THE Prairie Climate Resilience PROJECT

Indicators of Adaptive Capacity to Climate Change for Agriculture in the Prairie Region of Canada

Comparison with Field Observations

July 2009

- **Darren Swanson,** IISD
- **Jim Hiley,** Agriculture and Agri-food Canada (AAFC)
- **Henry David Venema,** IISD
- **Richard Grosshans,** IISD

IISD Working Paper for

Adaptation as Resilience Building: A policy study of climate change vulnerability and adaptation on the Canadian Prairies

Project funded by

- The Climate Change Impacts and Adaptation Directorate, Natural Resources Canada

iisd International Institute for Sustainable Development / Institut international du développement durable

Published by the International Institute for Sustainable Development

The International Institute for Sustainable Development contributes to sustainable development by advancing policy recommendations on international trade and investment, economic policy, climate change, measurement and assessment, and natural resources management. Through the Internet, we report on international negotiations and share knowledge gained through collaborative projects with global partners, resulting in more rigorous research, capacity building in developing countries and better dialogue between North and South.

IISD's vision is better living for all—sustainably; its mission is to champion innovation, enabling societies to live sustainably. IISD is registered as a charitable organization in Canada and has 501(c)(3) status in the U.S. IISD receives core operating support from the Government of Canada, provided through the Canadian International Development Agency (CIDA), the International Development Research Centre (IDRC) and Environment Canada; and from the Province of Manitoba. The institute receives project funding from numerous governments inside and outside Canada, United Nations agencies, foundations and the private sector.

International Institute for Sustainable Development
161 Portage Avenue East, 6th Floor
Winnipeg, Manitoba, Canada
R3B 0Y4
Tel: +1 (204) 958–7700
Fax: +1 (204) 958–7710
Email: info@iisd.ca
Website: www.iisd.org

Indicators of Adaptive Capacity to Climate Change for Agriculture in the Prairie Region of Canada: Comparison with Field Observations

Darren Swanson, International Institute for Sustainable Development (IISD)
Jim Hiley, Prairie Farm Rehabilitation Administration (PFRA)
Henry David Venema, IISD
Richard Grosshans, IISD

This paper can be downloaded from www.iisd.org/pdf/2007/climate_adaptive_cap.pdf

This document may be cited as:

Swanson, D.A., J.C. Hiley, H.D. Venema and R. Grosshans, 2009. Indicators of Adaptive Capacity to Climate Change for Agriculture in the Prairie Region of Canada: Comparison with Field Observations. Working Paper for the Prairie Climate Resilience Project, Winnipeg: International Institute for Sustainable Development.

Table of Contents

Summary

Indicators of the capacity of agriculture producers and agro-ecosystems to adapt to climate stress were developed for 53 Census Divisions across Canada's Prairie region using Statistics Canada sources. The purpose of the indicators were: to guide the selection of sites for farm-level study of adaptive behaviours; to help illuminate the types of policy interventions that support farm- and community-level adaptation to climate variability and change; and to help identify Prairie locations that are most vulnerable to future climate change.

The indicators were grouped according to six determinants of adaptive capacity put forth by Smit *et al.* (2001), namely: (1) economic resources; (2) technology; (3) infrastructure; (4) information, skills and management; (5) institutions and networks; and (6) equity. For each determinant, up to four specific indicators were developed and then normalized to create an overall aggregated index for each determinant. An overall index for each Census Division was compiled based on the average of the determinant indices.

The spatial results revealed that Census Divisions exhibiting the highest adaptive capacity were clustered near large urban centres in three main corridors (shown below). From east to west, these areas were: Winnipeg, extending west to Brandon and south to the U.S. border; Saskatoon, extending southeast to Regina and then west to the Alberta border; and Calgary, extending southeast to the U.S. border. Census Divisions exhibiting the lowest relative adaptive capacity were typically along the northern boundaries of the Prairie agricultural region.

These adaptive capacity indicators and indices provide a new perspective on available statistics and information. With conceptual guidance from the literature we were able to develop 20 representative indicators across six determinants using existing data and information. The most notable exception was the lack of data describing surface and groundwater resources across the Prairies, a serious data gap for understanding vulnerability to future climate change. Our analysis highlights the importance of multiple perspectives in assessing adaptive capacity—all six of the determinants were reflected in field interviews with producers and producer organizations across the Prairies and 15 of the 24 indicator categories developed were representative of what producers felt were important with respect to their capacity to adapt. The results also underscore the importance of on-the-ground study in understanding vulnerability and adaptive capacity of producers and agro-ecosystems across the Prairies—of the 15 indicator categories developed, only nine were supported by indicators that accurately represented what producers reported as being important to them in aiding their adaptive responses. Adaptive capacity is not a one-size-fits-all concept, and as such the use of aggregated statistics to inform the design of policies to facilitate adaptive capacity to future climate change must be augmented by site-specific research and deliberation.

