Spatial Analysis of Agricultural land Conversion and its Associated Drivers in Alberta

by

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A thesis submitted in partial fulfillment of requirements for the degree of

Master of Science

in

Agricultural and Resource Economics

Department of Resource Economics and Environmental Sociology

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Abstract

Alberta is a region undergoing substantial agricultural land use changes due to rapid economic and population growth, however the extent of such changes and the driving forces behind have not been assessed in detail due to data limitations. This three-part study makes use of recent developments in remote sensing data to assess the extent and model the drivers of agricultural land converted to developed (built-up) land uses in Alberta from 2000 to 2012. To give context to the issue of conversion, a comprehensive review of agricultural land use changes within the Whitezone of Alberta was completed. A first difference spatial lag model was developed to look at the drivers of agricultural land conversion at the county level. To improve the resolution and the diversity of factors being assessed, a township level geographically weighted regression model was developed to analyze the spatial non-stationarity of environmental and socioeconomic influences of conversion. Agricultural land conversion and intensification from pasture to annual cropping uses were the two major agricultural land use changes found. Agricultural land conversion was revealed to have strong neighbour spillover effects both directly and by way of mobile populations. Factors influencing conversion rates were found to be spatially heterogeneous in both magnitude and sign, which reflects the wide variety in agricultural land conversion processes occurring throughout the province. The combination of results within this study has the potential to be useful to policy makers in Alberta at various jurisdictional levels.

With population growth expected to continue, the effects of population increases on agricultural land conversion in particular have strong implications for the future of the province.

Acknowledgments

I would like to thank Feng Qiu for her enthusiastic guidance throughout the thesis writing process. Her positive energy and personal involvement in my research was contagious and helped me maintain vigor for the task at hand. I would also like to thank my committee member, Vic Adamowicz for his helpful direction towards the questions that needed to be asked.

I thank my family, close friends, and especially Brett for all of their continual support through the past two years. Whether it was listening to my endless opinions on the issue, or sharing their own, the encouragement was appreciated in so many ways.

I have special thanks for my REES cohort, with whom I shared many struggles with over the past two years. The camaraderie that was developed between all of us made coming to the office an enjoyable experience and the work much less arduous.

I would also like to thank Jason Cathcart for his advice and corroboration from Alberta Agriculture and Rural Development.

Last, but not least, I'd like to thank the sources of my funding, the Alberta Land Institute and Farm Credit Canada. The financial support and resources allowed me to not only complete my thesis, but also to develop a much greater understanding of an issue that has been deeply relevant to mine and my family's lives.

The examination committee for this thesis consisted of the following individuals:
Dr. Feng Qiu (Resource Economics and Environmental Sociology), Dr. Vic Adamowicz (Resource Economics and Environmental Sociology), Dr. Brent Swallow (Resource Economics and Environmental Sociology), and Dr. Jason Cathcart (Alberta Agriculture and Rural Development).

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Chapter 1. Introduction

Alberta is a province undergoing substantial land use changes due to its rapidly expanding economy and population. Growth in both these areas has resulted in residential and industrial development on the urban fringe and beyond. The development is often at the expense of high quality agricultural land that surrounds the urban areas of Alberta. This study assesses the extent and distribution of agricultural land converted to development that has occurred from 2000 to 2012 and analyzes the patterns and drivers of this process. To give context to the issue, all agriculturally relevant land use changes in the province are first assessed, followed by a focus on agricultural land conversion and fragmentation. The patterns and drivers of agricultural land conversion are then examined both at the provincial and local levels. Understanding of the trends and drivers of agricultural land conversion allows for policy recommendations on how to address undesired forms of this land use change.

1.1 General Problem

Losses of agricultural land to urban development are a growing global issue due to continued urbanization of rising populations. Alberta is no exception, with a growing urban population due to its rapidly expanding, energy-fuelled economy. These agricultural land losses to residential uses raise concerns over food security, environmental degradation, and loss of open spaces. Up until now, assessments of the extent of agricultural land being converted in Alberta have been limited to census-based summaries due to the lack of spatial data.

Agricultural land conversion is of economic concern due to potential market failures in the form of negative externalities. These externalities include environmental impacts from the loss of agricultural land, the loss of farmland (open space) amenity values (Fleischer and Tsur 2009), and other externalities arising from increased residential sprawl (Breuckner and Largey

2008). In addition to these potential inefficiencies, the high likelihood of irreversibility of agricultural land converted to development is concern for future food production and food security. There are of course many positive economic outcomes resulting from this form of land use change, but markets capture these outcomes whereas they do not consider the various externalities. All of these concerns validate the importance of quantifying the extent of conversion in Alberta so that these potential issues may be considered within the decision-making procedures.

For the first time, Alberta is in the process of developing comprehensive watershed-based land use policy for the entire province. This regional policy will have long-term effects on the future of the province, which points to the importance of assessing and understanding recent agricultural land conversion. The Alberta government's policy directive of "sustain[ing] our growing economy, but balancing it with Albertans' social and environmental goals." (Government of Alberta 2008) also highlights the need for smart growth strategies based on the understanding of the ongoing conversion processes.

Looking to the future of the province, Alberta's population and its associated land use demands are expected to continue to grow an additional 50% by 2040 (Treasury Board 2012). This consistent conversion pressure on agricultural land is therefore in need of assessment so that policy-makers are able to be well informed on the agricultural land implications of future population growth. This study makes use of recent developments in remote sensing data to assess and explore various aspects of the agricultural land conversion issue in Alberta.

1.2 Research Objectives

The purpose of this research is to provide information on the extent and distribution of agricultural land conversion in Alberta as well as to explore the drivers of this process. To provide context of the regional concentration of conversion surrounding urban centers, the Capital Region surrounding Edmonton is separately assessed from the private land (Whitezone) in Alberta. The concentration of development reveals concerns that may be relevant for specific regions of the province, but not for the province as a whole. The results of this analysis give context and direction for concerned policymakers at both the provincial and regional levels. In addition to policy implications, the results provide valuable direction for future research into a variety of issues related to agricultural land conversion within Alberta. While the results have extensive implications, the analysis solely provides descriptive outcomes regarding agricultural land use/land cover changes in the study period. More specifically, the analysis in this thesis addresses the following objectives:

i. Use recent advances in remote sensing data to assess the agricultural landcover changes in Alberta's private land from 2000 to 2012
ii. Determine the extent and distribution of agricultural land conversion throughout Alberta
iii. Assess the agricultural land fragmentation occurring at the Provincial scale as well as the Capital region surrounding Edmonton.
iv. Explore the county level primary drivers of agricultural land conversion in Alberta to determine relevant policy implications for this level of regional governance.
v. Develop a geographically weighted, localized regression model to assess the spatial variation in environmental and socioeconomic factors influencing agricultural land conversion throughout Alberta
vi. Consolidate the results from the variety of analysis approaches employed within this study to determine relevant policy implications of agricultural land conversion processes.

1.3 Thesis Structure

This thesis takes a "three-paper" structure with each paper building upon the previous analysis. Chapter 2 is an analysis using remote sensing landcover data of changes to the agricultural land use situation in Alberta from 2000 to 2012 with a focus on agricultural land conversion and fragmentation. Chapter 3 employs a spatial autoregression framework in a county level analysis of the socioeconomic drivers of agricultural land conversion. Chapter 4 is a higher resolution, township level model of localized environmental and socioeconomic factor relationships to conversion. Chapter 5 concludes the thesis by summarizing the policy implications of the combined chapters, as well as a discussion of future research areas.

Chapter 2. An Assessment of Agricultural Land Use/Land Cover Changes in Alberta Between 2000 and 2012

2.1 Introduction

Land use/land cover changes are well recognized to have long-term environmental, economic, and social consequences (Lambin et al. 1999; Grimm et al. 2008; Uematsu, et al. 2013). The nature of long-term impacts ensures the need for forward thinking strategies that address future problems associated with various changes. Agricultural land use changes in particular have received much global attention as future and current concerns over food security, climate change, and sustainability grow (e.g., UNEP 2012; Foley et al. 2005; Deng et al. 2006; Irwin and Bockstael 2007; Lichtenberg and Ding 2008; Baumann et al. 2011; Li, Wu and Deng 2013; Corbelle-Rico and Crecente-Maseda 2014). The potential irreversibility of certain agricultural land use changes such as conversion to development raises specific concerns of the economic and environmental impacts of these losses. As worldwide attention to the issue builds, the identification of the extent and distribution of these changes becomes evermore important.

Many researchers have addressed this issue by assessing historical land use/land cover changes in various regions of the world (e.g., Lambin and Meyfroidt 2011; Goldewijk 2001; Soulard and Wilson 2013; Gajbhiye and Sharma 2012). While global analysis is important for large-scale applications, localized analysis is also necessary for enabling policy makers to address their own land use changes implications. The province of Alberta, in Western Canada, is one such region in need of assessment, as conflicts among different types of land uses have become a significant issue associated with rapid economy and population growth. The rise of this issue has instigated land use policy formation with the goal of balancing Alberta’s economic, environmental, and social future (Government of Alberta 2008). At this point, however, due to data limitations, little has been done beyond census based summary analysis to assess the extent and distribution of agricultural land cover changes.

Agricultural and other relevant land use changes in Alberta have been touched by a number of recent reports and articles. Alberta Agriculture and Rural Development (AARD 2002) assessed the loss of agricultural lands using an agricultural land base monitoring report from 1977-2002. The key focus of loss-assessment in this report was agricultural land being converted to development for residential, commercial, and industrial purposes. Conversion of land for these uses also causes the division and shrinkage of agricultural parcels, which raise another concern known as “farmland fragmentation”. New housing subdivisions, transportation routes, and energy and utility corridors can fragment agricultural land, resulting in pieces that are too small or unsuitable for some agricultural uses. Fragmentation may impose extra costs on agricultural businesses such as the inability to achieve economies of scale due to the inability to gain sufficient contiguous land. However, due to data unavailability, the report mainly focused on conceptual discussions instead of a formal assessment and quantification. Furthermore, the AARD report only quantified the agricultural land conversion to development uses. Other relevant land use changes, such as forested land lost to agricultural uses and abandonment of farm land on the marginal areas have been ignored, again because of data limitation. Young et al. (2006) analyzed a study area east of Edmonton using satellite imagery from 1977-1998. They found that the major land cover changes within this area of the province were shifts from perennial forage crops to annual commodity crops. Young et al.’s (2006) work was a comprehensive land use/land cover change assessment using remotely sensed data. However, the analysis was only conducted on a small study area, and the results were not sufficient to represent the whole province as to draw sound conclusions and make meaningful policy recommendations. Rashford, Bastian, and Cole (2011) utilized the Census of Agriculture data to investigate the cropland use changes in the entire Canadian prairies and reaffirmed the intensification observation as indicated by Young et al. (2006), with the proximate cause being commodity price increases. However, their work suffers from the same data limitation (e.g., inability to assess other types of land use changes and fragmentation) as the AARD (2002) report. Recent government reports and presentations emphasized the importance and need of accurately assessing the quantity and distribution of agricultural land changes, which has been thus far constrained by data availability (e.g., Government of Alberta 2008; Cathcart 2013).

This article thus makes use of recent advancements in remote sensing data to assess the extent and distribution of agricultural land use/land cover changes between 2000 and 2012. A comprehensive assessment focused on agriculturally relevant land cover changes is first performed. The main categories of changes looked at include additions, deletions, shifts in intensity, and conversion to development. Additionally, agricultural land fragmentation is evaluated using a number of metrics. Although fragmentation in general landscape and forestland as well as urban study has been considered in existing literature (e.g., Hahs and McDonnell 2006; Jaeger et al. 2007; Irwin and Bockstael 2007), little research has been conducted to quantify it in the context of agriculture. Our results, in the forms of tables, maps, and descriptive statistics, shall be able to provide valuable information that may be used to guide further research and policy design in Alberta.

2.2 Data

The land cover data is derived from the Land Cover for Agricultural Regions of Canada, circa 2000 and the Annual Space-Based Crop Inventory for Canada 2012. The years of the data are approximate because the satellite images that are combined require no interference from clouds and thus vary in the time they are taken. Both sets of land cover data are at the 30-meter resolution and are classified by Agriculture and Agri-Food Canada (AAFC). Based on 2200 independent ground reference samples the overall thematic landcover rating for the year 2000 classifications is 81.3% (AAFC 2000). An accuracy assessment for the 2012 data has not been completed as of 2014, however the use of the same classification technique as the former data provides confidence in the landcover accuracy. It is important to note that due to the discrete nature of the two years of data there is potential for baseline irregularities causing unexpected results. For example, the year 2000 was within an extremely dry period in Alberta, which may result in abnormal agricultural land uses in comparison to the general trend. The original land cover data for both years classified all of the major crops (e.g., wheat and canola) separately, and we grouped all of the crops into one category as cropland. The final raster dataset includes nine land use/land cover classes: water, exposed, developed (or built-up), shrubland, wetland, grassland, annual cropland, hay and pasture, and forests. Table 2.1 provides a brief definition for each class. Analyzing this high-resolution data at the province level however makes visualization difficult, so township (~9300 hectares) aggregated land use/land cover changes and resulting maps were created. The Alberta township shapefile is obtained from AltaLIS Ltd. The 2012 Land Suitability Rating System (LSRS) data is obtained from AARD. LSRS is an expert system that assesses the suitability of land for crop production based on measurable qualities of soil, climate, and landform.

Table 2.1 Summary Landcover Category Descriptions (AAFC 2000)

Classification	Definition
Annual Cropland	Annually cultivated cropland and woody perennial crops. Includes annual field crops, vegetables, summer fallow, orchards and vineyards.
Perennial Cropland and Pasture	Periodically cultivated cropland. Includes tame grasses and other perennial crops such as alfalfa and clover grown alone or as mixtures for hay, pasture or seed.
Built-up Land	Land predominantly built-up or developed; including vegetation associated with these cover conditions. This may include road surfaces, railway surfaces, buildings and paved surfaces, urban areas, parks, industrial sites, mine structures and farmsteads.
Forested Land	Mixed coniferous and broadleaf/deciduous forests or treed areas
Shrubland	Predominantly woody vegetation of relatively low height (generally +/-2 meters)
Exposed Land	Predominately non-vegetated and non-developed. Includes: exposed lands, bare soil, snow, glacier, rock, sediments, burned areas, rubble, mines, and other naturally occurring non-vegetated surfaces.
Grassland	Predominantly native grasses and other herbaceous vegetation, may include some shrubland cover. Land used for range or native unimproved pasture may appear in this class.
Wetland	Land with a water table near/at/above soil surface for enough time to promote wetland or aquatic processes (semi-permanent or permanent wetland vegetation, including fens, bogs, swamps, sloughs, marshes etc)
Water	Water bodies (lakes, reservoirs, rivers, streams, salt water, etc...)

2.2.1 Study Area

The province of Alberta is divided into two primary zones that delineate public land (Greenzone) and private land (Whitezone). For the analysis below, only the Whitezone (42 percent of the province) is considered because agricultural land occurs primarily on private land. Within the Whitezone, the Corridor region connecting Alberta's two primary cities of Edmonton and Calgary is a hotspot for development due to it being the center of the economy and the population. Within the Corridor region, a focal point of development is the Capital Region that surrounds the city of Edmonton (Figure 2.1). In addition to the City of Edmonton, this region includes five counties with approximately 71 percent of its area in agricultural uses as of 2012. For these reasons, the Capital Region (4.9 percent of the Whitezone) provides context for the

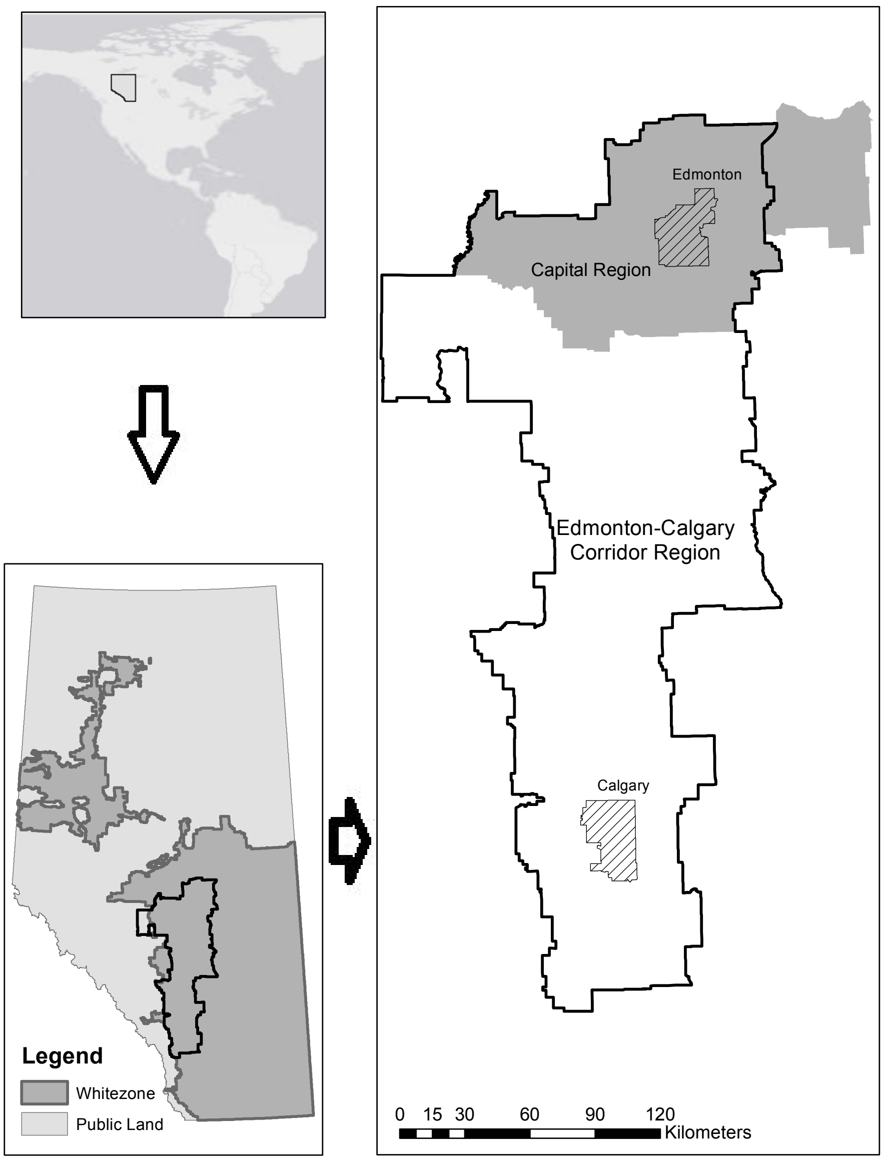

Figure 2.1 Study Area Map

regional concentration of agricultural land use/land cover changes. This chapter assesses the agriculturally relevant land use/land cover changes for the entire Whitezone as well as a separate analysis of the rapidly changing Capital Region.

