on how tree coverage and tree protection regulations can be detected using remote sensing (Nowak et al., 1996, Parmehr et al., 2016, Lee et al., 2017, Guo et al., 2019, Hilbert et al., 2019, Timilsina et al., 2020) since changes to tree coverage can be indicative of other land cover changes (Lee et al. 2017).

History of Remote Sensing and Change Detection

Over the past several decades, remote sensing technology has advanced as imagery available from satellite platforms has improved (Jensen and Cowen, 1999, Rogan and Chen, 2004, Weng, 2012). The increase in image resolution has driven new methods to analyze data obtained through remote sensing including pixel-based algorithms, sub-pixel-based algorithms, object-oriented algorithms, and artificial neural networks (Weng 2012). Advancement of remote sensing technology has also led to its application to various fields, including: land use and land cover; building, property line, transportation, and utility infrastructure; digital elevation model creation; socio-economic characteristics; energy demand and production potential; critical environmental area assessment; meteorological data; and disaster emergency response (Jensen and Cowen, 1999). LiDAR (Light Detection and Ranging) has also been a proven method to study land cover and urban morphology (Yan et al., 2015). LiDAR can also penetrate tree cover to detect buildings and other impervious surfaces are often blocked from satellite and aerial photography (Yan et al., 2015).

Remote sensing has long been used to study changes in land cover (Jensen and Cowen, 1999, Rogan and Chen, 2004). Jensen and Cowen (1999) discussed a study using Landsat MSS data taken in between 1979 and 1981 to show how urban and non-urban land cover changed near Charleston, SC, although at a low resolution (79m by 79m). Green et al. (1994) also provided an early example of using remote sensing to find land cover changes in the Portland, OR area, while providing a statement that acknowledges that a change has occurred is relatively uninformative unless the change can be linked to its impacts. More recently, remote sensing has been used to study how land coverage has changed in both urban (Wu et al., 2006, Fichera et al., 2012, Li et al., 2020, Das and Angadi, 2022) and rural (Houet et al. 2010, Qacami et al., 2022) settings. Additionally, remote sensing has been used to show how land

and tree coverage patterns have changed due to reconstruction following natural disasters (Fichera et al., 2012, Guo et al., 2019).

Impact of Government Policy and Regulations

Government policies and regulations can have a profound effect on land cover in a region. Research shows that changes to economic policy (Wu et al., 2006, Houet et al., 2010, Li et al., 2020), building and land use regulations (Fichera et al. 2012), conservation policy (Wu et al., 2006, Li et al., 2020, Qacami et al., 2022), and tree protection regulations (Hilbert et al., 2019) have all affected patterns of regional land cover change.

Economic Policy and Development Regulations

As the result of economic reforms in the late 1970s, urban areas in China have experienced rapid growth (Wu et al., 2006, Li et al., 2020). Wu et al. (2006) and Li et al. (2020) note that built-up urban area increased in the Municipality of Beijing and in Gansu Province, respectively, due to these economic reforms. In the case of both cities, built up areas largely replaced farmland and unused land.

Research has also shown that other types of government policy can affect detectible land cover, including agricultural policy (Houet et al., 2010) and changes to building and land use regulations (Fichera et al., 2012). Houet et al. (2010) found that land cover changed in the U.S. state of South Dakota and in the Brittany region of France because regulations by the United States Department of Agriculture and the European Union, respectively, caused farmers to change the crops they grew, which in turn caused changes in the regions' landscapes. Fichera et al. (2012) found that building and land use regulation changes in the Campania region of Italy in response to a major earthquake in 1980 caused urban development to be refocused to areas that were previously used as farmland rather than in the established urban areas.