Introduction

In 2003, the Canadian Senate Committee on Agriculture and Forestry published a report entitled *Climate Change: We Are at Risk*, concluding that Canadian agriculture will be affected by climate change, and noting that more frequent and widespread drought on the Prairies is expected. Schindler and Donahue (2006) warned of an impending water crisis in Canada's western Prairie Provinces. They stated that "in the near future climate warming, via its effects on glaciers, snowpacks, and evaporation, will combine with cyclic drought and rapidly increasing human activity in the western Prairie Provinces to cause a crisis in water quantity and quality with far-reaching implications." This is a troubling scenario for the future of Canada given that the Prairies are home to 80 per cent of the farms in Canada (AAFC, 2005) and produce almost half of the total value of Canadian agri-food exports (AAFC, 2008).

A consistent theme in the vulnerability and adaptation literature, both in Canada and internationally, is that our current knowledge of the nature of adaptive capacity is insufficient to reliably predict adaptation responses or devise appropriate government policy frameworks (Smit *et al.*, 2001). Furthermore, implementing successful adaptation policies will require a better understanding of the potential options, existing farm-level risk-management practices and government decision-making frameworks (Smit and Skinner, 2002).

The Prairie Climate Resilience Project, a collaborative initiative of the International Institute for Sustainable Development (IISD), Agricultre and Agri-food Canada (AAFC) and the University of Manitoba, endeavours to help address this policy gap. The hypothesis for this research is that rural agro-ecosystems with high exposure to historic climatic stress differ in their vulnerability and resilience, and by investigating these differences we can learn valuable lessons about the nature of adaptive capacity.

The Prairie region stretches across 550,000 square kilometres, spanning the provinces of Manitoba, Saskatchewan and Alberta. Prairie agriculture takes place in a physiographic region known as the Western Interior Basin that includes the northern portion of the Great Plains "ecozone," essentially the northern geographic limit of arable land in North America.

The earliest scientific assessment of the Prairie region challenged the notion of viable agriculture in the area. From 1857 to 1860, Captain John Palliser led a group of scientists into what was then a virtually unknown (to Europeans) territory. They identified a triangular region, roughly bounded by the lines adjoining Cartwright, Manitoba; Lloydminster, Saskatchewan; and Calgary, Alberta as the Palliser Triangle (Figure 1); an arid region unsuitable for settled cultivation. Palliser warned that disaster would befall those who tried to settle the region. A subsequent Prairie expedition by Henry Youle Hind in 1858–1859 had a more modest geographic scope and reached different conclusions from those of Palliser.

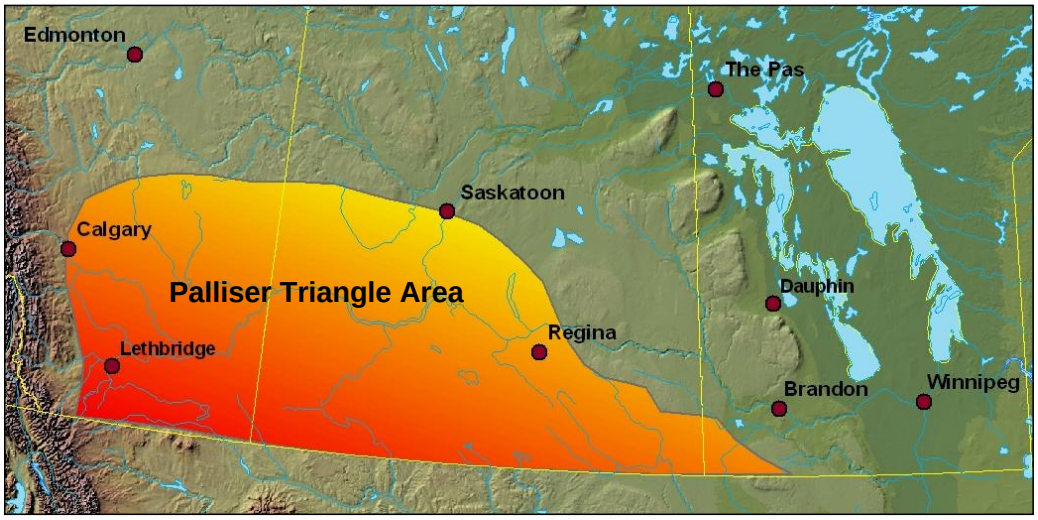

Figure 1. The Palliser Triangle within the Prairie agricultural region (from Spry, 1968, in Lemmen *et al*., 1997).

Government policy followed Hind's recommendations and the early settlement of the Prairies coincided with an unusual sustained run of moist years from the late 1890s to the early 1900s. In fact, 12 years of average or above-average precipitation were recorded during that period of settlement. Enhanced soil moisture reserves and other favourable conditions in the growing season (i.e., frost-free days, etc.) produced good crop yields with bumper harvests in 1905 and 1915. These early successes encouraged further agricultural expansion and population increases. Despite the initial promise of prosperous farming, the twentieth century has been punctuated by frequent and prolonged drought, such as those in 1906, 1936–38, 1961, 1976–77, 1980, 1984–85, 1988 and 2001–2003 (Godwin, 1986; Gan, 2000; Wheaton *et al.*, 2005).

The combination of fertile soils and—on average—adequate precipitation, have generally been favourable to agricultural production since the original settlement. The region is home to approximately 170,000 farm operators (Statistics Canada, 2001), representing 80 per cent of all farms and total farm area in Canada. Red meats, grains and oilseeds typically account for over 80 per cent of market receipts (Statistics Canada, 2001).

