Spatiotemporal Dynamics and Spatial Determinants of Urban Growth in the Greater Coeur d'Alene Area of Idaho

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AUTHORIZATION TO SUBMIT THESIS

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ABSTRACT

Urbanization is the key driver of land use change across the globe and in the United States. When examining urban growth in many natural amenity-rich regions, such as northern Idaho, the tension between urban and population growth and land developability or conservation has been of greater importance. In this study, I conducted and analysis of both the urban growth patterns and fragmentation as well as the specific determinants of urban growth. Results derived from spatial-temporal dynamics analysis suggest that both macro-level economic contexts (e.g., the economic recession of 2008) and local level accessibility measurements play a key role in shaping the patterns of new urban growth in the greater Coeur d'Alene region. Furthermore, by suing logistic regression analysis, we found that there has been a very high preference to develop land near to existing city boundaries and in close proximity to water and high percentage of Bachelor degrees. The application of a spatial regime model and geographically weight logistic regression not only improved model prediction accuracy and goodness of fit, but also allowed us to examine the local variations and influences of each of the independent variables.

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Chapter 1: Introduction

1.1 Introduction

Urbanization has been a hallmark of human history and results in a massive in-migration from rural areas to cities. According to the report of United Nations published in 2014, by the year 2007, more than 50% of the world's population lived in cities, and the ratio is expected to increase to 60% by the year 2050 (United Nations 2012). This acceleration of human-driven land use change causes problems as far-reaching as from food production to wildlife habitat (Allen 2006 and Andersson 2006)

As opposed to the rest of the country, the western United States is characterized by low density urban areas and significant amounts of public land (Brown et al. 2005, Alig et al. 2004). Due to its richness in natural amenity, urban or exurban growth is an issue that has become more prevalent due to retiring baby boomers and the wealthy seeking recreation and proximity to nature (Nelson et al. 2014, Pavelka & Draper 2014, Gosnell & Abrams 2009). Since the 1990s, there has been an especially high in-migration movement in high amenity locations (Nelson et al. 2014), and amenity and accessibility have become the key determinants of the quality of urban life, residential location choices and consequent urban land use change (e.g., Chiesura 2004; Nilsson 2014; and Li et al. 2016).

These issues have led local governments to enact various policies that more closely examine the interactions between their natural amenities and land use change, especially tied to urban or extra-urban growth (Dieleman & Wegener 2004, Steel & Lovrich 2000). This type of urbanization often tends to result in dynamic ecological stress, resulting in concerns about environmental degradation and sustainable urban development (Andersson 2006, Heimlich & Anderson 2001, Lewis et al. 2009).

Understanding the impetus behind urban growth and broadly defined land use change in an amenity rich region will allow for planners to more efficiently anticipate and estimate the expansion of metropolitan areas in ways that can enhance the relative value of their surrounding environment. More importantly, in recent years, the quantification of urban growth or sprawl has shifted from an aggregate (census units) to disaggregate (individual land use types) due to the advancement of Geographic Information Systems (GIS) technologies and the finer resolution of relevant data, such as remote sensing and cadastral data (Irwin & Bockstael 2004, Dahal et al. 2016, Zhang et al. 2017 and Luo & Wei 2009). More studies are still needed due to the rapidly changing landscapes in these areas. This study integrates spatial analytical techniques and urban growth studies while paying particular attention to amenity attractions derived from ecosystems in northern Idaho.

1.2 Literature Review

Urban land use models and spatial patterns of urban growth

The economic rationale behind land use change can be traced back to the bid-rent model developed by von Thünen (1826) drawing upon the agricultural land development concept (Chapin & Kaiser Jr., 38). Aside from von Thünen, Losch (1954) and Isard (1956), along with others explored and discussed urban growth from an economic standpoint known as the equilibrium theory, or the transportation costs vs. the market value of goods in terms of spatial distribution. The von Thünen model, which places the market and the majority of the population in the center of an isolated state with agriculture and other physical amenities of a region located in concentric circles outward (von Thünen et al. 1966).

More recently, William Alonso (1960, 1964), examined the interaction between land values and land use in urban settings. The basic form of this theory states that a homebuyer tends to select a parcel of land to buy based on a combination of three categories: quantity of land, commuting distance to city center, and the quantity of the composite good, which is the package of all other goods in the area (Chapin & Kaiser Jr 1979, 39 and Alonso 1960;1964). Alonso is not alone in this basic thought in what determines the urban land market and associated land use implications, other authors such as Wingo (1960), Fiery (1947), and Guttenburg (1960) also look at new developments being a function of transportation costs to the workplace, in this case, the city center, as well as the social implications of residential developments.

Recent years have witnessed the massive urban sprawl in the United States, and substantial attention has been paid to the issues of urban growth patterns (or spatial-temporal characterization of urban growth) and models (e.g., Dahal et al., 2016). Despite its popularity, it eludes a strict definition due to its complexity (Angel et al. 2007, Barnes et al. 2001, and Wilson et al. 2003).

Interwoven with urban growth is the process of suburbanization, which is the process by which an urban area expands into mostly low-density residential areas near systems of high transportation (i.e. public transportation or highways) (Adamson 1955 and Mieszkowski & Mills 1993). One of the main drivers behind suburbanization is the increasingly lower transportation costs in term of commuting time and distance for employment in the central city. The effect of this is mainly felt on agricultural production, landscape and pricing (Lopez et al. 1988). This type of growth occurs in what is typically known as the rural-urban fringe.

The rural-urban fringe, as defined by Pryor (1968), is the

> "…zone of transition in land use, social and demographic characteristics, linking between (a) the continuously built up urban and suburban areas of the central city, and (b) the rural hinterland, characterized by the almost complete absence of nonfarm dwellings, occupations and land use, and of urban and rural social orientation; an incomplete range and penetration of urban utility services; uncoordinated zoning or planning regulations; areal extension beyond although contiguous with the political boundary of the central city; and an actual and potential increase in population density, with the current density above that of the surrounding rural districts but lower than the central city."

Since 1937 and T.L. Smith's discussion of the urban fringe around Louisiana, researchers have studied the trends of urban growth specifically at the boundary between urban and rural areas, which emphasized the housing, urban sprawl and land use dynamics (Anderson & Collier 1956, Smith 1937, Sinclair 1967, Theobald 2005, Eagle et al. 2014, Lopez et al. 1988, Heimlich & Anderson 2001).

It is worth noting that the spatial-temporal characteristics of urban growth have become less exact in its distribution than some theoretical models discussed above, with the rural-urban fringe being more irregular in that there is the city center, the suburban (less dense) development, agricultural areas, and then forests/wilderness (Wehrwein 1942). Researchers identified a wide arrange of urban growth patterns, such as dispersion, compaction, fragmentation, heterogeneity, patchiness, and clustering (Botequilha-Leitao et al. 2006, McGarigal 2006). Irwin & Bockstael (2007) regarded residential low density development at the rural-urban fringe as prevalent. This exurbanization, or sprawl, has led to a number of negative consequences such as fragmentation, or the scattered development of new urban areas. Urban areas tend to grow in irregular shapes and directions as a function of local land use characteristics, infrastructure and regulation/policies (Irwin & Bockstael, 2004). The most significant feature of urban growth in the United States (or urban sprawl) is highly fragmented and low-density housing (Coisnon et al. 2013). As stated by Coisnon et al. (2013), the fundamental forces of urban sprawl are physical geography, population growth, and the cost of commuting and the rise of household incomes. This outward urban expansion typically converts agricultural land more than any other land use type (Roe et al. 2004).

In the United States, however, spatial patterns of urban growth typically follow a pattern of expansion and coalescence. As will be discussed later, these represent the differing forms of urban growth of infill and spontaneous growth. In a typical scenario, urban growth first occurs as spontaneous growth, or growth that occurs outside the contiguous urban area. As the urban area continues to develop, this growth expands on the edge of existing urban areas and eventually infills and coalesces the developed urban areas into an unbroken urban unit (Kaza, 2013). As found in Kaza (2013), rural counties experienced fragmented urban growth during the early 2000's and urban counties experienced coalesced growth patterns.

With the technological advances in both satellite imagery and the methods used to analyze urban growth patterns, such as GIS and spatial analysis, quantifying and analyzing the urban growth processes has become more practicable (Gao & Li 2011, Luo

& Wei 2009 and Su et al. 2012; Dahal et al., 2016). Urban growth patterns are the differing shapes and spatial dispersion of urban areas over time. Quantifying these measurements is done through a process of calculating landscape metrics using methods and measurements described in McGarigal et al. 2002). McGarigal et al. (2002) originally developed these metrics in the application of ecological studies, but they havebeen recently used in the description of urban growth processes (e.g. Herold et al. 2002, Deng et al. 2009, Luck & Wu 2002, Angel et al. 2007, Irwin & Bockstael 2007; Dahal et al., 2016).

One of the most common initial examinations of urban growth is analyzing and identifying the different types of urban growth forms. Urban growth forms are proximity-based categories of new urban areas in relation to existing urban areas (Camagni et al. 2002; Dahal et al. 2016; Xu et al. 2007). The results of this analysis are then able to be used in conjunction with other spatial analysis, such as gradient analysis, particularly using GIS.

Determinants of Urban Growth

Previous studies have found different drivers of urban growth and urban land use change such as physical, socioeconomic, neighborhood, and land use and planning policies (Dahal & Lindquist 2017; Li et al, 2013). To identify these factors of urban growth, different statistical methods are employed, such as logistic regression and its variations. Most studies measuring the determinants of urban growth draw upon the application of non-spatial logistic regression (Cheng & Messer 2003). This model is suitable for examining urban growth from a global, or aggregate, level based on the explanatory variables discussed earlier. It is simple because this method is characterized by its ability to handle binary dependent variables (1 and 0), urban growth in this case, as well as the model having no expectation of a linear relationship between the dependent and independent variables (Cheng & Masser 2003).

An issue with using this basic logistic regression in urban growth modeling is that it is unable to capture the spatial heterogeneity of each variable as it is a global, or aggregate, regression. As a result, there are several variations of the logistic regression that can be used to capture this.

Some methods that eliminate spatial autocorrelation or take spatial heterogeneity into account are spatial logistic regressions, which can come in the form of spatial filtering, spatial autologistic regressions, and geographically weighted logistic regressions. By applying spatially explicit modeling techniques, researchers highlight the effects of each individual variable based on location criteria, such as inside and outside of a certain geographic area. The applications of both non-spatial logistic regression technique and the GWR logistic regression provide nuanced evidence while considering the issue of spatial heterogeneity (Nakaya et al. 2015, Luo & Wei 2009, Zhang et al. 2017). Non-spatial logistic regressions are not able to fully capture spatially varying effects of a variable due to the coefficient values being generalized over the whole study area instead of capturing local variations (spatial nonstationarity) (Brunsdon et al. 1998, Fotheringham 2002, and Openshaw 1993). Over the past two decades, this issue has been explored more and more with the main focus being the desire to create 'mappable' regression results, which necessitates the use of a GWR and locally varying coefficient values (Brundson et al. 1998). This method has gained popularity over the past decade due to its ability to visualize the individual variables' impact over space and time

(Atkinson et al. 2003, Fotheringham 2002, and Dahal & Lindquist 2017). In this project, this method has special value as it can examine the local variability of the coefficients as well as the local significance of each variable: something that is not shown by using the typical logistic regression.

Amenity Migration

This study focuses on amenity driven urban growth and its implications for ecosystem services in Northern Idaho, a region characterized by richness in natural amenities. With the exception of a few major cities that constitute capitals and few other large metropolitan areas, the American West is mostly comprised of rural areas, far away from typical urban amenities, such as employment, healthcare, shopping, entertainment, etc. (Chi & Marcoullier 2013, Isserman et al. 2009). Growth that does occur despite these limitations is directly driven by access to natural amenities (Chi & Marcoullier 2013, Isserman et al 2009, Kwang-Koo et al. 2005). The results of this type of growth are often accompanied by shifts the traditional economic and entrepreneurial efforts common in rural areas (such as logging and mining), to that of a service based economy for those of higher economic standing, which serves to incentivize further growth (Gosnell & Abrams 2009).

Recently, a particular focus is presented on midsize cities, metropolitan areas with populations between 50,000 and 300,000, and the interactions with the rural areas surrounding them (US Census Bureau 2014 and Allen et al. 2016). The rural-urban interactions in these midsize cities present a particular challenge in future urban planning due to the tight physical and economic constraints that the rural areas present.

As amenities are one of the key reasons that a city will expand in a certain direction (e.g. Li et al. 2016, Roe et al. 2004, and Coisnon et al. 2014), these natural amenities, as described by Brueckner et al. (1999), are closely tied to local physical geography. Close proximity to these natural amenities have shown to have had a positive impact on residential location choices, housing development, and general health and well-being (Nilsson 2014, Ambrey & Fleming 2011, and Bertram & Rehdanz 2015). There is a high premium placed on the areas with high urban amenity access, as areas with significant access to such areas are worth considerably more than those without access (Anderson & West 2006; Ambrey & Fleming 2011). The desire for these areas can cause significant amounts of population influx (Chi & Marcoullier 2013, Nelson et al. 2014).

Primary access to these amenities is typically determined by income, or those who can afford to be located nearest the desirable amenity (Anderson& West 2006, Ng 2008, and Gosnell & Abrams 2011). In a process titled ‘rural gentrification,’ Hines (2010) conducted an anthropological study of in-migration into Park County, Montana, an area not dissimilar from Kootenai County, ID, which is the study region in this thesis. The relative strength of the high degree of in-migration in Hines (2010) was driven by the idea of ‘permanent tourism’, the desire to visit amenity-rich areas on a more permanent basis and not for any of the socioeconomic reasons typically found in larger cities. Some of these amenities include, but are not limited to, resorts, lakes, rivers, and forests.

This form of urban growth is not limited to the United States, as the entire world has similar reasons for migration to certain places. In particular, Brueckner et al. (1999) discusses the disparities between central Paris and downtown Detroit as being directly associated with the amenities these two downtown areas are able to provide over suburban areas. There have been many studies that analyze amenity driven urban growth (e.g. Allen & Lu 2003, Dahal et al. 2016, Ng 2008, Li et al. 2016, Atkinson-Palombo 2010, and Irwin & Bockstael 2007). In general these studies discovered that a significant portion of the urban growth to the area was due to its proximity to these natural and or urban amenities.

Many others examine the physical geography of an area from a limiting standpoint, such as slope and density of different land types, instead of examining the relationship between urban growth and proximity to the different natural amenities listed above (Hu & Lo 2007, Li et al. 2016, Luo & Wei 2009, and Zhang et al. 2017). Nilsson (2014), Kwang-Koo et al. (2005) and Chi & Marcoullier (2013), quantitatively discuss the specific draw of natural amenities as a key determinant of urban growth. More studies are needed to quantify the patterns of urban growth in this setting especially using GIS and further explore the spatiality of urban-growth determinants that include both socioeconomic and physical conditions as well as natural amenities.

1.3 Research Questions

The main questions to be answered in this project are, given the amount and direction of urban growth, what are the major drivers of urban growth and how urbanization could have a negative impact on the landscape particularly through the lens of urban land fragmentation? Connected to these questions, how could accessibility, zoning and other land use policies alter the effect of amenities on urban growth in Coeur d’Alene? Also, how does applying more spatially explicit methods such as landscape metrics and GWR modeling help us understand the direction, magnitudes and patterns of urban land expansion, and spatial varying effects of these type of drivers? Methodologically, the study aims to quantify the directionality and intensity of urban growth from 1992-2011 through landscape metrics-based analysis in a GIS environment and tie the directionality of urban growth to municipal and county boundaries, and will also determine the global and local determinants of urban growth using logistic and Geographically Weighted Logistic Regression (GWLR) from 2001-2011.

1.4 Study Area

Situated in northern Idaho, Kootenai County is home to Lake Coeur d'Alene and the city of Coeur d'Alene (Figure 1). It has an area of 3,407.62 km2 and an estimated population of 154,311 as of 2015 (U.S. Census Bureau, 2017).

Throughout its history, Kootenai County has been most famous for its natural resource attraction and extraction. Most prominent among these natural resources is the lumber mills that were a significant portion of the local economy as well as the recreational attraction of the forests and lakes. Also shown in Figure 1, the Coeur d'Alene River, which drains into Lake Coeur d'Alene and flows into the Spokane River, is home to the Bunker Hill Superfund Site, one of the largest such sites in the United States. This has had serious repercussions on water quality in the river and the lake as heavy metal contamination in the soils of the Coeur d'Alene basin is 'ubiquitous' (Brown et al. 2003, Sheldrake & Stifelman 2003 and Kootenai County Planning Commission 2010, 12). Over the past 50 years, however, both of these industries have declined in production, with Bunker Hill becoming a Superfund site and the economic shift from lumber mills in Coeur d'Alene to resorts and a tourist economy due to falling lumber prices (Kramer 2008).

The residents of Kootenai County are predominantly concentrated in the CDA metropolitan area, which is located in the Rathdrum Prairie, as seen in Figure 1. The population demographics are, as of the 2010 Census, 94.5% Caucasian, 4.4% Latino, 1.3% Native American, and <1% for other ethnicities. Of the residents, 92.1% of the residents have a high school degree and a further 23.1% have at least a Bachelor's degree. The per capita income of Kootenai County (in 2014 dollars) was $25,190 with a population density of 111.3 people per square mile (U.S. Census Bureau 2014).

