**Investigating the Spatial Effects of Agricultural Land Abandonment and Expansion**

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***Selected Paper prepared for presentation at the 2016 Agricultural & Applied Economics Association Annual Meeting, Boston, Massachusetts, July 31-August 2***

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**Abstract**

This study investigates the agricultural land abandonment and agricultural land expansion in the case of the Edmonton-Calgary Corridor, Canada. Using remote sensing data from 2000 to 2012, we include environmental and socio-economic factors to explore the drivers of land use conversions between agriculture and natural land. This research also adopts spatial techniques to allow for spatial effects from neighboring areas' land-use activities. Key results from this study include: (1) higher land suitability for agriculture is negatively associated with agricultural land abandonment; (2) road density contributes to land use conversions between agriculture and natural land; and (3) land-use activities and decisions have strong spatial effects on neighboring regions, and the incorporation of spatial interactions can result in less biased results. In addition, an investigation of bidirectional land transitions helps in better understanding the associated gains and losses of agriculture and natural land.

**Keywords**: agricultural land abandonment; agricultural land expansion; spatial effect; spatial regression model

## 1. Introduction

Land use and land cover changes (LULCCs) have been identified as a worldwide trend through their interactions with climate, ecosystem, biodiversity, and human activities (IGBP, 1999; Martínez et al., 2011; van Doorn and Bakker, 2007). In LULCC studies, the conversion of agricultural land has received considerable attention (Beilin et al., 2014; Díaz et al., 2011; Zhang et al., 2014). While losses of agricultural land to developed uses have been widely discussed (Francis et al., 2012; Irwin and Bockstael, 2007), recent literature has started to pay more attention to the issue of land use transitions between agriculture and natural land bases that mainly refer to agricultural land abandonment (i.e., the conversion of agriculture to natural land) and agricultural land expansion (i.e., natural land conversion to agriculture) (Baumann et al., 2011; Claassen et al., 2008; Gellrich et al., 2007; McGranahan et al., 2015).

Both agricultural land abandonment and agricultural land expansion have been found to be related to a variety of environmental and ecological consequences. Positive impacts from agricultural land abandonment include the stabilization of soils and carbon sequestration (Laiolo et al., 2004; Tasser et al., 2003), while negative influences are the gradual loss of landscape complexity and a higher risk of natural disasters (Bielsa et al., 2005; Serra et al., 2008). For the case of agricultural land expansion, the loss of natural land to agriculture leads to reductions in biodiversity and landscape complexity, rise in flood probability and the emergence of desertification (Flez and Lahousse, 2004; Izquierdo and Grau, 2009; Monteiro et al., 2011). The shifts between agriculture and natural land therefore lead to a key question of what has been gained or lost due to the bi-directional transitions.

Given the increasing research focus on the transitions between agriculture and natural land, a mix of biophysical, ecological, economic and social factors that drive agricultural land abandonment and agricultural land expansion have been identified. Environmental factors primarily include land quality or capability (Lubowski et al., 2008; Monteiro et al., 2011), precipitation and temperature (Cabanillas et al., 2012; Marti’nez et al., 2011) and elevation or altitude (Nahuelhual et al., 2012; Trincsi et al., 2014). In specific, land quality or capability acts as a proxy for land’s suitability for agricultural uses, and land with higher quality or capability is considered to be more likely to remain in agricultural uses (Di’az et al., 2011). In contrast, impacts from elevation, precipitation and temperature may present more mixed effects, varying from region to region (Alix-Garcia et al., 2012; Hatna and Bakker, 2011). However, recognizing the importance of the above environmental constraints does not preclude socio-economic factors from influencing landowners' decisions regarding land uses. Rather, factors associated with human activities are often deemed more direct drivers of LULCCs. According to previous research, population density (Marti'nez et al., 2011) and agricultural land prices (Alix-Garcia et al., 2012; Li et al., 2013; Serra et al., 2008) are regarded as the main socio-economic factors that impact agricultural land-use decisions. Road density is another underlying driver that affects land-use decisions, as it can be viewed as a measurement of market connectedness and accessibility, which is positively associated with urban proximity and better infrastructure (Guiling et al., 2009; Jiang et al., 2012).

Recent literature on LULCCs has indicated that spatial distributions of the landscape are endogenously determined, and neighborhoods' land-use decisions may strongly affect the focal land use and land cover changes (Irwin and Bockstael, 2002). Taking agricultural land abandonment as an example, farmland abandonment may lead to the fragmentation of agricultural land bases, which in turn may discourage the nearby agricultural businesses due to inability to obtain sufficient contiguous farmland to enjoy economies of scale in the future (Gellrich et al., 2007). Another aspect that explains the spatial interaction comes from the similarity of biophysical and socio-economic conditions within certain regions (Monteiro et al., 2011). Ignoring spatial interactions may lead to biased estimates, which may in turn lead to misleading implications and policy recommendations. Therefore, scholars have begun to consider spatial interactions in the empirical analysis of land use changes to resolve the bias caused by spatial dependence (Chomitz and Tomas, 2003; Hansen and Naughton, 2013).