Although grain production has historically been associated with agriculture in the Prairie region and continues to account for the majority of production by total area, in recent years the portfolio of commodities produced on the Prairies has diversified. Farmers now produce the traditional range of crops and livestock along with specialty crops such as mustard seed, dry peas and lentils, and less conventional types of livestock including bison and elk. In addition, irrigation systems are now extensive in the southern part of the Prairie region with 630,000 hectares currently irrigated (PFRA, 2000), almost 500,000 hectares of which are in southern Alberta, where agriculture produces a wide variety of cash and feed crops including grains, oilseeds, pulses and forages as well as corn, sugar beets and vegetables.

Theoretical and conceptual background

The *vulnerability* of a socio-economic and environmental system to climate change is conceptualized as a function of a system's *exposure* to climate change effects and its *adaptive capacity* to deal with those effects. The more exposed a system is to a particular climate stimulus, the greater the system vulnerability; conversely, the greater the adaptive capacity of the system to a given climate event, the lower its vulnerability. Smit and Pilifosova (2003) express this relationship formally as:

$$V_{it}^{\ s} = f(E_{it}^{\ s}, A_{it}^{\ s}) \qquad [1]$$

Where

$V_{it}^{\ s}$ = vulnerability of system i to climate stimulus s in time t

$E_{it}^{\ s}$ = exposure of system i to stimulus s in time t

$A_{it}^{\ s}$ = adaptive capacity of system i to deal with stimulus s in time t

The emergence of the vulnerabilities approach coincides with the realization that experiences and lessons learned building resilience to existing climate stresses are important pre-requisites for future adaptation (Red Cross, 2002; ISDR, 2002). Regions with high historic climatic variability can be particularly important examples of adaptive capacity and climate resilience (or lack thereof). Polsky and Easterly (2001), for example, studied agricultural adaptation to climate variability in the U.S. Great Plains using a Ricardian approach that included an index of historic climatic variability. They concluded that farmers and institutions in districts with high historic climate variability had adapted and were more resilient to climate variability, but that the underlying reasons and sustainability of these adaptations were unclear, varied spatially and needed to be investigated with field-level study of individual farms, farmers and the institutions affecting agriculture.

A number of research studies for indicators of adaptive capacity (related to climate change and other stressors) have attempted to provide a conceptual framework and operational method to measure adaptive capacity. Smit *et al.* (2001) identified six determinants of adaptive capacity in the context of climate change as a contribution to the third assessment report for the Intergovernmental Panel on Climate Change (Table 1). While not specific indicators themselves, the rationale associated with each determinant does provide guidance for the development of indicators.

Table 1. Determinants of adaptive capacity from Smit *et al.* (2001)

Determinant	Rationale
Economic resources	Greater economic resources increase adaptive capacity
	Lack of financial resources limits adaptation options
Technology	Lack of technology limits range of potential adaptation options
	Less technologically advanced regions are less likely to develop and/or implement technological adaptations

Information and skills	Lack of informed, skilled and trained personnel reduces adaptive capacity
	Greater access to information increases likelihood of timely and appropriate adaptation
Infrastructure	Greater variety of infrastructure can enhance adaptive capacity, since it provides more options
	Characteristics and location of infrastructure also affect adaptive capacity
Institutions	Well-developed social institutions help to reduce impacts of climate-related risks and therefore increase adaptive capacity
	Policies and regulations may constrain or enhance adaptive capacity
Equity	Equitable distribution of resources increases adaptive capacity
	Both availability of and entitlement to resources are important

Framework and Analytic Approach

Our selection of indicators was constrained by data that already existed on the Prairies. Fortunately, Canada has a world-renowned census system and we were therefore able to mine Canada's censuses of agriculture and population for data relevant to adaptive capacity. But in order to mine this available data, we had to first be clear in what we wanted to measure.

With some slight modification on our part, as noted in italicized text, we adopted the framework of Smit *et al.* (2001) as follows:

- economic resources;
- technology;
- information, skills *and management*;
- infrastructure;
- institutions *and networks*; and
- equity.

We renamed two of the determinants to note our expansion of the scope of coverage therein. The information determinant was modified to include *skills and management* to reflect our broader view of the human abilities required to effectively use information. In addition, we included in the institutions determinant a *networks* component to highlight the importance of social capital (Putnam, 2001).

For each of the six determinants we developed a list of aspects (that is, indicator categories) that defined the span of each determinant. The aspects were a compromise between what the literature stressed as important (our wish list) and data available for the Prairies. Data sources with Prairie-wide spatial coverage included the Census of Agriculture (2001), Census of Population (2001), and environmental, transportation and other topical information sets of variable vintage.

Compilation of these data sources to a common spatial unit facilitated the analysis of adaptive capacity across the study area. As Statistics Canada's censuses of population and agriculture were the principal data sources, the chosen base units were the federal agency's Census Divisions (CDs) and Census Sub-divisions (CSDs). There are 60 CDs in the Prairie Provinces, of which 53 are located in the Prairie agricultural region. These divisions are used by Statistics Canada to carry out its Census of Population every five years. CSDs are municipalities or areas treated as municipal equivalents. Summation of other data sources to CDs and CSDs was accomplished through overlay in a geographic information system (GIS) using a common geographic coordinate and projection. While the availability of data for each indicator at the CSD level was assessed for finer resolution analysis, this paper presents an application of the method at the CD level.