Conservation Policy

There is also evidence showing that enacting conservation policy has been effective at causing or preventing land cover change. Wu et al. (2006) found that a 1994 ordinance intended to protect agricultural areas in the Municipality of Beijing slowed the conversion of the area's cropland to urban uses. They also found that existing conservation policy, such as nature preserves and parks, prevented land cover changes elsewhere in the Municipality of Beijing. Li et al. (2020) also found that conservation policies intended to protect natural lands and agricultural lands resulted in different areas being converted to built-up urban areas. Conservation policies were found to be effective in preserving forest land in the High Atlas region of Morocco as well (Qacami et al., 2022).

Tree Cover

There has likewise been significant research in identifying urban tree cover using remote sensing. Being able to identify areas where urban tree coverage has changed is important because changes to tree coverage can correspond to other land cover changes, such as changes to impervious surface coverage (Lee et al. 2017). Early remote sensing efforts in studying tree cover involved studying aerial photography. Nowak et al. (1996) used several methods (crown cover scale, transect method, dot method, scanning method) to study aerial photography of cities across the United States and found that tree coverage varies from city to city based on the physical characteristics of the region. Building on this work, Parmehr et al. (2016) compared a random point sample analysis of aerial imagery to an analysis of LiDAR and found that both methods have at least 95% accuracy.

Remote sensing has been used to detect changes to tree coverage over many geographies, including Christchurch, New Zealand (Guo et al., 2019), Hobart, Australia (Timilsina et al., 2020), and Los Angeles County, CA (Lee et al., 2017). Each of these studies found that tree coverage decreased over their study periods for various reasons, such as the removal of hazardous trees and reconstruction of property following a major earthquake (Guo et al., 2019) and the increase of impervious surface associated with property redevelopment (Lee et al., 2017).

Several papers also were able to show that government policies and regulations have affected tree coverage. Hilbert et al. (2019) performed a study of 43 cities in Florida and found that increased housing density resulted in a lower percentage of tree coverage. This study also found that cities with tree protection ordinances had higher urban tree cover, and that cities with protections to heritage trees (particularly old and large trees) had even higher tree coverage. Pike et al. (2021) built on this study and showed that tree protection regulations are effective at preserving trees after residential construction, reducing tree canopy loss and increases in impervious surface area. However, the ability of government policies and regulations to protect and expand tree coverage is limited. Lee et al. (2017) found that tree canopy coverage in Los Angeles County, CA decreased, and impervious surface coverage increased, on single-family residentially zoned lots between 2000 and 2009 even though Los Angeles County adopted a policy to promote planting new trees. Any gains in tree coverage from the newly planted trees were offset by the removal of trees on residentially-zoned lots.

Methods

Study Area

My study will be focusing on land cover changes in King County, WA between 2010 and 2020. King County is located in the Puget Sound region of Washington, bounded by Puget Sound to the west and the Cascade Mountains to the east. According to the United States Census Bureau (2021), the population of King County increased from 1,931,249 in 2010 to 2,269,675 in 2020. The need to accommodate this increase in population resulted in an increase in building density in the largest cities in the county (Seattle and Bellevue), as well as along planned light rail lines in several other suburbs.

In general, the built-up urban area in King County is focused around the City of Seattle, near Puget Sound and Lake Washington in the western half of the county. The geography of the county becomes more mountainous further east in the county, supporting more rural land uses and resource-based industry, such as mining and forestry. Eastern King County is sparsely developed and unlikely to have experienced significant land cover changes (aside from timber harvesting for forest industries) over the study period. Therefore, my study area will exclude the easternmost portions of King County and instead focus on the areas of King County between Puget Sound to the west and the Snoqualmie Valley to the east.

Data Sources

To test whether land cover changes can be detected using remote sensing technology, I am planning on using three sets of multi-spectral aerial or satellite imagery of King County dated roughly 2010, 2015, and 2020. As stated in the introduction above, the City of Mercer Island, WA implemented changes to their single-family residential development code in 2017. Using three sets of imagery will provide two pairs of dates (2010 to 2015 and 2015 to 2020) that will allow analysis examining how patterns of land cover change have changed over the study period. Because the City of Mercer Island's regulations changed in 2017, roughly in the middle of the planned study period, it will be used as a control in the analysis of whether land cover changes are related to changes in governmental regulations.