Although previous studies have incorporated elaborate discussions of agricultural land abandonment and expansion (see van Vliet et al., 2015), the majority of these cases were reported in Europe, the United States and South America (e.g., Di'az et al., 2011; Izquierdo and Grau, 2009; Munroe et al., 2013). Few studies have explored the context of Canada, especially the prairie region where agricultural land conversions have occurred extensively. Furthermore, no empirical work in the field of agricultural land abandonment and expansion has included spatial interactions to allow for spatial effects from neighboring areas' land use conversions. In this study, we implement a spatial regression analysis of both agricultural land abandonment and expansion in the Edmonton-Calgary Corridor of Alberta to better understand the spatial, environmental, and socioeconomic factors that drive such land-use conversions. We contribute to the current literature by quantifying both agricultural land abandonment and agricultural land expansion to investigate underlying mechanisms from a more nuanced perspective. We further adopt three spatial regression models (i.e., spatial autoregressive model, spatial error model and spatial autocorrelation model), as opposed to the classic linear regression model using ordinary least squares (OLS), to investigate more detailed drivers of agricultural land conversions incorporating spatial effects.

## 2. Study Area, Data and Methods

### *2.1 Study area*

The Edmonton-Calgary Corridor lies in the province of Alberta and has become one of the top urbanized areas in Canada (Statistics Canada, 2002). The ECC region spans an area of around four million *ha* and encompasses the two largest cities (Edmonton in the north and Calgary in the south) in the province. According to the census, the capital city of Edmonton had a metropolitan population of around 0.8 million (City of Edmonton, 2012), and the city of Calgary had an estimated population of 1.1 million (City of Calgary, 2012) in 2012. The Queen Elizabeth II Highway (also referred to as Highway 2) connects the 12 surrounding counties, which runs through the region from north to south like a central spine (Figure 1).

[Figure 1 is about here]

Agriculture has a long history spanning more than a century in the province, and Alberta has become the third largest producer and exporter of agri-food products in Canada (Government of Alberta, 2014). Although the ECC region only covers about 6% of the total province area, it has about a quarter of the province's best land that is suitable for agricultural uses. As Alberta has experienced substantial economic and population growth in recent years and is expected to continue the developing trend, the province's agricultural land bases, especially those in the ECC area, have been largely challenged by the expansion of residential, recreational and industrial areas. During 2000-2012, approximately 62,500 *ha* of land within the ECC region were converted to developed uses. Of all the land converted to development, about 83% came from agricultural land bases. Furthermore, almost 90% of the land converted from agriculture to developed uses was of high-quality soil.[1]

The Government of Alberta has been paying particular attention to land-use issues and policies to support a healthy environment, diverse communities, and a thriving economy, which involves extensive planning and collaboration among municipalities. A document called the *Land Use Framework* (LUF) was established in 2008 to serve as a blueprint to align provincial and local initiatives for policies such as land-use patterns. One of the key strategies designed to improve land-use decisions is the call to define seven regions within the province and to develop a regional plan for each of these regions. In addition, a healthy economy as well as ecosystems and environment were identified as main desired outcomes in the document. Specifically, the use and enjoyment of land and natural sources as well as the protection of land, air, water and biodiversity were highlighted.

*2.2 Data*

All the dependent and explanatory variables were aggregated to the Alberta Township System (ATS) level, which is a comparatively fine lattice network that divides the whole province into a so-called "township" that is about 9.7 × 9.7 *km* in size (or 9,400 *ha*). We conducted the analyses at the township level as many existing land-use and environmental studies and reports in Alberta are based on the ATS system (Alberta Geological Survey, 2015; Qiu et al., 2015), so it can facilitate results comparisons and policy recommendations.

The 30-meter resolution land use raster images for 2000 and 2012 were provided by the Agriculture Agri-Food Canada (AAFC). The 2000 image contains 11 different land-use classes, including Annual Crops, Hay and Pasture, Developed (or Built-Up), Water, Barren, Shrubland, Wetland, Grassland, Coniferous Trees, Deciduous Trees and Mixed Trees. The 2012 image has nearly 40 land use classes comprising the last ten classes and detailed crop type classifications (e.g., wheat, canola, corn). To better compare across datasets, we processed the data into nine land use and land cover classes: Annual Crops, Developed (or Built-Up), Exposed, Forests, Grassland, Hay and Pasture, Shrubland, Water, and Wetland. In our analysis, we mainly focused on two land use conversions: agricultural land abandonment

[1] These numbers were calculated based on the land cover and soil suitability data obtained from Agriculture and Agri-Food Canada (AAFC) and Alberta Agriculture and Rural Development (ARD).