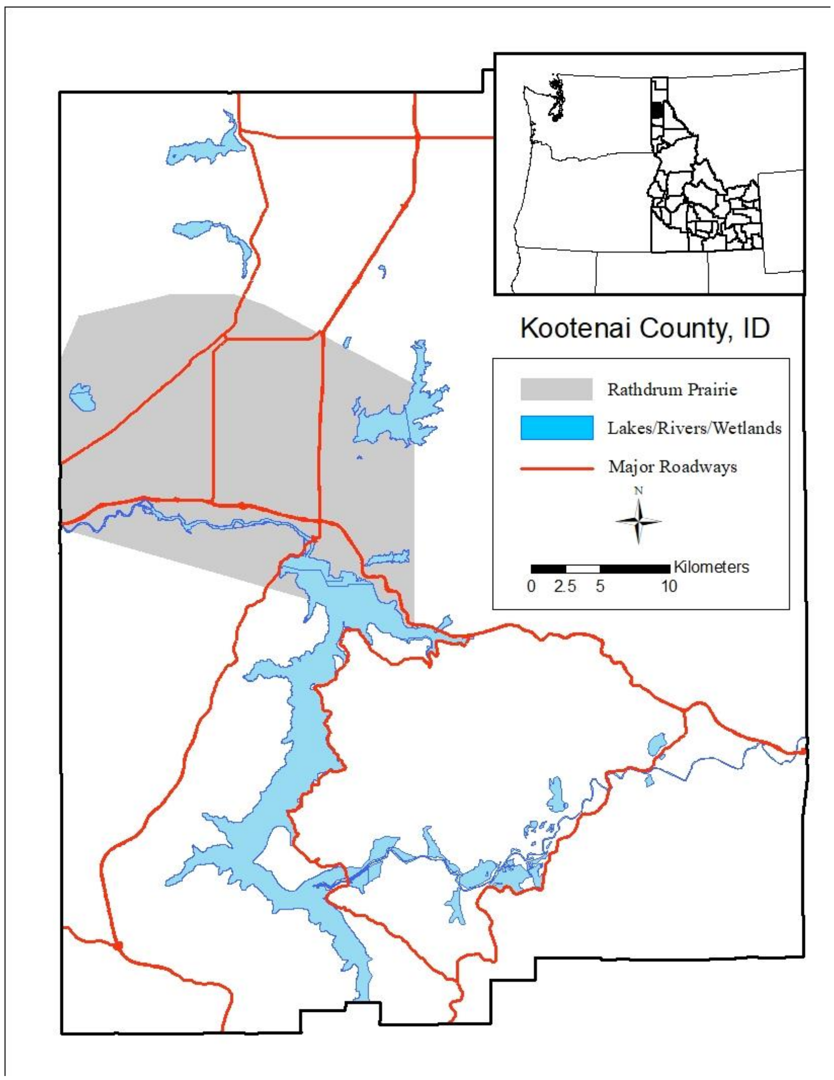


Figure 1.1: Kootenai County, ID

During the 1990's, the area experienced a tremendous amount of growth, from 69, 795 in 1990 to 108,685 in 2000 (U.S. Census Bureau 2014). Furthermore, the population then grew to 138,910 by 2010. This represents a population growth rate of 55.7% (5.57% per year) in the 1990s and 27.4% (2.74% per year) in the 2000s. Assuming a steady annual growth rate between 3% and 1%, the national average, the population of the county is expected to be between 160,000 and 240,000 people in 2025 (Kootenai County Planning Commission 2010, 4).

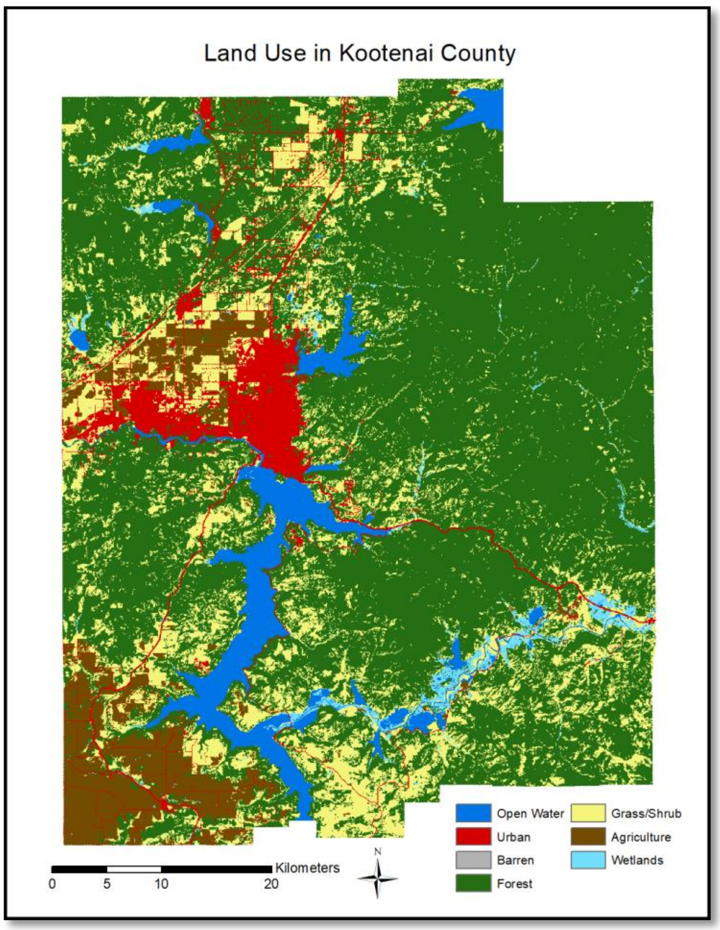


Figure 1.2: The Land Uses of Kootenai County

The forests surrounding the lake and city are the other key landscape amenities central to the area. These forests are an attractive home to various outdoor activities, such as hiking and camping. As of 2010, the residents of Kootenai County have listed forests, lakes, rivers as some aspects of the environment that have the highest intrinsic value while maintaining a high value on environmental conservation (Kootenai County Planning Commission 2010, 11).

As of 2007, there were approximately 32,000 acres of incorporated areas and another 80,000 acres within the Area of City Impact Zone (Kootenai County Planning Commission 2010. 14). The most current land use distribution (2011), as seen in Figure 2, is a predominantly forested county with significant amounts of agricultural land surrounding the urban areas. A vast majority of the urban area is concentrated in the Coeur d'Alene metropolitan area to the north of Lake Coeur d'Alene and the Spokane River.

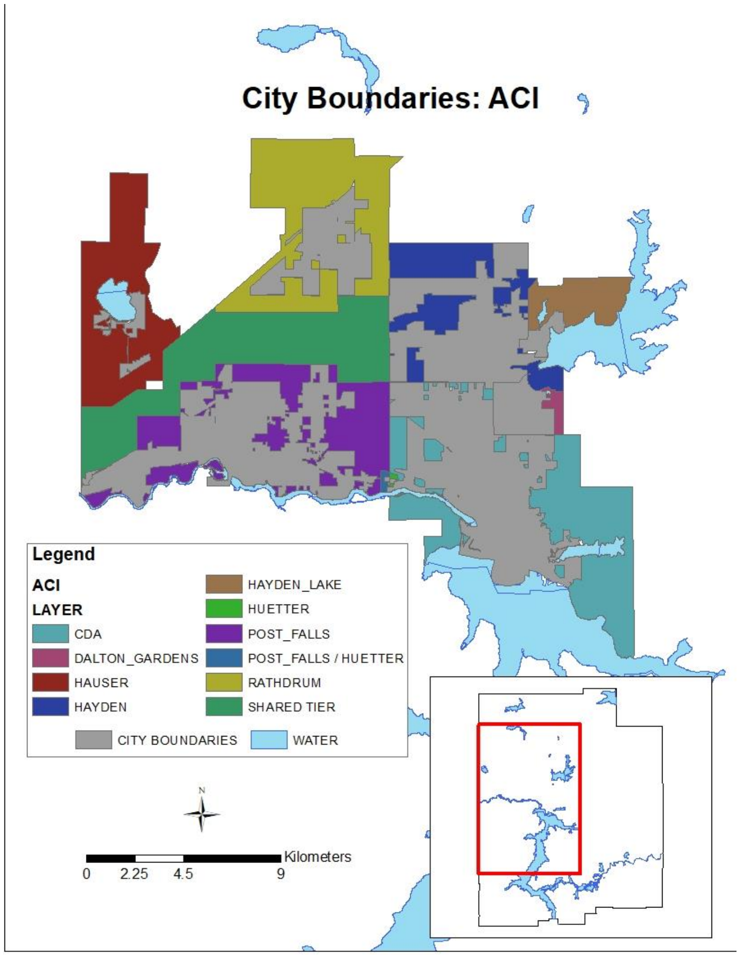


Figure 1.3: The Area of City Impact Zones

The urban growth boundaries of Coeur d'Alene, as well as the other cities in Kootenai County, provide limits to the growth that can occur for an individual city. Named Areas of City Impact (herein referred to the ACI), the entirety of the Rathdrum Prairie is reserved for the 4 main cities of Kootenai County, as seen in Figure 1.3. The zoning policies of Kootenai County provide a template for future urban growth as well as the preservation of existing open spaces, such as parks, forests, and lakefront (Kootenai County Planning Commission 2010, 14). As the majority of the urban growth in Kootenai County during this time period occurred in these cities, a minimum bounding rectangle was constructed around the various ACI within the Rathdrum Prairie as a focused study are for both the spatial patterns and spatial determinants chapters.

1.5 Scope of the Thesis

Through the case study of the greater Coeur d'Alene area, this thesis research aims to advance our understanding of the spatial-temporal dynamics and determinants of urban growth in an amenity-rich region using GIS.

The objectives of this thesis research are twofold: first, it aims to characterize urban growth in the greater Coeur d'Alene area through the lens of urban intensification and urban growth types, consisting of a patch analysis of the urban land to determine the amount of urban outlying expansion, edge-fill expansion, and infill expansion, a gradient analysis to determine the rate of change, and summary statistics to determine the land cover types that experienced the greatest amounts of non-urban to urban land use change. Particular attention will be paid to the issue of accessibility to major amenity features such as lakes, rivers and urban facilities and the effects of policy variables, such as zoning codes, urban growth boundary, and city limits (Zhang et al. 2017). Second, it will apply a Geographically Weighted Logistic Regression (GWLR) to measure the determinants of urban growth while taking into account the spatially varying effects of different drivers (see Luo and Wei, 2009).

1.6 Research Significance and Organization of Chapters

This study is an applied research project that offers more nuanced evidence for the relationship between human and natural systems in greater Coeur d'Alene area than non-spatial projects. By modeling urban growth in this amenity rich region, the work aims to supply updated evidence that urban planners or policy makers can use to search for innovative solutions addressing urban sustainability and the tension between human and natural systems (Bolund & Hunhammar 1999). The findings are closely tied to local policy making with respect to environmental impacts of urbanization on property values and personal well-being (e.g. Walls et al. 2015, Shultz & Schmitz 2008, Barbier et al. 2014 and Plane & Klodawsky 2013), and are transferrable to other areas in American west.

The remainder of the thesis is organized into four chapters. Chapter 2 will focus on the discussion on methodology and data acquisition, followed by two empirical analysis chapters Chapter 3, on spatial patterns of urban growth and, Chapter 4 on spatial determinants of urban growth). Lastly, Chapter 5 summarizes and discusses the major findings and implications for urban planning and policies.

Chapter 2: Data and Methods

This chapter summarizes methods used in characterizing and analyzing the spatial temporal dynamics and determinants of urban growth in the greater Coeur d'Alene area. By integrating GIS spatial analysis techniques and datasets derived from parcel level and pre-processed remote sensing data, this thesis project aims to quantify the amount and direction of urban growth and demonstrate how accessibility and other land use characteristics alter the effect of amenities on urban growth in the Coeur d'Alene metropolitan area. Regression analyses are carried out to address relative importance of different drivers of urban growth to answer the question of how applying more spatially explicit methods such as landscape metrics and GWR modeling help us understand the direction, magnitudes and patterns of urban land expansion, and spatial varying effects of different drivers.

2.1 Data

The data for this thesis project is divided into two parts, pre-classified National Land Cover Dataset (NLCD) data and socioeconomic and GIS data (e.g., roads, waterways, and population centers). As shown in Table 2.1, much of the data used is in the form of GIS data gathered from governmental agencies, such as the Kootenai County GIS department, the US Census Bureau, and the NLCD, which is a free product developed by the United States Geologic Survey, and non-governmental agencies such as InsideIdaho and GoogleEarth. The study emphasizes both spatial and temporal dynamics of urban growth in Kootenai County and the Coeur d'Alene metropolitan area with an emphasis on the Rathdrum Prairie area. This research addresses the detailed geographies of urban growth in Coeur d'Alene and how drivers of urban growth could exhibit spatially varying effects by using a GWLR regression model.

With respect to data that can characterize urban growth, previous studies use both remote sensing data and parcel level data mostly gathered from local tax offices to reach an understanding of urban growth. Remote sensing data offers customized time series analysis as well as classification consistency throughout the study area but can be problematic due to the heterogeneity of urban areas, such as parks, tree cover, and other objects that can affect classification (Herold et al. 2002). On the other hand, tax records could help analyze urban growth as they are up to date with the current zoning and land use of areas that may be hidden from satellite imagery (Carrión -Flores & Irwin 2017; Irwin & Bockstael 2007; and Irwin & Bockstael 2004). Using the two datasets assists in both visualization of the study area as well as ensures land use accuracy at the local level.

Table 2.1: Data used and sources

Data Type	**Data Description**	**Year of coverage**	**Data source**
NLCD	Land Use data (30m)	1992, 2001, 2011	Mrlc.com
Agricultural	Agricultural vs. non-agricultural land	1992, 2001, 2011	Mrlc.com
Forest Land	Forest vs. non-Forest land	1992, 2001, 2011	Mrlc.com
Urban Extent	Urban vs. non-Urban land	1992, 2001, 2011	Mrlc.com
Grassland	Grass vs. non-Grass land	1992, 2001, 2011	Mrlc.com
Transportation	Major roadways	1990s, 2000s	Kootenai County GIS
Digital Elevation Model	10m resolution elevation	1999	inside.idaho.edu
Hydrology	Location of Rivers and Lakes	Constant	Kootenai County GIS
City Location	Geographic location of Cities	Constant	GoogleEarth
% Population White	% white population at the block group level	2000	Census.gov
Average Household Income	Average annual household income at the block group level	2000	Census.gov
% Bachelor	% population with a Bachelor's Degree	2000	Census.gov
% Renter	% of the population that rents	2000	Census.gov

The NLCD is a division of the Multi-Resolution Land Characteristics consortium, which is a group of federal agencies (EPA, NOAA, USFS, USGS, BLM, NASS, NPS, NASA, USFWS and US Army Corps) that formed in the mid-1990s. These agencies coordinate and develop land cover information at the national level for a variety of applications (MRLC.gov). The objective of the products is to provide researchers with current, complete, consistent and public domain information on the land cover of the United States (MRLC.gov).

In order for the different years of NLCD data to be compatible with each other in 1992, 2001, and 2011, a broad classification of land use types, typically urban, agricultural, water, and forest is needed (Crowther Jr. 2015, Dahal et al. 2014, Huang et al. 2009, Graham & Congalton 2009, Luo & Wei 2009, Zhang et al. 2017). The NLCD has gone through two separate classification schemes, with different classifications being used for 1992 and 2001-2011 (Homer et al. 2007, Homer et al. 2015, Vogelmann et al. 2001 and Fry et al. 2011). This change makes a direct comparison of all different land cover types between these two datasets challenging. A retrofit change product was developed by the NLCD to reconcile the differences between these two different classification methods, but is not intended to capture local land cover changes (Fry et al. 2009). Furthermore, examining the amount of growth using the NLCD retrofit product does not reflect the population change that occurred in this area during the 1990s. The population of Kootenai County grew by 4.62% (3,909 people) per year between 1990 and 2001; the corresponding urban change in the retrofit product is, by comparison, significantly lower at a rate of 51.06 hectares per year (U.S. Census Bureau 2014). As a result, the 1992 dataset was compared to the 2001 dataset using the urban/nonurban classifications and methods found in other studies (Graham & Congalton 2009, Crowther Jr. 2015 and Fry et al. 2009). Reconciling the differences between the 1992 and 2001 NLCD dataset is completed through a reclassification of both datasets to a more general version of their native classifications. Table 2.2 shows the classifications for 1992 and 2001 and their corresponding Anderson Level I class.

Table 2.2: The Anderson Level I Crosswalk with the 1992 and 2001 NLCD Datasets (Fry et al. 2009)

1992 NLCD Class		**2001 NLCD Class**		**Anderson Level I Class**	
11	Open Water	11	Open Water	1	Open Water
12	Perennial Ice/Snow	12	Perennial Ice/Snow	8	Ice/Snow
85	Urban/Recreational Grasses	21	Developed, Open Space	2	Urban
21	Low Intensity Residential	22	Developed, Low Intensity	2	Urban
22	High Intensity Residential	23	Developed, Medium Intensity	2	Urban
23	Commercial/Industrial/Transportation	24	Developed, High Intensity	2	Urban
31	Bare Rock/Sand/Clay	31	Barren	3	Barren
32	Quarries/Strip Mines/Gravel Pits			3	Barren
33	Transitional			3	Barren
41	Deciduous Forest	41	Deciduous Forest	4	Forest
42	Evergreen Forest	42	Evergreen Forest	4	Forest
43	Mixed Forest	43	Mixed Forest	4	Forest
51	Shrubland	51	Dwarf Scrub	5	Grassland/Shrub
		52	Shrub/Scrub	5	Grassland/Shrub
61	Orchards/Vineyards/Other			6	Agriculture
71	Grasslands/Herbaceous	71	Grassland/Herbaceous	5	Grassland/Shrub
81	Pasture/Hay	81	Pasture/Hay	6	Agriculture
82	Row Crops	82	Cultivated Crops	6	Agriculture
83	Small Grains			6	Agriculture
84	Fallow			6	Agriculture
91	Woody Wetlands	90	Woody Wetlands	7	Wetlands
92	Emergent Herbaceous Wetlands	95	Emergent Herbaceous Wetlands	7	Wetlands

2.2 Methods

Most studies aimed at examining urban growth, the conversion of non-urban to urban pixels, have done so by addressing the spatiotemporal dynamics of urban growth. Spatial-temporal dynamics in this study are focused on quantifying the extent and rate of urban growth in different study periods (i.e., 1992-2001 and 2001-2011). Besides the magnitude of urban growth, urban growth forms, gradient analysis and buffer-zone based analyses, and landscape metrics are used to provide nuanced evidences with respect to both the patterns and quality or fragmentation aspects of urban growth.