2.3 Methods and Results

2.3.1 Agricultural land use change overview

Alberta's agricultural landbase includes nearly one quarter of the province's area and incorporates a diverse range of agricultural uses that include raising livestock, intensive cropping, forage production, and specialty crops. Summary results of land cover changes from 2000 to 2012 for each class are presented in Figure 2.2. Detailed land use/land cover transition matrices showing numbers and percentage changes between 2000 and 2012 are presented in appendices 1-3.[1]

From 2000 to 2012, Alberta's agricultural land base decreased by a net of about 845,200 hectares (-5.63%). This substantial decrease is comprised of multiple sources of loss and as expected for a diverse province, is spatially heterogeneous. Figure 2.3A displays this heterogeneity in a township level grid of net agriculture land use changes for the Whitezone (private land) of Alberta. The area surrounding Edmonton and north of Edmonton is a region experiencing some of the largest decreases in agricultural land. Additionally, the zone in the center of the province displays large decreases in land under agricultural use. Even though the overall trend is a decrease in land, there are areas in the province that have net increases. An eastward stretch of

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[1] It is important to note however, that due to the discrete, two-year nature of the land cover analysis there is a large potential for many of these changes to be temporary. Agricultural commodity's price fluctuations as well as moisture and temperature anomalies can cause land to go in and out of use. This consideration is important when interpreting and extrapolating the trends in the following analysis.

land south of Edmonton, as well as the area just north of Calgary experienced substantial increases. In the Peace County to the north and the southern irrigation zone there are scattered areas of increases as well.

Since the Edmonton area is a hotspot for agricultural loss, a more detailed look at the land cover changes surrounding this area is advantageous. The Capital Region's (see Figure 2.1) agricultural land base lost about 97,090 hectares from 2000 to 2012, which amounts to a 10.8% loss of agricultural land (Appendix 3). This number is double the provincial percentage and illustrates the substantial changes in land use that have, and continue to occur in the Edmonton metropolitan area.

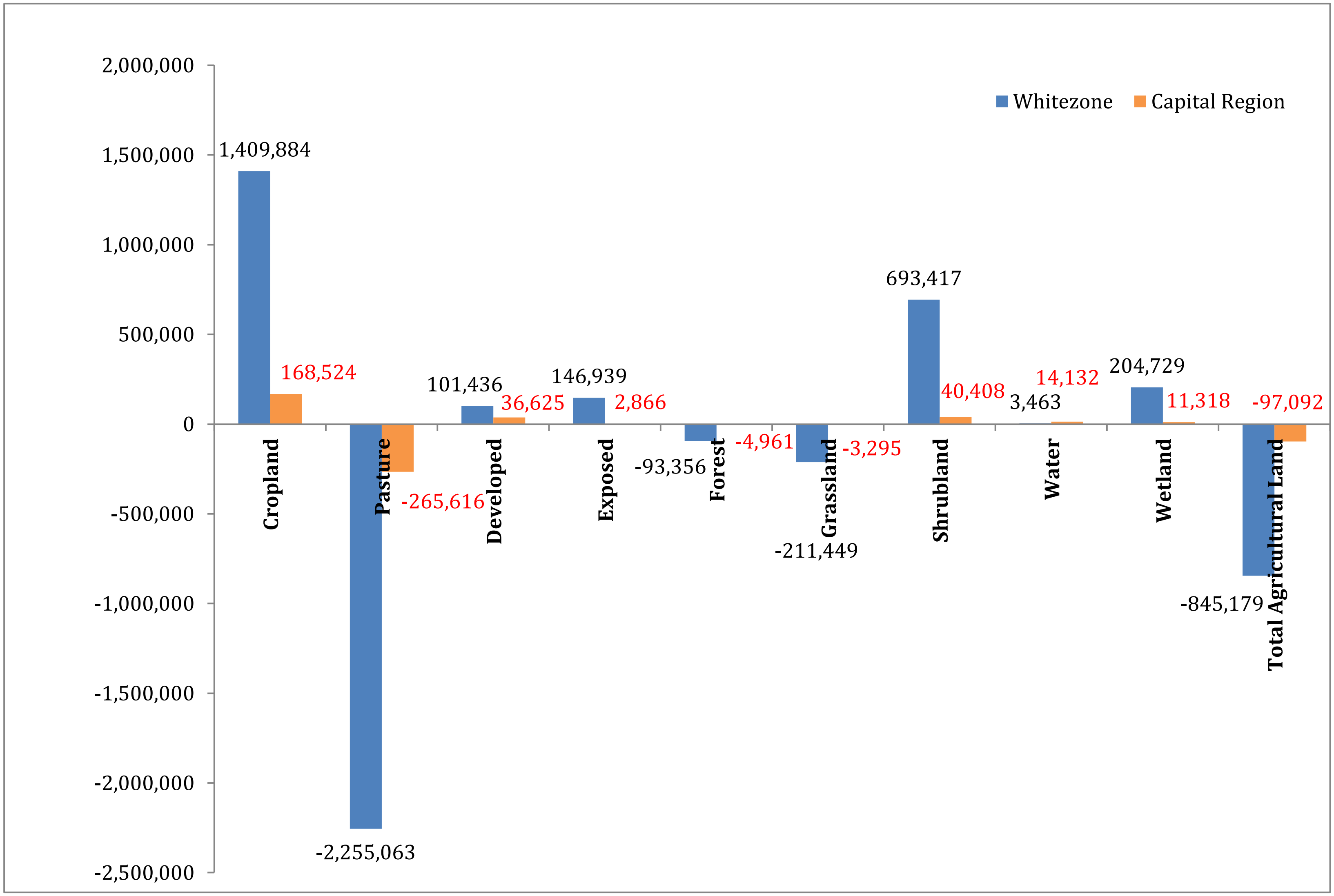

Figure 2.2 Land Use/Land Cover Changes (hectare) within Alberta for the Whitezone and the Capital Region

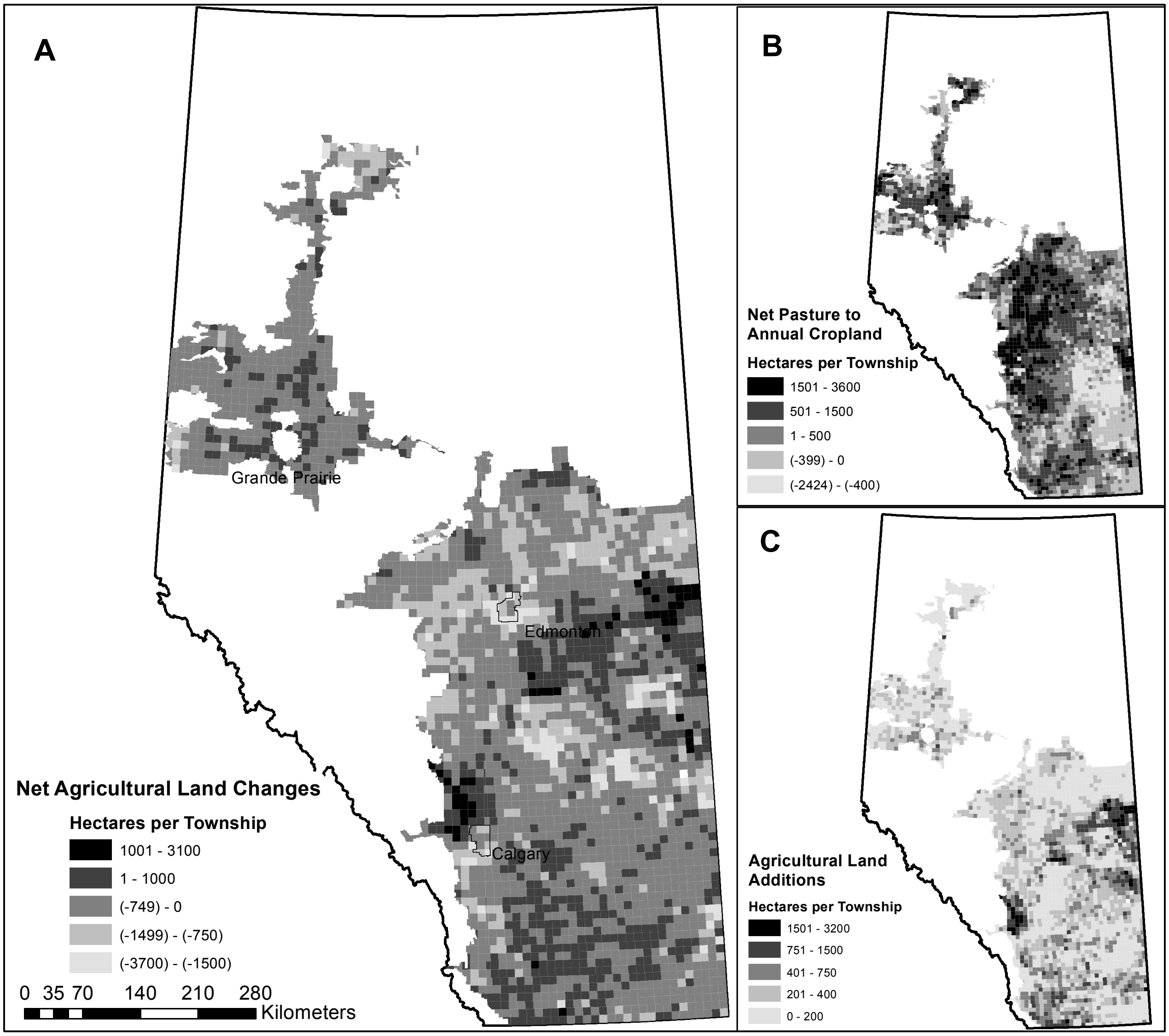

Figure 2.3 Township Aggregated Land Use/Land Cover Change Summaries (A) Net agricultural land Change (B) Net Pastureland to Cropland Shift (C) Agricultural land Additions

2.3.2 Shifts within the agricultural land base

Changes within the category of agricultural use are prevalent in the period from 2000 to 2012. Intensive annual cropland and extensive pastureland have significant exchanges that may be due to both crop rotations and external forces. There are rotational changes for producers who interchange land between intensive cropland and forage production, which will most often result in proportions of the two categories remaining quite even. However, there are also structural changes to farmers' production decisions that are due both to environmental factors and economic drivers.

The net total change between uses is 1,379,300 hectares of pastureland converted to cropland, which represents a net change of 22.9% of pastureland being altered to cropland (Appendix 1). This result is consistent with the predictions from Rashford, Bastian, and Cole (2011). Figure 2.3B displays these net changes and reveals strong spatial patterns. As shown, the Edmonton to Calgary corridor by far experiences the greatest shifts in agricultural intensity. To look at this trend in greater detail, the Capital Region alone had a net change of 186,150 ha of pastureland to cropland (Appendix 3). This represents a large 40.6% change of pastureland to cropland over the period of 2000 to 2012. Conversely, the lower quality soil areas in the south region of the province see the opposite change happening in a significant pattern. The northern region in the north has a substantial shift to cropland as well.

The drivers behind these changes are a combination of environmental, economic, and policy factors. As an overall driver of intensification, higher cash crop prices cause producers to move from forage production and livestock grazing to annual crops such as canola and wheat (Rashford, Bastian, and Cole 2011). Over the study period wheat and canola prices have increased while livestock prices have stayed relatively constant (Statistics Canada 2013), which may have a significant impact on the shift to annual crop production. The corridor area where intensification is most prominent has the highest land suitability rating, which is a measure of soil quality, landscape, and climate factors (Figure 2.4C). The lowest land suitability rating is for the area southeast of Edmonton where cropland has been changed to pastureland. This southeastern area shifting to more pastureland despite the rising commodity prices shows that land that is more suitable for grazing and forage production will be brought in to meet the demands for products. These changes are most likely not permanent, as they could be reversed with time if no significant infrastructure upgrades were associated with the shift.

2.3.3 Additions to the agricultural land base

Although the net change in the agriculture land base was a decrease of 5.83%, this time period also had areas of agricultural expansion. Figure 2.3C displays the grassland, shrubland, and forested land that were expanded into by agricultural uses.[2] The expansion happening in the north is mostly due to clearing forest, while the majority of the rest of expansion has occurred into grasslands. Similar to the distribution of pastureland shifting to cropland, expansion has taken place mostly on the high quality land in the province not already in agricultural production (Figure 2.4C).

Two of the focal points for additions to the agricultural land base are to the east of Edmonton and a region to the northwest of Calgary where substantial expansion into grasslands has taken place. This shift can be interpreted as another form of intensification within the Alberta agriculture industry. Just as shifts from pasture to cropland revealed producers seeking to maximize returns from the land, shifts from grassland to pasture and annual cropland are most likely due to the same principle. The move from 'native' grassland (that may be used for grazing) to tame pasture and forage production may also be in part supply compensation for the large losses of pastureland to cropland within the corridor area.

Agricultural expansion into forested land was mostly spread out in the Peace region and north central Alberta, with a focal point of expansion occurring southeast of Edmonton. The expansion is mostly motivated as discussed by high commodity prices and growing scarcity of

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[2] To examine the agricultural land additions, deletions, and conversion as well as fragmentation, we aggregated the annual cropland and pasture/forage production classes into one category as agriculture.

agricultural land. In the north region especially, this land use change that involves high conversion costs is only economically viable due to high-expected profits.[3] Unfortunately, due to the restricted Whitezone boundary of this analysis, public land dispositions that bring public land into private use may be missing from this analysis. For instance, in the most northerly agricultural area of La Crete about 55,000 hectares of forested land is in the process of being auctioned off for agricultural uses (MacArthur 2011). This substantial addition to the land base is not included in the review.

The Capital Region had relatively few additions to the agricultural land base. This is not surprising because this relatively densely populated region does not have much land remaining that has not already been expanded into for agriculture. As a result, combining forest, Shrubland, and Grassland conversions, only 27,900 hectares were added with 88% of that coming from forested land

[3] For this land cover change in particular it is important to mention the error potential in the data. The resolution and classification of the satellite data used for the land use/land cover changes analysis has potential error due to irregularities in satellite images or in the computational land cover judgment. It may therefore be the case that a portion of this reclaimed land is actually attributed to classification issues along roadways.

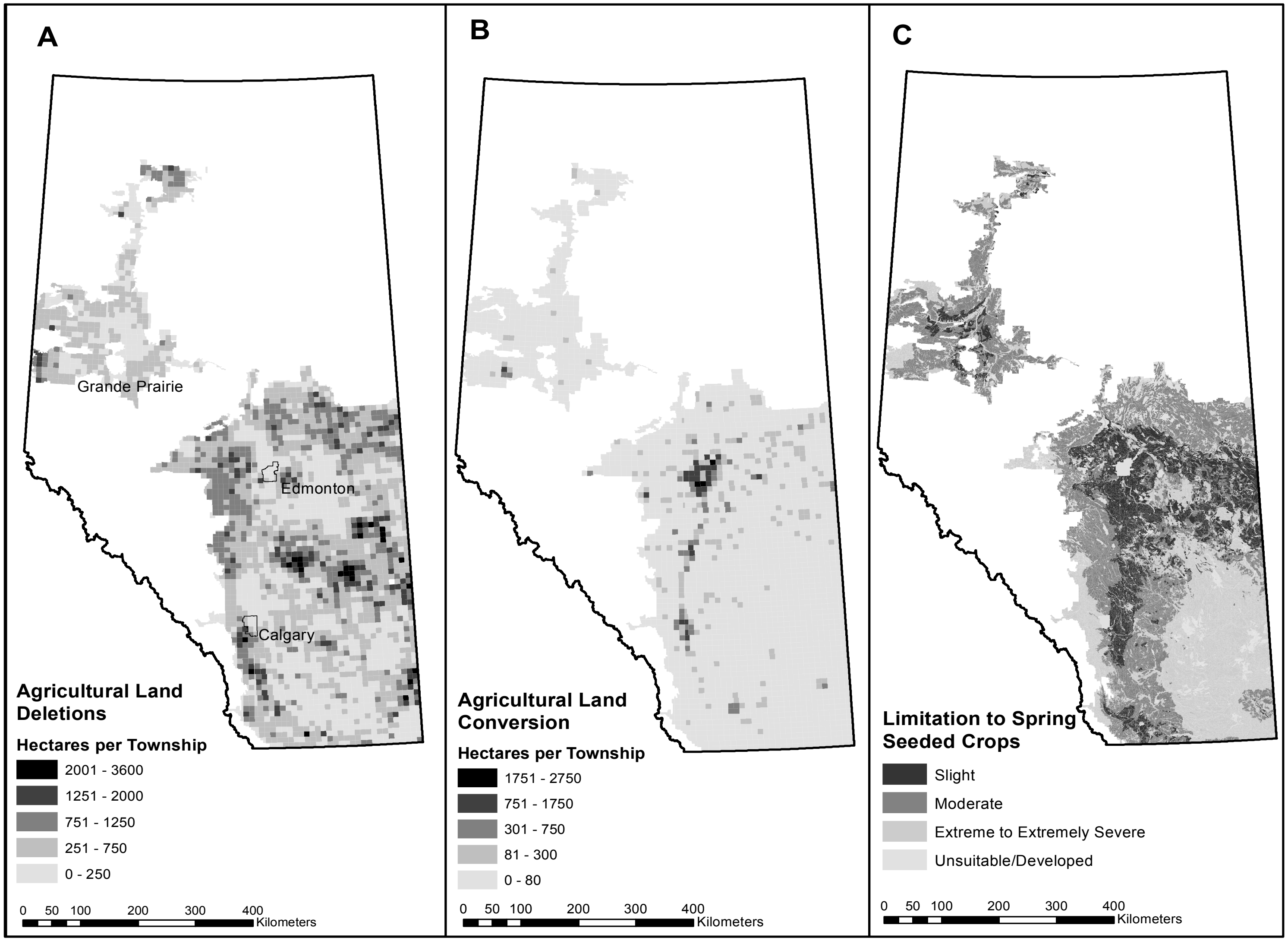

Figure 2.4 Township Aggregated Land Use/Land Cover Change Summaries and Land Suitability Rating System (A) Agricultural land Deletions (B) Agricultural land Conversion (C) Limitations for Spring Seeded Crops Rating

2.3.4 Deletions from the agricultural land base

From 2000 to 2012 agricultural land shifted to a number of different land cover categories including grassland, shrubland, forested, and developed. These shifts differ greatly in the associated level of permanence. Losses of agricultural land to shrubland may be a temporary change due to fields being too wet to cultivate in a specific year, but a shift to residential development is most unlikely to be reversed. Due to this large difference in deletions, the potentially temporary changes will be discussed first followed by a detailed look at the long-term land cover change of agriculture to development.