The data were compiled within a GIS using digital boundary files for Statistics Canada census collection (Statistics Canada, 2001). Census Division polygons were calculated by projecting the digital data to North American Datum (NAD) 83 Universal Transverse Mercator (UTM) zones for each square kilometre. Each UTM zone was treated separately.[1] Area estimates were calculated for the Census Divisions. The base layer for the GIS projections was the North America shaded relief map (National Atlas of the U.S., 2005).

Within this chosen spatial framework, we identified 24 representative aspects of adaptive capacity (four for each determinant) for which we anticipated that relevant data could be summarized (Figure 2). The selection of a consistent number of aspects denoted our view that each determinant made an equal contribution to the concept of adaptive capacity. In that the literature provided no definitive direction to the topic of weighting, we deemed this decision to be prudent.

The primary purpose of the analysis was to identify CDs with relatively higher or lower adaptive capacity and describe those determinants and aspects therein that contributed to these findings. This information would then be combined with data on the degree of historic climate stress experienced to help identify regions with relatively higher or lower vulnerability to climate change. In the context of the Prairie Climate Resilience Project, this information provides general locations and broad insights for field-based researchers studying those factors that may contribute to adaptive capacity.

Comparison of adaptive capacity across CDs required, first, that the individual indicators for each determinant be aggregated to a determinant value and, second, that these determinant values be aggregated into an overall index of adaptive capacity. The main conceptual challenge in such an exercise is the disparate units for each of the individual indicators that make up each determinant.

[1] UTM zones 10–15, www.dmap.co.uk/utmworld.htm.

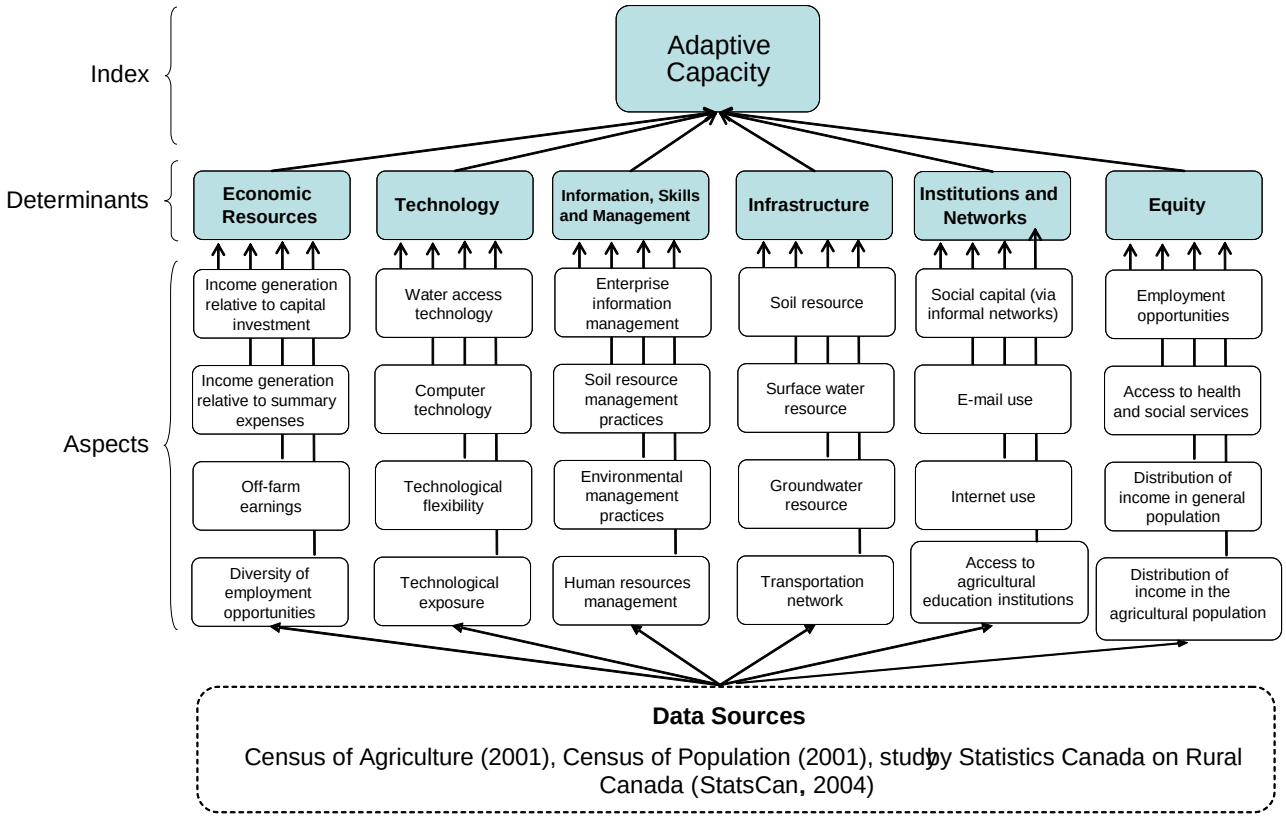

Figure 2. Framework for adaptive capacity to climate change on the Canadian Prairies.

We identified an indicator for each aspect that was specific, measurable and time-bound. These indicators are summarized in Table 2.