Since the primary focus of this study is to review land cover changes caused by land use regulation changes, aerial or satellite imagery selected for this study should be in the "leaf off" period between November and March. This will reduce the degree to which the ground will be obscured by tree cover. I anticipate that aerial or satellite imagery to be used for this project can be obtained from government agencies, such as King County or the Washington State Department of Natural Resources.

LiDAR data will also be used for this analysis, where available, as it is able to penetrate the tree canopy and show changes to buildings and impervious surfaces that would otherwise be obscured by tree cover. Like the aerial and satellite imagery above, LiDAR data from approximately 2010, 2015, and 2020 will be acquired to determine if there patterns of land cover change have changed over the study period. I anticipate that available LiDAR data will be obtained from government agencies, such as the Washington LiDAR Portal administered by the Washington State Department of Natural Resources.

Data Classification and Analysis

I am planning on classifying land cover identified in each of the aerial or satellite images into broad categories, including Built-up Area, Cropland, Pasture, Forest, and Water. The classification process will be automated due to the scope of the project study area. I will be performing manual checks on the automated classification to ensure that the land cover has been classified correctly.

If LiDAR data is available for the study area, data will be used to classify whether an area is covered by a building, is covered by another type of impervious surface, is covered by trees and other vegetation, and is bare. This classification process will also be automated due to the size of the study area, with manual checks to ensure the accuracy of the land cover classification.

To ensure that the data sources are consistent, they will be converted to a common projection that will be determined at a later date. Once the data is projected, they will be classified and compared with one another using ArcGIS change detection tools. Tools that may be useful for my analysis include Compute Change Raster, Analyze Changes Using CCDC (Continuous Change Detection and Classification), and Change Detection Wizard. I am planning to create a script to automate this process with manual spot checks of the results to make sure that the land cover changes were detected correctly.

Regulatory Analysis

Once the land cover change analysis is complete, I will review the data to see where land cover changes have changed between the time periods from 2010 to 2015 and from 2015 to 2020. In particular, I will identify the jurisdictions (cities or portions of unincorporated King County) that experienced the most changes in their land cover change patterns. I will conduct a review of those jurisdictions' development regulations to see if there have been changes in the regulations that may have caused land cover change to either accelerate or slow down. All city and county codes are publicly available on the respective city or county websites, so I will review the online versions of the codes of the identified areas. If further information is needed (such as older versions of city or county codes that may not be prominently posted on the jurisdictions' websites), I will reach out to city or county staff for assistance. I will also check to see if the State of Washington adopted regulation changes that would cause development patterns to change between 2010 and 2020.

Planned Project Timeline	
Data Acquisition	March
Research Change Detection Methods	April
Data Classification	April
Data Analysis	May
Regulatory Analysis	June
Project Completion	Early August

Conclusion

I anticipate that the results of my analysis will show that land cover changes are most pronounced further from King County's urban core, with changes in more established urban areas being less pronounced. This is because cities in outlying areas have more opportunities to develop in areas that are not used for urban uses (such as crop or forest land). Development in existing urban areas largely involves redevelopment of previously developed lots, which results in more modest changes in land cover.

I also anticipate that changes in land use regulations can be identified based on land cover changes, especially in areas outside of the urban core. As described in the literature review, several studies (Wu et al., 2006, Houet et al., 2010, Fichera et al., 2012, Li et al., 2020, Qacami et al., 2022) show the correlation between the adoption of regulations and land cover changes. Being able to identify government regulation changes through the use of land cover change analysis would be helpful to the following groups:

- Municipal land use professionals would be interested in knowing which nearby jurisdictions have recently changed their regulations when they are doing research for code updates.
- Property developers would be interested in knowing if there have been recent code changes in a jurisdiction where they are planning a project.
- Property owners would want to know if land cover and land use changes in their neighborhood were caused by recent regulation changes.

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