Agricultural land losses were distributed largely around the periphery of high quality soils in the corridor area (Figure 2.4). A prominent focal point of abandonment was from the center to the eastern edge of the province. Total changes from agricultural use to grassland, shrubland, and forest are 1,325,300 hectares (Appendix 1), with 75% of these losses being from pastureland. This figure represents an 8.8% decrease in agricultural land over the 12-year period, however as mentioned, the changes may be temporary. The Capital Region had 64,050 hectares of agricultural land changed to grassland, shrubland, and forested land (Appendix 3). Similar to the province, 82% of these losses were from less intensive pastureland.

One source of these temporary changes is the economics of production. In years where forage is readily available at lower prices, producing forage may not be profitable within certain regions. For this reason, good moisture and strong production may be strong driving forces for tame pasture being underutilized and classified within shrubland or grassland categories.

A prominent source of temporary change is the moisture regime and the associated ability of producers to cultivate the land. In times of high moisture some low lying areas, and occasionally whole fields are not grazed or left unsown. This may be the explanation for the southeastern hotspot of abandonment. The southernmost region of the province however did not experience the same decrease as the southeast area, which is most likely due to the intensive irrigation infrastructure that allows producers to manage drainage much more effectively.

2.3.5 Agricultural land conversion

A much more permanent agricultural loss is land converted to residential, commercial, and industrial uses. As a consequence of Alberta's growing economy and population, an increasing amount of agricultural land has been developed around both large and small urban centers. This development has included both peripheral expansion as well as widespread country residential development. Figure 2.4B reveals that the focal point of agricultural conversion was the corridor region connecting and including Edmonton and Calgary. Small areas of conversion were also scattered around the cities of Grande Prairie in the north, and Lethbridge and Medicine Hat in the south. The total agricultural land conversion for the Whitezone was 123,900 hectares from 2000 to 2012 (Appendix 1). This reflects a 0.82% loss of Alberta's agricultural land. However, in the Capital Region the proportional loss is much greater (Figure 2.5). In this region, where the conversion is most evident, 38,250 hectares of agricultural land was developed which represents a 4.3% loss in the regions agricultural land. This conversion has primarily taken the form of suburban development on the periphery of the city as well as large expansion of the surrounding towns. The Corridor region is the center of development as it is both the focal point of economic activity and houses the accompanying bulk of its population. For many years the growing population along with their booming incomes has resulted in a continually growing demand for suburban development on the urban fringe as well as for acreages in the country. In the Edmonton area (Capital Region), which is surrounded by high quality agricultural land, this encroachment has removed a much larger proportion of land relative to the Whitezone.

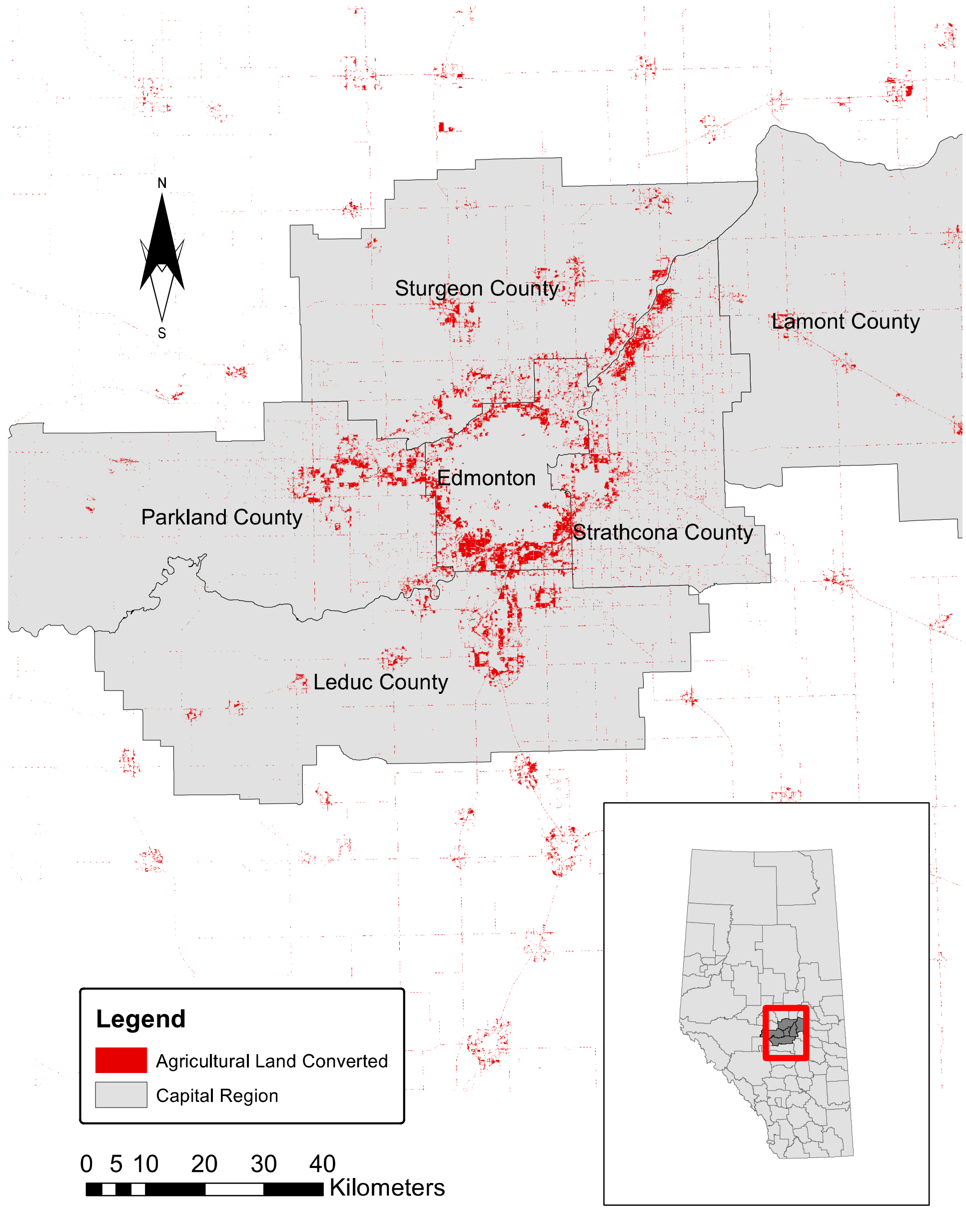

Figure 2.5 Agricultural Land Conversion in the Capital Region

Quantification of agricultural land that is lost is important, but the quality (agricultural potential) is also an important aspect of this conversion as it reflects the future agricultural productivity and agri-business profitability. It is particularly relevant in the current application as the corridor region coincides with the highest quality agricultural land in the province. Table 2.2 below breaks down the quantity of agricultural land converted from each Land Suitability class.

The results show that nearly 70% of land being converted is within the two highest land suitability ratings. In the Capital Region the proportions of high quality agricultural land being converted are slightly lower (see note) with 61% being land in suitability class 2 and 3.

Table 2.2 Agricultural Land Conversion by Land Suitability Rating for the Whitezone and Capital Region from 2000 to 2012

	Whitezone		Capital Region	
Land Suitability Class	Converted (ha)	Percent of Total Conversion	Converted (ha)	Percent of Total Conversion
2	42,841	35%	19,282	50%
3	41,700	34%	4,230	11%
4	12,150	10%	1,398	4%
5	3,586	3%	255	1%
6	3,444	3%	442	1%
7	1,827	1%	156	0%
9*	18,353	14%	12,493	33%
Total	123,902	100%	38,257	100%

*Note: LSRS Class 9 is land that is considered urban or water. Urban classification is based on urban boundaries, which has resulted in agricultural land within the boundary of Edmonton being improperly classified as 9 instead of its actual suitability level.

2.3.6 Agricultural land fragmentation

Fragmentation of agricultural land is an issue with the potential to decrease agricultural productivity and increase land use conflicts (Carjsens and van der Knapp 2002; Latruffe and Piet 2013). These negative impacts are accompanied by the lowering of restrictions on development, which may lead to an increase in conversion. For these reasons, it is important to assess the degree of agricultural land fragmentation that may precede further conversion to development or reduce the viability of agricultural production in specific areas.

The presence of agricultural land fragmentation was tested with a variety of metrics that capture size, shape, and spatial distribution effects. Definitions and the relationship with fragmentation are presented in Table 2.3. Fragmentation was measured for both the entire Whitezone of Alberta and, due to the concentration of development around the Capital Region, the city of Edmonton with a 30-kilometer buffer. This buffered zone was used instead of the Capital Region because of the potential influence on the metrics of the irregular shape associated with the Capital Regions boundaries. Metrics used for addressing size effects include mean patch size and effective mesh size. These measures differ in interpretation only in the effect of small agricultural patches on the metrics value.

Table 2.3 Land Fragmentation Metrics Explanation

Metric	Formula	Explanation	Intuition
Patch Density (+)	$\frac{n_k}{A}$	The total *n* patches of land use *k* divided by the total landscape area *A*	A higher value indicates an increase in the number of separate parcels
Mean Patch Size (-)	$\frac{\sum a_{ik}}{n_k}$	The sum of land use k's patch area divided by total *n* patches of land use *k*	A lower value indicates that parcel size is on average smaller
Mean Perimeter-to-Area Ratio (+)	$\frac{\sum {}^{l_{ik}}/_{a_{ik}}}{n_k}$	The sum of the ratio between length (l) of the patches perimeter and area (*a*) of each respective patch in land use *k*	A higher value indicates that parcels have become more complex
Effective Mesh Size (-)	$\frac{\sum a_i^2}{A_k}$	The sum of each patch's area (*a*) squared and divided by the total area (*A*) of land use *k*	Same intuition as Mean Patch Size, except that the addition of small parcels has little effect

Note: The ( ) contain the metric's relationship to fragmentation

Table 2.4 provides 2000 and 2012 fragmentation index measures for the Whitezone and the Edmonton buffering area. For mean patch size, the addition of a small patch lowers the metric value. However, with effective mesh size, the addition of a small patch has little effect on the metric. This concept is reflected in the results for both the Whitezone and Edmonton area analysis. Mean patch size increased by 50% and 37% respectively, and effective mesh size increased by greater amounts of 177% and 58%. The large difference in these values shows the varying impacts that large patches had on increasing the patch size value. A much larger increase of the effective mesh size within the Whitezone shows that additions of large patches through the study period were much more prevalent than in the Edmonton area.

Table 2.4 Agricultural Land Fragmentation Metric Results (2000, 2012)

	Whitezone of Alberta			Edmonton with 30km buffer		
Metric	2000	2012	% Change	2000	2012	% Change
Patch Density (+)	0.47	0.29	-37.01	0.89	0.56	-36.73
Mean Patch Size (-)	125.86	188.59	49.84	81.90	112.24	37.05
Mean Perimeter-to-Area Ratio (+)	748.07	560.44	-25.08	787.94	566.04	-28.16
Effective Mesh Size (-)	115519	319856.8	176.89	12804.7	20209.6	57.83

Shape effects from fragmentation were measured with a simple mean perimeter-to-area ratio for each study area. Impacts from the shape of agricultural land are important for farm level efficiency and economies of scale (Gonzalez et al. 2007). For the Whitezone the metric decreased 25%, while the Edmonton area metric decreased 28% from 2000 to 2012. The relatively similar finding reflects a province wide reduction in the level of agricultural polygon complexity. It may be that this result is a response to rising agglomeration of agricultural land as found by the effective mesh size metric.

The metric that captures spatial distribution of agricultural land is patch density. Spatial distribution has a large impact on the efficiency of agricultural production as well as the extent of conflict that farmers may encounter with residential and other competing land users. Whitezone wide as well as in the Edmonton area, patch density decreased substantially due to a decrease in the total number of noncontiguous patches. This metric is limited in meaning, but it gives a measure of the number of patches within the total landscape.

Results from the various metrics revealed trends somewhat contrary to the concern of increasing fragmentation. The metrics all show that fragmentation both in the Whitezone and the Capital region has decreased over the study period. A potential cause of this is the ongoing consolidation of farms, which maintains parcels of agricultural land in larger groups. A highlight report from the Census of Agriculture (Statistics Canada 2011a) found that from 2006 to 2011 the number of large farms increased by 18%. Larger farms have the potential to consolidate land, which may cause the measure of the remaining patches to become larger, offsetting the effects of losing agricultural land to fragmentation. The mean perimeter to area ratio results show that even though there is development happening throughout the province, agricultural land patches are in fact becoming less complex and more uniform. It may be the case that agricultural land conversion has occurred upon highly fragmented land, which effectively lowers the indices values by removing the most fragmented polygons from the landscape.

The results display the multiple impacts that fragmentation has on the agricultural landscape, and the need for approaching the issue with a suite of metrics to comprehensively measure the effects of increasing development. Although the findings do not support the fragmentation concern from a provincial perspective, if the fragmentation indices for the entire Whitezone are compared to those for the Edmonton buffered region, it becomes clear that fragmentation was higher in the buffer regions surrounding Edmonton than for the whole private zone.

2.3.7 Land Use Framework regions

In 2008, the Alberta government enacted the Land Use Framework (LUF) policy to coordinate increasingly competitive land uses within the province. To account for the province's great diversity in land uses, policy areas are divided into seven watershed-based regional plans. Each of these regional plans is therefore unique to the land use issues based on the economic, geographic, and social conditions within each region.

Due to this policy structure, a LUF region based analysis of the largest agriculturally related land cover change was conducted and the results are presented in Table 2.5. These results show that for almost all regions, the main change is pastureland shifting to cropland. The exceptions are the Lower Athabasca region that had a significant portion of agricultural land shifted to shrubland and the Red Deer region that experienced a large movement of pastureland to grassland. A notable change is the expansion of cropland into forested lands within the Upper and Lower Peace regions, which totals nearly 55,000 hectares. In the South Saskatchewan region there is a large shift of 194,014 hectares of grassland to cropland, which in addition to the large pasture to cropland change reveals a significant shift towards annual cropping practices.

The LUF regional analysis also highlights the spatial distribution of agricultural land conversion. Within the North Saskatchewan region 1.5% of agricultural land was converted to development, which is only closely contested by the Lower Athabasca region (1.4%) in terms of proportion, but not in absolute terms. The concentration of conversion in the Edmonton region is reaffirmed.

Table 2.5 Summary of Three Major Agricultural Landcover Changes for each LUF Region (2000-2012)

LUF Region	3 Main Agricultural Landcover Changes (Ha)*			Agricultural Land Conversion (Percentage)	Total Agricultural Land (Ha)
Lower Athabasca	Agricultural land to Shrubland **50,761**	Net Pasture to Cropland **23,491**	Pasture to Forest **7,285**	4,064 (1.4)	295,947
Lower Peace	Net Pasture to Cropland **80,882**	Pasture to Shrubland **30,607**	Forest to Cropland **14,415**	1,775 (0.3)	514,556
Upper Athabasca	Net Pasture to Cropland **201,351**	Pasture to Shrubland **77,886**	Forest to Cropland **29,181**	6,603 (0.6)	1,148,829
Upper Peace	Net Pasture to Cropland **148,725**	Forest to Cropland **39,825**	Pasture to Shrubland **34,036**	5,398 (0.4)	1,541,678
North Saskatchewan	Net Pasture to Cropland **473,788**	Pasture to Shrubland **175,952**	Grassland to Pasture **80,013**	63,617 (1.5)	4,338,642
South Saskatchewan	Net Pasture to Cropland **293,407**	Grassland to Cropland **194,014**	Pasture to Grassland **148,617**	24,810 (0.6)	3,943,982
Red Deer	Pasture to Grassland **169,528**	Net Pasture to Cropland **158,059**	Pasture to Shrubland **69,227**	17,621 (0.5)	3,211,983

* Agricultural land makes up a very small percentage of the land area in the LUF regions of Lower Athabasca and the Lower Peace. Due to this, the main agricultural landcover changes may not represent the largest general landcover changes within each region.

2.4 Conclusions

Global land use changes and food security concerns have increased the need for a better understanding of agricultural land use changes. This article made use of remote sensing data to analyze agriculturally relevant land cover changes within the western Canadian province of Alberta. The significant patterns in agricultural land use/land cover changes that were found provide valuable insight into the agricultural impacts of a rapidly growing economy.