(i.e., conversion from agriculture to natural land) and agricultural land expansion (i.e., conversion from natural land to agriculture). Agriculture was comprised of annual crops and pasture, and natural land consisted of grassland and shrubland. The hectares of both conversion cases were calculated at the township level, serving as dependent variables.

Township-level historical weather data were from the Alberta Agriculture and Rural Development (ARD). We computed the 13-year average values of daily mean temperature and accumulative precipitation for the growing season (April through September). The 1-km resolution elevation raster data was released by the Commission for Environmental Cooperation (CEC). Elevation at the township level was computed by the weighted mean in the area. Land suitability or capability for agricultural uses was generated based on the Land Suitability Rating System (LSRS) provided by ARD. The LSRS is Canada's nationwide, 7-class (Class 1 to Class 7) evaluating system to determine the suitability of land for agricultural uses. The rating criteria not only consider soil type and soil quality, but also take into account measurable factors, such as weather conditions and topography. Class 1 is the highest suitability classification across Canada. Given Alberta's relatively arid climate and severe winter, the province's highest quality land for the production of annual crops is classified under Class 2 and Class 3, which indicates no significant limitation other than weather conditions. We calculated the proportion of land with suitability ratings of 2 or 3 within each township, and a larger value means that the land is more suitable for agricultural land uses.

In addition to the four environmental variables described above, we generated other three socio-economic factors. Road density was used to account for transportation costs and market accessibility levels. Road network raster data for 2012 were provided by AltaLIS Ltd. The lengths of roads for each township were added and then divided by the respective township area. The population in the province is censused and released by Statistics Canada every five years. Since there is no record for 2012, we used the 2011 census data to approximate the population in 2012. In 2011, there were 3,629,380 residents across the whole province. We derived the township-level population densities for the ECC region based on road-density weights. This practice mimics real conditions to a great extent, since densely populated areas are usually associated with high road density. We computed agricultural land value for each township based on the market values of agricultural land transactions obtained from ARD. The original land value was provided at the county level for each land suitability class. For each township, we calculated the proportion of land in each land suitability class, and then multiplied this proportion by the initial agricultural land value for each class within the respective county.

Descriptions of all these explanatory variables are presented in Table 1.

[Table 1 is about here]

*2.3 Econometric Models*

To investigate the influences of environmental and socio-economic factors on both agricultural land abandonment and expansion incorporating the spatial effects, we adopted three spatial models in this article. The OLS model is also presented for comparison purposes. For the model specification, we start with a classic linear model using OLS as follows:

$$y_i = \alpha + \sum_{p=1}^{P} x_{ip}\beta_p + \varepsilon_i \tag{1}$$

where $y_i$ is the values of land use conversions (i.e., agricultural land abandonment and expansion) at the township *i* (unit in 1,000 *ha*); $x_i$ is a vector of environmental and socio-economic factors in the same township, including daily mean temperature in the growing season (unit in *°C*), accumulative precipitation in the growing season (unit in 1,000 *mm*), elevation (unit in *km*), proportion of land with suitability ratings of 2 or 3 (unit in *%*), road density (unit in *m/ha*), population density (unit in *person/ha*), and agricultural land value (1,000 *CAD$/ha*); $\varepsilon_i$ is an *i.i.d.* unobserved error term. If $\varepsilon_i \sim N(0, \sigma_i^2 I)$, then OLS estimators from Equation (1) are unbiased.

A corresponding spatial autoregressive model (SAR), also known as a spatial lag model, is presented in Equation (2):

$$y_i = \alpha + \sum_{p=1}^{P} x_{ip}\beta_p + \rho \sum_{i \neq j}^{J} w_{ij} y_j + \varepsilon_i \tag{2}$$

where the spatial lag, $\sum_{i \neq j}^{J} w_{ij} y_j$ is the weighted average of the neighboring township's land use conversion. We are particularly interested in $\rho$, which is the spatial autoregressive coefficient that measures the overall spatial effects. The coefficient $\rho$ describes the land use conversion in a township that is influenced by its neighboring townships.

Next, a spatial error model (SEM) which allows for spatial dependence in unobserved factors can be expressed as in Equations (3) and (4):

$$y_i = \alpha + \sum_{p=1}^{P} x_{ip}\beta_p + \varepsilon_i \tag{3}$$

$$\varepsilon_i = \lambda \sum_{i \neq j}^{J} w_{ij}\varepsilon_j + \mu_i \tag{4}$$

where $\sum_{i \neq j}^{J} w_{ij}\varepsilon_j$ is the weighted average of the other township's residuals. The spatial error coefficient, $\lambda$, captures and quantifies the inherent similarity (when $\lambda$ > 0) or dissimilarity (when $\lambda$ < 0) of unobserved factors that affect neighboring townships' land-use decisions.