The procedure used to calculate normalized values for each of the determinant indicators relative across Census Divisions is shown in Equations 2a and 2b and is based on the method employed by the United Nation's Human Development Index as described by Morse (2004). Similar methods are described by Krajnc and Glavic (2005a, 2005b) for integrated assessment and by O'Brien *et al.* (2004) in the context of climate change vulnerability assessment.

$$\text{Normalized Value} = \frac{(\text{Value for CD to be normalized} - \text{minimum value for all CDs})}{(\text{Maximum value for all CDs} - \text{minimum value for all CDs})} \quad \text{[where higher is better]} \qquad \text{[Eq 3a]}$$

$$\text{Normalized Value} = \frac{1 - (\text{Value of CD to be normalized} - \text{minimum value for all CDs})}{(\text{Maximum value for all CDs} - \text{minimum value for all CDs})} \quad \text{[where lower is better]} \qquad \text{[Eq 3b]}$$

Each indicator within a determinant was considered to be of equal importance. Based on this assumed weighting, a single aggregated value for the determinant was calculated as the average of the normalized indicator values. Each determinant was considered to be of equal

importance in calculating the overall adaptive capacity index for each CD. Based on this assumed weighting, a single overall adaptive capacity index for each CD was calculated as the average of the aggregated determinant values.

Table 2. Indicators identified for the aspects of adaptive capacity

Determinant	Aspect	Indicator
Economic resources	Income generation relative to capital investment	Ratio of gross farm receipts to total capital investment. Higher is better.
	Income generation relative to summary expenses	Ratio of income to expenses. Higher is better.
	Off-farm earnings	Off-farm earnings as a per cent of total family income where families have at least one farm operator. Higher is better.
	Diversity of employment opportunities	Ratio of off-farm contribution of time to on-farm contribution of time. Not available with current dataset. Alternative was the ratio of employment in agriculture to employment in other industries within CD. Lower is better.
Technology	Water-access technology	Ratio of value of irrigation equipment to value of all other farm equipment. Higher is better.
	Computer technology	Ratio of farms reporting use of computer to all other farms. Higher is better.
	Technological flexibility	Ratio of value in tractors under 100 hp to total value of all other tractors. Lower is better.
	Technological exposure	Ratio of technologically demanding to less demanding farm types. Higher is better.
Information, skills and management	Enterprise information management	Ratio of farms reporting computer livestock and crop record keeping to all other farms. Higher is better.
	Sustainable soil resource-management practices	Ratio of area of no-till or zero-till seeding to tilled area. Higher is better.
	Sustainable environmental-management practices	Ratio of farms reporting windbreaks and shelter belts to all other farms. Higher is better.
	Human-resources management	Ratio of total farms reporting paid agricultural labour to all other farms. Higher is better.
Infrastructure	Soil resources	Proportion of area in dependable agricultural land. Higher is better.
	Surface-water resources	Ratio of surface-water area to total land area. Higher is better.
	Groundwater resources	No. and/or yield of wells. Higher is better.
	Transportation network	Ratio of high-capacity to low-capacity roads. Higher is better.
Institutions and networks	Informal operating arrangements	Ratio of total farms reporting formal agreements to total no. of farms reporting sole proprietorships and partnerships without written agreement minus miscellaneous category. Lower is better.
	E-mail use	Ratio of total farms reporting e-mail use to all other farms. Higher is better.
	Internet access	Ratio of farms reporting Internet use to all other farms. Higher is better.
	Opportunity to access agricultural-education institutions	Distance between centroids of each Census Division and the nearest regionally significant agricultural education institution. Lower is better.
Equity	Employment opportunities	Unemployment rate from Statistics Canada's 2001 Census of Population 20 per cent Sample Data for Population of 15 years and over. Lower is better.
	Opportunity to access health and social services	Ratio of labour force in health and social-service occupations to all other occupations. Statistics Canada 2001 Census of Population 20per cent Sample data for Population. Higher is better.
	Distribution of income – general population	Rating by Alessandro's work as published in Catalogue no. 21-006-X1E (Rural/urban divide is not changing; income disparities persist).
	Distribution of income – agricultural producers	Ratio of farms reporting sales in excess of $250,000 to all other farms. Lower is better.

Results

The relative rankings of the Prairie Census Divisions according to the adaptive capacity index is presented spatially in Figure 3. Table 3 provides a detailed listing of results including the Census Division's geographic code, the overall adaptive capacity index and ranking relative to all other CDs, the values and rankings for each of the six determinants, and the normalized values for the indicators that are averaged to make up each determinant value. The results are organized according to ranking—the CD with the highest composite adaptive capacity index is listed first, while the CD with the lowest overall ranking appears last in the table.

Of interest from a policy perspective are the locations of clusters of very high- and very low-ranking CDs and, additionally, which determinants are the principal contributors to these rankings. From such an analysis we can better understand potential areas and avenues for policy intervention.

The general spatial pattern of overall adaptive capacity as revealed by Figure 3 shows clusters of very high adaptive capacity (that is, the top quintile showing the top-10 CDs) and high (second-highest quintile) near large urban centres in each province with progressively decreasing adaptive capacity to the northern periphery of agriculture in the Prairie region. This is perhaps not surprising considering that many of the individual indicators for the determinants favour proximity to urban centres—e.g., off-farm earnings, diversity of employment opportunities, transportation network, email/Internet use, access to agricultural educational opportunities and employment opportunities.