The main findings show four principal agricultural land use transitions that occurred during the study period of 2000 to 2012. The first major land use change found was pasture and forage production lands being switched to more intensive annual cropping uses. This intensification trend of agriculture reflects the persistent increases in commodity prices during the study period. Primary producers using high quality land thus have the incentive to cultivate more land (previously pasture) to take advantage of the profit potential from annual cropping. Additions to the agricultural landbase from shrubland, forest, and grassland were found to be substantial in regions throughout the province. Similar to the transition of pastureland to annual cropland, this form of agricultural expansion reflects the strong profitability potential that annual commodity crop production has. Also reflecting the intensification of agricultural land, expansion into areas of available land for agriculture has potentially large environmental implications that would be important to address in subsequent research. Contrary to the additions taking place, a larger number of losses of mostly pastureland also occurred throughout the province. Transition of agricultural land to shrubland, grassland, and forested land occurred mostly upon the more marginal agricultural land available for agriculture. These losses can be attributed to both non-permanent pasture underutilization and high moisture conditions in the latter year resulting in land being left unused. The potential for these changes to be temporary is an important consideration that would be useful to address with future land cover data and analysis. A loss of agricultural land that is effectively permanent and occurring upon the highest quality areas is the conversion to developed land. Our results show that a significant amount of land in the corridor connecting the two largest cities of the province has undergone this process. This finding is consistent with the expected urban expansion into agricultural land and validates concerns outlined in the AARD report (2002) on conversion and fragmentation.

The fragmentation metric results however were not consistent with the concerns found in the AARD report. All four metrics used found decreasing fragmentation at both the Whitezone level and for the Capital Region. That this is occurring despite the significant presence of agricultural conversion in the Capital Region reveals that development is filling in the gaps and removing the previously disjointed sections of agricultural land. Removing these portions has a stronger effect on the metrics then additional fragmentation of agricultural land. It is also important to recognize that the resolution of this analysis may not capture the small-scale fragmentation caused by well sites and access roads. The 30-by-30 meter pixel resolution may not be able to properly incorporate the presence of well sites or low-density housing which is usually less than 200 m^2 (Irwin and Bockstael 2007). Higher resolution land cover data would be useful to corroborate the fragmentation conclusions made in this article.

The limited resolution of the data is not only a potential issue in measuring fragmentation, but also for measuring small scale land use changes. 30-meter resolution landcover data has the potential to obscure small changes in landcover categories such as wetlands and development in the form of country residential. Individually such changes are negligible, however the accumulation of many such overlooked changes has the potential to over or underestimate land use changes. An additional limitation is in the discrete, two-period nature of the landcover data. This form of analysis may obscure the real trends of some land use changes occurring by highlighting just two years observations within a period of twelve. This may be the case for a number of agricultural land use changes, however agricultural land converted for development is primarily non-reversible, in which case this two-period analysis is a reliable assessment.

The province of Alberta is a region with significant agricultural land undergoing many changes. Values for these changes in the form of maps, tables, and summarized statistics provide valuable guidance into a range of land use related issues. Policy makers aiming to target areas of significant undesirable changes may use this guidance, as well as researchers who aim to determine relevant drivers, consequences, and policies associated with these land use transitions. This article provides an important starting point in analysis to encourage future work and understanding of the dynamic agricultural land use processes in Alberta.

Chapter 3. Assessing Neighbour Influences and Population Growth on Agricultural Land Conversion in Alberta

3.1 Introduction

Around the world, significant attention has been drawn to the issue of urban expansion into agricultural land (Francis et al. 2012; Shalaby, Ali, and Gad 2012; Rahman et al. 2011). The problem has been growing to the point it is at now where many governments and organizations want to manage the growth to maintain some degree of both agriculture production and rural landscape quality (Bengston, Fletcher, and Nelson 2004; Nickerson 2001; Irwin, Bell, Geoghegan 2003). Issues of agricultural land conversion are highly relevant in the province of Alberta, which has experienced significant agricultural land conversion due to its rapidly expanding economy (AARD 2002; Young et al. 2006). This growing economy has attracted many migrants to the corridor zone connecting and including the two metropolitan cities of Edmonton and Calgary with respective populations of 1.1 and 1.2 million as of 2011 (Statistics Canada 2011b). To accommodate the rapid population influx in this zone, expansion in the form of urban, suburban and country-residential development has encroached upon agricultural land. With Alberta's population expected to expand another 50 percent by 2040 (Alberta Treasury Board 2012) this issue will continue to grow with potential accelerating impacts. It is important to note that due to historical settling patterns, the majority of agricultural land being lost to residential expansion is of the highest quality within the province (e.g., Francis et al. 2012; AARD 2002). The 'Alberta Land Stewardship Act' revealed the strong concern regarding these losses by stating that the "The Lieutenant Governor in Council is responsible for establishing, supporting or facilitating funding and cost-sharing initiatives, mechanisms and instruments to support the protection, conservation and enhancement of agricultural land or land for agricultural purposes” (Government of Alberta 2009). Arguments outlining the consequences due to these losses are also popularly acknowledged (AARD 2002; Cathcart 2013), however the extent, location, and potential drivers of these losses have not been reliably quantified due to the past lack of data availability. The objectives of this study are to take advantage of recent developments in remote sensing data to first assess the extent and spatial distribution of agricultural land conversion within Alberta, and then use census data to identify the major drivers of this process.

Agricultural land conversion has had quite a large amount of attention in the literature as the issue continues to grow (see, for example, Seto and Kaufmann 2003; Carrion-Flores and Irwin 2004; Li, Wu, and Deng 2013). Consequently, modeling these land use changes with environmental and socioeconomic data combined have been done using a number of econometric specifications (Seto and Kaufmann 2003; Carrion-Flores and Irwin 2004; Jat, Garg, and Khare 2008). Some of these land-use modeling applications acknowledge the issue of spatial dependence (Irwin, Bell, and Geoghegan 2003; Baumann et al. 2011). However, the neighbouring land use effect is often not directly quantified with the exception of a recent work of Li, Wu and Deng (2013).

Conventional wisdom and theoretical analyses (e.g., von Thünen 1966; Segerson, Plantinga, and Irwin 2006; Irwin and Geoghegan 2001) both suggest that an important consideration in land use patterns is spatial dependence between neighbouring parcels of land. This is due partly to the similarity in features of adjacent land and characteristics of socioeconomic factors, which lead to the clustering of land uses (Irwin and Geoghegan

2001). Furthermore, farmland conversion is often a consequence of urbanization and population growth in nearby cites and suburban areas. New residential development tends to be clustered (often close to the urban areas) because it improves efficiency in services. Improvements in infrastructure facilities, construction of roads, growth of markets, enhanced employment opportunities, and policy changes in neighbouring areas will further influence local farmland use decisions (Crecente, Alvarez, and Fra 2002; Drummond et al. 2012). Therefore, the ability to quantify spillovers from neighbouring areas is important, especially for policy design. Neighbour effects in the Alberta situation may be expected to have a large influence due to the concentration of existing population, population growth, and agricultural land conversion in the Edmonton-Calgary Corridor.[4] Due to both the scale and the speed of population growth, residential expansion in neighbouring municipalities is likely to play a large role in determining the distribution of agricultural land conversion. This context reaffirms the importance of using a spatially explicit modeling approach to assess the drivers of this process (Brady and Irwin 2011).

Taking this into consideration, we adopt a spatial model accounting for the spillover effects from neighbouring land use activities as well as population growth and investigate the agricultural land conversion situation in the Alberta context. The study applies the spatial lag approach to the case study of Alberta, where substantial conversion has occurred. Our results shall provide new insights into empirical research on farmland conversion and urbanization in areas of high economic and population growth.

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[4] The Edmonton-Calgary Corridor (ECC) makes up just 6% of the provincial land base, yet as of 2011 contains 74.2% of the population (Statistics Canada 2011b). The ECC includes Edmonton, Calgary, and twelve counties (Sturgeon, Parkland, Strathcona, Leduc, Brazeau, Wetaskawin, Ponoka, Lacombe, Red Deer, Mountain View, Rocky View, and Foothills) connecting these urban centers.

The following section outlines the data used and explores the context of agricultural land conversion in Alberta. Methods of analysis are then discussed and applied in combination for the final model specification. The results from the final spatial model are compared to simplified models and the evident benefits are reviewed. To summarize and conclude, the policy implications of the findings are discussed, followed by closing remarks.

3.2 Data and Descriptive Summary

3.2.1 Data

The 30-meter resolution data for agricultural land conversion is derived from the Land Cover for Agricultural Regions of Canada, circa 2000, and the Annual Space-Based Crop Inventory for Canada 2012. Agriculture and Agri-Food Canada (AAFC) classified both sets of land cover data into nine landcover categories (Table 3.1). The pre-classified raster datasets were differenced to find the changes in land cover from agricultural (includes annual croplands and hay/pasture lands) to developed (built-up) land. The overall accuracy rating for this land cover classification was found to be 81.3%. Land Suitability Rating System Data in polygon form along with a township grid polygon for visual analysis was sourced from Alberta Soil and Information Center (2001). The socioeconomic dataset was procured from the 2001 and 2011 Census of Agriculture and Census of Population for the respective years.[5]

[5] Population and Agricultural data were not available for the years 2000 and 2012, so the nearest years for which Census of Population and Census of Agriculture data are collected were used instead.

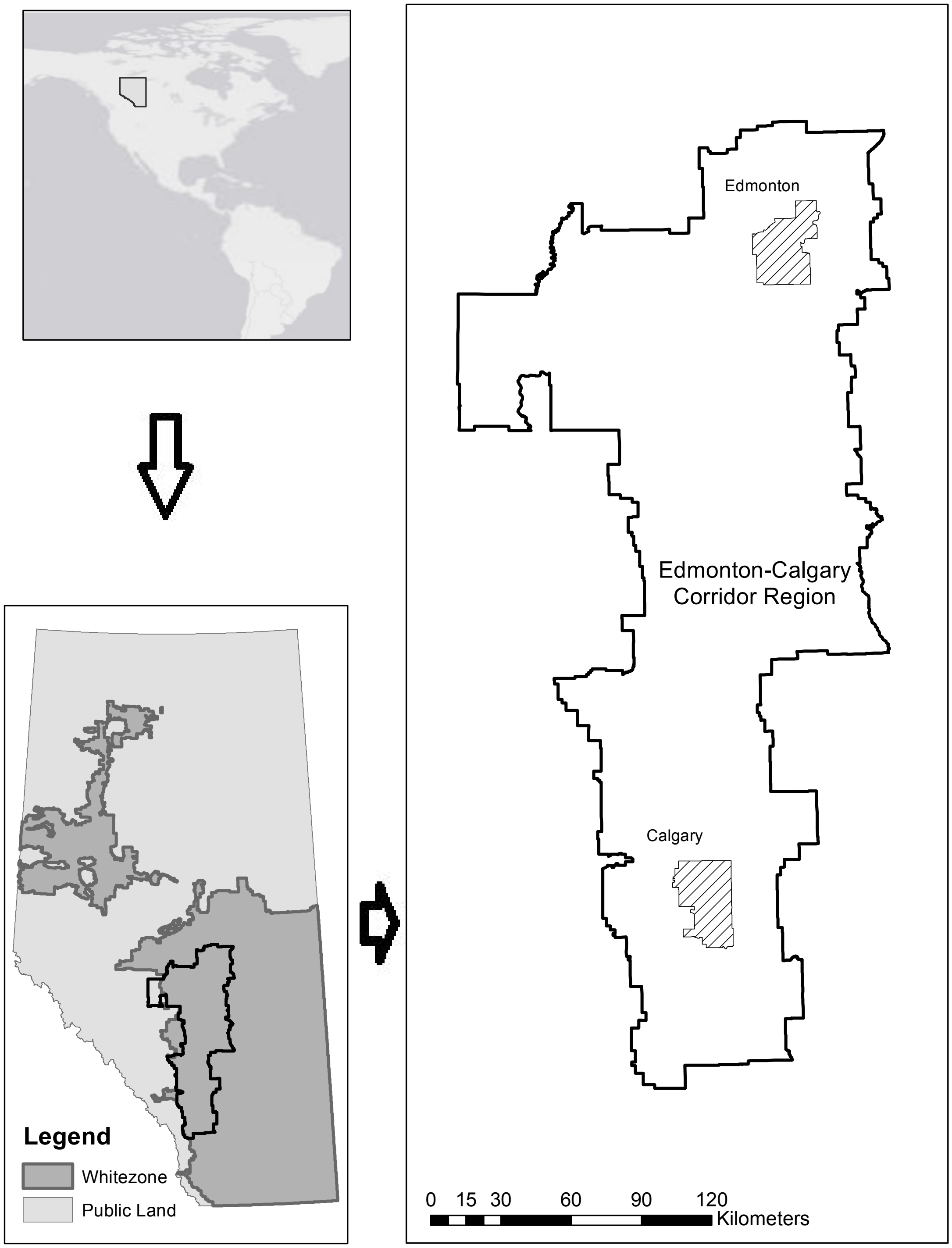

Figure 3.1 Study Area

Table 3.1 Definition of land cover classes in classified data (AAFC 2000)

Classification	Definition
Annual Cropland	Annually cultivated cropland and woody perennial crops. Includes annual field crops, vegetables, summer fallow, orchards and vineyards.
Perennial Cropland and Pasture	Periodically cultivated cropland. Includes tame grasses and other perennial crops such as alfalfa and clover grown alone or as mixtures for hay, pasture or seed.
Built-up Land	Land predominantly built-up or developed; including vegetation associated with these cover conditions. This may include road surfaces, railway surfaces, buildings and paved surfaces, urban areas, parks, industrial sites, mine structures and farmsteads.
Forested Land	Mixed coniferous and broadleaf/deciduous forests or treed areas
Shrubland	Predominantly woody vegetation of relatively low height (generally +/-2 meters)
Exposed Land	Predominately non-vegetated and non-developed. Includes: exposed lands, bare soil, snow, glacier, rock, sediments, burned areas, rubble, mines, and other naturally occurring non-vegetated surfaces.
Grassland	Predominantly native grasses and other herbaceous vegetation, may include some shrubland cover. Land used for range or native unimproved pasture may appear in this class.
Wetland	Land with a water table near/at/above soil surface for enough time to promote wetland or aquatic processes (semi-permanent or permanent wetland vegetation, including fens, bogs, swamps, sloughs, marshes etc)
Water	Water bodies (lakes, reservoirs, rivers, streams, salt water, etc...)

3.2.2 Farmland conversion

A summary of the changes in agricultural land and developed land uses from 2000 to 2012 in the Alberta Whitezone (Figure 3.1) (private land) is presented in Table 3.2. The total net loss of agricultural land to development between 2000 and 2012 was approximately 124 thousand hectares. In 2000, total developed area in Alberta was approximately 303 thousand hectares, with that value increasing to 404 thousand ha in 2012. This represents almost a 33% increase. Of the land converted to developed use over that period, nearly 80% was converted from agricultural land.

Table 3.2 Agricultural and Developed land cover/ land-use (LCLU) changes

Landcover 2000	Landcover 2012							
	Agricultural Land*	**Developed**	**Exposed**	**Forest**	**Grassland**	**Shrubland**	**Water**	**Wetlands**
	Hectare	**Hectare**	**Hectare**	**Hectare**	**Hectare**	**Hectare**	**Hectare**	**Hectare**
Agricultural Land	**13,257,414**	**123,902**	**89,414**	**237,973**	**464,365**	**622,971**	**89,800**	**115,406**
Developed	38,125	**247,765**	1,477	3,691	5,026	3,857	863	2,220
Exposed	5,287	**1,428**	141,897	1,474	2,895	2,396	1,180	1,587
Forest	285,633	**12,468**	2,994	3,299,353	7,545	77,938	6,800	41,641
Grassland	523,579	**14,090**	54,172	28,223	3,339,864	49,020	7,502	33,232
Shrubland	23,251	**2,204**	2,095	33,234	7,437	800,661	1,180	8,264
Water	5,205	**881**	11,260	8,125	2,735	5,139	453,444	110,325
Wetlands	17,573	**1,722**	1,775	28,942	8,368	9,761	39,806	706,540

* Note: Agricultural land includes both Cropland and Pasture landcover categories

Table 3.3 summarizes the agricultural land conversion by land suitability class. Due to historical advantages of settlements around high quality agricultural land, the cities that have grown and prospered within the Corridor region are doing so at the expense of agricultural land. The coinciding high quality agricultural land in this region is thus the majority of agricultural land being lost to residential, infrastructure, and associated development. Table 3.3 reveals that of the 123,902 hectares of agricultural land converted to developed from 2000 to 2012 in Alberta's Whitezone, 68.3% of it was from the two highest quality soil categories (the best cultivated farmland in Alberta).

Table 3.3 Agricultural Land Conversion by Land Suitability Rating for the Whitezone from 2000 to 2012

Land Suitability Class[a]	Converted (ha)	Percent of Total Conversion
2	42,841	34.6%
3	41,700	33.7%
4	12,150	9.8%
5	3,586	2.9%
6	3,444	2.8%
7	1,827	1.5%
9[b]	18,353	14.8%
Total	123,902	100%

[a] Land Suitability Class represents the suitability ranking of land for spring seeded agricultural crops. The highest quality land in Alberta is class 2 due to climactic limitations.
[b] LSRS Class 9 is land that is considered urban or water. Urban classification is based on urban boundaries, which has resulted in agricultural land within the boundary of Edmonton being improperly classified as 9 instead of its actual suitability level.

The primary area of agricultural conversion was the corridor region connecting and including Edmonton and Calgary (Figure 3.1). Small areas of conversion were also scattered around Grande Prairie, Lethbridge, and Medicine Hat. The 30m resolution results were aggregated at the township level (about 9300 hectares) to provide visually appropriate spatial patterns of conversion. Figure 3.2 provides a summary of the agriculture-to-developed land use changes (A) and changes of the developed area (B). The two land-use change pictures exhibit nearly identical spatial patterns. This is consistent with the results presented earlier that inferred that most newly-developed land was converted from agriculture.