Finally, we estimate a spatial autocorrelation model (SAC), also known as a spatial mix model, that includes both spatial lag and spatial error effects as follows:

$$y_i = \alpha + \sum_{p=1}^{P} x_{ip}\beta_p + \rho \sum_{i \neq j}^{J} w_{ij}y_j + \varepsilon_i \tag{5}$$

$$\varepsilon_i = \lambda \sum_{i \neq j}^{J} w_{ij}\varepsilon_j + \mu_i \tag{6}$$

where if $\lambda = 0$ and $\rho \neq 0$, the SAC model reduces to an SAR model; if $\rho = 0$ and $\lambda \neq 0$, it leads to an SEM model; and if $\lambda = 0$ and $\rho = 0$, it simplifies to a non-spatial linear regression model.

The weight matrix used for all three spatial models was based on queen contiguity. The queen contiguity defines neighbors (i.e., townships in this study) as polygons that share a point and/or length of border. Queen contiguity is less stringent than rook contiguity, which defines neighbors as those who share a border of the same length. Contiguity-based weighting matrices have been widely used in land use and land cover changes research (Caldas et al., 2007; Hansen and Naughton, 2013; Walker et al., 2000). We chose queen contiguity over rook and distance-based weight matrices based primarily on intuition and goodness-of-fit. For a comprehensive discussion of weight matrices, we refer readers to Anselin (1988) and the reference therein.

## 3. Results

### *3.1 Descriptive results*

Table 2 shows the changes of agriculture and natural land from 2000 to 2012 in the ECC. The net change of agricultural land in the ECC between 2000 and 2012 was a loss of about 179 thousand *ha*, which was a result of total loss of approximately 1.1 million *ha* and a total gain of 0.94 million *ha*. Meanwhile for the natural land in the same time period, the net change was a gain of nearly 54 thousand *ha*, with a total gain of 175 thousand *ha* and total loss of 121 thousand *ha*. In terms of transitions between agriculture and natural land, approximately 151 thousand *ha* of agricultural land was abandoned to natural land and about 91.5 thousand *ha* of agricultural land expanded onto natural land. This led to a total loss of agricultural land to natural land of about 60 thousand *ha*.

[Table 2 is about here]

While the above statistical summary provides the general trend of land use and land cover changes, maps at the township level can demonstrate a more detailed view of land-use transitions. Figure 2 shows the hectares of agricultural land abandonment (left) and agricultural land expansion (right). As we can see, agricultural land abandonment primarily occurred in the peripheral regions in the ECC, with counties to the west (i.e., Parkland County) and east (i.e., Strathcona County) of Edmonton, Foothills County to the south of Calgary most evident. These counties are home to several provincial parks and have implemented proactive strategies to conserve land in its natural state in recent years (EALT, 2014; Parkland County, 2014). Such transitions might reasonably be expected, as most of these lands are surrounding existing water and wetland systems and have been designated as conservation buffers under the land-use strategy, *Growing Forward,* of the Capital Region (Capital Region Board, 2009). Another document by Land Wise Inc. (2013) mentioned the conversion of cultivated annual cropland to native perennial cover in the Parkland region for conservation purposes. In addition to wild land preservation, abandonment of marginal agricultural land also reflects the unprofitability of certain production practices.

For agricultural land expansion, Rocky View (the county surrounding Calgary) and Mountain View County demonstrated themselves as “hotspots,” especially the western part of both counties. The *Agricultural Context Study* by the Rocky View municipal district mentioned that the soils in the western portions of the county are classified as having low to very severe limitations for agricultural crop production (Rocky View Municipal District, 2009). These soils are often vegetated with permanent or native pasture and may be used to support livestock and wildlife grazing. In addition, these regions have some of the few existing irrigation infrastructures in the ECC, which also create a localized advantage and secure water source for agricultural activities. Thus, not surprisingly, we observe that a large amount of marginal lands in this area were brought into agricultural production since 2000. The motivation behind this transition is straightforward. On the one hand, the ECC is experiencing large losses of prime agricultural land around Edmonton and Calgary as well as areas along Highway 2 due to urbanization, and the ECC lost substantial farmland due to conservation (and other purposes) in the northeast region. On the other hand, farming has become relatively more profitable in recent years, especially since the 2006/2007 world food crisis and agricultural commodity prices have remained high.

[Figure 2 is about here]

*3.2 Empirical results*

The standard approach in most spatial analyses is to begin with a non-spatial linear regression model using OLS, and then test whether or not spatial effects exist. If so, spatial models such as the spatial error and/or lag model can be further considered. We followed the conventional process developed by Anselin et al. (1996) and conducted Lagrange Multiplier (LM) tests, including the robust LM tests for comparison. Results from the LM tests are presented in Table 3, which indicate very strong evidence of spatial effects. Table 4 presents the empirical results of both agricultural land abandonment and expansion.