2.2.1 Landscape Metrics

Landscape metrics are the quantifications of a land cover type within a set patch size. It is a widely used method of analyzing the fragmentation of urban areas and patterns of urban land expansion. Before any analyses are run, the spatial statistics tool in the Patch Analyst toolset, developed by the Spatial Ecology Program at the Centre for Northern Forest Ecosystem Research as an extension to ArcGIS (Rempel et al. 2012 and McGarigal & Marks 1994) was used to group the individual polygons into patches. To ensure the quality of the analyses, cell patches with a combined area of less than 7,200 square meters (8 cells) were eliminated from the study area, as used in Dahal et al. (2017).

Also derived from the Spatial Statistics tool are several landscape metrics that are calculated to conceptualize the urban form at the class level. The most common of these are number of patches (NP), largest patch index (LPI), edge density (ED), patch density (PD), mean patch size (MPS), area-weighted mean patch fractal dimension (AWMPFD), Shannon's Diversity Index (SDI), and percent class area (%CA) (McGarigal & Marks

1994). For the purposes of this thesis the landscape metrics that will be calculated are listed in Table 2.3.

Table 2.3: Landscape Metrics and Descriptions (McGarigal 2006 and Rempel et al. 2012)

Landscape Metric	**Abbreviation**	**Units**	**Description**
Number of Patches	NumP	N/A	Number of patches of the corresponding patch type
Total Edge	TE	M	Total perimeter of the patch type
Edge Density	ED	m/ha	The amount of meters perimeter per hectare
Mean Patch Size	MPS	Ha	The average area of all patches in the landscape
Area-Weighted Mean Shape Index	AWMSI	N/A	The average shape of the patches weighted by the individual size of the patches (values >1)
Mean Perimeter-to-Area Ratio	MPAR	m/ha	The average ratio of the perimeter to area
Mean Patch Edge	MPE	m/patch	Average perimeter of the patches

Calculation of these landscape metrics is used to analyze the overall changes in urban land patterns centered on amenity features (e.g., lakes and rivers). At such a fine scale (30 meters), the landscape metrics characterize the urban growth form, growth trends, and fragmentation of the urban areas along different major development corridors in the cities (e.g., transportation networks).

2.2.2 Urban Growth Form

Urban growth forms are the different paths growth can take based on their location relative to previously existing urban land. This is calculated by running an intersect function between areas of new urban growth and old urban areas. There are three different forms of urban growth (UGF's), infill, edge-expansion, and spontaneous, as seen in Figure 2.1.

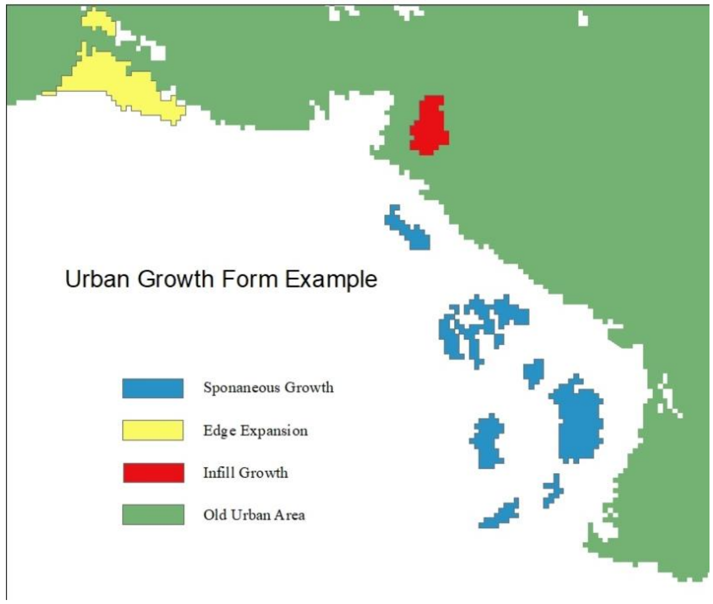


Figure 2.1: Examples of Different Urban Growth Forms

Following Xu et al. (2007), the study employs the ratio of shared boundary value between the old and new urban land patches divided by the total boundaries of existing urban land patches to differentiate the three type of urban growth, including infilling, edge expansion, and spontaneous. The ratio S is calculated based on Eq 1 below:

$$S = L_c/P \qquad \text{Eq. 1}$$

where $L_c$is the length of the common boundary of a new urban area and pre-growth urban areas and P is the perimeter of the new urban area.

Infilling is characterized as $S \geq 0.5$, or more than half of the patch is surrounded by old urban areas, edge-expansion is characterized by $0 < S < 0.5$, or a patch that is less than half surrounded but more than zero, and spontaneous growth is characterized by $S = 0$, or not connected to any old urban patch (Xu et al. 2007). Dahal et al. (2016) used the same method, yet arrived at a value of 0.45 as the threshold between infill and edge expansion. This value was arrived at by experimentation. In the case of Dahal et al. (2016), however, the study areas were solid and unbroken urban areas in which significant infill growth was impractical. Due to the significant area that could be infilled in 1992, the threshold of 0.5 was used to determine infill growth in this study.

2.2.3 Gradient Analysis

Gradient analysis is a useful method in examining the spatial patterns of urban growth as a function of distance from varying socioeconomic and physical objects (Luck & Wu 2002; Dahal et al. 2016). There are several different methods of conducting a gradient analysis and characterizing spatial patterns of urban growth. One of the most common methods is by using concentric zones, as employed by Dahal et al. (2016), Xu et al. (2007), and Zhang et al. (2017). This is done by creating concentric buffers centered on the city center or downtown and quantifying the area of newly developed land in different buffer zones. The process to measure the outward growth trend is to construct buffers of a selected width (1 km in the case of Dahal et al. (2016) and 200 meters in Xu et al. (2007)) from the edge of the original urban area and calculating the amount of newly developed land within each buffer zone. For this thesis, the gradient analysis is conducted using a buffer of 500 meters, the width of which was determined through experimentation due to the differences in study area size in the literature (Figures 2.2-2.4). Dahal et al. (2016) created these buffers around old urban areas and major roadways. Given the importance of the lakes and rivers to the economic and recreational health of the area, a gradient analysis of urban growth near the lakes and rivers is also conducted to quantify this relationship using the same buffer distance. While the river is used as a major transportation corridor with significant commercial implications to the area, the lake is also a significant recreational draw to the area and is worthy of similar weight.

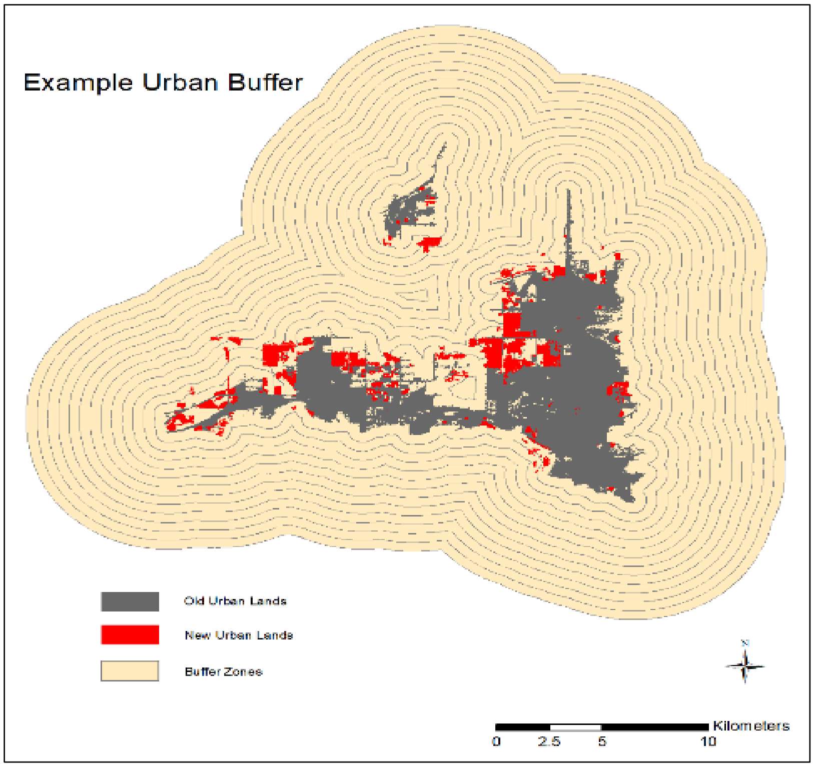


Figure 2.2: Example of Urban Boundary Buffer

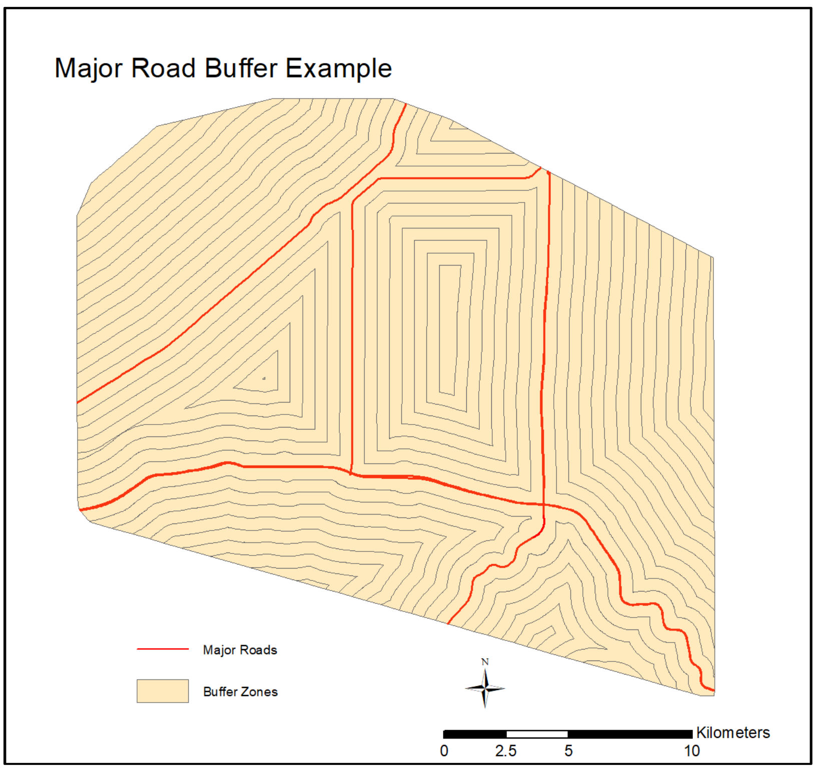


Figure 2.3: Example of Major Road Buffer

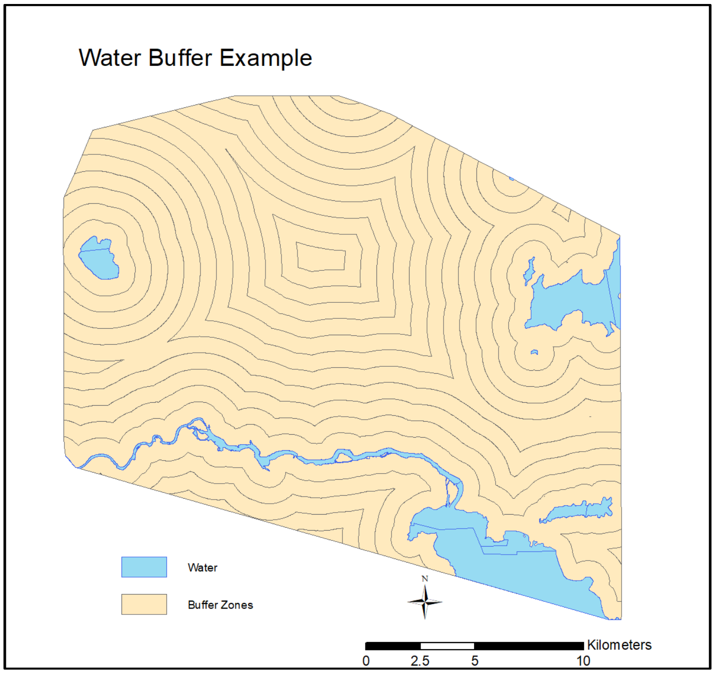


Figure 2.4: Example of Water Buffer

2.2.4 Regression Analysis

In order to determine the drivers of urban growth, regression analyses are employed to determine the relationship between urban growth and various socioeconomic and physical factors underlying the land conversion from non-urban to urban uses. With respect to modeling urban growth determinants, the study uses both non-spatial logistic regression and spatial logistic regression to explore the effects of different types of variables (See Table 2.4). The original regression model used to examine urban growth determinants was the logistic regression model. In this study, the major data representing urban growth in this project are derived from pre-classified remote sensing data. After experimentation with several pixel sizes, using a minimum resolution of 30 meters and a maximum 300 meters as found in Luo & Wei (2009) and Cheng & Masser (2003), a pixel size of 120 meters was determined to be the best fit due to the lack of sample points of the 300 meter pixel and the superfluous number of pixels of the 30 meter pixel. To gather these points, a fishnet of polygons (120 meters by 120 meters) was created with the calculated centroids of these polygons acting as the original point data.

The sample point selection was determined by first taking, a selected sample of all pixels that experienced non-urban to urban change at the selected 120 meter pixel resolution. 1,386 pixels were found to have experienced non-urban to urban change. Following the literature (e.g. Liao and Wei 2015, Dahal & Lindquist 2017, and Luo & Wei 2009) a random selection of the same amount of points was taken from the areas that did not experience urban growth. Areas that physically prohibit growth (i.e. lakes and rivers) were eliminated from the random sample area as seen in Figure 2.1. This resulted in a complete selection of 2,772 pixels/points or observations.

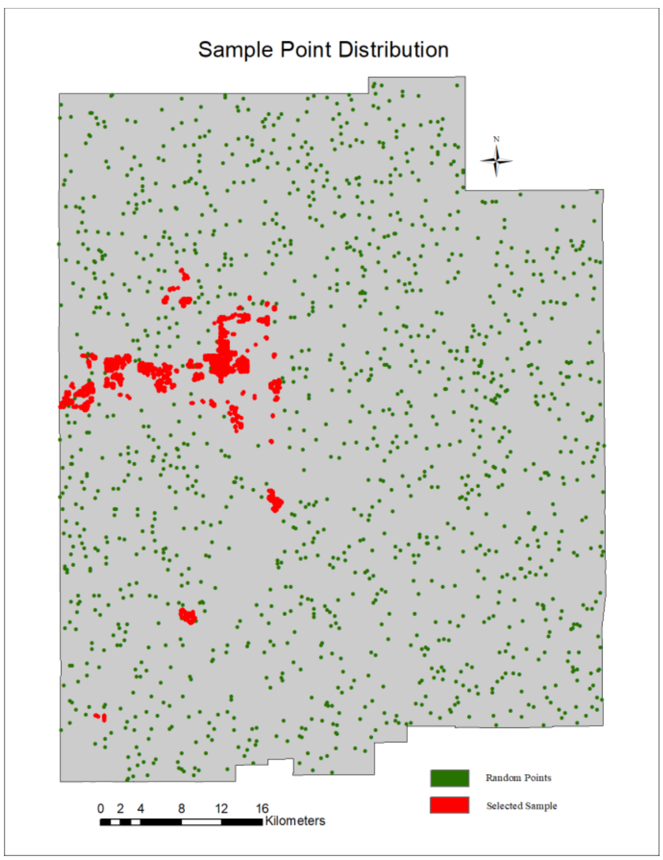


Figure 2.5: Point Selection for Regression Analysis

Major variables used to gauge the drivers of urban growth during 1990s and 2000s are proximity to infrastructure, physical environment, and socioeconomic factors (Table 2.4). Firstly, proximity to major urban infrastructures and amenities is captured by distances to road networks (EucDist_Ma) and distances to city centers (EucDist_Ci). Slope and elevation are used to quantify the effects of physical constraints on urban growth. Focal statistics are used to quantify the impacts of neighborhood land uses on urban growth and are measured on a scale of 0-1. Thirdly, a set of socioeconomic variables are also employed to capture the effects of socioeconomic factors such as income and education could have an impact on urban growth (Cheng & Masser 2003, Bertram & Rehdanz 2015, Zhang et al. 2017, and Chi & Marcoullier 2013).