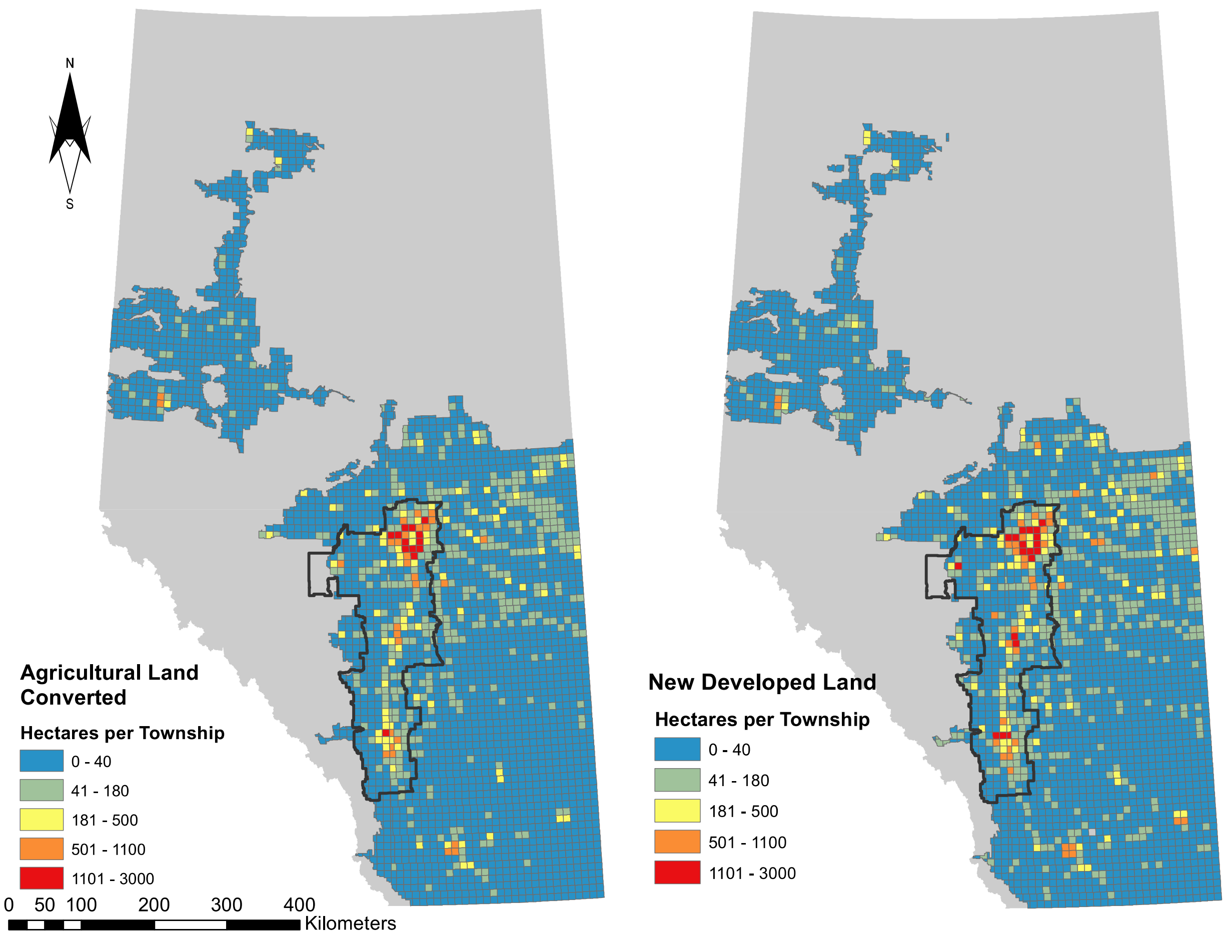

Figure 3.2 Agricultural Land Conversion (A) and New Development (B) in Alberta from 2000 to 2012

Farmland conversion displays the strong concentration within the Corridor area, with 51% of agricultural land conversion in this 6% land base of the province. Specifically, Edmonton, Calgary, Red Deer, and areas closely along Highway 2 that connects these three urban centers are experiencing the highest rate of conversion. The results can be explained by the rapid development and population growth in these areas. For example, from 2006 to 2011, the Edmonton census metropolitan area added about 125 thousand residents (12.1% increases), while the Calgary census metropolitan area grew by 12.6%, an increase of nearly 136 thousand people. These two metropolitan areas accounted for almost 75% of Alberta's total population growth. Under Alberta's current land use policy and zoning, high population growth demands more land for residential, infrastructure facilities, and recreational facilitates uses which causes increases in land values and encourages farmland to be converted into development.

3.3 The Empirical Method and Results

In land use literature, there is extensive work that breaks down the factors and processes behind land use determination. A dominant framework in its simplest form is that land use determination is driven by long-term rent maximization (Capozza and Helsley 1989). Land use change by extension is dependent on relative rent levels while taking into account the costs of conversion (Schatzki 2003). The factors influencing conversion costs and rents of agricultural use versus development uses are thus considered factors relevant to agricultural land conversion. Verburg et al. (2004) outline that these factors affecting land use include a mix of socioeconomic, biophysical and proximate variables relevant to the specific change. Modeling the conversion of agricultural land to developed uses needs to consider competing influences from population pressure (residential development value) and agricultural productivity with consideration for conversion costs. The following model incorporates these factors while controlling for a number of potential sources of bias.

A difficult compromise in any empirical analysis is the tradeoff between resolution and availability of corresponding data. In this analysis, landcover data are available at a 30m resolution, however socioeconomic data for agriculturally relevant factors are only available at the county level. While parcel level data relates to land use change decisions much more effectively, in order for the land cover changes to be matched with the population and farm census data it is necessary to aggregate it to the corresponding county level. Using this aggregate value may mask individual land use decisions, however some influences of agricultural land conversion such as municipal policy act only at the county level. Considering this reality, county level analysis allows for valuable, policy relevant insight into the nature of the drivers affecting each county.

Taking all this into consideration, the model specification below incorporates environmental and socio-economic factors into a spatially explicit framework to account for the complexity of agricultural land conversion processes.

3.3.1 Neighbour influences

As has been discussed, land use decisions (individual households and regional decision makers) are likely affected by their neighbours' land-use activities and decisions. To incorporate neighbouring land conversion activities into the modeling, a spatial lag model (Anselin 1988) might be adopted to quantify the relationship between neighbouring activities (Irwin and Geoghegan 2001). A simple equation that includes the average farmland conversion in the neighbouring areas can be expressed as

$$y_{it} = \rho \sum_{j=1}^{J} w_{ij} y_{jt} + \beta' x_{it} + \theta' z_i + e_{it} \qquad (3.1)$$

where y_{it} is the aggregate land conversion from agriculture to developed land in county i at time t; the term $\sum w_{ij} y_{jt}$ is called the spatial lag, since it represents a linear combination of agricultural land conversion values constructed from neighbouring areas observations and w_{ij} is the weight assigned to neighbour j; ρ is the corresponding spatial autoregressive coefficient that measures the degree of spatial dependence and x_{it} represents a vector of time-varying explanatory variables. All the regional-specific and time-invariant variables (such as the property tax rates, zoning regulation, distances to nearby markets) for county i are included in the vector z_i, and e is a stochastic error term. However, it may be the case that not all neighbouring spillovers effects are captured by conversion spillovers To further incorporate the spillover effects from neighbouring population growth, a spatial lag term of population density can be added to the Eq. (3.1):

$$y_{it} = \rho \sum_{j=1}^{J} w_{ij} y_{jt} + \beta' x_{it} + \gamma \sum_{j=1}^{J} w_{ij} Pop_{jt} + \theta' z_i + e_{it} \tag{3.2}$$

Population density spillover effects were considered to capture the inherent neighbouring development pressure attributed to the mobility of people. Conversely, spatial lags of farm income and irrigation changes were not included, as the theoretical impacts are only on their own land use. The inclusion of both spatially lagged conversion and population density terms raises concerns of double counting being that population density is a theoretically dominant driver of conversion. There is however strong potential that population density has spillover effects not attributed to the conversion spillover values due to commuting and the overall high mobility of Albertans. Additionally, the nonlinear relationship between conversion and population density eases concerns of multicollinearity between spatially lagged terms. An important note on the spatially lagged population density variable interpretation is that due to feedback effects between neighbours the coefficient cannot be taken as a marginal spillover effect, but may be used as an indicator of the relationships direction (Lesage and Pace 2009).

3.3.2 Omitted and/or unobserved variables

Many existing studies (e.g., Lambin et al. 2001; Verburg et al. 2004) have highlighted the complexity of land use change issues. Specifically, Lambin, Geist, and Lepers (2003) proposed a general framework for investigating land-use changes based on a comprehensive literature survey. The authors suggested that land-use changes should be modeled as a combination of five fundamental causes: pressures, opportunities, policies, vulnerability, and social organization. In empirical applications, many of these factors such as vulnerability and policy, are difficult to measure, hard to obtain, or may be measured on a different scale than the county-level census data in the current application. The correlation between these unobserved factors and explanatory variables such as population density would bias the estimation results. Many explanatory variables including property taxes, road systems, soil and climate conditions, and social norms, though vary substantially by region, they are usually time-invariant within the same area, at least in the short term. Therefore, one remedy to control for these unobserved factors is to use a first-difference model to address this source of bias. To address the unobserved time-invariant effects, we can first-difference Eq. (3.2). The new model evaluates the changes in each independent variable as factors that affect the change in the dependent variable. An advantage of this approach is that any variables that are constant through the study period drop out of the equation. As a result, the first difference approach removes factors including zoning and tax policies, environmental factors (described below), and regional preference heterogeneity, as long as these removed variables are time invariant. First-differencing the dependent variable, however, requires panel data. In this study, we have two years of land use data, which only allows us to calculate one land conversion from agriculture to developed land. Using the change in developed land ($\tilde{y}_i$) as a proxy was justified due to approximately 80% of added developed land in the study period being upon agricultural land. Visual inspection of the two maps provided in Figure 3.2 also offers evidence of the overlap. Thus, the change of the developed land was used as a proxy for farmland conversion. This, along with the first-difference of the population density and other relevant time-varying drivers were used to generate the following regression equation:

$$\Delta\tilde{y}_i = \rho\sum_{j=1}^{J} w_{ij}\Delta\tilde{y}_j + \beta^{'}\Delta x_i + \gamma\sum_{j=1}^{J} w_{ij}\Delta Pop_j + \varepsilon_i \qquad (3.3)$$

3.3.3 Model specification

Following previous studies (e.g., Veldkamp and Lambin 2001), the various explanatory variables (as discussed in Lambin, Geist, and Lepers 2003) were grouped into two broad categories: environmental and socioeconomic factors. The socioeconomic variables included are changes in population density (ΔPop), farm income ($\Delta FInc$), and cropland under irrigation ($\Delta Irrig$). Farm income is included to control for farmlands competitive ability with development pressures. Where the agricultural industry is doing well, producers are better able to compete with development projects and reduce the agricultural land converted. Irrigated cropland is included in the model to capture the effects that high conversion costs have on agricultural land use conversion processes. Irrigation has a high cost associated with its implementation; so irrigated land has an associated barrier to being developed. Another variable that affects farm profitability is an agricultural parcel's distance from city centers (von Thünen 1966). This value is however a constant measure, and is removed from the final model specification that involves differencing.

The group of environmental variables that usually affect agricultural land conversion includes elevation, slope, soil quality, and climate condition (Li, Wu and Deng 2013). All of these variables have potential to influence the profitability of agriculture, and thus the ability to compete with development values. These variables are however time-invariant, at least in a short time period. They are thus dropped out of the model under the first-differenced specification outlined in the Eq. (3.3). An additional consideration in the model specification is the potential for non-linear influences from explanatory variables. Farm income and irrigation changes have little theoretical basis for non-linear effects due to the nature of their relationships with agricultural returns. Marginal increases in agricultural returns as well as marginal increases in irrigation infrastructure investments are assumed to have linear effects in regards to the competitive ability against development returns. Varying population densities however have variable residential structural characteristics (e.g., country residential, suburban, apartment) that may have a non-linear effect on the marginal quantity of land used (McDonald 1989). Non-linearity in its simplest form can be accounted for by including the squared term (Pfaff 1999). Putting it all together, the final spatial regression model can be expressed as

$$\begin{aligned} \Delta\tilde{y}_i &= \rho\sum_{j=1}^{J} w_{ij}\Delta\tilde{y}_j + \beta_1\Delta Pop_i + \beta_2\Delta Pop_i^2 + \beta_3\Delta FInc_i + \beta_4\Delta Irrig_i \\ &+\gamma_1\sum_{j=1}^{J} w_{ij}\Delta Pop_j + \gamma_2\left(\sum_{j=2}^{J} w_{ij}\Delta Pop_j\right)^2 + \varepsilon_i \end{aligned} \qquad (3.4)$$

where $\Delta\tilde{y}_i$ is the change of developed land from 2000 to 2012 in county i. ΔPop is the change in population density, $\Delta FInc$ is the change in average farm income per hectare, and $\Delta Irrig$ is the change in the hectare of irrigated cropland from 2001 to 2011, and ε is a stochastic error term. $\sum w_{ij}\Delta\tilde{y}_j$ and $\sum w_{ij}\Delta Pop_j$ represent the average spillover effects of neighbouring land conversion and population density growths. The standard approach in most spatial regression analysis is to start with a non-spatial linear regression model, and then test whether or not the spatial lag or error model needs to be used. We follow the conventional procedure and conduct the LM test and its robust version developed by Anselin (1988) and Anselin and Bera (1998). The test results are presented in Table 3.4.

Table 3.4 Lagrangian Multiplier Test Statistics of the Global OLS Model

Test Statistic	Value	P-value
Lagrange Multiplier (lag)	26.04	0.000
Robust LM (lag)	27.86	0.000
Lagrange Multiplier (error)	0.01	0.90
Robust LM (error)	1.84	0.18

The weight matrix used is based on the threshold distance of 35 *km*.[6] Use of this distance results in the spillover effect occurring primarily in the smaller counties that occur in the Corridor region. Larger counties that are more widely distributed do not effectively have spillovers as the distance between county centroids exceeds the threshold distance. The results show strong evidence of residual spatial autocorrelation and indicate that a spatial lag model as opposed to a spatial error model is most appropriate, which is consistent with our model specification. We also conducted a bi-Moran's *I* test for changes of developed land Δy_i and changes of neighbouring population density $\sum w_{ij} \Delta Pop_j$. The results show evidence of strong spatial correlation. This provides justification of including the lagged population density term in our specification of Eq. (3.4). Descriptive statistics of the variables are presented in Table 3.5.

[6] To determine the appropriate weights matrix, a first order contiguity Queen weights matrix was compared to distance-based weights matrices. Distance based weights were tested at 5 kilometer intervals from a minimum distance of 20 *km* to a maximum of 180 km. The 35 *km* threshold was chosen on the basis of intensity of spatial correlation (the highest Z-score associated with Moran's *I* test).

Table 3.5 Descriptive Statistics

Definition of variables	Mean	Std. Dev.	Min	Max
Dependent				
Changes of developed land (ha)	1469.14	2131.77	18.68	11775.6
Independents				
Population density change (persons/km^2)	6.83	39.18	-0.22	260.00
Changes of average farm income ($/ha)	16.44	73.80	-367.86	339.36
Changes of irrigated cropland (ha)	-228.69	6677.87	-28222.0	26395.0
N=68				

3.3.4 Empirical results

Results from non-spatial linear regression (Model 1), spatial lag (Model 2), and spatial lag with lagged changes of population density (Model 3) are provided in Table 3.6 for comparison, but the discussion will be focusing on results from Model 3. The non-spatial regression model is estimated by the OLS technique and the two spatial models are estimated using the maximum likelihood method.

Of the three model results presented in Table 3.6, Model 3 is the strongest fit (R-Squared of 0.86). Diagnostic Breusch-Pagan tests for heteroskedasticity within all three models showed that the null of no homoscedasticity was not rejected, so it is not an issue needing to be addressed in any of the models. The neighbouring influence of land use is found to be highly significant and positive in both Models 2 and 3, which indicates strong spillover effects. A larger estimate within model 2 however shows that without accounting for population spillovers that are prevalent within mobile populations, the direct conversion neighbouring effects are overestimated. Both Models 2 and 3 show a strong quadratic relationship between population density and agricultural land conversion. The coefficient estimates for spatially lagged

Table 3.6 Spatial regression results, Dependent variable: change in developed land (ha, 2000 to 2012)

	Model 1	Model 2	Model 3
Variables	OLS	Spatial Lag	Spatial Lag with Poplag
ΔPop	***156.3	***125.3	***135.9
ΔPop *squared*	***-0.50	***-0.40	***-0.43
$\Delta Irrig$	-0.025	-0.02	*-0.03
$\Delta FInc$	-0.92	-1.48	-0.82
Wlag	-	***0.41	***0.16
Wpop	-	-	***305.7
Wpop squared	-	-	***-1.16
R-Squared	0.54	0.73	0.86
Breusch-Pagan	0.69	0.83	0.93

(***,**,* denote significance levels of respectively, 0.01, 0.05, 0.1)

population density changes also show a strong positive quadratic spillover relationship to agricultural land conversion. Within Model 3, the irrigation coefficient estimate was significant and negative as expected. The results indicate that an increase of 100 irrigated hectares of agricultural land will reduce conversion by 3 hectares in a given county. However, contrary to expectations, the farm income coefficient was insignificant. The result can be interpreted two ways; the first being that agricultural land values (as a function of farm income) cannot compete with residential development values at any level, so that farm income has no impact on development. It may also be that the discrete two-year nature of the data fails to capture the true changes in farm income that may be occurring in the study period.

3.4 Discussion

Overall, the results from the spatial model are consistent with expectations and intuition. In the OLS estimation, the population density coefficient and the squared term are respectively 156.3 and -0.5. When spatial dependence is controlled for in the population lagged specification, the coefficients change to 135.9 and -0.43, reflecting the importance of the spatial model approach in capturing spillover effects of land use changes. Comprehensively higher coefficients in the OLS estimation versus the two spatial lag models show that when spillover effects are not captured, the estimated effects from a county's own factors tend to be overestimated, which indicates an efficiency issue. Additionally, the conversion spillover effect in Model 2 is much higher than Model 3, which controls also for population spillover effects. This result implies that a portion of neighbour effects is due not only to direct conversion spillovers, but also to neighbouring population effects. Neighbouring populations have this impact because of the mobility of people who have recreational, commercial, and industrial demands on neighbouring counties land uses.