[Tables 3 is about here]

First, we consider the OLS results. For agricultural land abandonment, the coefficients of all environmental drivers, such as land suitability, elevation, growing season temperature, and precipitation, are statistically significant. In specific, if land is of higher quality or more suitable for agricultural uses, it is less likely to be abandoned to natural uses and tends to remain in agricultural production. These findings are consistent with Alix-Garcis et al. (2012) and Li et al. (2013). On the other hand, growing season temperature and precipitation are, counterintuitively, positively correlated with agricultural land abandonment. This is not a surprising result because the regions (Foothills County and western part of Red Deer County) with a large amount of farmland abandonment are located within the area of highest precipitation and temperatures (ALI, 2014). Although these regions have high temperatures and sufficient rainfall, the dominant land is rocky and mountainous with agricultural suitability classes of 5-7. With respect to the socio-economic factors, road density imposes a negative impact on agricultural land abandonment, with a significant coefficient estimate of -0.008. This outcome is consistent with other studies (Alix-Garcia et al., 2012; Li et al., 2013) and intuition as well. Higher road density reflects a lower transportation cost and thus makes agricultural products more convenient for consumers and markets to access. For the case of agricultural land expansion, it seems that only environmental impacts matter. Although land suitability and temperature play the same role as in agricultural land abandonment, the effects are comparatively smaller.

We next consider the results by taking spatial effects into account, incorporating a spatially lagged dependent variable (as the SAR model), a spatial error variable (as the SEM model) as well as both spatial lag and spatial error (as the SAC model). For agricultural land abandonment, the SAR model is superior considering both the pseudo $R^2$ and the significance of the spatial coefficient. We thus focus on the discussion based on the SAR model. First, taking the lagged dependent variable into account improves the overall fitness of the model with the pseudo $R^2$ of 0.62, relative to the adjusted $R^2$ of 0.20 in OLS. Results suggest strong spatial effects brought by neighboring townships regarding agricultural land abandonment, as the estimate for the spatial lag variable, $\rho$, is positive and significant. This indicates that if the mean agricultural land abandonment in all neighboring areas increases by 1 *ha*, on average it will result in an additional 0.65 *ha* of agricultural land being abandoned to natural land in the focal township. This finding is not surprising in terms of land-use practices. In reality, landowners often manage the agricultural land in small parcels; however, the implementation of land-use policies (e.g., taxes, bylaws, planning) usually covers the whole county or city. Therefore, land-use decisions are often influenced by nearby land-use activities and often simultaneously influenced by common factors such as taxes and bylaws within the same municipal area. Regarding agricultural land expansion, both spatial lags and errors are significant. The spatial lag effects indicate that a piece of natural land is more likely to be brought into agricultural production if its surrounding areas are experiencing conversions to farmland uses. This is consistent with reality and intuition. For one thing, to enjoy economies of scale in the near future, existing farms will seek expansion into nearby contiguous areas. Therefore, if there is already natural land converted to agricultural uses in a certain place, the natural land in nearby areas is more likely to be converted in the near future. The spatial error effects may come from unobserved factors such as the spatial distribution of certain wildlife habitats.

[Tables 4 is about here]

## 4. Discussion and Conclusion

Researchers and policymakers are often interested in exploring the gains and losses associated with agricultural land conversions. One hot aspect is the benefit-cost analysis of urbanization of agricultural land (e.g., Baumann et al., 2011). Meanwhile, interests and concerns regarding agricultural land abandonment have increased in recent decades (e.g., Alix-Garcia et al., 2012; Beilin et al., 2014; Prishchepov et al., 2013). However, existing literature on farmland abandonment usually does not explore the opposite conversion (i.e., bringing natural land into agricultural uses), which often occurs simultaneously in the same study area. Investigation of both types of transitions will help to better understand the situation and the associated gains and losses: not only the economic viability of the agricultural industry, but also the environmental sustainability. An investigation of the switching transitions may also help evaluate the current environmental conservation programs as they may produce spillover effects and encourage developing native grassland into agricultural production in other non-targeted areas.

In this study, we find both types of land use conversions occurred substantially in the study area from 2000 to 2012. Agricultural land abandonments were most evident in regions such as Parkland County and Strathcona County, as these two counties have implemented active strategies to conserve land in its natural status. In addition, the 2003 outbreak of BSE (also known as mad cow disease) caused a great number of cattle farms to go bankrupt and further encouraged abandonment of their pastureland. Agricultural land expansions from natural land bases were more active in the west of Rocky View and Mountain View Counties.