The sections below provide a more detailed analysis of the areas exhibiting highest and lowest relative adaptive capacity in the Prairies. For a detailed presentation and analysis of the individual determinants we refer the reader to Swanson *et al.* (2007).

Census Divisions exhibiting the highest adaptive capacity

There exists a corridor in each province where all the CDs rank consistently in the first quintile (i.e., top ten) of adaptive capacity in the Prairie region. The highest-ranking corridor extends from the Winnipeg/Portage la Prairie area south to the U.S. border along and to the east of the Red River. The second-highest-ranking corridor exists in the Calgary area and extends southeast through to the United States border between Lethbridge and Medicine Hat. In Saskatchewan, a corridor of high-ranking adaptive capacity extends through the central part of the province from the Saskatoon and Regina areas.

The highest-ranking CD in the whole Prairie region extends around the communities of Morden and Winkler in southern Manitoba. These are not large urban centres, yet this CD ranks the highest in terms of adaptive capacity based on census data. For this CD, the determinant values were as follows:

- economic resources (ranked 19th);
- technology (ranked 8th);
- information, skills and management (ranked 5th);
- infrastructure (ranked 2nd);
- institutions and networks (ranked 28th); and
- equity (ranked 10th).

The three highest ranking CDs in Alberta are found in the south-central part of the province owing to high and very high rankings for all determinants except the equity determinant. The technology determinant warrants some analysis given that three of the four Census Divisions in this cluster rank in the top ten. The water access indicator (as measured by the value of irrigation equipment relative to all other farm equipment) was not a major factor except for the fourth-ranked Census Division east of Lethbridge where it ranked first among all 53 Census Divisions. Computer technology (as measured by ratio of farms reporting the use of computer) and technological flexibility (as measured by ratio of the value of tractors under 100 hp to all other equipment) contributed significantly to the high ranking for this determinant.

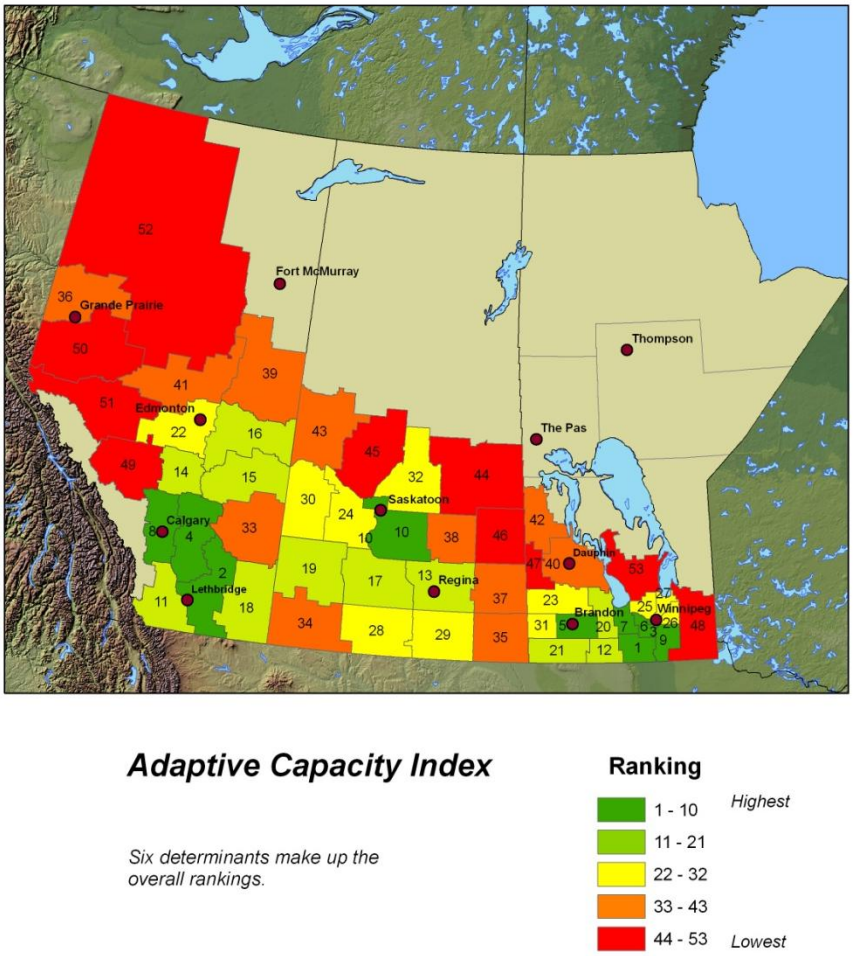

Figure 3. Map showing the rankings of the Prairie Census Divisions according to the adaptive capacity index.

The institutions and networks was another strong determinant of adaptive capacity for this cluster of CDs with all ranking in the top ten. Important indicators within this determinant were email and Internet use and access to agricultural education institutions to facilitate exposure to new and emerging viewpoints and information sources. Curiously, only two of the four Census Divisions in this cluster ranked in the top 10 in relation to economic resources, despite the province being one of the wealthiest in the country.