Consistent with this principle, neighbour's spillover effects show a strongly significant positive effect in Model 3. The coefficient estimate of 0.16 is interpreted as each hectare of agricultural land conversion that occurs in the neighbouring counties results in 0.16 hectares of conversion in that county. This neighbour impact partially captures the clustering effect of new development, primarily evident in the Edmonton to Calgary corridor area. Similarly, population density spillover effects are found to be strongly positive, but increasing at a decreasing rate. Therefore, as the population density changes of neighbouring counties increases the marginal spillover impact of each additional person per square kilometer decreases. Interpreting the coefficient estimate is difficult because of feedback effects from neighbour's conversion that create direct and indirect effects. For this reason, the spillover effect from population increases is greater than the coefficient on *Wpop.*

Both of the spatial lag effects described above display the importance of regional consideration when addressing issues of agricultural land conversion. A policy maker that considers managing their constituents own land resources and strategies in isolation from neighbours will be making inefficient decisions with potentially adverse impacts. Population spillover effects highlight the critical effect that highly mobile populations have on conversion in neighbouring counties. The long commutes that occur in quickly growing urban areas (Axisa, Newbold, and Scott 2012) coupled with increasing suburban travel (Pisarski 2006), especially in high income regions (Cervero and Murakami 2010) suggests that Alberta is very susceptible to such mobility driven spillovers. Thus strategies and policies should instead be made in conjunction with neighbours, especially in areas of high growth such as the Edmonton-Calgary Corridor. In an area such as the Corridor, an individual county experiences agricultural land conversion due to large population growth within its own borders, but substantial growth in neighbouring counties may have significant influences. If these spillover effects are not considered, policy may fall short of its goals, or it may be the case that inefficient agricultural land conversion is not minimized, but is instead diverted to a neighbour. Due to the concentration of conversion within the Edmonton to Calgary Corridor it is possible that the spillover effects are much greater within this region than the rest of the province. This potential non-stationarity is a specification issue that may need to be addressed in subsequent research.

As discussed, population density changes was found to have an increasing, but at a decreasing rate, relationship with agricultural land conversion. The interpretation of the estimates is that holding all else constant and not considering spillover effects of population an increase of 1 person per square kilometer results in 135.4 hectares of agricultural land being converted to development [$(135.9 \times 1) - (0.43 \times 1^2)$]. With larger increases in population density the marginal increase in conversion decreases until a threshold is met where an increase in population has no marginal conversion effect. This threshold is at a change in population density of 316 persons per square kilometer. The presence of this effect implies that with large increases in population there appear to be structural changes to residential development that result in less agricultural land being converted. Structural changes of this sort may be due to the economics of high-density populations, or a factor of changing social preferences with regards to urban expansion into agricultural land. It is also possible that this effect is due to non-linear marginal costs of providing infrastructure to the expanding cities of Edmonton and Calgary. This result is intuitive with densification present in the major urban centers of Edmonton and Calgary. Increases in population density within these two cities do not have an equal marginal effect on agricultural land conversion as population increases in suburban or country residential forms. Population density changes are found to be the dominating cause of agricultural land conversion, which is most likely due to the strong residential expansion occurring during the study period.

The results discussed in this paper show the dominating effect of population changes and their associated spillover effects, which as mentioned, is expected to increase province wide by another 50% in the next 28 years. Assuming that over the next 28 years, the changes are evenly distributed over time, the population within the Whitezone will increase by about 310,000 people from the year 2012 to 2017 (5 years). Using the estimated parameters from Model 3, holding all else constant while ignoring the feedback loops that neighbour effects produce, and assuming the population changes are proportionally distributed throughout the Whitezone in the same form as the study period with no government intervention, the estimated agricultural land conversion from 2012-2017 is about 65,600 hectares. Comparably the conversion estimate from the global

OLS parameter estimates is about 23,300 hectares, or about 35% of Model 3's estimate. The large disparity between these estimates illustrates the importance of controlling for spatial dependence in a model of agricultural land conversion.

3.5 Conclusions

This study has assessed agricultural land conversion to developed uses and investigated the determinants of agricultural land conversion focusing on the neighbouring impacts of land uses as well as population growth. The results show that spillover effects can be attributed to both neighbour conversion activities as well as neighbouring population growth. It becomes apparent that controlling for this spatial dependence is important for producing estimates with minimized risk of bias.

An important relevant factor not included in the spatial agricultural land conversion model is government policy and regulation. Zoning for residential uses, as well as property tax regimes have the potential to strongly impact the land use decision of the landowner. For this analysis, the first difference model controls for any heterogeneous policy that is constant through the study period, but it is possible that some zoning or tax policy may not be constant. If this were the case it would be important to include as a relevant factor. The resulting greater understanding of the effects of changing policy would be valuable for assessing the usefulness of regional based policies and growth management strategies. It may also be the case that the non-linear population growth parameter is capturing a policy response within high growth areas, which results in decreasing marginal conversion effects.

A limitation of this model is in the resolution of the outcomes due to the aggregated nature of the socioeconomic census data. Aggregation of this sort takes away the impacts that individual landowners have on conversion, which is critical to the development process. While this is a recognized limitation, it is not a weakness for the model when looking at the province level issue of conversion and will be addressed in subsequent research.

Chapter 4. Geographically Weighted Regression of Agricultural Land Conversion Drivers in Alberta

4.1 Introduction

Global land use change has accelerated in the 21st century, fuelled by rising populations and the process of urbanization. Urbanizing the growing population has increased the demand for agricultural land to produce food, while at the same time urban encroachment has removed land from production (Grimm et al. 2008). This conflicting phenomenon has resulted in substantial concern over the extent of agricultural land being converted to urban development (Cleland 2013). While it is a global issue, certain regions are subject to the brunt of agricultural land conversion pressure due to a complex mix of socioeconomic and environmental factors. The Western Canadian province of Alberta is one such region currently experiencing this issue due to brisk, energy-fueled economic and population growth.

Alberta is a large province spanning approximately 66 million hectares, about one quarter of which is under various agricultural uses. Running down the center of the highest quality agricultural land belt is the Edmonton to Calgary Corridor. While areas around small towns throughout the province are under some conversion pressures, this Corridor region where 74.2% (Statistics Canada 2011b) of the provincial population resides, is the area experiencing the majority of agricultural land conversion (Cathcart 2013). Although the entire Corridor region has undergone a similar pressure from increasing populations and associated development, differing circumstances in sub-regions has resulted in varying agricultural land conversion outcomes. The objectives of the study are to assess the regionally varying socioeconomic and environmental factor relationships to agricultural land conversion between 2000 and 2012 in the province of Alberta.

Due to the global relevance of the issue, assessments of the factors driving agricultural land conversion are prevalent in recent literature (e.g., Seto and Kaufmann 2003; Baumann et al. 2011; Li, Wu, and Deng 2014). As a guide in determining relevant factors to include, Lambin et al. (2001) state that land use of a particular parcel is determined by the response of people to economic opportunities. Therefore, in the case of agricultural land conversion, all factors affecting the relative profitability of agricultural versus residential development on land are relevant factors (Carrion-Flores and Irwin 2004). Many studies have used this framework within a variety of modeling alternatives to address the complex suite of environmental, socioeconomic, and policy factors influencing agricultural land conversion (e.g., Chomitz and Gray 1996; Irwin, Bell, and Geoghegan 2003; Chakir and Parent 2009).

To understand the conversion process and its drivers, researchers have employed a variety of spatially explicit models. These include parcel-level cellular automata (Wu and Webster 1998), parcel-level probit (Carrion-Flores and Irwin 2004), spatial lag logit (Li, Wu, and Deng 2013), and geographically weighted regression (GWR) (Luo and Wei 2009) models. All of these approaches consider the critical issue of spatial dependence in land use modeling (Anselin and Bera 1998), though they do so in different ways. The first three models account for spatial relationships arisen from unobserved spatial heterogeneity, however they do not allow for factor relationships to vary spatially. Luo and Wei's use of GWR considers the potential for non-stationary observed factors by allowing for spatial variation in the factor parameter estimates.

Analysis of agricultural land conversion previously employed a spatial lag framework with county aggregated data. The aggregated nature of this analysis provided policy relevant results for Alberta, however finer regional patterns of conversion may have been obscured. This paper makes use of high resolution, township-level data to compare spatial lag estimation to spatially varying geographically weighted regression. Results from this estimation provide useful direction regarding the underlying trends behind the pattern of agricultural land conversion across the province of Alberta. Following a section on data and methods, the third section employs a spatial lag configuration to model agricultural land conversion in Alberta from 2000 to 2012 and compares it to a standard OLS regression. A geographically weighted regression model is then developed and the results are discussed. The final section provides policy implications, avenues of potential further research and concluding remarks.

4.2 Data and Methods

4.2.1 Study Area

Alberta's country-leading average annual GDP growth of 3.7% over the past twenty years (Alberta Treasury Board and Finance 2014) has resulted in a huge population growth. The Edmonton and Calgary census metropolitan areas were the two main receiving areas for this growth, with respective 2006 to 2011 population increases (2011 population) of 12.1%(1,159,869) and 12.6%(1,214,839) (Statistics Canada 2011b). Although similar growth has occurred in these two cities, the respective population densities of 123 persons/km^2 and 238 persons/km^2 reveal a difference in urban structure. A difference such as this reflects the heterogeneity in factor relationships that most likely exists. Due to province wide growth, the study area includes the entire private land area of Alberta (Whitezone) shown in Figure 4.1. The area includes 3017 townships, which experienced a combined 123,900 hectares of agricultural land conversion from 2000 to 2012.

Figure 4.1 Study Area

4.2.2 Data

Assessment of the agricultural land conversion occurring from 2000 to 2012 was completed using pre-classified 30m landcover data for each of the years from Agriculture and Agri-Food Canada. The two landcover datasets were differenced and the agricultural land (2000) that transitioned to developed land (2012) was aggregated to the township level to be used as the dependent variable so that the value was a hectares measure of agricultural land converted to development. The township aggregation was employed because the highest resolution population and household income data are at the Dissemination Area (smallest census geographical units in Canada) level, which has an average area of 11,600 hectares, close to the township average of 8,550 hectares.

Socioeconomic data were procured from the 2011 Census of Population and Census of Agriculture, as this was the closest year to the study period. We received road network data from Geobase (2012) and spatial grain elevator data on active elevators within the study period from an associate. Land suitability rating system (LSRS) data were sourced from Alberta Agriculture and Rural Development's 2012 AGRASID 4.0 release.

4.2.3 Variables

Analysis of the factors affecting agricultural land conversion must consider the complex interactions between environmental and socioeconomic factors. Under the assumption that land use alternatives are chosen based on maximizing rents (Capozza and Helsley 1989), any factor that influences either agricultural or development returns should be included. The wide range of factors include environmental and socioeconomic aspects of the land and its users, some of which may be difficult to observe. With potential omitted unobserved variables there is concern of bias, which was previously addressed with a first differencing technique. This higher resolution analysis however seeks to provide information on the relationships of both environmental and socioeconomic factors with agricultural land conversion, so a first difference technique was not used. For this reason, GWR was used as it provides not only a method for analyzing the non-stationarity of factors, but it also allows for the identification of potential omitted variables based on regional patterns. The dependent variable used is the hectares of agricultural land converted to developed (built-up) landcover between 2000 and 2012. Table 4.1 lists the environmental and socioeconomic factors with theoretical basis for influencing the rate and spatial distribution of conversion.

4.2.3.1 Agricultural Returns

Many variables have been recognized to affect agricultural land returns in land use modeling literature. The main factors shown to be significant determinants of agricultural returns are land quality (Chakir and Parent 2009), climate (Li, Wu, and Deng 2013), and proximity to market (Carrion-Flores and Irwin 2004). To represent these factors a couple of variables are used in conjunction with an agricultural land value variable that captures heterogeneous influences of agricultural returns. This value is necessary to include due to the impact that farm type has on

Table 4.1 Variable Descriptive Statistics

Variable	Description	Mean	Std. Dev.	Min	Max
Dependent					
Conv	Hectares of agricultural land converted to development	41.1	143	0	2,742
Explanatory					
Agricultural					
LValue*	Agricultural land value in $000's/ha including value of buildings	6.1	10.3	0	170.3
HighSuit	Hectares of agricultural land within land suitability classes 2 and 3	3220	3,042	0	9,453
Dist_mkt	Kilometers from township centroid to nearest grain elevator	35.9	28	0	184
Development					
Pop_den	Population density in persons / square kilometer	13.2	111	0	2,490
Pop_den^2	Population Density Squared	12,425	199,241	0	6,201,579
Income	Household Income in $000's per household	95.2	25	43.8	346
Dist_city	Kilometers to nearest city with population >100,000	253	170	0	758
$Dist\_city^2$	Kilometers to nearest city with population >100,000 squared	92,695	122,485	0	574,651
Edmonton	Dummy variable (1= closer to Edmonton than Calgary, 0 = closer to Calgary)	0.59	0.49	0	1
N = 3017					

*Note: *LValue* captures both agricultural rents as well as premiums from future development potential. For this reason it could be included within both Agricultural and Development variable categories.

agricultural returns.

The agricultural land value (*LValue*) was derived from Census of Agriculture (2011) county level data. Included within the value are the land value and the reported value of the buildings upon the land. Plantinga and Miller (2001) outline that land value incorporates not only agricultural rents, but also the value from potential future urban development. Determining the relative nature of these two rent sources is difficult, however the model specification already includes population density as a proxy for development rents. As a result, *LValue* may be expected to have a positive relationship with conversion in areas surrounding urban centers due to the strong urban expansion pattern within the study period. County level values were adjusted to the township level by using the relative percentage of high quality agricultural land (three highest LSRS ratings) in the township versus the county it is within. Thus, townships with a higher percentage of top quality agricultural land relative to the county will have higher average agricultural capital values than the county average.

Alberta has large variability in its land quality, with the highest quality soils surrounding the corridor area connecting Edmonton and Calgary. Historical settlement in highly fertile areas has resulted in urban growth being at the expense of high quality agricultural land. Due to this, land quality may be a significant factor relating to agricultural land conversion. Climate and elevation are also considered important environmental factors (Li, Wu, Deng 2013), but are not separately included within the analysis. We incorporated these relevant factors by using the number of hectares of agricultural land in the highest two LSRS classes (*HighSuit*), which considers soil quality, climate, and other topography in its classification system.

Finally, market proximity is also considered a significant factor in determining agricultural returns (von Thünen 1966; Carrion-Flores and Irwin 2004). For the largest agricultural land use activity of annual cropping, market proximity is characterized by the distance to the nearest grain elevator. To calculate this value, the distance from the township centroid to the nearest operational elevator (*Dist_mkt*) by way of the road network was calculated.

4.2.3.2 Development Returns

For the province of Alberta, the primary source of agricultural land conversion is residential development in the form of urban expansion, country residential, and associated services (roads, utilities, etc.) (AARD 2002). Residential expansion in these various forms is driven by population growth fueled demand (Heimlich and Anderson 2001), and spatially distributed based primarily on proximity to the urban center (von Thünen 1966).

To account for the large population growth, this study selected the 2011 population density figures to account for residential pressure. Township level data was not avaliable as previously mentioned, however using dissemination area (DA) data (slightly larger on average than townships), a road density weighted value was calculated[7]. The calculation employed a weighting technique because a simple intersection method would not account for the uneven population distribution within dissemination areas. Road density was used as a weighting value as it is a reliable tool for determining the distribution of population (Glover and Simon 1975). A squared value of population density was also included to account for non-linear density effects (McDonald 1989) that may be present due to differing forms of residential development (e.g., Urban, country residential, etc.)

Distance to the urban center is another factor included in quadratic form to account for non-linear effects. Carrion-Flores and Irwin (2004) validate this form for its importance in characterizing the eventual threshold effect of the distance from urban centers. Alberta however, has two main population centers exerting residential pressure on the province. To account for these two centers, the distance value was measured as the distance from each township centroid

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[7] The calculation was performed by first intersecting the DA data with the township grid. Each portion of the DA was assigned a proportion of the DA population figure based on the proportion of the DA's area as well as the relative road density within the fragment of the DA.

to the nearest of Edmonton or Calgary by way of the road network (*Dist_city*). A dummy for townships closer to Edmonton than Calgary (*Edmonton*) was included to account for differing distance effects surrounding the two urban centers.

Alberta's strong energy extraction industry has drawn many job seekers to the province by the prospect of high incomes. These high incomes increase the ability for people to purchase property, which in turn drives housing and land prices upward (Capozza and Helsley 1989). For this reason a measure of average household income was included as a factor that influences development returns. DA level census data was intersected with the township grid and values were weighted upon area to obtain township values. A number of DA's were missing data, so a spatial interpolation method was used to approximate average values[8].

Including all of the above variables has the potential for multicollinearity issues, which in the case of GWR can cause serious bias (Fischer and Getis 2010). A correlation analysis was run to check for this issue (Table 4.2), and found that with the exception of the squared terms, no variables had any significant correlation.

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[8] For determining household income values, any township that included a section of a DA with missing data, was considered a missing data point. An areal interpolation method in ArcGIS was used to fill in missing data points. To interpolate, a rational quadratic function was used that had a lag size of 10 kilometers and 10 total lags.

Table 4.2 Correlation analysis of explanatory variables

	Pop_den	Pop_den^2	HighSuit	LValue	Income	Dist_mkt	Dist_city	Dist_city^2
Pop_den	1							
Pop_den^2	0.937	1						
HighSuit	-0.038	-0.051	1					
LValue	0.041	0.005	0.101	1				
Income	0.222	0.152	0.084	0.037	1			
Dist_mkt	-0.087	-0.058	-0.475	-0.051	-0.062	1		
Dist_city	-0.124	-0.085	-0.280	-0.135	-0.114	0.252	1	
Dist_city^2	-0.071	-0.046	-0.228	-0.107	-0.071	0.235	0.962	1

4.3 Global and Spatial Regression

4.3.1 Model Specification

Multivariate regression is a common method used for examining factors influencing land use change (Lambin, Geist, and Lepers 2003). To assess the Alberta-wide influence the factors discussed in the previous section have on agricultural land conversion the following simplified global regression equation was employed:

$$y = \alpha + \beta_i X_i + e_i \tag{4.1}$$

where y is hectares of agricultural land converted, β_i is a set of coefficients for each of the relevant X_i explanatory variables affecting agricultural and development returns and ε_i is a stochastic error term.