Table 2.4: Dependent and Independent Variables used in Logistic Regression and GWLR

Dependent Variable	**Types**	**Description**
Urban Change	Dummy	Land-Use conversion from rural to urban
Explanatory Variables		
Proximity to Infrastructure		
EucDist_Ma	Continuous	Euclidean distance to roadways
EucDist_Ci	Continuous	Euclidean distance to city centers
EucDist_Hy	Continuous	Euclidean distance to waterways
Physical Attributes		
Slope	Continuous	Slope of sampled pixels
DEM	Continuous	Elevation of sampled pixels
Physical Density		
FocalSt_Ag	Continuous	Density of Agricultural land
FocalSt_Wa	Continuous	Density of Water
FocalSt_Fo	Continuous	Density of Forest Areas
Socioeconomic Factors		
% Population White	Continuous	% white population at the block group level
Average Household Income	Continuous	Average annual household income at the block group level
% Renter	Continuous	The percent of the population that rents property
% Bachelor Degree	Continuous	The percent of the population with a Bachelor Degree

Aside from the basic logistic regression formula (see Eq. 2.1), the spatial regime method examines the influence each independent variable has on the dependent variable based on sub-regions in the study area. In this thesis, the spatial regime interaction term is defined using sample points within and outside of the ACI.

$$logit(Y) = \beta_0 + \sum_{k=1}^{n} \beta_k X_k + \varepsilon$$

Eq. 2.1

The dependent variable Y of the logistic regression was a presence or absence event, when Y=1, it denotes a pixel converted from non-urban to urban uses, and Y=0 otherwise. P(y=1) indicates the probability of nonurban to urban land conversion (Eq. 2.1).

A spatial regime model is a logistic regression based on some spatial characteristic, called an interaction term. Equation 2.2 shows the model formula of the logistic regression with the interaction terms.

$$\begin{bmatrix} y_i \\ y_j \end{bmatrix} = \begin{bmatrix} X_i & 0 \\ 0 & X_j \end{bmatrix} \begin{bmatrix} \beta_i \\ \beta_j \end{bmatrix} + \begin{bmatrix} \varepsilon_i \\ \varepsilon_j \end{bmatrix}$$

Eq. 2.2

Equation 2.3 is the GWLR model, where p_i is the probability that the independent variable equals 1 at location *i*. The right-hand side of the equation is the effects of the independent variables based on the bandwidth kernel used.

$$logit(p_i) = \sum_k \beta_k(u_i, v_i) x_{k,i}$$

Eq. 2.3

For this thesis, the GWLR (Eq. 2.3) was employed to examine the spatial variations of drivers behind urban growth. This method allows for the same regressions as before to be performed at the local level to determine the spatial variations of determinants. This method is placed at a higher premium than that of its global counterpart due to the model performing a logistic regression analysis at every sample point. This can lead to some severe computational requirements, particularly with datasets numbering in the thousands with many different dependent variables to calculate. The result, however, is a measurement of the effect that location has on the independent variable, in this case, urban growth.

Chapter 3: Spatiotemporal Dynamics of Urban Growth

This chapter focuses on the spatial and temporal dynamics of urban growth in the greater Coeur d'Alene area. By using landscape pattern analysis, the chapter provides a comprehensive and spatial-temporal characterization of urban growth trends, directions and patterns in the Coeur d'Alene area. Particular attention is paid to the draws of important amenity features (e.g., rivers and lakes).

3.1 Urban growth and land use

Based on the analysis of NLCD data, Kootenai County has experienced a significant amount of urban growth - 9,813 hectares - from 1992-2011 (Figure 3.1). The magnitude of urban land expansion is relatively moderate in the 2000s, as compared to that in the 1990s. Annual growth rate of urban land use was 785.1 ha/year in the 1990's and 196.11 ha/year in the 2000's, respectively. In general, the lion's share of urban growth occurs in in the Area of City Impact, which accounted for 63% and 92% of total urban land expansion during 1992-2000, 2000-2011 time periods, respectively (Figure 3.1).

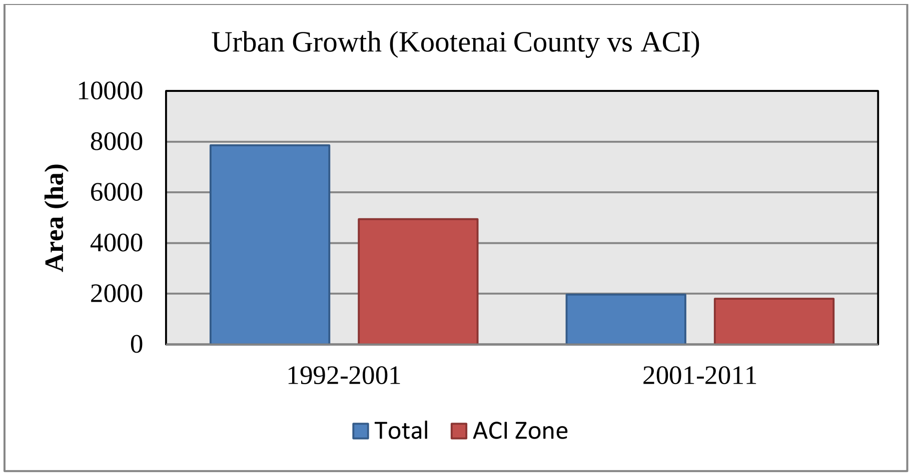


Figure 3.1: Comparison of Urban Growth: ACI vs. Kootenai County

Notes: The reason for the disparity between the proportionality between the different time periods is the amount of ‘noise’ that is present in the 1992-2001 Kootenai County dataset. ‘Noise' simply refers to the interference/inaccuracy of the dataset that creates areas of false positives; in this case, urban growth areas in which none occurred.

Urban growth is also accompanied by the inflows of migrants. As shown in the Table 3.1, population growth driven by amenity migration in the 1990s was more drastic than in the 2000s. With respect to the spatial pattern of demographic change, the population growth rates of the ACI are consistently larger than those in the county as a whole. The recent economic downturn tends to associate with the sluggish economic growth in the United States, and correspondingly, slower population change (Chi and Marcouiller 2011).

Table 3.1: Comparison of population growth: ACI vs Kootenai County (Source: U.S. Census Bureau)

	Area of City Impact		**Kootenai County**	
	Growth	Growth rate	Growth	Growth rate
1990-2000	28,250	7.1%	39,098	5.5%
2000-2010	25,027	3.67%	29,369	2.68%

Table 3.2 demonstrates the sources of new urban areas by applying a land use matrix. Between 1992 and 2011, the majority of the land use change came in the form of

forest to grassland and agriculture to grassland, with the next most drastic change coming from barren and urban land. This change is also visible in Figure 3.2.

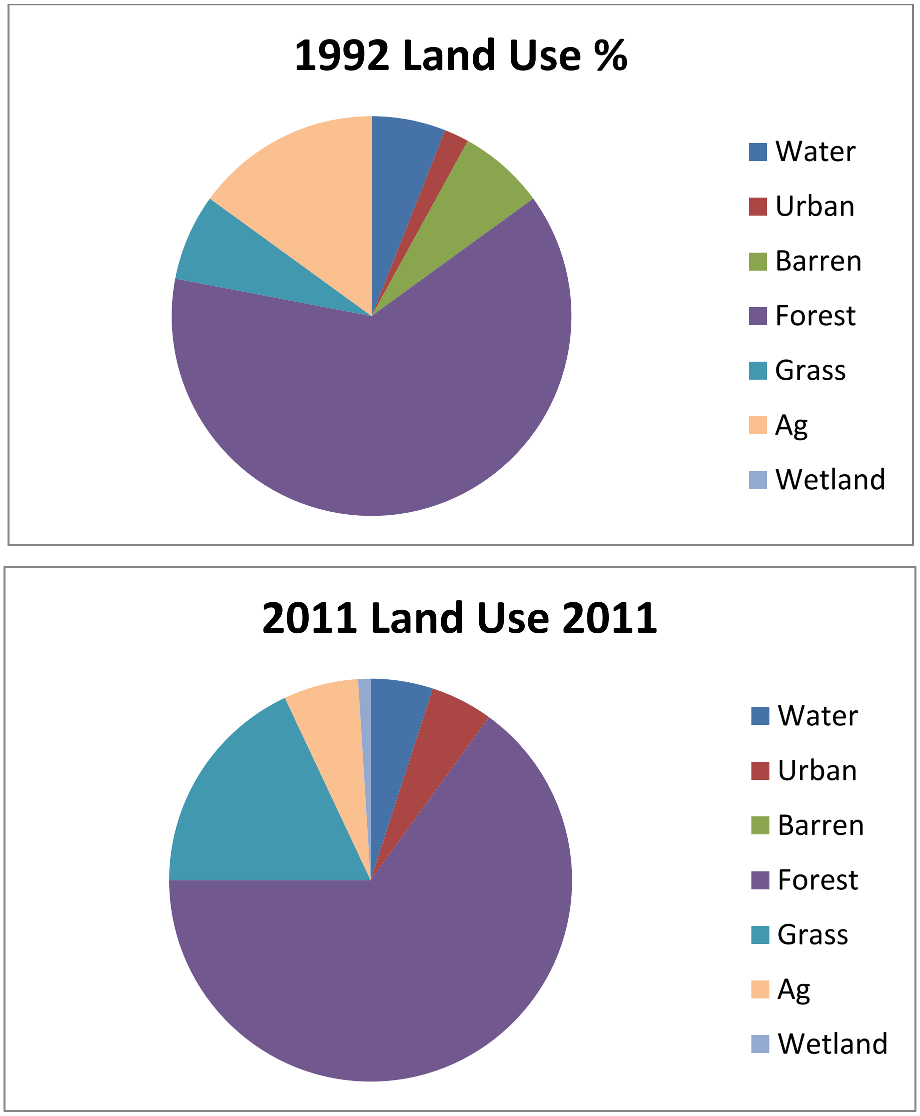


Figure 3.2: Land Use Percentages

Table 3.2: Land use change matrix in Kootenai County, 1992-2011

Land Use Change Matrix (ha)									
		2011							
		Water	Urban	Barren	Forest	Grass	Ag	Wetland	Total Land 1992
1992	Water	**17385**	106	6	948	196	2	411	19059
	Urban	40	**5759**	3	1286	1161	154	83	8490
	Barren	22	753	**2**	13898	8504	132	300	23614
	Forest	203	2481	1	**190237**	19946	143	2014	215028
	Grass	57	3866	6	7502	**10452**	1079	946	23912
	Ag	45	5298	27	5127	19329	**19176**	522	49527
	Wetland	76	19	0	163	69	2	**429**	760
	Total Land 2011	17831	18285	48	219165	59660	20691	4708	

Figure 3.3 below further shows the spatial distribution of new urban areas in Coeur d’Alene. Much of the urban growth occurred either to the west or north of the city. This holds with the physical geography of the area (Figure 3.4) as there is severe elevation change to the east and south along with the Spokane River and Lake Coeur d'Alene.

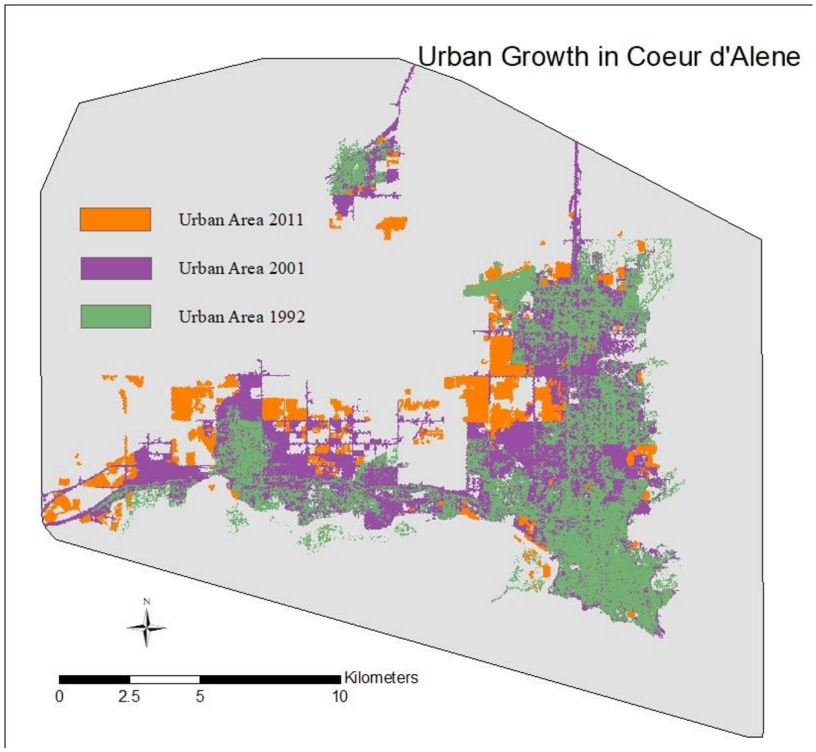


Figure 3.3: Urban Growth in Coeur d'Alene

Examining the digital elevation model in Figure 3.4 shows the high degree of rugged terrain that comprises the county. As a result, the only direction that urban growth is feasible is to the north and to the west of Lake Coeur d'Alene (the Rathdrum Prairie), which are areas of high agriculture production. As mentioned above, due to newer urban development, agricultural uses in the suburban areas would be less competitive in the land market, following land use models (Irwin et al. 2003). It should be noted that many old urban areas were used as industrial land uses before the 1990s while these areas were converted into new residential developments. This change could not be captured due to the limitation of the NLCD data and land classification methods used in this study. However, economic restructuring does play a key role in determining urban land use change and to some extent drive urban land expansion in the region.

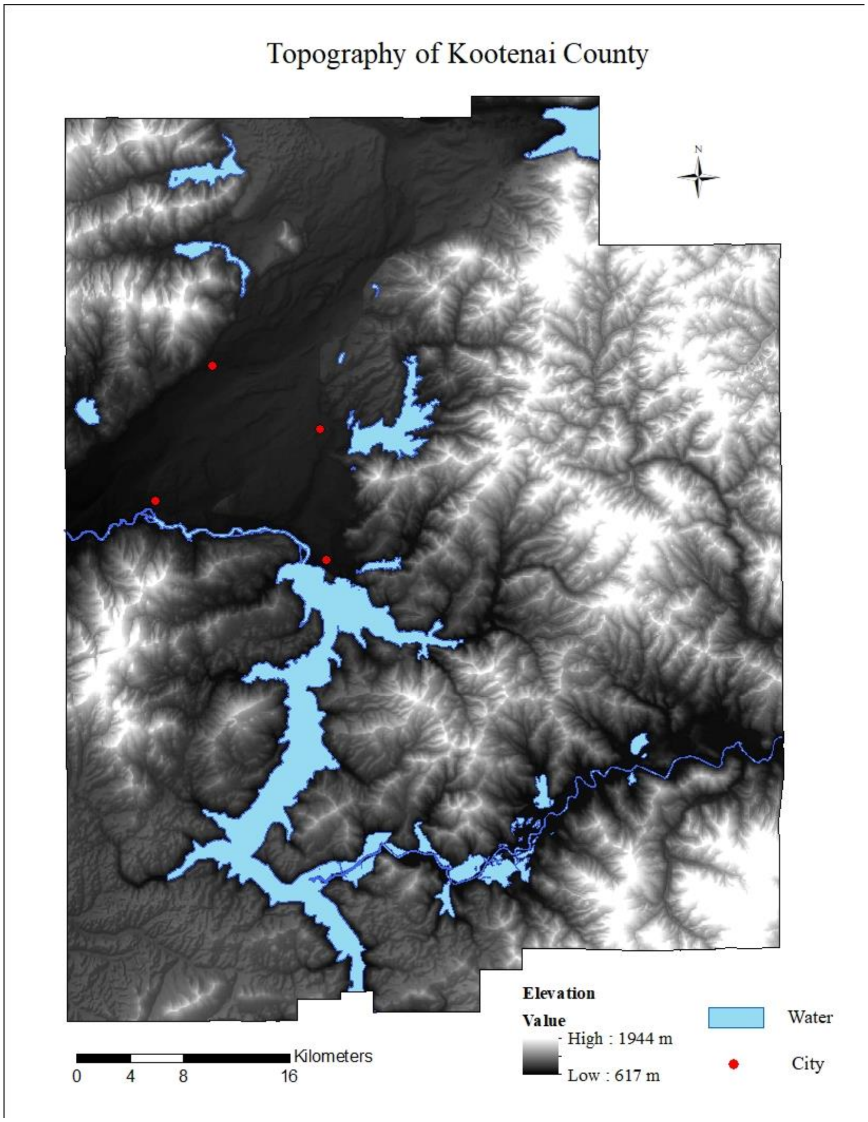


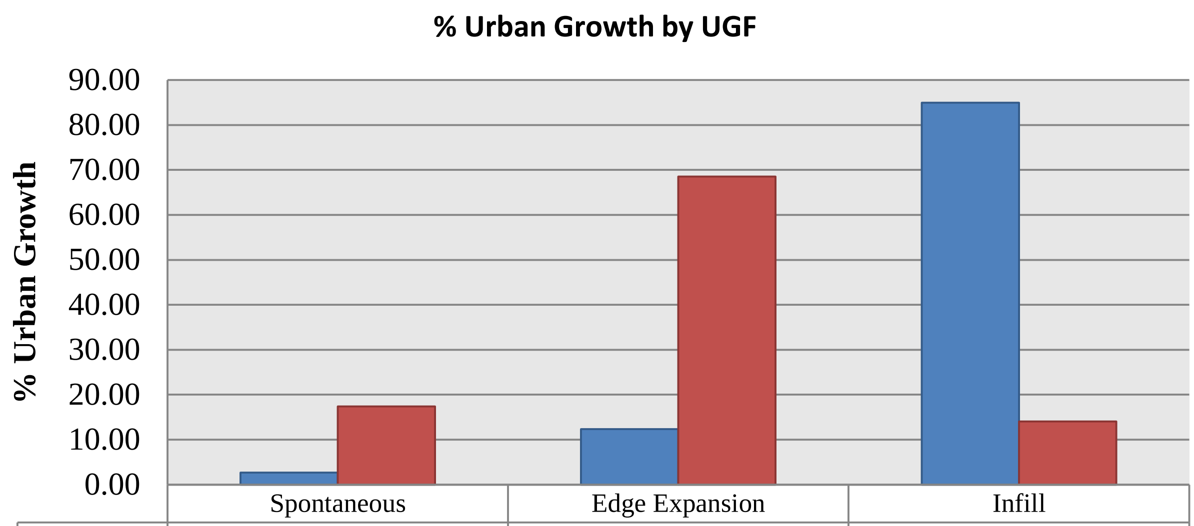
Figure 3.4: Elevation and Topographical Conditions in Kootenai County

3.2 Urban Growth Form

One of the key methods in examining urban growth is to look at their forms which reflect the different dynamics of urban land expansion process. As discussed in Xu et al. (2007), the three major types of urban growth forms (UGF) are Spontaneous, Edge Expansion and Infill. Figures 3.5 and 3.6 show the amounts and spatial distribution of different urban growth forms in the two time periods in the ACI.