In Saskatchewan, the two highest-ranking CDs are in the central part of the province and include the cities of Saskatoon and Regina. They show very high to high rankings on all determinants with the exception of the information, skills and management determinant in which they ranked average. Average and high-ranking CDs exist to the west of Saskatchewan's higher-ranking corridor and extend to the Alberta border. Two CDs with high scores are located on the western boundary of this area and extend to the Alberta border. These areas show average to high scores on all determinants with the exception of very low rankings on the economic resources and infrastructure determinants, respectively.

The tenth overall ranking for the Saskatoon area is largely influenced by top 10 rankings in the economic resources and institutions/networks determinants. In terms of economic resources, the diversity of employment opportunities was a large factor. In terms of institutions and networks, access to educational institutions was an important factor as was the extent of social capital as measured by the proportion of informal operating arrangements (e.g., partnerships without written agreement and sole proprietorships). The rationale for the latter being that informal business relationships require closer personal relationships as compared to more formal contractual arrangements. And given this, it can be potentially easier for these farms to rely on their network of relationships to help during times of need.

Census Divisions exhibiting the lowest adaptive capacity

Equally important to observations of Census Divisions exhibiting the highest adaptive capacity are observations on the other end of the spectrum. The first and most obvious observation is that CDs with the relatively lowest adaptive capacity all line the northern extremity of the Prairie eco-zone, with the exception of southwest and southeast Saskatchewan. Below we analyze cases in each province to better understand why these northern CDs rank lower in adaptive capacity to climate change.

In viewing Figure 3 for Manitoba we see the trend holding true for which all of the northernmost CDs in the Prairie eco-zone are ranked in the lowest 10 overall. Manitoba's Interlake region is situated between Lake Winnipeg and Lake Manitoba. This Census Division exhibits the lowest ranking (53rd) for adaptive capacity of all Prairie CDs, despite being located within a few hours drive of some of the highest-ranking Census Divisions in the Prairie agricultural region. Of the six determinants of adaptive capacity and their underlying indicators, which are contributing the most to this low ranking? There are approximately 1,500 farms reporting in this Census Division. The individual determinants rank as follows:

Table 3. Adaptive capacity indices, determinant averages and normalized indicator values.