This classic method of analysis however has well recognized limitations in land use models due to spatial dependency within land use patterns (Anselin 1998; Brady and Irwin 2011). As addressed in the previous chapter, a common method of addressing spatial dependency is using a spatial lag equation

$$y_{it} = \rho \sum_{j=1}^{J} w_{ij} y_{jt} + \beta' x_{it} + e_{it} \tag{4.2}$$

where $\sum w_{ij} y_{jt}$ is the spatial lag term that accounts for spatial dependency and X_{it} is the a set of all explanatory variables discussed in the previous section.

A spatial lag framework accounts for spatial dependency, but this framework assumes that factor relationships are constant throughout the province. Given the high potential for non-stationarity in factor relationships (Fotheringham et al. 1998), this framework may be masking the strong variation in agricultural land conversion patterns. Geographically weighted regression assesses the potential for this heterogeneity by estimating localized regression coefficients. Preceding the localized regression, this paper first considers results from global and spatial lag models to test the efficacy of each approach in describing the process of agricultural land conversion in Alberta.

4.3.2 Global/Spatial Results

Both the global regression and the spatial lag model were estimated using the maximum likelihood procedure with the results given in Table 4.3. The goodness of fit measure shows significant improvement from the global models R-squared value of 0.49 to the spatial models 0.58. These measures imply moderately reliable goodness of fits with potential for improvement.

Table 4.3 Global/Spatial Model Estimation Results

Global Model			Spatial Lag Model		
Conv	Coefficient	P-value	Conv	Coefficient	P-value
Pop_den	***2.14	0	Pop_den	***1.92	0
Pop_den^2	***-0.001	0	Pop_den^2	***-0.001	0
LValue	***0.89	0	LValue	***0.80	0
HighSuit	0.001	0.24	HighSuit	0.001	0.23
Income	**0.19	0.01	Income	**-0.16	0.03
Dist_mkt	***-0.42	0	Dist_mkt	*-0.14	0.05
Dist_city	***-0.26	0	Dist_city	***0.13	0
$Dist\_city^2$	***0.001	0	$Dist\_city^2$	***-0.0002	0
Edmonton	***31.31	0	Edmonton	***11.00	0
constant	***34.57	0	constant	*-19.05	0.06
			Ylag	0.76	0
R-squared	*0.49*		*R-squared*	*0.58*	

(***,**,* denote significance levels of respectively, 0.01, 0.05, 0.1)

Within both of the models all of the explanatory variables were significant with the exception of the high quality land (*HighSuit*) parameter. As expected, population density had a positive non-linear relationship with conversion that was consistent in both models. The non-linear relationship reflects that with higher populations, less agricultural land is converted, consistent with urban densification (Loibl and Toetzer 2003). Agricultural land value also had a positive estimated coefficient that remained the same in both models. As expected this result reflects the development premium incorporated in agricultural land surrounding urban centers.

Proximity to market had the opposite effect then was expected. The negative coefficient shows that agricultural land close to elevators is more likely to be developed upon than land farther away. This relationship is most likely due to the coincidence of elevators within rural towns. In effect, this measure does not capture a higher return for agricultural land, but is capturing the development pressure from small urban areas.

The two models have similar results, however the household income and distance to nearest city variables change signs while remaining significant. As a result, interpreting the two variables effects is difficult to do. The previous chapter examined the marginal effect overestimation that occurs in the absence of a spatial lag in the model. This is also evident in this chapter's analysis, however the sign change as a result of the spatial lag implies that an underlying spatial effect other than spillovers may be impacting the estimation.

The positive and significant Edmonton dummy variable in both models provides more evidence of potential spatial non-stationarity. An increased conversion rate in the Edmonton area reveals a difference from the Calgary area that may be due to non-stationary factor relationships. In summary, the spatial lag results show firm explanatory power in describing the factors affecting agricultural land conversion, however spatial non-stationarity is still a significant issue. Geographically weighted regression is an appropriate approach for considering this issue and examining the spatial variation in agricultural land conversion throughout Alberta.

4.4 Geographically Weighted Regression

4.4.1 Model Specification

Geographically weighted regression (GWR) is a relatively new technique used most often to investigate unspecified spatial relationships by accounting for spatial non-stationarity (Fotheringham et al. 1998). The investigation has the ability to reveal true spatial variation in parameters based on cultural, political, or personal preference heterogeneity. Another use discussed by Fotheringham et al. is to identify potential omitted variables, which can be recognized by analysis of the coefficient estimate patterns. Based on the global and spatial lag model results, one or both of these effects may be causing the difficult interpretation of the parameter estimates.

GWR employs the basic global model, with the addition of a weighting structure and subsequent individual estimation for each sample point as developed by Fotheringham et al. (1998):

$$y_{ij} w_j = \alpha_0(u_i, v_i) + \sum_k \beta_k(u_i, v_i) X_{ijk} w_j + e_i \tag{4.3}$$

where $\alpha_0\left(u_i, v_i\right)$ and $\beta_k\left(u_i, v_i\right)$ are respectively, the constant term and coefficient estimates for variable k at location i with the coordinates u, v using sample points j that are weighted by w_j. The sample points included within the coefficient estimation for location i depend upon the weighting structure chosen. Most common of structures is the Gaussian weight (Wheeler 2014), which is a continuous function that decreases in exponential form with distance from the target estimation location:

$$w_j = \exp\left[-\left(\frac{d_{ij}}{\gamma}\right)^2\right] \tag{4.4}$$

where w_{ij} is the weight for point j in the model estimation of location i. The distance between these points is d with γ being a bandwidth value that controls the spatial relationship. Two types of bandwidths are available for use depending on the nature of the data. Adaptive bandwidth is the first one, whereby the bandwidth varies so that each localized regression contains an equal number of sample points, in contrast with the fixed bandwidth that is a constant value. For this analysis a fixed bandwidth was used due to the even sample distribution evident in the Alberta township grid (Guo et al. 2008). Determination of the optimal bandwidth value of 23.83km was completed by use of a golden bandwidth search function, which minimizes a corrected Akaike Information Criterion (cAIC) value. The corrected AIC accounts for the non-uniformity in degrees of freedom between bandwidth options, and allows for the value to be compared and the optimal bandwidth to be identified (Fotheringham et al. 2002).

4.4.2 Results

GWR estimation was completed using the same township dataset with 3017 data points that was used for the global and spatial lag models. The resulting output is a set of coefficient maps with pseudo t-statistics (Tu 2011) that show the estimates and their associated significance[9] for each sample point (Figure 4.2). While the coefficient maps show obvious spatial variation and a comparison of R-squared values (Table 4.4) reveals model improvement, a formal statistical test of non-stationarity is needed. The software used (GWR4.0), produces just such a test in an ANOVA procedure that reveals whether the GWR model is an improvement from the global regression alternative (Fotheringham et al. 2002). A F-test statistic of 7.56 was estimated, so the null of the GWR model having no improvement over the global model was rejected.

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[9] T-stats in GWR analysis are calculated based on the coefficient divided by the standard error. Standard error values are calculated using normalized residual sum of squared error values from the localized regressions (Fotheringham et al. 2002).

Table 4.4 Summary of Goodness-of-fit Measures

Model	R-Squared
Global	*0.49*
Spatial Lag	*0.58*
GWR	*0.77*

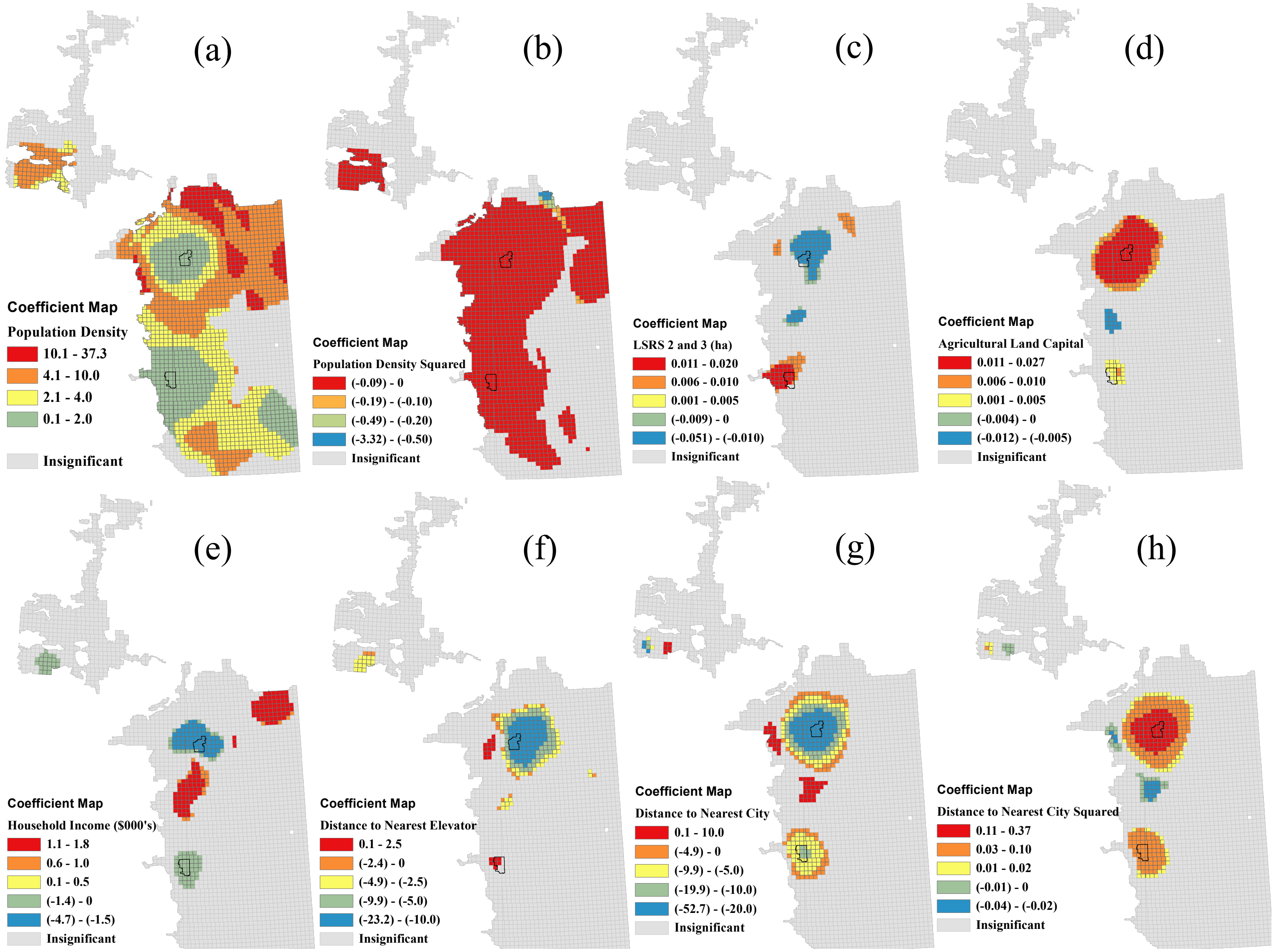

Figure 4.2 GWR coefficient maps

Estimates from the GWR model show that for all of the variables with the exception of the population density parameters, positive and negative coefficients are estimated. In addition to this strong evidence of non-stationarity, the insignificance of variables in many parts of the province implies that the global and spatial models inappropriately 'fit' a model to areas where no relationship occurs. Effectively, this analysis assists in defining an appropriate scope for agricultural land conversion analysis, which is important in the case of the diverse Albertan circumstance.

Figure 4.2a and 4.3b show non-linear population density relationships with conversion that are quite consistent with the global and spatial models. Urban areas in the Edmonton and Calgary regions had small coefficients similar to the global values, however rural areas had much larger marginal impacts from increasing population densities. Differing effects of population are intuitive to the differing availability of land for development and structure of rural residential expansion versus higher density urban structure. A closer inspection into the distribution of linear population density coefficients validates the presence of a non-linear relationship with conversion by highlighting the urban and rural marginal effect variance.

The high quality agricultural land parameter results in Figure 4.2c had large variation with significant negative estimates for the Edmonton and Red Deer regions, and positive coefficients around Calgary and two small areas outside Edmonton. Negative values imply that low quality land is preferable for development, which may be the case for the results northeast of Edmonton. This area is the Industrial heartland of the province, with substantial development for upgrading and oil processing. Contrary to residential development, this land may have been strategically placed upon lower quality agricultural land further from the city. It may also be the case that this effect is derived from land suitability classification error[10]. In the case of Calgary and the two other positive coefficient areas (towns of Onoway and Lac La Biche), high quality agricultural land coincidently occurs around the urban areas where residential expansion has occurred, which may explain the positive relationship. Appendix 4b shows that west of Calgary there is very little high quality agricultural land, and there is also little conversion occurring. However, on the other three sides of the city where there is substantial high quality land the majority of conversion occurs. This pattern provides an explanation for the positive coefficient estimates found around Calgary.

Agricultural land values map of marginal effects (Figure 4.2d) shows positive estimates surrounding Edmonton and Calgary and negative estimates in the Red Deer area. The positive

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[10] Land within city boundaries is automatically classified as 'unsuitable' for agriculture, so high quality agricultural land within the sprawling Edmonton boundary is wrongfully classified. This may also be the case for the Calgary region, however there is less total agricultural land within its boundary.

areas suggest that as expected higher land values are correlated to higher levels of conversion due to the incorporation of future development premiums. The strong relationships surrounding Edmonton and Calgary most likely are the cause for the positive global and spatial model estimates. A much larger and stronger positive effect in the Edmonton area suggests that there are far-reaching, large premiums associated with potential development of agricultural land. Conversely, negative relationships in the Red Deer area are due to the high agricultural land values pervasive in the greater area surrounding Red Deer (Appendix 4c). Within this area, high land values are less influenced by urban development premiums, but are instead most likely due to both high quality land (Appendix 4b) as well as high household incomes from Red Deer to Calgary (Appendix 4d).

The confusing change in signs of the household income parameter within the global and spatial models is addressed in the localized GWR results (Figure 4.2e). Income had a negative relationship with conversion around Edmonton, Calgary, and Grande Prairie. This may be interpreted in a number of ways, all the while considering household incomes relationship is to new conversion only occurring within the study period. One explanation is that lower relative income households were the majority of people moving to new development on the urban fringe. This can occur due to central residential areas become more desirable by high-income people as population density increases and commuting times from suburbs increase (Cervero and Murakami 2010). Lower income people moving to suburban areas due to increasing central housing prices is a phenomena recognized in literature (Loibl and Totzler 2003). Another interpretation is that higher income households demand more open space, which results in them locating in areas with little conversion activities. It may be the case that once high-income households have moved to these areas they exert pressure to reduce further conversion and preserve the open spaces surrounding them. It may also be the case however that high income households are situated in areas with little agricultural land left to develop upon, such as in the city center.

In contrast to the Edmonton and Calgary regions, the opposite result in the Red Deer and Bonnyville regions may be due to a couple of reasons. The positive relationship suggests that new development in these two urban areas may be in a form more desired by high-income residents. For example, high-income households who wish to be connected to Edmonton and Red Deer desire living in the Highway 2 corridor region. It may also be the case that opposite to Edmonton and Calgary these regions continue to have agricultural land available for conversion.

The distance to elevator estimates (Figure 4.2f) reveal a strongly negative relationship outward from the eastside of Edmonton that decreases with distance as well as a negative region around Grande Prairie. Negative values are conflicting with theory that proximity to market improves profitability. The incidence of elevators within rural towns however suggests that this variable is instead capturing the effect of conversion pressure around the towns with elevators. Small regions of positive relationships west of both Edmonton and Calgary show areas that experience substantial conversion with no immediate elevators. In terms of magnitude the positive areas have much smaller marginal distance effects then the negative terms, which indicates that the positive relationships are slight.

Distance from the nearest city coefficient estimates revealed a strong, non-linear relationship with conversion that had much larger marginal values than the global or spatial model (Figure 4.2g and 4.2h). The large, negative values especially evident in the Edmonton region and lesser so surrounding Calgary show the concentration of conversion for residential expansion within the province’s two main cities. The reversal of parameter signs from the global to the spatial model is explained by contrastingly positive estimates in the Drayton Valley and Red Deer regions. Both of these regions experienced high level of conversion, but independently of Edmonton and Calgary, which revealed localized positive values. The following discussion section takes a closer look at conversion patterns by including higher resolution coefficient assessments for areas of interest, alongside interpretation of the evident spatial relationships.

4.4.3 Discussion

Variation in patterns of urban growth and development into agricultural land are well explained by GWR. An especially important consideration is the lack of significance of localized models in the northwest and southeast portion of the province. For this reason, fitting a global model to the study area is inappropriate. The Edmonton to Calgary Corridor region, where the majority of conversion has taken place is intuitively so, the region with the most pronounced relationships with conversion factors. Differences in Edmonton and Calgary coefficient patterns are of particular interest due to the similar regional populations, but disparity in conversion rates. In the previous section, figure 4.2a showed differing marginal effects between urban and rural population densities, but no variation was apparent between Edmonton and Calgary. A closer look at this variation in population density marginal effects is necessary.

Figure 4.3 illustrates the strong difference in population density effects between the Edmonton census metropolitan area (CMA) and the Calgary CMA. Both of the CMA's have coefficients lower than the global model estimates, however the Edmonton region has the lower values. This result reveals that an extensive area surrounding the city and extending west has medium density residential areas. Marginal impacts of population in the Calgary CMA are higher than Edmonton throughout, which suggests that the residential structure in the area around Calgary is lower density (given the lower conversion rates than Edmonton). An explanation for this outcome is that urban fringe development around Edmonton has higher associated population densities (and lower marginal conversion effects) than the country residential development causing the lower conversion rate in the Calgary CMA. Another good descriptor of residential expansion patterns is the relationship of household incomes to conversion.