Agricultural land had a net loss of 60 thousand *ha* from grassland and shrubland. However, this does not necessarily indicate a gain from the preservation of wild land/environment perspective. Accompanied by the gains in the northeastern regions, the ECC region lost a significant amount of native grassland and shrubland in the southwestern areas. These lands have been developed into agricultural uses and have caused serious ecological and environmental losses, such as further degradation of the soil, the land loss and the fragmentation of ecological habitats for certain wild animals like bison, deer and moose which are typical in the study area (Prairie Conservation Forum, 2006). The negative environmental consequences are likely to continue as these converted agricultural lands will induce pressure on the nearby open lands and wild animals due to spatial effects.

Finally, this study adopts the spatial regression models as tools to investigate the drivers of land use conversions. Land-use activities and decisions have strong spatial effects on neighboring areas. Incorporating the spatial interactions can generate less biased results and provide more effective policy/decision recommendations. Spatial regression models can be used to empirically examine the magnitude and statistical significance of spatial effects, which should be of particularly use in public policy evaluation and development.

**Acknowledgements**: The authors thank the Alberta Land Institute (ALI) for financially supporting this research, and Xiaofeng Ruan for data assistance.

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**Table 1. Detailed Descriptions of Explanatory Variables at the Township Level (n=245)**

| Explanatory Variables | Description | Mean | S.D. | Min. | Max. |
|---|---|---|---|---|---|
| Environmental factors | | | | | |
| Precipitation | Growing season cumulative precipitation (1,000 mm) | 0.36 | 0.04 | 0.28 | 0.48 |
| Temperature | Growing season daily mean temperature (°C) | 11.44 | 0.69 | 8.79 | 12.93 |
| Elevation | Elevation (km) | 764.27 | 0.69 | 0.61 | 1.40 |
| Land Suitability | Proportion of land with suitability ratings of 2 or 3 | 0.73 | 0.31 | 0 | 1 |
| Socio-economic factors | | | | | |
| Population Density | Population density (person/ha) | 0.71 | 2.81 | 0.01 | 24.90 |
| Road Density | Road density (m/ha) | 13.14 | 14.42 | 1.50 | 115.90 |
| Land Value | Agricultural land value (1,000 CAD$/ha) | 3.76 | 1.92 | 0 | 6.87 |

**Table 2. Land Use and Land Cover Changes (LULCC) in the Edmonton-Calgary Corridor: 2000-2012**

| | Developed | Agricultural Land | Natural Land | Others | Total Land |
|---|---|---|---|---|---|
| LULCC_2000 (ha) | 158,941 | 2,665,735 | 289,659 | 849,537 | 3,963,872 |
| LULCC_2000 (% of total land) | 4.01 | 67.25 | 7.31 | 21.43 | 100.00 |
| LULCC_2012 (ha) | 221,477 | 2,487,227 | 334,150 | 931,018 | 3,963,872 |
| LULCC_2012 (% of total land) | 5.59 | 62.75 | 8.68 | 22.98 | 100.00 |
| Net Change (ha) | 62,536 | -178,508 | 44,491 | 81,481 | 0 |
| Net Change (% of total land) | 1.58 | -4.50 | 1.12 | 2.06 | 0.00 |

**Table 3. Lagrange Multiplier (LM) Tests for Spatial Dependence**

| | Agricultural Land Abandonment[a] | | | Agricultural Land Expansion[b] | | |
|---|---|---|---|---|---|---|
| | LM (lag) | LM (error) | LM (SAC) | LM (lag) | LM (error) | LM (SAC) |
| Statistic | 400.004 | 401.719 | 413.245 | 61.358 | 67.595 | 69.526 |
| (P-value) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) |
| Robust Statistic | 11.525 | 13.240 | - | 1.932 | 8.168 | - |
| (P-value) | (0.001) | (0.000) | | (0.165) | (0.004) | |

[a]: The weight matrix is based on Queen Contiguity, order 1.

[b]: The weight matrix is based on Queen Contiguity, order 3.