As seen in Figure 3.5, for the 1990s, only 2.7% of growth occurred as spontaneous, 12.37% growth as edge expansion and infill growth comprising 84.93% of growth. In the 2000s, urban growth was more evident and consistent between the spontaneous and infill UGFs with 17.42% and 14.07%, respectively. The majority of urban growth occurred as edge expansion with 68.51%. These results are fairly consistent with other similar studies, such as Dahal et al. (2017), Xu et al (2007) and Wu et al. (2016), in which edge expansion and infill growth alternated in dominance in an ebb and flow pattern. This study, however, was unable to definitively reach similar conclusions due to data restrictions in the mid-1990's that prevented a more thorough analysis of the extremely large infill value.

As seen above, there was a stark difference in the amount of urban growth in different forms that occurred within the ACI. Figure 3.6 is a comparative map that shows the spatial distribution of the different UGFs in the 1990's and 2000's. In the 1990s the majority of the growth occurred as infill growth (more than 50% of the patch's perimeter shared with the old urban area), with very sparse edge expansion and scattered spontaneous growth. In the 2000s, there was, proportionally, a much higher amount of edge expansion growth as compared to the other types. As stated in the previous section, the majority of the urban growth occurred in a north/west direction as constricted by the physical geography; severe elevation/forest to the west and lake/river to the south (Figure 3.4).



	Spontaneous	Edge Expansion	Infill
1992-2001	2.70	12.37	84.93
2001-2011	17.42	68.51	14.07

Figure 3.5: Urban Growth Form by Percentage Area

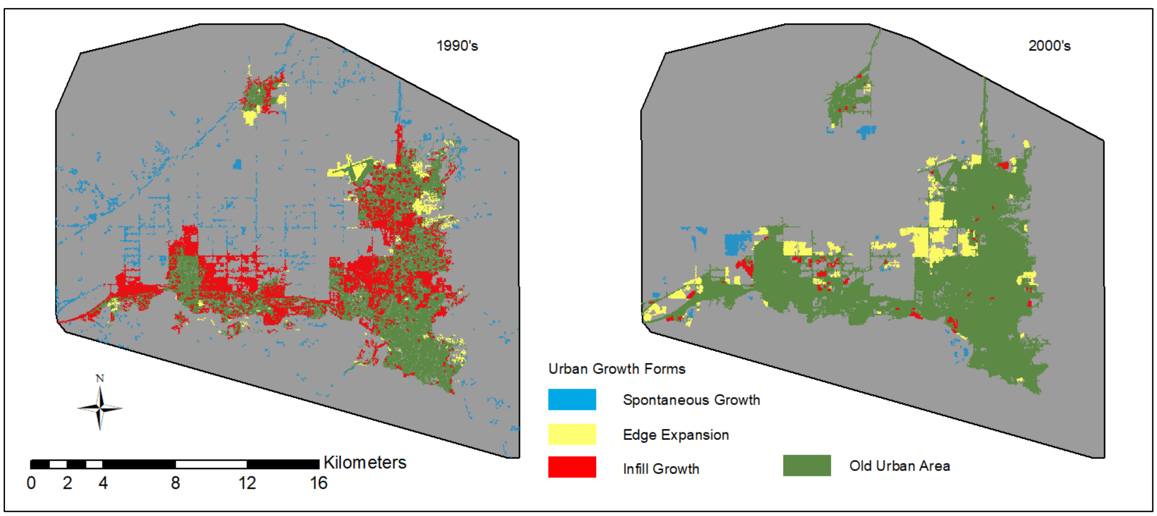


Figure 3.6: Urban Growth Form Distribution

3.3 Gradient Analysis

At the intra-urban level, urban growth is also driven by a number of accessibility measurements including distances to rivers and lakes, distances to major transportation infrastructure and distances to urban or other service centers, while being constrained by policy variables such as urban growth boundaries. A gradient analysis was conducted to quantify the influences of urban growth boundary and different accessibility measures on the magnitude of urban land expansion. Figures 3.7, 3.8, and 3.9 show the results and indicate that accessibility has both positive and negative impacts on urban growth.

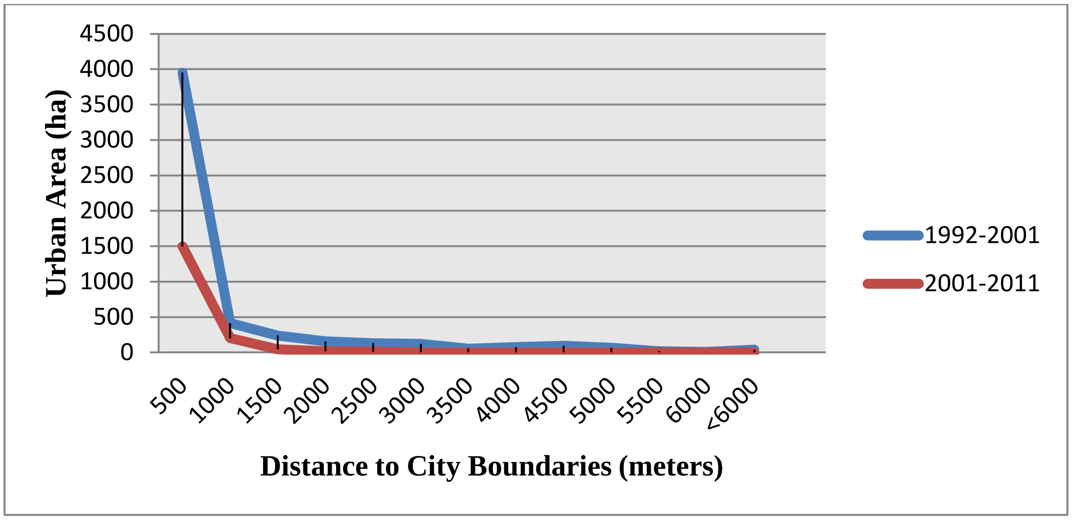


Figure 3.7: Urban Growth Proximity to City Boundaries

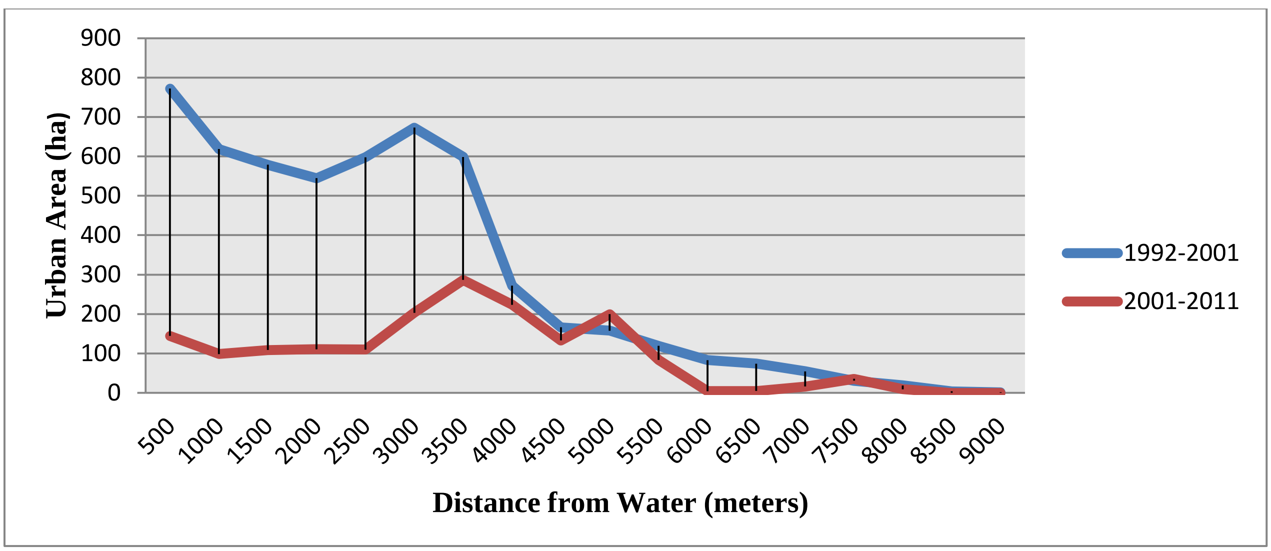


Figure 3.8: Urban Growth by Access to Rivers and Lakes

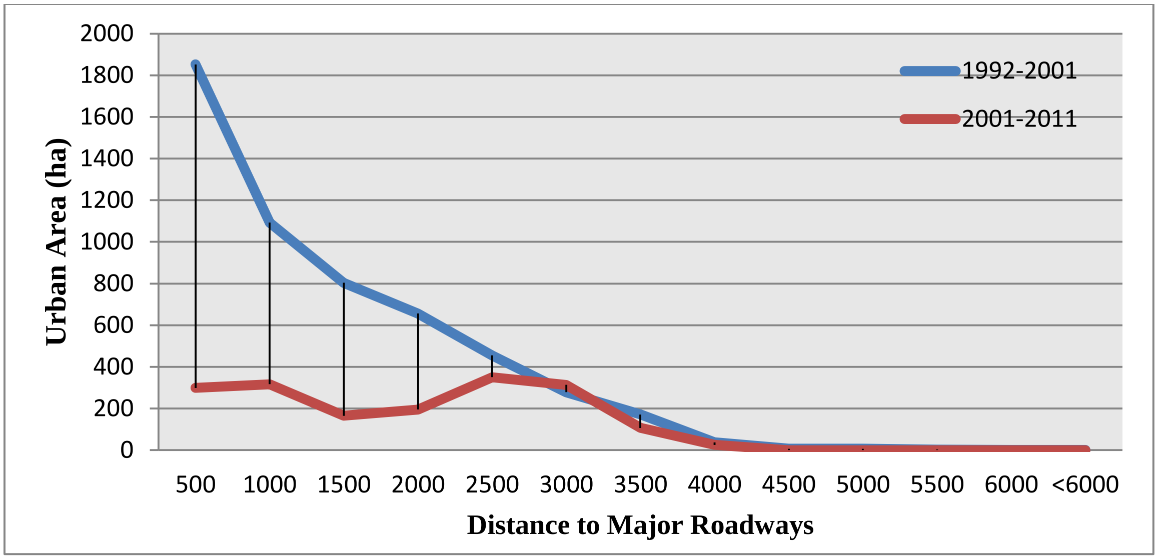


Figure 3.9: Urban Growth by Access to Major Roadways

For the distance from urban growth boundaries (Figure 3.7), there was a consistency in the pattern of urban growth as a function of distance in both time periods. There was a significant amount of growth within the first 1,000 meters which diminished to urban growth values of less than 250 ha after 1,500 meters. This exponential growth pattern is similar to the results found in other studies that indicate urban growth boundary or zoning does have a profound impact on urban growth (e.g., Zhang et al., 2017).

As expected, access to major lakes and rivers (Figure 3.8) tend to enhance the probability of the land to be converted into urban land use. Specifically, the majority of the growth occurred within 4 kilometers to either rivers or streams. There is a variation in the pattern as compared to the counterparts with respect to distances to the city center, characterized by a multiple valley and peak graph. One reason for this is the fact that this analysis examines the new urban areas, meaning that, for the cities that already border the lake/river, some distance needs to be travelled to fully encompass the draw the lakes/rivers have on urban growth; which is represented by the second and third spikes in the area measurements. On the other hand, the finding may be confounded by the fact that some of the lakefront land was used for industrial or manufacturing activities which could be converted into urban land uses in the recent years but could not be quantified due to data limitation.

Measuring the amount of urban growth as a function of distance from major roads (Figure 3.9) leads to some interesting results. For the 1990s, the growth area consistently falls as the distance increases. This indicates a significant draw to major roads, but can also validate the city boundary results due to the location of the major roads running through the center of the metropolitan area, which is consistent with Xu et al (2007), Dahal et al. (2016) and Zhang et al. (2017). In the 2000s, however, the values are drastically different. There seemed to be no emphasis on developing land near to major roads as the values remain relatively constant for 3 kilometers away from the major roadways.

3.4 Landscape Metrics

Landscape metric measurements, based on Table 2.3 and derived from McGarigal & Marks (1994) and Rempel et al. (2012) are calculated at the patch level and represent average values across the study area. With the urban growth patches being determined simultaneously with the metrics, Figure 3.10 below illustrates the selected landscape metrics for the ACI, focusing on the levels of fragmentation during the 1992-2001, 2001-2006, and 2006-2011. One of the key differences between the 1990s and 2000s is the number of patches (NumP). This also denotes a relative measure of fragmentation as 1992-2001 had 364 patches compared to the 303 in 2001-2006 and 268 in 2006-2011. This follows with the trends found in much of the previous literature in which there is a general decreasing trend in number of patches, typically due to the coalescence of patches

(Herold et al. 2003, Xu et al. 2007, and Zhang et al. 2017). Other studies that have shown an increase in patch numbers are due to the very long time series associated with the studies, 80 years in the case of Jenerette & Wu (2001) and Wu et al. (2011) and 40 years in Dahal et al. (2016).

In the case of Coeur d'Alene, the mean patch size (MPS) sharply increases throughout time, which indicates a coalescence of urban areas. The edge density (ED) coincides with the mean patch size pattern, with values that decrease over time, with values of 265.05 m/ha, 110.23 m/ha, and 93.6 m/ha in 1992, 2001 and 2011, respectively. This corresponds to the patch shapes in the 2000's being more efficient than in the 1990's. The ED values in the literature, which are similar to results found here, are roughly reciprocal to the number of patches (McGarigal & Mark 1994, Herold et al. 2002, Cifaldi et al. 2004, Deng et al. 2009). This means that, as the number of patches decreases, the edge density will increase. Mean Patch Size (MPS) is not a metric that is typically used alongside ED and, when it is, there is a positive correlation between them (Dahal et al. 2016 and Deng et al. 2009).

The Area-Weighted Mean Shape Index (AWMSI) is the average shape (unitless) index that weights the patches according to their size. With values for the 1990s and 2000s being 17.01, 15.74 and 16.15, respectively, there is a significant difference in the average patch shape. Values larger than 1 denote patches that are irregular in shape, in this case, circular. For the 1990s, this could be due to a significant amount of urban growth occurring along new or existing roadways, which creates long and narrow patches. The opposite is the case in the 2000s, where the growth is mostly restricted to areas directly bounding the old urban areas and more closely resembling the perfect circle shape. The increase between 2001 and 2011 indicates a decrease in shape efficiency over time. The Mean Perimeter to Area Ratio indicates a negative correlation to the AWMSI. The Mean Patch Edge significantly increases over time, which indicates the size of the patches increased, which in turn indicates a less fragmented landscape.

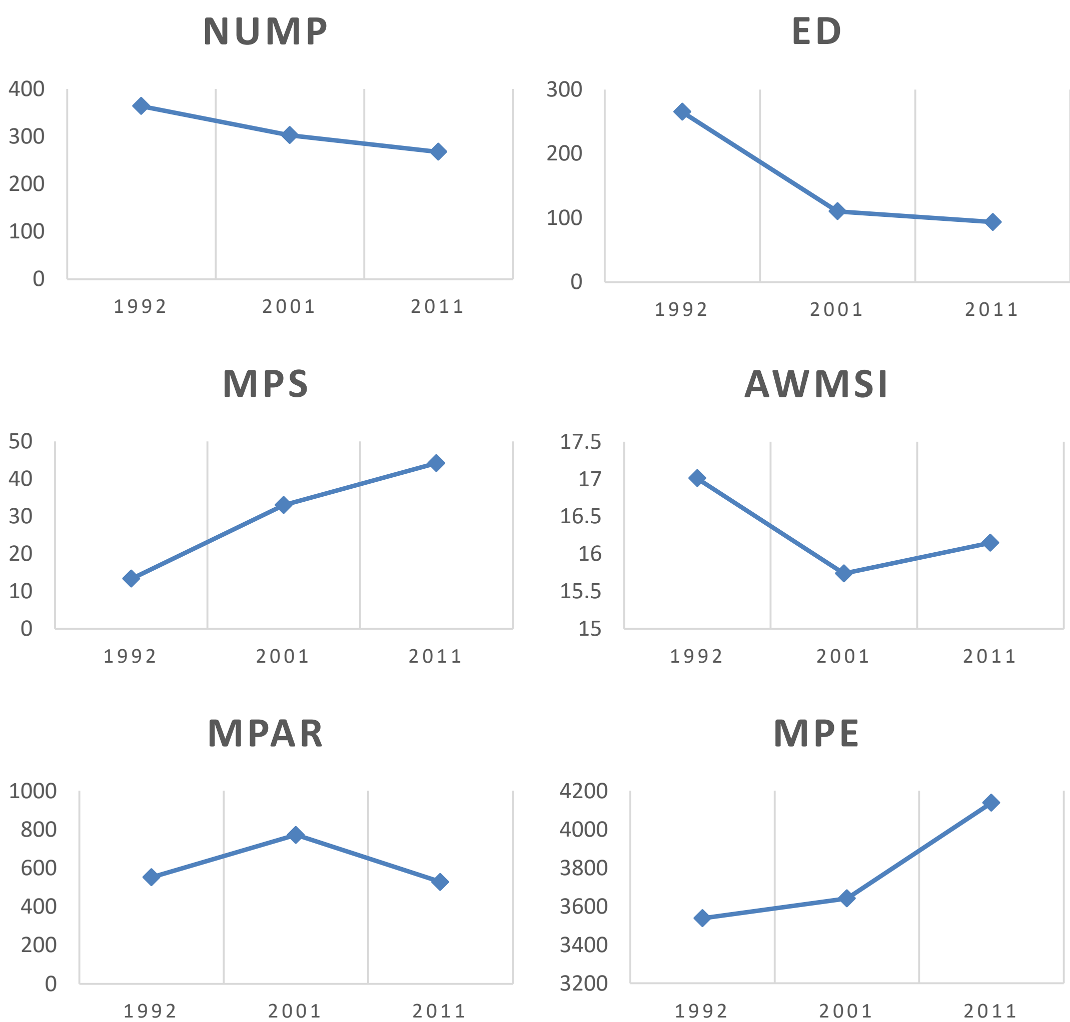


Figure 3.10: Fragmentation of Urban Land Patches

Urban structures or distances to city centers are found to have an impact on urban fragmentation (Irwin & Bockstael 2007). Therefore, additional gradient analysis, in conjunction with fragmentation or landscape metric-based analysis was conducted on the newly developed patches (Figure 3.11). To begin with, the spatial extents of the urban growth were different for each time period, 6000 m in the 1990s, 2000 m between 2001 and 2006, and 3000 m between 2006 and 2011, as seen in Figure 3.3.