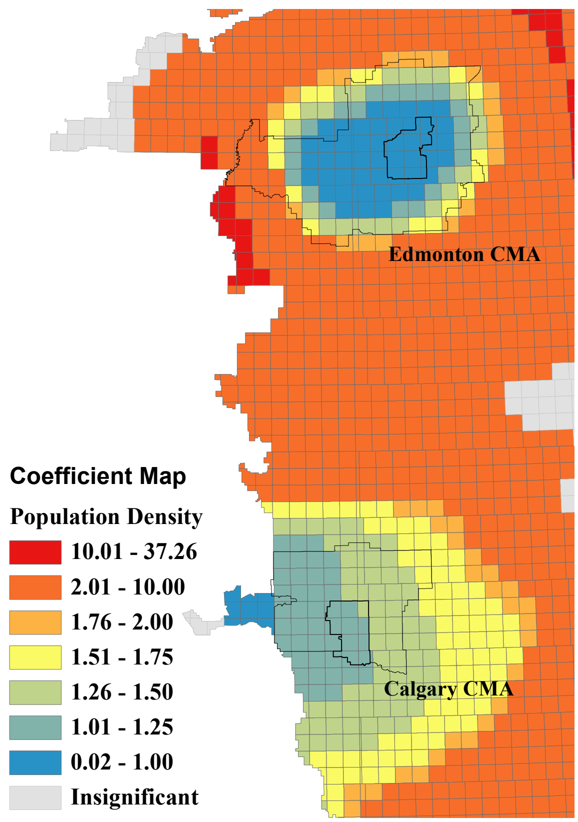

Figure 4.3 Population density coefficient estimates in the Edmonton to Calgary Corridor

Household income was found in the previous section to have a negative relationship with conversion within the mature cities of Edmonton and Calgary. Higher detail coefficients shown in Figure 4.4 show that Edmonton had much greater negative estimates than Calgary. This relationship may however be misleading due to the high incomes in central parts of each city that have no agricultural land available for conversion. A stronger presence of this effect in the Edmonton area reflects the large urban footprint of the city and its surrounding cities. It may also

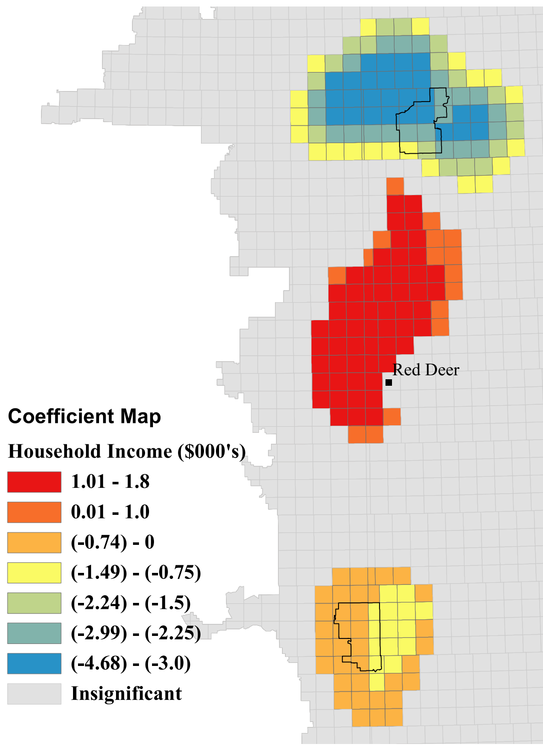

Figure 4.4 Household income coefficient estimates in the Edmonton to Calgary Corridor

be the case that the Edmonton area has less central economic activity than Calgary, which allows high-income people to live far out in areas with little conversion activities and commute to work that is closer than the downtown core. The structure of residential development occurring around both urban centers is also illustrated in the coefficients for the distance to urban center variable.

The estimates for marginal effects of distance in the city regions were negative as expected due to the main source of conversion being residential development on the urban fringe. Once again, the cities of Edmonton and Calgary had different coefficient estimates, which imply a difference in urban structure (Figure 4.5). Edmonton's large negative values and extensive area of significance may be interpreted that conversion is extensive throughout a large surrounding area. Similarly, Calgary has decreasing conversion with increasing distance from the city center, but the extent of conversion is much more limited. This critical difference reiterates that the residential sprawl into agricultural land is substantially more extensive in the Edmonton region then the Calgary area despite Calgary's higher population.

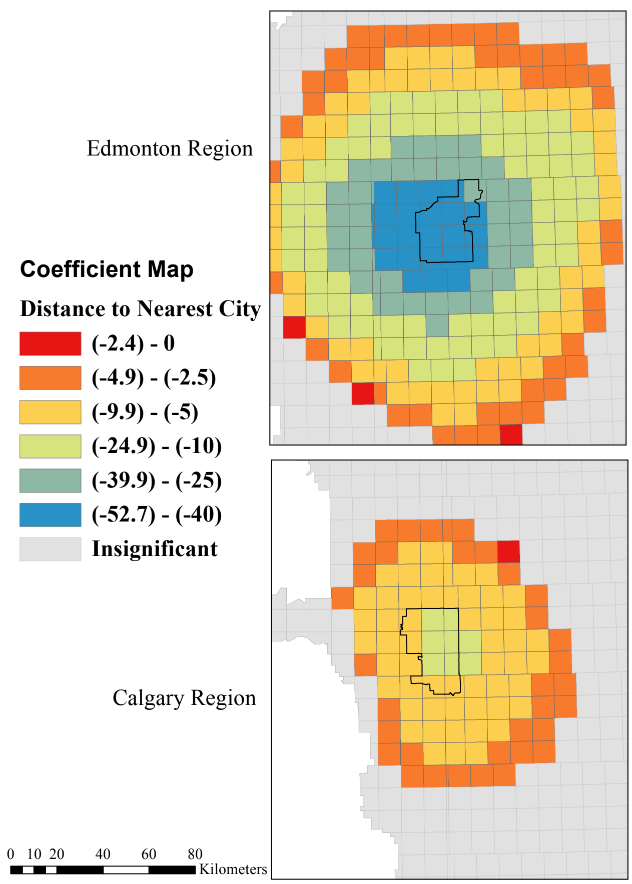

Figure 4.5 Distance to Edmonton and Calgary coefficient estimates

4.5 Concluding Remarks

The analysis in this chapter assisted in developing an in-depth perspective of agricultural land conversion patterns throughout Alberta. Employing recent advancements in remote sensing capabilities, both a global OLS and a spatial lag model were developed to understand the relationships of conversion to a number of relevant environmental and socioeconomic factors. These models were then compared and improved upon by a localized regression model and explored in detail. Large spatial variation in parameters revealed key differences in agricultural land conversion between rural and urban areas, as well as between the two main cities of Edmonton and Calgary.

The global and spatial models had all significant parameter estimates except for the high quality land variable. A strong positive non-linear relationship to population density revealed a difference in residential structure dependent on density, where high-density areas resulted in significant marginal reduction of conversion. Household income and distance to the city switched signs from the global to the spatial model, which implies more complex underlying spatial relationships that need to be addressed with a more localized approach.

Geographically weighted regression provided this approach, and was found to have a significant improvement in goodness-of-fit from the global and spatial models. Localized coefficients revealed that due to the concentration of conversion in the Edmonton-Calgary corridor, many other parts of the province had no significant relationship. This outcome implies that fitting a global regression model to a large, diverse area such as Alberta is an inappropriate method. Furthermore, localized parameter estimates showed significant spatial variation between the two major population centers of Edmonton and Calgary.

Differences in the Edmonton and Calgary region's respective conversion rates were explored in the context of a few aspects of urban structure. Lower population density and large negative distance estimates surrounding Edmonton implies a more extensive suburban growth relative to Calgary. Additionally, the large negative household income effect around Edmonton reaffirms the larger footprint of Edmonton and its surrounding cities.

GWR provides improved analysis of factors affecting conversion over global models, which delivers direction for further analysis of anomalous patterns of agricultural land conversion. Interpreting parameter estimates is difficult to do with only the data provided, but requires a more in-depth consideration of local circumstances. A difference in conversion patterns between Edmonton and Calgary is an area of study needing to involve many factors. While this chapter considers many factors, other important underlying considerations such as political structure and cultural preferences have potentially significant influence. Further research may delve into these factors to provide policy recommendations on managing undesired agricultural land conversion.

Chapter 5. Conclusion

Analysis of landcover data from 2000 to 2012 revealed a number of substantial agricultural land use changes. Foremost of these were agricultural intensification on high quality land and agricultural land conversion to development, which were also focused on high quality land within the Edmonton to Calgary Corridor region. Investigation of county level drivers revealed strong spillover effects in addition to positive, non-linear population effects on conversion. However, the subsequent localized analysis of factors showed that strong spatial variation in the effects of factors influencing conversion exists within the province. The following section discusses the implications of these findings and possible research extensions.

5.1 Policy Implications

The results from Chapter 2 inform policymakers within Alberta of the extent of agricultural land conversion as well as the quality of the land being lost. The total provincial loss of agricultural land to development was small (0.8%); however within the Capital Region, the proportion lost to development was much higher at 4.3%. This concentration of conversion within rural municipalities surrounding the major urban centers reveals the potential for targeted policy to reduce undesired conversion. Additionally, the form of conversion occurring from 2000 to 2012 was identified by the fragmentation analysis. The unexpected decrease in fragmentation revealed that conversion has occurred on land already fragmented in the urban fringe and suburban areas, and agriculture consolidation surpassed fragmentation in the rural areas. The former situation directs policy to the initial issue of country residential sourced fragmentation that precedes full agricultural land conversion. Policymakers wishing to reduce conversion will have to also consider small-scale country residential expansion that may follow this period of infill conversion.

The spatial model results in Chapter 3 will help direct policy makers to the drivers influencing the extent and distribution of conversion. Region-varying population density effects indicate that the presence of dense urban growth significantly reduces conversion effects. This effect suggests that the use of densification strategies to reduce the marginal conversion impact of anticipated future population growth might be desirable in certain areas. Additionally, spillover effects from both neighbouring population growth and farmland conversion have significant conversion effects. This result indicates the critical need for regional policy to target the reduction of conversion. Without regional coordination, individual county efforts to reduce conversion may only transfer to their neighbours or be offset by neighbouring municipality policy actions. This consideration is important for the development of the Alberta Land Use Framework's mandated regional plans.

The regional variations in factors influencing agricultural land conversion assessed in Chapter 4 provided further direction on localized urban expansion patterns. Strong variation in the marginal impacts of population density and distance to the urban center revealed that the Edmonton region had substantially more extensive suburban sprawl into agricultural land than Calgary. This difference outlines the opportunity for Edmonton regional policy makers to observe and compare with the Calgary circumstances, and potentially to learn from its development strategy.

5.2 Further Research

Landcover change analysis revealed that many agriculturally relevant land use changes occurred from 2000 to 2012. The analysis into the distribution of these changes provides strong direction for further research analyzing the consequences of a variety of land use changes. Another suitable research extension would be determining the effect that fragmenting agricultural land has on the conversion likelihood. The descriptive results outlined in this study give direction for many potential follow-up research analyzing Alberta's agricultural land use trends.

As previously mentioned in the localized regression discussion, Edmonton may want to learn from Calgary's development strategy by considering certain aspects influencing the structure of development. However, for an approach to be developed to accomplish this, a comprehensive analysis of the policies, political circumstances, and cultural influences within the two cities would need to be performed. Further research into these influences on conversion would provide valuable policy direction for Edmonton as well as other Canadian cities. GWR results also pointed to a number of other factors related to agricultural land conversion that would be useful to address locally. The stark difference in the sign of the household income parameter estimates from Red Deer to Edmonton and Calgary, which supports the Environmental Kuznets Curve hypothesis, should be investigated in greater detail.

A limitation within the GWR analysis was identified through the household income coefficient estimates. The townships within central areas of Edmonton and Calgary do not have any available agricultural land for conversion within the study period. High-income households in these central areas may have resulted in negative coefficient estimates, which may be misleading. For this reason, further research into drivers of conversion may counter this issue by using the percentage of land converted as the dependent variable in these models.

Two other limitations in this thesis analysis are the restricted resolution and the two-period nature of the landcover data. Higher resolution landcover data would be useful in assessing the fragmentation and small-scale conversion that might have been missed by the 30m data used. In future research, more observation years may be incorporated to allow for fixed effects and panel methods of analysis to be employed to increase the robustness of these models.

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Appendix 1. Landcover Changes Matrix for the Whitezone (Private Land) of Alberta: 2000 to 2012

Landcover 2000	Landcover 2012 Cropland**		Developed		Exposed		Forest		Grassland		Pasture		Shrubland		Water		Wetland		Total	
	Hectare	%*	Hectare	%	Hectare	%	Hectare	%	Hectare	%	Hectare	%	Hectare	%	Hectare	%	Hectare	%	Hectare	%
Cropland	7,434,881	29.11	66,775	0.26	59,884	0.23	52,280	0.2	122,934	0.48	1,015,484	3.98	154,711	0.61	38,766	0.15	41,818	0.16	8,987,533	35.19
Developed	28,169	0.11	247,765	0.97	1,477	0.01	3,691	0.01	5,026	0.02	9,956	0.04	3,857	0.02	863	0	2,220	0.01	303,026	1.19
Exposed	3,712	0.01	1,428	0.01	141,897	0.56	1,474	0.01	2,895	0.01	1,575	0.01	2,396	0.01	1,180	0	1,587	0.01	158,145	0.62
Forest	185,440	0.73	12,468	0.05	2,994	0.01	3,299,353	12.92	7,545	0.03	100,193	0.39	77,938	0.31	6,800	0.03	41,641	0.16	3,734,371	14.62
Grassland	323,945	1.27	14,090	0.06	54,172	0.21	28,223	0.11	3,339,864	13.08	199,635	0.78	49,020	0.19	7,502	0.03	33,232	0.13	4,049,683	15.86
Pasture	2,394,787	9.38	57,127	0.22	29,531	0.12	185,693	0.73	341,431	1.34	2,412,262	9.45	468,259	1.83	51,035	0.2	73,588	0.29	6,013,712	23.55
Shrubland	13,368	0.05	2,204	0.01	2,095	0.01	33,234	0.13	7,437	0.03	9,883	0.04	800,661	3.14	1,180	0	8,264	0.03	878,325	3.44
Water	3,325	0.01	881	0	11,260	0.04	8,125	0.03	2,735	0.01	1,880	0.01	5,139	0.02	453,444	1.78	110,325	0.43	597,114	2.34
Wetland	9,792	0.04	1,722	0.01	1,775	0.01	28,942	0.11	8,368	0.03	7,781	0.03	9,761	0.04	39,806	0.16	706,540	2.77	814,486	3.19
Total	10,397,418	40.72	404,461	1.58	305,084	1.19	3,641,015	14.26	3,838,234	15.03	3,758,649	14.72	1,571,743	6.15	600,577	2.35	1,019,215	3.99	25,536,396	100

* The percentage of total landcover

**Agricultural land includes both Cropland and Pasture landcover categories

Appendix 2. Summary Landcover Change Table for the Whitezone of Alberta (2000-2012)

	Cropland	Developed	Exposed	Forest	Grassland	Pasture	Shrubland	Water	Wetland	Total	Agricultural Land*
Landcover 2000 (Hectares)	8,987,533	303,026	158,145	3,734,371	4,049,683	6,013,712	878,325	597,114	814,486	25,536,396	15,001,246
2000 (%)	35.19	1.19	0.62	14.62	15.86	23.55	3.44	2.34	3.19	100.00	58.74
Landcover 2012 (Hectares)	10,397,418	404,461	305,084	3,641,015	3,838,234	3,758,649	1,571,743	600,577	1,019,215	25,536,396	14,156,067
2012 (%)	40.72	1.58	1.19	14.26	15.03	14.72	6.15	2.35	3.99	100.00	55.43
Net Change	1,409,884	101,436	146,939	-93,356	-211,449	-2255063	693,417	3,463	204,729	0	-845,179
Change as % of Total Land	5.52	0.40	0.58	-0.37	-0.83	-8.83	2.72	0.01	0.80	0.00	-3.31
Change as % of Own Class	15.69	33.47	92.91	-2.50	-5.22	-37.50	78.95	0.58	25.14	0.00	-5.63

*Agricultural Land Is the combination of Cropland and Pasture Land

Appendix 3. Landcover Change Matrix for the Capital Region of Alberta: 2000-2012

Landcover 2000	Landcover 2012: Cropland**		Developed		Exposed		Forest		Grassland		Pasture		Shrubland		Water		Wetland		Total	
	Hectare	%*	Hectare	%	Hectare	%	Hectare	%	Hectare	%	Hectare	%	Hectare	%	Hectare	%	Hectare	%	Hectare	%
Cropland	355,777	28.35	20,470	1.63	1,596	0.13	4290	0.34	67	0.01	39,833	3.17	7,609	0.61	5,993	0.48	2,195	0.17	437,829	34.88
Developed	3,381	0.27	70,583	5.62	121	0.01	979	0.08	11	0	704	0.06	474	0.04	341	0.03	268	0.02	76,863	6.12
Exposed	258	0.02	199	0.02	5,197	0.41	32	0	0	0	97	0.01	47	0	84	0.01	51	0	5,964	0.48
Forest	18,276	1.46	3,653	0.29	131	0.01	153173	12.2	48	0	6,256	0.5	4,002	0.32	1,190	0.09	2,447	0.19	189,175	15.07
Grassland	1,541	0.12	145	0.01	11	0	528	0.04	1,681	0.13	1,217	0.1	294	0.02	75	0.01	193	0.02	5,684	0.45
Pasture	225,977	18	17,787	1.42	1,497	0.12	22391	1.78	546	0.04	143,863	11.46	29,144	2.32	12,468	0.99	4,340	0.35	458,012	36.49
Shrubland	439	0.04	131	0.01	17	0	597	0.05	13	0	185	0.01	12,389	0.99	67	0.01	114	0.01	13,953	1.11
Water	156	0.01	257	0.02	205	0.02	806	0.06	7	0	63	0.01	99	0.01	31,794	2.53	6,974	0.56	40,361	3.22
Wetland	548	0.04	263	0.02	55	0	1420	0.11	15	0	177	0.01	304	0.02	2,482	0.2	22,001	1.75	27,266	2.17
Total	606,353	48.31	113,488	9.04	8,830	0.7	184214	14.68	2,389	0.19	192,396	15.33	54,361	4.33	54,493	4.34	38,583	3.07	1,255,107	100

* The percentage of total landcover

**Agricultural land includes both Cropland and Pasture landcover categories

Appendix 4. Spatial data descriptive statistics