**Table 4. Regression Results from OLS, SAR, SEM and SAC Models (n=435)**

| Variables | Agricultural Land Abandonment[a] | | | | Agricultural Land Expansion[b] | | | |
|---|---|---|---|---|---|---|---|---|
| | OLS | SAR | SEM | SAC | OLS | SAR | SEM | SAC |
| Constant | -3.639*** | -2.117*** | -1.852* | -2.106*** | -1.864** | -1.075 | -2.256*** | -0.896 |
| | (0.707) | (0.601) | (1.102) | (0.569) | (0.761) | (0.735) | (0.861) | (0.635) |
| Land Suitability | -0.460*** | -0.255*** | -0.295*** | -0.254*** | -0.334*** | -0.225*** | -0.193*** | -0.241*** |
| | (0.062) | (0.063) | (0.065) | (0.063) | (0.067) | (0.068) | (0.066) | (0.074) |
| Elevation | 0.369** | 0.256** | 0.368 | 0.266** | 1.660*** | 0.546 | 1.711*** | 0.430 |
| | (0.160) | (0.115) | (0.322) | (0.104) | (0.172) | (0.336) | (0.281) | (0.329) |
| Temperature | 0.267*** | 0.165*** | 0.181*** | 0.168*** | 0.133*** | 0.088* | 0.133** | 0.080* |
| | (0.047) | (0.040) | (0.068) | (0.039) | (0.051) | (0.048) | (0.054) | (0.044) |
| Precipitation | 2.684*** | 0.852 | 0.211 | 0.736 | -1.894*** | -0.455 | -1.199 | -0.369 |
| | (0.512) | (0.542) | (0.941) | (0.509) | (0.551) | (0.637) | (0.768) | (0.591) |
| Road Density | -0.008*** | -0.004* | -0.007*** | -0.005** | -0.002 | -0.004 | -0.003 | -0.004 |
| | (0.003) | (0.002) | (0.002) | (0.002) | (0.003) | (0.003) | (0.003) | (0.003) |
| Population Density | 0.008 | 0.000 | 0.009 | 0.002 | -0.016 | -0.007 | -0.006 | -0.008 |
| | (0.016) | (0.012) | (0.011) | (0.012) | (0.018) | (0.016) | (0.016) | (0.016) |
| Land Value | 0.021** | 0.011* | -0.007 | 0.010* | -0.005 | -0.005 | -0.005 | -0.005 |
| | (0.009) | (0.007) | (0.009) | (0.006) | (0.009) | (0.008) | (0.009) | (0.007) |
| $\rho$ | - | 0.668*** | - | 0.671*** | - | 0.793*** | - | 0.842*** |
| | | (0.148) | | (0.143) | | (0.211) | | (0.202) |
| $\lambda$ | - | - | 0.797*** | -0.158 | - | - | 0.659*** | 0.679*** |
| | | | (0.030) | (0.197) | | | (0.060) | (0.185) |
| Adj. $R^2$ | 0.196 | - | - | 0.596 | 0.356 | - | - | - |
| Pseudo $R^2$ | - | 0.621 | 0.150 | 0.622 | - | 0.448 | 0.356 | 0.447 |

[a]: The weight matrix is based on Queen Contiguity, Order 1.

[b]: The weight matrix is based on Queen Contiguity, Order 3.

***, **, and * indicate the coefficient is significant at 1%, 5%, and 10% level, respectively. Standard errors are in parentheses.