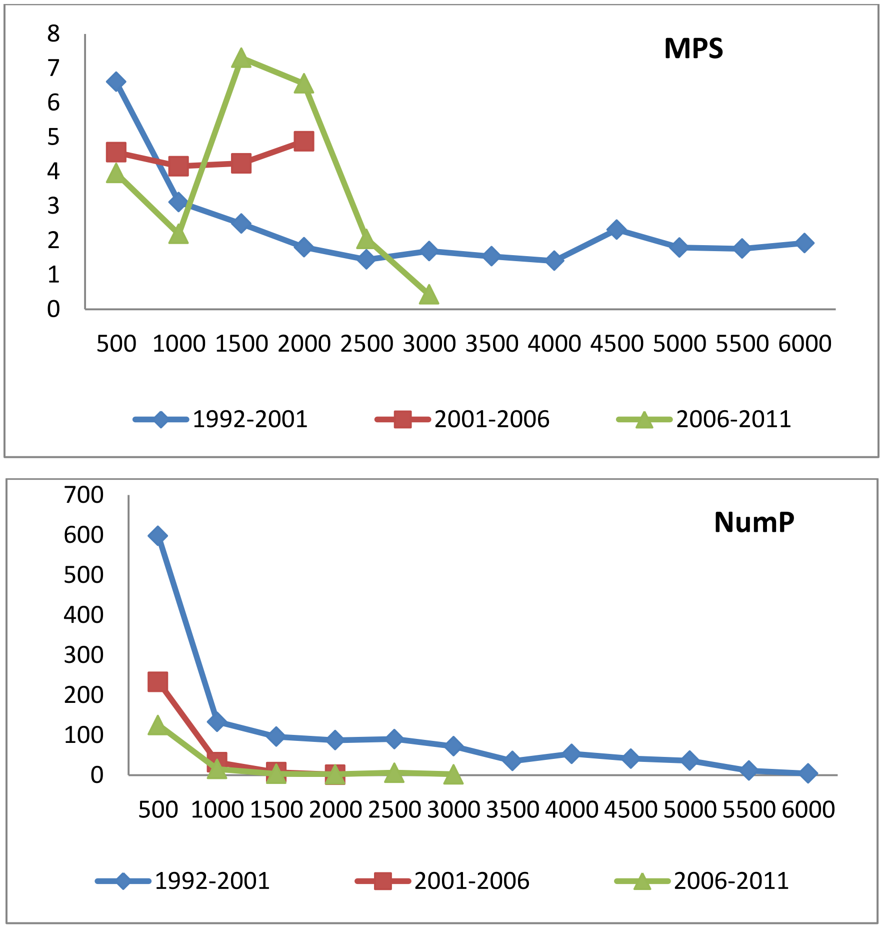


Figure 3.11: Landscape Metrics by Distance from Old Urban Areas

Figure 3.11 examines the landscape metrics of urban growth as a function of distance from old urban areas. NumP values may be significantly different than the global values, but the patterns are much the same in that there is a very large value within the first 500-1000 meters of the old urban boundary followed by a drastic drop in the numbers of patch beyond 1 kilometer to the city center. Also, as shown in Figure 3.11, the MPS values provide some interesting results. In the 1990s, there was a mean patch size of 6.75 ha, which dropped slowly until it plateaued at roughly 2 ha. The values for

2001-2006 and 2006-2011 exhibit a different pattern. 2001-2006 show a fairly constant patch size with values ranging between 4 and 5 ha. 2006-2011 exhibits a very large difference in the average patch size in that there are several peaks and valleys regardless of distance. One reason this could be the case is due to the very small number of patches to draw the average size from (153 patches).

3.5 Summary

This chapter analyzes the spatial-temporal dynamics of urban growth during 1991-2011. Coeur d'Alene experienced a significant amount of urban growth in the 1990's and significantly less during the 2000's. The patterns of urban growth show infill growth were most prevalent in the 1990's and spontaneous/edge expansion was the most common during the 2000's. Additionally, results of urban growth form and gradient analysis provide additional evidence for the importance of accessibility for urban growth. Results of gradient analysis suggest the association between accessibility measures and the magnitude of urban growth, highlighting a very large portion of urban growth occurring nearest to the major roads, city or urban growth boundaries, and water ways and decaying by distance. Furthermore, urban fragmentation analysis suggests recent urban growth was more likely to be associated with less fragmented landscape which is out of the expectation and inconsistent with the literature. However, the possible explanation is that the edge expansion form dominates the recent urban growth, which may have resulted in more compact new urban land patches in the case of Coeur d'Alene.

Chapter 4: Spatial Determinants of Urban Growth

In order to more comprehensively quantify the underlying drivers of urban growth, this chapter employs advanced spatial analytical methods to explore spatial determinants of urban growth. This chapter begins with a brief discussion on the variables used in the model and discusses how these variables can exert an influence on urban land use change in the greater Coeur d'Alene area. Secondly, both non-spatial logistic regression and spatially explicit regression models are used to provide nuanced evidence regarding urban growth determinants.

4.1 Variable and Model Selection

Urban growth can be driven by a variety of factors. Table 4.1 below shows the independent variables that are used in the subsequent regression models. The first group of variables is focused on the accessibility effect (e.g. Li et al. 2017, Hu & Lo 2007, Shu et al. 2014), including access to the city center (EucDist_Ci), distance to water (EucDist_Hy), and distance to major roads (EucDist_Ma). A number of variables including elevation (DEM), slope, agricultural density (FocalSt_Ag), water density (FocalSt_Wa), and forest density (FocalSt_Fo) were used as proxies of physical geographic factors (e.g. Allen & Lu 2003, Chi & Marcoullier 2013). The model also considers important socioeconomic factors such as the average income (AveIncome), percent population with a Bachelor Degree (Percent_Ba), percent white population (Percent_Wh), and percent of the population who rents properties (Percent_Re). This analysis calculates the probability of urban growth or urban land development occurring based on the influence of the independent variables, as seen in Table 4.1.

Table 4.1: Descriptive statistics of Independent Variables (Whole County)

Independent Variables	Description	Min	Max	Mean	Std.
Accessibility					
EucDist_Ci	Euclidean distance to cities (meters)	551.50	43421.20	12147.10	10694.97
EucDist_Hy	Euclidean distance to water (meters)	0	23043.00	4319.00	3793.04
EucDist_Ma	Euclidean distance to major roadways (meters)	0	24546.80	3624.10	4216.16
Physical conditions					
DEM	Elevation of the area (meters)	629.50	1818.90	804.40	193.08
slope	Slope of the area (Degrees)	0	36.70	7.31	9.29
FocalSt_Ag	Neighborhood density of agriculture	0	1	0.17	0.31
FocalSt_Fo	Neighborhood density of forest	0	1	0.41	0.41
FocalSt_Wa	Neighborhood density of water	0	0.79	0.01	0.05
Socioeconomic					
AveIncome	Average Household Income	$17,484	$88,166	$40,120	$11,507.79
Percent_Ba	% of population with a Bachelor degree	7.20	49.51	18.87	7.87
Percent_Wh	% of white population	49.60	98.75	94.91	7.55
Percent_Re	% of population renting properties	8.33	75.05	18.54	7.63

Note: a stepwise regression was run and results illustrated that for the ACI, the percentage of Renter would be a better determinant of urban growth based on its relationships with the other independent variables than the Percent Ownership while for the entire county, it was found that both the elevation and Percent Owner were not needed in the model.

A coefficient correlation matrix was created to determine if any of the variables showed any significant correlation (Table 4.2). The correlation coefficients do not indicate the presence of serious multicollinearity among the predictors. Using a general threshold of 0.75, set by Li et al. (2016) and Cifaldi et al. (2004), this analysis indicates that variables are independent of one another and can justifiably be placed in the same regression model if the matrix has a value of less than 0.75. Also, in order to be able to gauge the impact of the independent variables relative to one another, the variables were standardized (Shu et al. 2014, Menard 2004).

Table 4.2: Results of the coefficient correlation test

KC	rastercalc	EucDist_Ci	EucDist_Hy	DEM	slope	EucDist_Ma	FocalSt_Ag	FocalSt_Fo	FocalSt_Wa	Percent_Wh	Percent_Ba	AveIncome	Percent_Re	Percent_Ow
rastercalc	1													
EucDist_Ci	-0.71	1												
EucDist_Hy	-0.36	0.45	1											
DEM	-0.61	0.62	0.62	1										
slope	-0.65	0.6	0.46	0.73	1									
EucDist_Ma	-0.46	0.5	0.77	0.74	0.65	1								
FocalSt_Ag	0.35	-0.23	-0.08	-0.3	-0.38	-0.2	1							
FocalSt_Fo	-0.76	0.56	0.39	0.7	0.76	0.57	-0.52	1						
FocalSt_Wa	-0.05	0.02	-0.17	-0.11	0.03	-0.07	-0.09	-0.03	1					
Percent_Wh	0.09	-0.32	0.03	0.02	0.06	0.11	-0.23	0.13	-0.01	1				
Percent_Ba	-0.02	0.03	-0.34	-0.05	0.04	-0.12	0	0.06	0.09	-0.03	1			
AveIncome	0.19	-0.45	0.03	-0.13	-0.11	0.04	0.02	-0.09	-0.07	0.41	0.05	1		
Percent_Re	0.36	-0.24	-0.2	-0.29	-0.29	-0.24	0.22	-0.39	0.03	-0.37	-0.32	-0.2	1	
Percent_Ow	-0.36	0.24	0.2	0.29	0.29	0.24	-0.22	0.39	-0.03	0.37	0.32	0.2	-1	1

ACI	UC2001_202	EucDist_Hy	DEM	slope	EucDist_Ma	FocalSt_Wa	FocalSt_Ag	FocalSt_Fo	EucDist_Ci	Percent_Re	Percent_Ow	Percent_Wh	Percent_Ba	AveIncome
UC2001_202	1													
EucDist_Hy	0	1												
DEM	-0.41	0.07	1											
slope	-0.46	-0.2	0.66	1										
EucDist_Ma	-0.22	0.11	0.51	0.39	1									
FocalSt_Wa	-0.04	-0.3	-0.1	0.09	-0.05	1								
FocalSt_Ag	0.19	0.36	-0.26	-0.37	0.03	-0.13	1							
FocalSt_Fo	-0.56	-0.23	0.67	0.73	0.37	0.03	-0.49	1						
EucDist_Ci	-0.38	-0.13	0.26	0.29	0.43	-0.05	-0.02	0.31	1					
Percent_Re	0.33	-0.19	-0.31	-0.2	-0.28	0.09	0.05	-0.32	-0.19	1				
Percent_Ow	-0.33	0.19	0.31	0.2	0.28	-0.09	-0.05	0.32	0.19	-1	1			
Percent_Wh	-0.31	-0.13	0.39	0.35	0.23	-0.06	-0.24	0.45	-0.03	-0.54	0.54	1		
Percent_Ba	-0.17	-0.38	0.25	0.34	0.33	0.14	-0.18	0.4	0.17	-0.24	0.24	0.53	1	
AveIncome	-0.22	-0.25	0.22	0.27	0.22	0.04	-0.15	0.32	0	-0.52	0.52	0.75	0.68	1

4.2 Results of Logistic Regression

This section focuses on the results of the logistic regressions. The coefficient estimates themselves represent the positive/negative relationships between the independent and dependent variables. For instance, the larger the positive coefficient value is, the higher the chance the dependent variable has of occurring and smaller negative values indicate a higher chance of urban growth the smaller the value is. Results of the regressions were divided into two different spatial extents, the ACI and the entire county.

Tables 4.3/4.4 shows the results of the logistic regression model. Of the independent variables, only one, the percentage of the population that rents, was insignificant with a p-value of 0.2. The rest of the variables had p-values smaller than the 0.01 threshold of 99% confidence interval. The coefficient estimates were a mixture of positive and negative values, with the majority being negative of varying strengths. The Adjusted R^2 value of 0.844 indicates that the model can correctly explain 84% of the variance.

One key factor to notice in Table 4.3 is that all of the coefficient estimates are negative with the exception of Percent_Ba. In order to more directly examine the interactions between the dependent and independent variables, the odds ratios were calculated. Specifically, these values indicate the odds of urban growth occurring based on a one unit increase in the independent variables. As seen below, the majority of the values are below 1, which is strongly associated with the indication of the negative coefficient values. These values indicate that the odds of urban growth occurring with a one unit increase in the independent variable decreases with the unit increase.

Conversely, as is the case with the Percent_Ba variable, the odds ratio is above 1, which indicates that urban growth is 1.251 times more likely to occur with a 1% increase in population with a Bachelor's degree.

Table 4.3: Results of logistic regression analysis of urban growth determinants

Kootenai County Logistic Regression						
Variables:	Estimate	Odds Ratio	Std. Error	z value	Pr(>|z|)	Sign. Codes
(Intercept)	2.63E+01	2.709e+11	2.98E+00	8.844	< 2e-16	***
Accessibility						
EucDist_Ci	-5.31E-04	9.994e-01	4.21E-05	-12.616	< 2e-16	***
EucDist_Hy	-3.59E-04	9.996e-01	7.02E-05	-5.114	3.15E-07	***
EucDist_Ma	-3.25E-04	9.996e-01	7.74E-05	-4.197	2.70E-05	***
Physical Geography						
Slope	-8.73E-02	9.164e-01	2.83E-02	-3.079	0.00208	**
FocalSt_Ag	-9.45E-01	3.885e-01	3.49E-01	-2.708	0.00677	**
FocalSt_Fo	-6.96E+00	9.533e-04	5.44E-01	-12.784	< 2e-16	***
FocalSt_Wa	-1.03E+01	3.361e-05	1.78E+00	-5.784	7.29E-09	***
Socioeconomic						
AveIncome	-7.78E-05	9.999e-01	1.03E-05	-7.544	4.55E-14	***
Percent_Ba	2.24E-01	1.251e+00	2.35E-02	9.546	< 2e-16	***
Percent_Wh	-1.94E-01	8.240e-01	2.51E-02	-7.699	1.37E-14	***
Percent_Re	-2.34E-02	9.768e-01	1.83E-02	-1.278	0.20117	
Signif. Codes 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 < ' '						
Number of Obs: 2772 ROC: 0.9831 -2 Log Likelihood: 785.16						
Moran's I of Residuals: 4.92e-5 PCP: 97.83% Adjusted R^2 0.844						

Table 4.4: Results of standardized logistic regression analysis of urban growth determinants

KC Logistic Regression (Standardized)					
Variables:	Estimate	Std. Error	z value	Pr(>|z|)	Sign. Codes
(Intercept)	-4.27487	0.40358	-10.592	< 2e-16	***
Accessibility					
EucDist_Ci	-5.68248	0.4504	-12.616	< 2e-16	***
EucDist_Hy	-1.36238	0.26638	-5.114	3.15e-07	***
EucDist_Ma	-1.36934	0.32626	-4.197	2.70e-05	***
Physical Geography					
slope	-0.81085	0.26339	-3.079	0.00208	**
FocalSt_Ag	-0.29236	0.10797	-2.708	0.00677	**
FocalSt_Fo	-2.85301	0.22318	-12.784	< 2e-16	***
FocalSt_Wa	-0.54229	0.09376	-5.784	7.29e-09	***
Socioeconomic					
AveIncome	-0.89494	0.11863	-7.544	4.55e-14	***
Percent_Ba	1.76294	0.18468	9.546	< 2e-16	***
Percent_Wh	-1.45995	0.18963	-7.699	1.37e-14	***
Percent_Re	-0.17867	0.13978	-1.278	0.20117	
Signif. Codes 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 < ' '					
Number of Obs: 2772 Log Likelihood: -392.58					
Moran's *I* of Residuals: -1.22e-03 Adjusted R^2 0.844					

Due to the coefficients being standardized, they can be directly compared as to their relative strength in determining urban growth locations (Shu et al. 2014, Menard 2004). First, the accessibility effect is evident. The accessibility coefficients all show relatively strong, and statistically significant, negative values. This indicates a strong preference to develop in areas that can easily access the city, major roadways and water bodies or Lake Coeur d'Alene. The physical geography of the area also provided an important impetus for growth. For example, forest density and water density are slightly more significant than the agriculture density and slope. This indicates a strong preference to develop in areas of low physical density and shallow slope.

The socioeconomic variables presented some interesting and mixed results. While the Percent_Ba variable is positive as expected, the remaining variables are negative, and highly significant with the exception of Percent_Re. This indicates a preference to develop in areas where the average income and percent white people are lower, but average education is higher. A possible explanation is that only census block/tract level data are available to measure these effects and the aggregation of these socioeconomic statistics at the block/tract level may not fully capture the social fabric at the neighborhood level. Moreover, as mentioned in Chapter 3, some lakefront neighborhoods in Coeur d'Alene were also converted from industrial land use to urban or residential use recently. This could not be fully captured in the urban land expansion model used in this study.

Table 4.5 shows the results of the logistic regression model for urban growth within the Area of City Impact Zone. The model performance had an R^2 value of 0.49 which indicates that the model explains 43% of the variation. Most of the variables reflect the similar association with urban growth as the entire county. The access to city centers and water bodies results in a higher likelihood of non-urban to urban conversion. Furthermore, neighborhood land uses such as forest and water bodies impose challenges for new urban land development. However, results also indicate the proximity to transportation infrastructure or roadways is not closely tied to urban development if the reference points are restricted to those within the ACI region. This indicates that within a more urbanized context, old urban areas have occupied those locates characterized by high accessibility to roads, limiting the chance to new urban growth in these locations. Physical conditions such as slope and elevation have had strong impacts on urban growth.

Similarly, the neighborhood densities are among the strongest of the independent variables, with neighborhood land use configurations with respect to the density of forests and water impose physical constraints on new urban development. This indicates a preference to develop in areas where the forests and water do not dominate the landscape: this model does not specify residents vs. developers.

Table 4.5: Results of logistic regression analysis for the ACI

ACI Logistic Regression					
Coefficients:	Estimate	Std. Error	z value	Pr(>|z|)	Sign. Codes
(Intercept)	-0.82473	0.08093	-10.191	< 2e-16	***
Accessibility					
EucDist_Ci	-1.28131	0.0662	-19.354	< 2e-16	***
EucDist_Hy	-0.66064	0.06117	-10.801	< 2e-16	***
EucDist_Ma	0.1501	0.07169	2.094	0.036276	*
Physical Geography					
DEM	-0.59692	0.17892	-3.336	0.000849	***
slope	-0.97225	0.12508	-7.773	7.67E-15	***
FocalSt_Ag	-0.09397	0.05	-1.879	0.060197	.
FocalSt_Fo	-1.73237	0.10528	-16.454	< 2e-16	***
FocalSt_Wa	-0.39956	0.05496	-7.27	3.61E-13	***
Socioeconomic					
AveIncome	-0.1719	0.07834	-2.194	0.028218	*
Percent_Ba	0.91823	0.08353	10.993	< 2e-16	***
Percent_Wh	-0.42158	0.08117	-5.194	2.06E-07	***
Percent_Re	0.09623	0.06666	1.444	0.148854	
Signif. Codes	0 '***'	0.001 '**'	0.01 '*'	0.05 '.'	0.1 < ' '
Number of Obs. 2772		-2 Log-Likelihood -1648.611			
PCP=83.44%	ROC=0.8987	Adjusted R^2 0.503			

In terms of socio-economic variables, there was only one positive coefficient, which was the percentage of the population with a Bachelor Degree. The remaining independent variables all had negative correlations of various magnitudes. For the socioeconomic variables, urban growth tends to occur in areas with lower share of High

School graduates and higher proportion of population with bachelor degrees. This indicates there is a preference to develop in areas with higher attained education. The last socioeconomic variable, percentage of white population, indicates a preference to develop in areas with a lower white population. However, this finding should be more carefully interpreted for the case of Coeur d'Alene, because the average percentage of white at the neighborhood level is higher than 95% with the lowest at 50%, indicating not very strong spatial variations of racial configurations at the neighborhood in this region. The percent renter did not show significance and, therefore, does not warrant analysis.

Based on the combined regression results, urban growth is more likely to occur in areas with low density of agriculture, forests, and water as well as slope, elevation, and percentage of the population that is white. Access to the city and water are also key determinants of urban growth between the two regressions, as the statistical significance remains high. Also, urban growth is more likely to occur in areas with a higher percentage of bachelor degrees.

4.3 Results of spatial regime regression

Table 4.6 presents the results of the spatial regime model. As opposed to the earlier regression models, spatial regime modeling provides additional nuanced understanding of the spatial heterogeneity of urban growth determinants. As discussed in chapter 2, the spatial regime model conducts a logistic regression based on the location of the points whether they are inside or outside of the ACI. Of the 22 regression coefficients that were eventually produced, only nine exhibited statistical significance; which were EucDist_Ci:In, EucDist_Ci:Out, EucDist_Hy:In, EucDist_Ma:Out, Slope:In, FocalSt_Fo:In, FocalSt_Wa:Out, Percent_Wh:In, and Percent_Ba:In. This allows spatial variability to be taken into account that cannot be seen in the global regressions. In particular, access to water, slope, forest density, percent white people and percent bachelor are only significant within the ACI, while access to major roadways and water density are significant outside of the ACI. The only variable to exhibit significance both inside and out of the ACI is access to cities.

With the exception of socioeconomic variables, the coefficient estimates are all negative, which indicates a desire to be closer to the water, in areas with less slope, low forest density, and low water density, while these effects are more likely to be evident in the more urbanized portion of the study area. In the case of the percent white population and percent bachelor population, the coefficient estimates are positive for urban land conversion within the ACI, which indicates the desire to be located in areas with higher percentage white people and higher percent bachelor degrees. Therefore, the results of spatial regime modeling may suggest that when the specific spatial or administrative setting is taken into account, socioeconomic contexts do have an expected impact on urban land use change at a finer scale.

Table 4.6: Results of logistic spatial regime regression model

KC Spatial Regime Model					
Coefficients:	Estimate	Std. Error	z value	Pr(>|z|)	Sign. Codes
Accessibility					
EucDist_Ci:Out	-2.30E-03	5.31E-04	-4.336	1.45E-05	***
EucDist_Ci:In	-8.29E-04	1.13E-04	-7.34	2.14E-13	***
EucDist_Hy:Out	2.18E-04	3.45E-04	0.631	0.528055	
EucDist_Hy:In	-4.53E-04	9.83E-05	-4.605	4.12E-06	***
EucDist_Ma:Out	-2.19E-03	5.35E-04	-4.095	4.22E-05	***
EucDist_Ma:In	-1.18E-04	1.46E-04	-0.813	0.416099	
Physical Geography					
Slope:Out	-3.90E-03	6.32E-02	-0.062	0.950761	
Slope:In	-1.95E-01	4.44E-02	-4.38	1.19E-05	***
FocalSt_Ag:Out	1.89E-02	1.35E+00	0.014	0.988864	
FocalSt_Ag:In	-2.82E-01	4.57E-01	-0.616	0.538119	
FocalSt_Fo:Out	-1.36E+00	1.50E+00	-0.906	0.365122	
FocalSt_Fo:In	-6.29E+00	7.08E-01	-8.883	< 2e-16	***
FocalSt_Wa:Out	-2.82E+01	1.08E+01	-2.618	0.008845	**
FocalSt_Wa:In	-5.25E+00	3.39E+00	-1.547	0.121946	
Socioeconomic					
Percent_Wh:Out	-1.24E+00	8.90E-01	-1.395	0.1629	
Percent_Wh:In	5.76E-02	1.53E-02	3.772	0.000162	***
Percent_Ba:Out	5.17E+00	1.01E+01	0.514	0.60758	
Percent_Ba:In	1.56E-01	3.51E-02	4.427	9.53E-06	***
AveIncome:Out	-1.89E-03	2.24E-02	-0.084	0.932846	
AveIncome:In	-3.68E-06	2.22E-05	-0.165	0.868723	
Percent_Re:Out	1.98E+00	4.63E+00	0.427	0.669485	
Percent_Re:In	4.33E-02	2.71E-02	1.599	0.109824	
Signif. Codes: 0 ‘***’ 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' '					
Number of Obs. 2772 ROC: 0.9886 -2 Log-Likelihood: 614.34					
Moran’s I of Residuals: 5.923e-3 PCP: 96.97% Adjusted R^2: 0.886					

4.4 Results of Geographically Weighted Regression

As shown in Table 4.7, the logistic spatial regime model shows a clear improvement over the global logistic model, so does the GWLR model, as evidenced by the lower AICc statistics. As explained earlier, the bandwidth kernel used in this particular thesis was a gaussian kernel. This is dissimilar from other studies in that they used the bi-square kernel, which only changes the values in so that the coefficient values are depressed and not necessarily inaccurate. Results of GWLR model suggest evident spatial varying effects of different urban growth drivers. For example, the coefficients associated with distance to city center could vary from -0.00072 to -0.0005. Similarly, the results of GWLR suggest evident spatial variations of the effect of distance to water bodies (from -0.00049 to -0.0004).

Table 4.7: Comparison between different regression models (GWLR, Spatial Regime, and Logistic Regression)

Model Comparisons			
	GWLR	Regime	Global
-2 Log-Likelihood	-365.8	-307.17	-392.58
Pseudo R-squared	0.809	0.886	0.844
Moran's I of Residuals	-3.25E-03	-5.59e-04	-1.22E-03
AICc	761.157538	660.34	809.16

Table 4.8: Summary Statistics for GWLR Results

Summary Statistics for GWLR Results					
Variable	Mean	Min	Max	Range	STD
Intercept	31.040301	25.41478	42.0721	16.657275	4.309951
Accesibility					
EucDist_Ci	-0.00058	-0.00072	-0.0005	0.00021	0.000053
EucDist_Hy	-0.000424	-0.00049	-0.0004	0.000137	0.000038
EucDist_Ma	-0.000275	-0.00039	-0.0001	0.000256	0.000057
Physical Geography					
slope	-0.103594	-0.11865	-0.0884	0.030206	0.008118
FocalSt_Ag	-0.881272	-1.11278	-0.6546	0.458135	0.126352
FocalSt_Fo	-6.970003	-7.30346	-6.6602	0.643243	0.15962
FocalSt_Wa	-10.297419	-10.922	-9.87	1.051958	0.260194
Socioeconomic					
Percent_Wh	-0.238898	-0.3605	-0.1791	0.181404	0.046058
Percent_Ba	0.219531	0.192454	0.25658	0.064126	0.015139
AveIncome	-0.000074	-8.1E-05	-6E-05	0.00002	0.000004
Percent_Re	-0.023769	-0.04051	-0.0018	0.038718	0.009737
ROC: 0.984 -2 Log-Likelihood: 731.6					
Moran's I of Residuals: -3.25e-03 PCP: 95.89% Adjusted R^2: 0.809					

Figures 4.1 and 4.2 show the interpolated regression results as produced by GWR4. As seen in these figures, the varying strengths of each variable are widely spread, each with a location of centralized strength. In Figure 4.1, coefficient surfaces are the interpolated based on the local regression points, using Inverse Distance Weighting, of the Euclidean distance measurements (see Liao and Wei, 2015; Zhang et al., 2017). Figure 4.2 examines the local t-scores of each coefficient. These t-scores are a measurement of local significance.

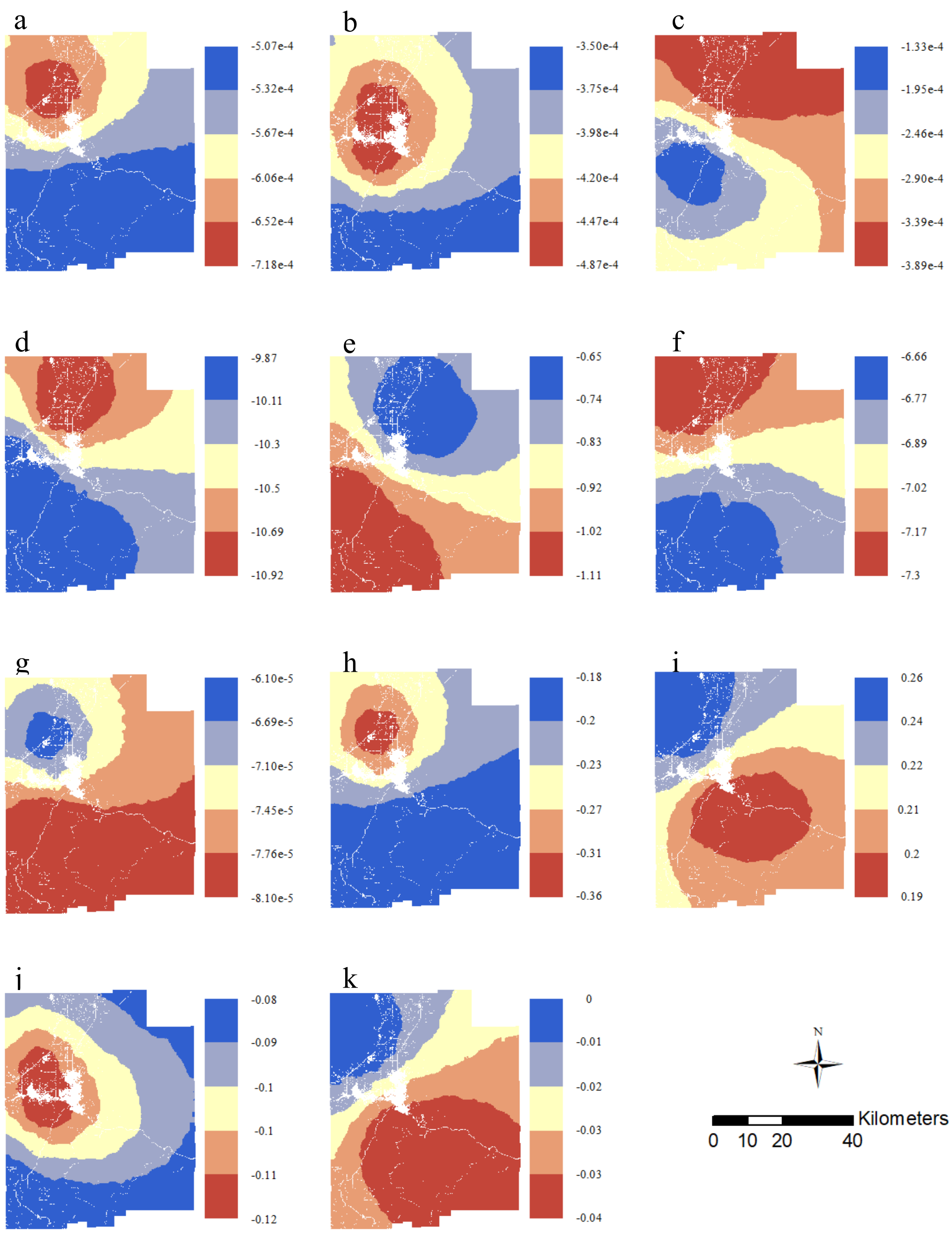


Figure 4.1: Coefficient Surfaces a)EucDist_Ci, b)EucDist_Hy, c)EucDist_Ma, d)FocalSt_Wa, e)FocalSt_Ag, f)FocalSt_Fo, g)AveIncome, h)Percent_Wh, i)Percent_Ba, j)Slope, k)Percent_Re

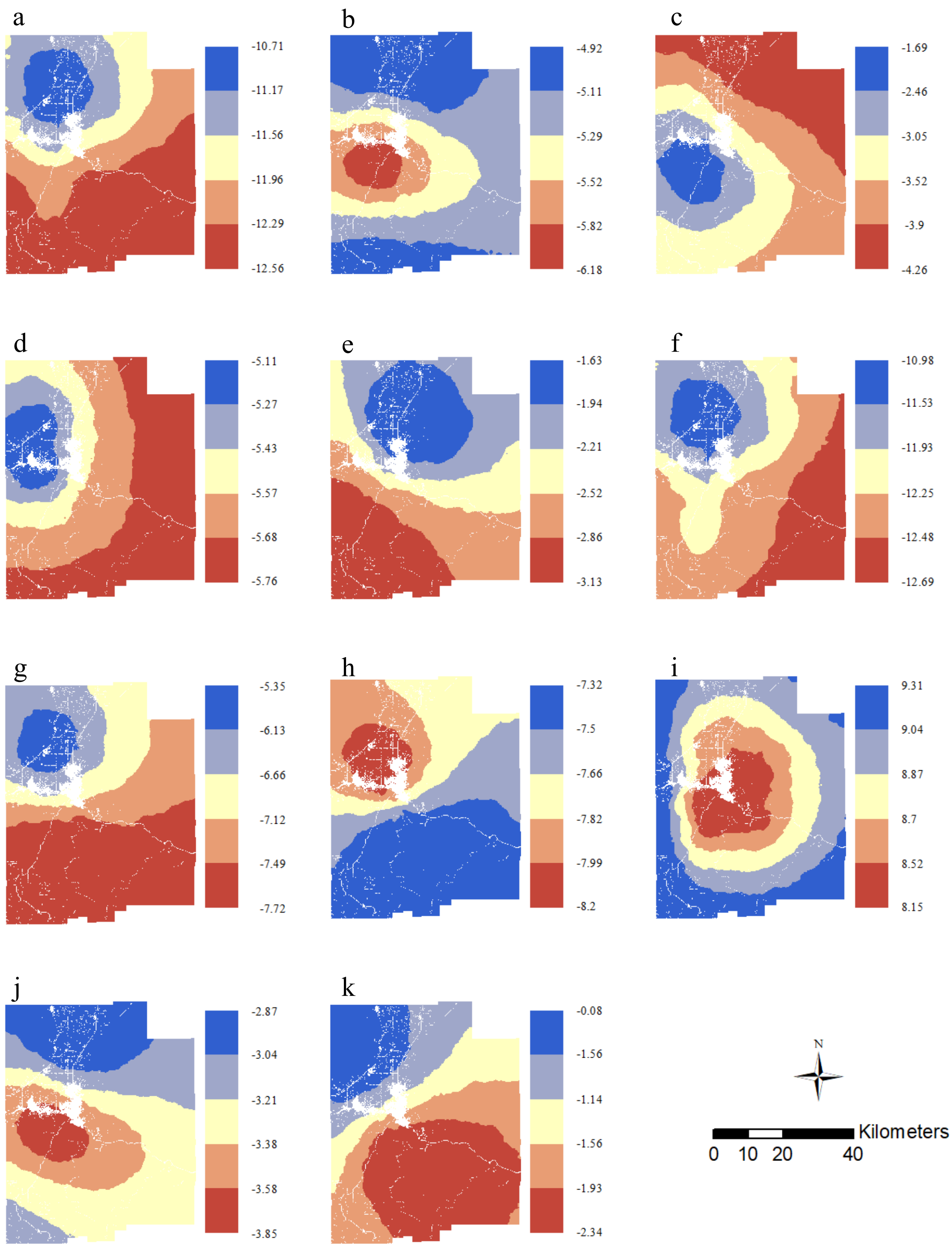


Figure 4.2: T-score Surfaces a)EucDist_Ci, b)EucDist_Hy, c)EucDist_Ma, d)FocalSt_Wa, e)FocalSt_Ag, f)FocalSt_Fo, g)AveIncome, h)Percent_Wh, i)Percent_Ba, j)Slope, k)Percent_Re

As was the case of the spatial regime model, most of the variable ranges are negative (Figure 4.1), highlighting the role played by accessibility factors in urban land use change. Also as seen with the spatial regime model, there is not a large degree of strength associated with any one of the particular variables with the exception of water density and forest density, which exhibited a very strong negative coefficient range.