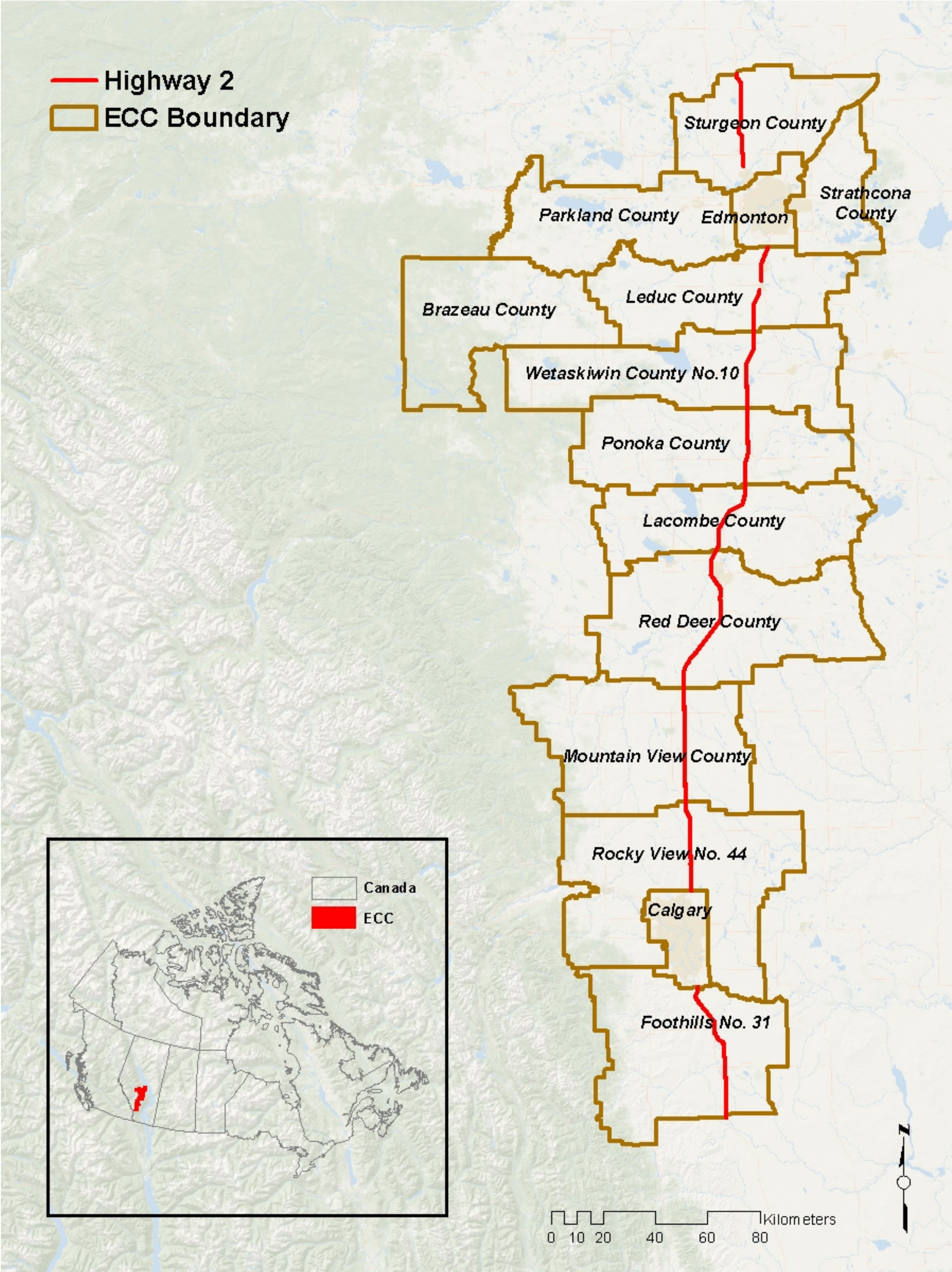


**Figure 1. Geographic Location of the Edmonton-Calgary Corridor (ECC), Canada**

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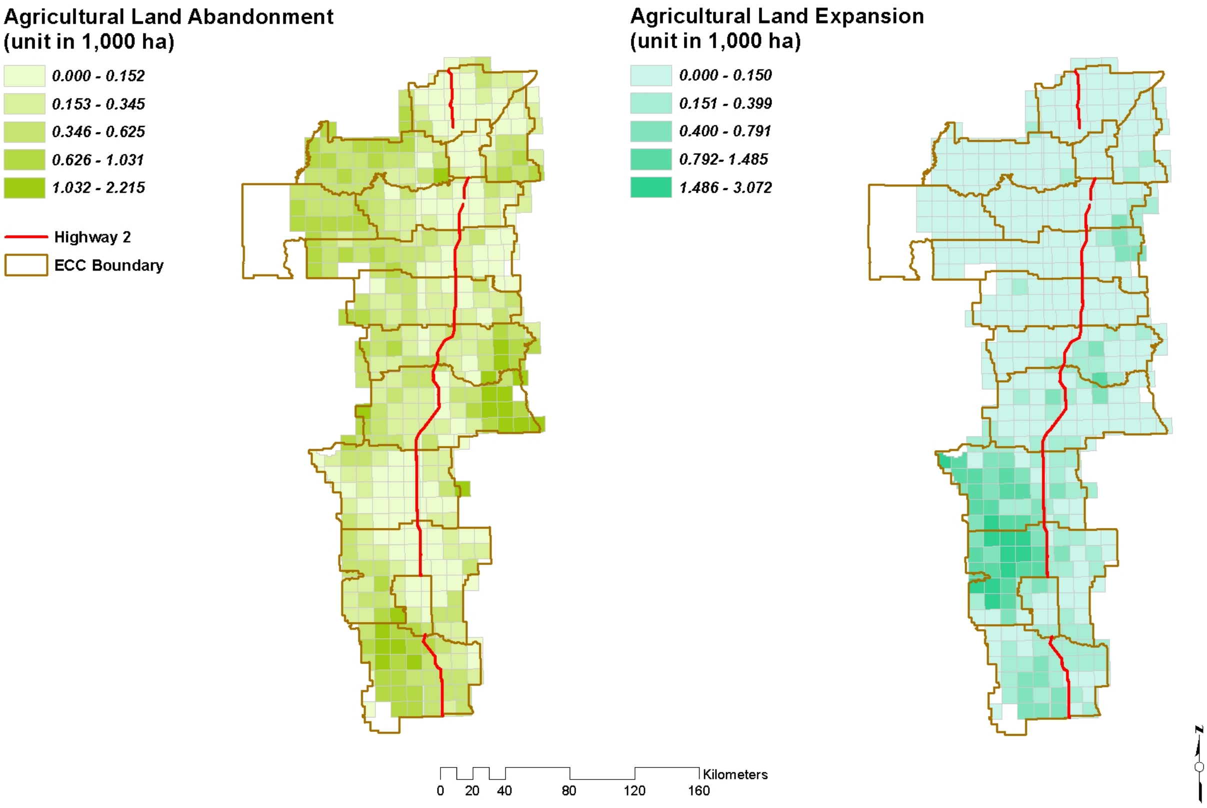


**Figure 2. Hectares of Agricultural Land Abandonment (Left) and Agricultural Land Expansion (Right) in the ECC during 2000-2012**