The first three maps in Figure 4.1 (a-c) Access to city center provides an expected distribution of influence, it is particularly strong in the area just to the northwest of the existing city boundaries while in the southern edge there is much less of a demand for access to the city. This is further validated by the T-score map being almost identical to the coefficient map, with the strongest values centered on the northwest of the city. Access to water (b in Figure 4.1), exhibits spatially varying effects on urban land use change, with the area of strongest negative value being center around the city boundaries next to the river and lake. The third map (c in Figure 4.1) is the Euclidean distance to major roads. The area with the highest negative value is concentrated along the areas with the highest road density, particularly to the north of the city near smaller cities such as Athol. In contrast, the effect of access to transportation infrastructure declines in the southern part of the study area.

The next three maps (d-f, in Figure 4.1) are of the density statistics of various physical attributes. The density of water (d in Figure 4.1) is the highest value of coefficients in the entire model. This indicates a strong desire to develop in areas with less physical constraints particularly in this case, just to the north of the city a belong northbound highway 95. The next variable is the density of agricultural lands (e in Figure 4.1). The coefficient estimates exhibit strong spatial variations based on the ranges of coefficients, particularly in the southwest portion of the county where the effect of agricultural land being less evident. This furthers our understanding that as the majority of urban growth that occurred over the study time period occurred in areas that were previously agriculture while they are more likely to occur in proximity to the city in the north. The next variable is that density of forest areas (f in Figure 4.1). The coefficient values of this particular variable demonstrate the strongest negative values coming to the northwest of the county and lowest occurring in the southwest. The results of GWR modeling tend to address the constraints of forestry for urban land use change have a stronger impact in the northern part of the city while in those rural part of the county, this effect would become moderate.

The next several variables are those of socioeconomic standing. The first of these is the average income (g in Figure 4.1), which has very small, negative coefficient surface values. Urban growth with larger average income is more likely to occur near Rathdrum while in the southern half of the county, urban growth is likely to occur with less higher average income. The percent of white people (h in Figure 4.1) in the area has almost the exact same pattern that as the average income. These results are contrary to the expected idea that urban growth should be more likely to occur in areas of higher percentage of white people, this map indicates the opposite (g and h in Figure 4.1). The entire southern half of the county is made up of very small towns and cities on the Native American reservations, areas white people typically do not move into. The next variable is the percent of bachelor's degrees (i in Figure 4.1) in the population. In this case the results are much more as expected, with the entire county being more likely to live in areas with more bachelor degrees per person and specifics of the northwest of the county exhibits the highest area in which urban growth could occur whereas just to the south east of the city is the lowest area.

The last variable deal of that is the slope (j in Figure 4.1). This coefficient surface also demonstrates the spatial variation of the influence of local physical conditions on urban growth. For example, in areas closer to the city center, this effect is more evident in those areas where spurring growth is likely to occur, and urban growth tends to be less prohibited by strong slopes in the rest of the county.

4.5 Summary

This chapter applies both non-spatial logistic regression and spatially explicit modeling techniques including spatial regime and GWLR to the dataset. Several interesting findings could be summarized. Firstly, spatial modeling or regressions tend to improve the performance of models with lower AICc statistics, as seen in Table 4.7 Secondly, as compared to the traditional logistic regression, regression model with consideration of spatial effects explain the most deviance and the determinants of urban growth. Thirdly, across different set of model results, accessibility factors are robust in the similarity of coefficient sign (negative) and relative strength; and the impact of neighborhood land use has also been evidenced, while forest and water densities tend to affect urban land use change more strongly. Lastly, results of the GWLR model further entails the spatial variations of different determinants. Overall, the north-south divide of different effects is clearly demonstrated which is line with the urban-rural continuum in the city of Coeur d'Alene on par with other landscape features such as the distribution of forest, water and agricultural land.

Chapter 5: Conclusion

5.1 Overview

Urbanization is now an issue that concerns most of the human population. The reasons for moving to cities are as diverse as the cities themselves. In the American west, the most common form of urbanization is that of suburban sprawl away from the city center. As these areas continue to grow, natural amenities can become more of a draw to an area than other attractions in a larger metropolitan area (Gosnell & Abrams 2009 and Nelson et al. 2014).

Aside from the obvious landscape change that occurs due to new developments that typically eliminate agricultural land, the effect on the health of the landscape is often of less import than the migration itself (Lewis & Alig 2009). Due to the health of these natural amenities being crucial to maintain urban growth, an increasing amount of attention is being paid to environmentally conscious development (Chi & Marcoullier 2013, Gosnell & Abrams 2009). Moving forward, more and more cities near natural amenities are planning their urban development and expansion in a way that both emphasizes and protects these areas as sources of both residential and tourist attraction (Marcouiller et al. 2002).

The goal of this project is to understand the patterns and drivers of urban growth from a context of access to natural amenities and urban areas. Understanding these patterns will allow researchers and city planners to make suggestions with greater confidence the expansion of city boundaries into previously rural areas. In summary, Chapter 1 of this thesis provided an overview of the concepts and existing literature of the subject. It also described the study area in detail as well as the identifying the research questions. Chapter 2 of the thesis identified the methodology of the project as well as the data used and potential limitations. Chapter 3 detailed the process and results of the spatial patterns of urban growth around the Coeur d'Alene area. Chapter 4 presented the results of the spatial determinants of urban growth both in the ACI and the entire county. This thesis ends by summarizing findings in relation to key research questions identified in Chapter 1.

5.2 Major Findings

5.2.1 Urban Growth patterns

The patterns of urban growth show a significant priority to growth near existing urban areas as well as being greatly influenced by both macro-level economic contexts and micro-level drivers such as accessibility, socioeconomic contexts at the neighborhood level, and physical geography. Urban land expansion was more evident during the 1990s when economic development and population growth were also strong. In contrast, the recent trend of urban growth has been shadowed by the recent economic recession and was significantly less robust. This was exemplified by the significantly decreased amount of urban growth that has occurred since 2000.

While zoning data was not used in this thesis, the spatial distribution of the individual ACIs can allow the researcher to infer the effect they have. As stated in Chapter 2, the ACI is an agreement between cities as an outer limit to which they can expand without encroaching on the future city limits of neighboring cities. The effects of this type of policy are quite large, as it can fundamentally change the socio-economic makeup of the county from that of a rural, agricultural zone to that of a metropolitan area (Gosnell & Abrams 2011).

Results also demonstrate relatively higher levels of fragmentation that occur with an increase of distance from urban growth boundary. This is also validated by the more efficient type patch size and shape that exists nearer to the city borders than that which exists further away. In other words, exurban growth may result in more fragmented new urban patches, imposing potential stress on natural ecosystem. Additional, the study traces the different phases of urban growth by addressing different urban growth types including infill, edge expansion and spontaneous. Recent urban growth is characterized by more compact form of edge expansion while infilling is more popular in the 1990s. Moreover, as edge and spontaneous expansion become the major growth types in recent years, the issue is more pressing in the future.

The results found in this thesis, particularly in terms of UGF distribution/intensity and landscape metrics, are quite similar to the general patterns found in the literature. The UGF formations in the literature found similar patterns in the relative dominance of Edge Expansion, Infill and Spontaneous growth; in that most of the growth represented was Edge Expansion after initial periods of Infill growth dominance (Dahal et al. 2016, Xu et al. 2007, and Zhang et al. 2017). In terms of the spatial patterns and gradient of urban growth, this thesis found results similar to the literature in that fragmentation of urban land increases with distance from urban areas and road networks (Dahal et al. 2016, Xu et al. 2007, and Luck & Wu, 2002).

5.2.2 Urban Growth determinants

By using both global and local methods of determining the drivers of urban growth, a more complete picture of the effects of various landscape features is identified. The global regression results validate the effects of key drivers which are conceptualized into accessibility, physical conditions and socioeconomic contexts. Results of the spatial regime model and the GWLR indicated that access to urban amenities is indeed the key driver of urban growth within the ACI.

The local regressions allow for a multi-scalar examination of the impact that various physical and social factors have on urban growth. Access to rivers and lakes are important driver in this region as expected. Water also holds a significant draw in areas where development could occur near the water.

The attraction of individual characteristics of the county can have momentous effects on the distribution and intensity of urban growth. In general, the proximity to city and water has played a key role in determining the probability of land use change from non-urban to urban uses. Specifically, access to water bodies in the region reflects the effect of its beautiful scenery and natural amenities. People choose to live in areas that are as close to cities and water as possible. The tension between the human and natural systems should be noted since most urban land is converted from agricultural land at the rural-urban fringe.

Throughout the literature, there have been few study areas that bear physical/economic similarity with Kootenai County. As such, direct comparisons of results between this thesis and the literature are difficult to measure. The comparisons that can be drawn show that there are similarities in that the differing independent variables exhibited spatially varying patterns with varying significance attached to these areas, particularly those of the Euclidean distance measurements (Dahal & Lindquist 2017, Liao & Wei 2012). One difference between this thesis and the literature is the high degree of influence that the physical density of forested areas exhibited on the development of urban land.

5.3 Implications for urban environmental planning

It widely held that the first and most impacted land use in urban growth is agricultural land due to its proximity to the urban fringe and quality of land for expansion (Ramachandra et al. 2015, Munroe et al. 2005, Irwin & Bockstael 2007, Wu 2006, Alig & Healy 1987, Delphin et al. 2016, Partridge et al. 2008, Huang et al. 2017 and Pryor 1968). As explored in Chapters 3 and 4, the direction of urban growth is restricted to the Rathdrum Prairie. Historically, one of the central crops was Kentucky Bluegrass production. Due to the changing air quality laws in Idaho, particularly Idaho House Bill 391 (2003), production significantly decreased (Idaho House Bill 391, 2003 and Wulfhorst et al. 2006). These policies dictated the conditions in which crop residue could be burned, which resulted in a significant economic loss for the crop owners, many of whom were either forced to switch crops or sell their property for residential development (Wulfhorst 2006). As this area is composed of urban areas and farmland, it is natural to assume that agriculture will eventually be eliminated as the area continues to sprawl. Due to the fact that the entire Rathdrum Prairie is within the boundary of an ACI, city planners project that urban growth will snuff out the majority of agricultural land in the area by 2030 (Kootenai County Planning Commission 2010, 13 and 14).

Figure 5.1 is a map produced by the Kootenai County Assessor's office for publication in the 2010 Comprehensive Plan detailing anticipated future land use. As seen in the Rathdrum Prairie area, the land use types are either incorporated (city) or transitional, which indicates an expectation of this land becoming incorporated with the six cities in the area.

The result of this type of zoning and growth could end up slowing the urban growth as the only available land for expansion will be relatively far from the main areas of recreation in Lake Coeur d'Alene and the forests to the east. Conversely, the further west that growth spreads, the closer to the large metropolitan area of Spokane, WA prospective development areas would be located, which could foster more metropolitan-driven growth in the future.

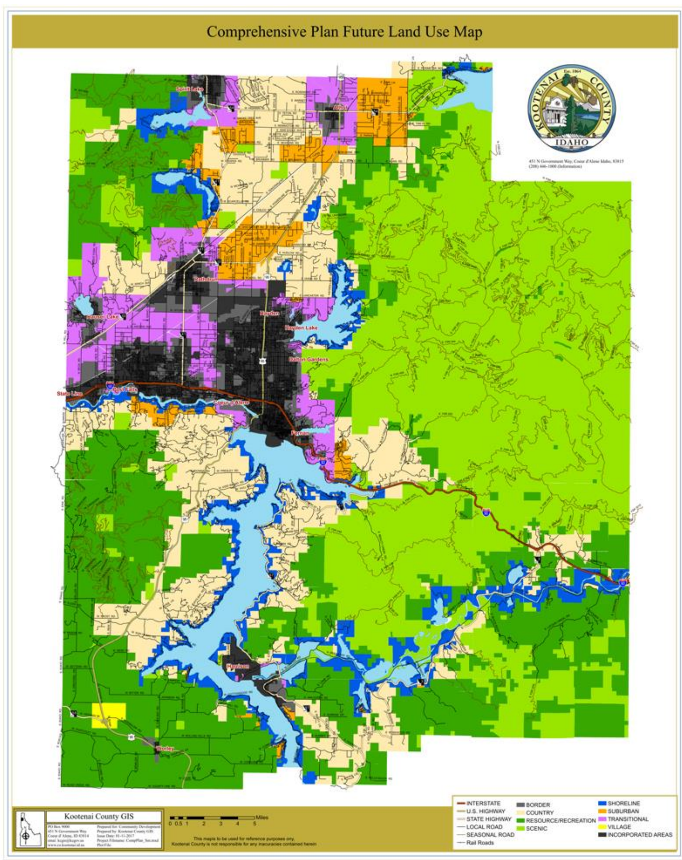


Figure 5.1: Future Land Use Map created by the Kootenai County Planners Office

5.4 Methodological Implications

The study employs a variety of spatial analysis and modeling techniques to urban growth modeling and characterization in a GIS environment. Specifically, using the spatially explicit models allows for better interpretation of the relative effects that various landscape metrics and socioeconomic factors have on urban growth. While a standard logistic regression is suitable for understanding the average or global effects that certain variables have on urban growth, it does not allow for any further examination. Using the spatial regime and GWLR, interpretation and, more importantly, visualization are made easier (Li et al. 2016, Su et al. 2009 and Luo & Wei 2009).

While some of the most common methods involve using a GWLR in analyzing urban growth, there are other methods they can use that take the spatial heterogeneity of these variables into account. One of the most commonly used methods that are used after these quasi-spatially explicit regressions is the local or spatially filtered regressions. Of these different types of models, the most common is spatial filtering; which involves taking space at the equation in creating eigenvectors that analyze the interactions between the different sample points. This model, combined with spatial filtering and other methods allows for better taking into account the local variations of the explanatory variables (Allen & Lu 2003; Carrion-Flores et al. 2016; Hu & Lo 2007; Liao & Wei 2015 and Tayyebi et al. 2013). This is a possible future direction for this work that would go towards validating the results found.

This thesis informs the literature on rural-urban interactions in that it indicates the strong push and pulls effects between urban growth and agriculture/natural amenity areas.

In the future, this thesis can assist local planners in determining the likely direction of urban growth based on the influence felt by the varying independent variables.

5.5 Limitations and Future Studies

As mentioned throughout the research, there are limitations to this project. As discussed earlier in this thesis, one of the main issues with chapter three was the amount of noise that was experienced in the NLCD data from 1992. This data product is as accurate as its counterparts in the 2000's, but the classification system used is drastically different that does not allow for direct comparison (Fry et al. 2009). Fry et al. (2009) developed a product meant to reconcile the differences between the different classification methods and time periods but was only meant for regional-scale research. This was further proved by the amount of urban growth in the AIC described by this product being almost nonexistent, a figure inconsistent with the population growth figures during the same time, as discussed in Chapter 2. The necessary work to reach a consistent classification structure would be to personally classify raw satellite imagery from all time periods, a process that is very computationally and time intensive, which is a future direction this project could take to validate these results.

One limitation in Chapter 4 is the decision to not use zoning data to examine the most susceptible zoning types to change. The zoning data itself is disjointed in that there are separate zoning maps for each of the cities over different time periods and, for the most part, do not exist in a digital format before the year 2000. In order to fully utilize this data, as used in Carrión -Flores & Irwin (2017), Dahal et al. (2016), Li et al. (2016), and Irwin & Bockstael (2004), multiple digitization projects would need to be undertaken that would be very expensive from both a time and resource allocation perspective in order to fully capture the required accuracy.

Another possible future area of interest in this thesis would be to study the locations from which the population growth came and link areas such as those with others around the country as areas that are likely to lose population to such areas of natural amenity. Similarly connected to this would be to analyze the impacts of the real estate market in their values on urban growth. It would be interesting to understand, not only the demographics and origins of the migrants but how they affect the real estate market in the area.

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