Census Division		Overall Adaptive Capacity Index (ranking in brackets)		Economic Resources						Technology						Information, Skills and Management					
Census Division Code	Number of farms			Income generation relative to capital investment	Income generation relative to expenses	Off-farm earnings	Diversity of employment opportunities	Average (rank)		Water access	Computer technology	Technological flexibility	Technological exposure	Average (rank)		Enterprise information management	Soil resource management practices	Environmental management practices	Human resources management	Average (rank)	
460803000	1,830	.524	(1)	0.292	0.576	0.369	0.767	.501	(19)	.040	.429	.859	.288	.404	(8)	.520	.053	.934	.717	556	(5)
482002000	3,329	.511	(2)	0.638	0.203	0.576	0.849	.567	(6)	1.000	.727	.902	.172	.700	(1)	.812	.359	.002	1.000	543	(7)
460911000	170	.508	(3)	1.000	0.028	0.875	1.000	.726	(1)	.000	.336	.561	.624	.380	(11)	.342	.060	.260	.319	245	(40)
482005000	2,875	.499	(4)	0.235	0.580	0.433	0.639	.472	(31)	.200	.827	.938	.095	.515	(4)	.829	1.000	.218	.677	681	(1)
460207000	1,246	.492	(5)	0.244	0.373	0.596	0.915	.532	(15)	.280	.470	.850	.144	.436	(6)	.750	.324	.698	.492	566	(4)
460710000	455	.487	(6)	0.315	0.903	0.410	0.641	.567	(5)	.040	1.000	.902	.202	.536	(2)	.823	.007	.145	.743	429	(21)
460709000	739	.484	(7)	0.285	0.698	0.419	0.791	.548	(10)	.120	.423	.774	.264	.395	(9)	.556	.064	1.000	.596	554	(6)
483006000	4,941	.459	(8)	0.057	0.325	0.859	0.988	.557	(9)	.000	.682	.606	.084	.343	(16)	.839	.279	.366	.232	429	(22)
460902000	1,655	.458	(9)	0.582	0.741	0.690	0.852	.717	(2)	.000	.420	.450	1.000	.468	(5)	.811	.068	.200	.761	460	(13)
479911000	3,564	.450	(10)	0.226	0.761	0.489	0.947	.606	(4)	.080	.356	.919	.088	.361	(14)	.388	.682	.273	.368	428	(23)
483003000	2,043	.443	(11)	0.153	0.443	0.590	0.690	.469	(33)	.280	.670	.720	.056	.432	(7)	1.000	.640	.229	.441	577	(3)
460804000	1,191	.443	(12)	0.286	0.711	0.066	0.188	.313	(51)	.000	.377	.888	.256	.380	(10)	.631	.161	.855	.796	611	(2)
479906000	3,901	.432	(13)	0.174	0.488	0.541	0.948	.538	(11)	.000	.412	.921	.033	.341	(17)	.404	.620	.117	.253	348	(28)
485008000	4,542	.426	(14)	0.162	0.359	0.594	0.887	.500	(20)	.000	.474	.638	.163	.319	(24)	.725	.156	.685	.366	483	(10)
484007000	3,316	.426	(15)	0.172	0.718	0.458	0.652	.500	(21)	.000	.383	.952	.039	.344	(15)	.517	.589	.403	.601	528	(8)
484110000	5,694	.421	(16)	0.150	0.531	0.562	0.746	.497	(23)	.000	.255	.881	.058	.299	(28)	.429	.646	.419	.364	464	(12)
479907000	2,795	.420	(17)	0.191	0.792	0.198	0.784	.491	(25)	.080	.309	.965	.011	.341	(18)	.406	.565	.390	.464	456	(15)
481001000	1,636	.417	(18)	0.159	0.701	0.252	0.871	.496	(24)	.520	.559	.949	.094	.530	(3)	.428	.444	.000	.879	438	(19)
479908000	3,058	.416	(19)	0.130	0.930	0.269	0.580	.477	(30)	.040	.456	.987	.003	.372	(12)	.383	.489	.108	.770	438	(20)
460708000	1,315	.408	(20)	0.279	0.611	0.387	0.431	.427	(40)	.080	.212	.844	.142	.319	(23)	.372	.117	.841	.501	458	(14)
460105000	1,556	.400	(21)	0.220	0.426	0.234	0.344	.306	(52)	.000	.284	.909	.053	.312	(27)	.412	.530	.449	.393	446	(18)
485011000	6,618	.400	(22)	0.075	0.350	0.743	0.982	.538	(12)	.000	.368	.420	.155	.236	(42)	.558	.159	.413	.149	320	(33)
460315000	1,907	.392	(23)	0.220	0.351	0.484	0.631	.421	(42)	.000	.255	.831	.053	.285	(31)	.464	.301	.359	.384	377	(25)
479912000	2,377	.389	(24)	0.199	0.771	0.211	0.487	.417	(43)	.040	.309	.969	.034	.338	(19)	.343	.669	.361	.411	446	(17)
461114000	830	.387	(25)	0.276	0.544	0.824	0.800	.611	(3)	.000	.280	.594	.213	.272	(35)	.606	.056	.188	.156	252	(38)
460912000	660	.386	(26)	0.221	0.243	0.865	0.907	.559	(8)	.000	.279	.512	.199	.247	(40)	.394	.087	.059	.009	137	(52)
461113000	539	.386	(27)	0.182	0.386	0.608	0.962	.534	(14)	.000	.227	.618	.260	.276	(33)	.256	.111	.183	.120	167	(51)
479903000	2,620	.381	(28)	0.150	0.891	0.085	0.143	.317	(50)	.000	.336	.974	.000	.327	(21)	.244	.444	.233	.396	329	(30)
479902000	2,692	.378	(29)	0.154	0.650	0.171	0.559	.383	(48)	.000	.285	.969	.001	.314	(26)	.259	.488	.169	.398	328	(31)
479913000	2,744	.377	(30)	0.175	0.704	0.197	0.467	.386	(46)	.000	.257	1.000	.013	.318	(25)	.320	.549	.371	.832	518	(9)
460206000	892	.372	(31)	0.303	0.268	0.352	0.625	.387	(45)	.000	.245	.745	.047	.259	(37)	.475	.498	.368	.472	453	(16)
479915000	4,382	.365	(32)	0.194	0.630	0.460	0.820	.526	(17)	.000	.182	.931	.068	.295	(29)	.233	.562	.183	.350	332	(29)
481004000	1,487	.365	(33)	0.174	0.436	0.000	0.271	.220	(53)	.080	.417	.955	.006	.365	(13)	.578	.384	.167	.734	466	(11)
479904000	1,790	.363	(34)	0.124	1.000	0.217	0.000	.335	(49)	.040	.333	.951	.000	.331	(20)	.346	.310	.352	.505	378	(24)
479901000	2,651	.349	(35)	0.165	0.415	0.250	0.704	.384	(47)	.000	.210	.937	.011	.290	(30)	.236	.463	.138	.258	274	(35)
487019000	3,531	.347	(36)	0.132	0.410	0.691	0.878	.528	(16)	.000	.392	.886	.025	.326	(22)	.353	.284	.418	.367	356	(26)
479905000	3,231	.334	(37)	0.213	0.348	0.518	0.609	.422	(41)	.000	.132	.897	.023	.263	(36)	.220	.344	.093	.267	231	(44)
479910000	2,534	.332	(38)	0.344	0.550	0.424	0.495	.454	(35)	.000	.139	.960	.018	.279	(32)	.174	.396	.063	.313	237	(43)
486012000	2,830	.330	(39)	0.109	0.319	0.912	0.897	.559	(7)	.000	.120	.647	.034	.200	(48)	.232	.193	.169	.184	195	(47)
460617000	1,812	.326	(40)	0.207	0.500	0.531	0.675	.478	(29)	.000	.021	.529	.032	.146	(49)	.163	.127	.258	.225	193	(48)
486013000	4,921	.322	(41)	0.178	0.324	0.675	0.787	.491	(26)	.000	.192	.566	.076	.209	(47)	.375	.123	.528	.168	298	(34)
460520000	885	.318	(42)	0.215	0.432	0.343	0.727	.429	(39)	.000	.109	.846	.066	.255	(39)	.283	.071	.277	.337	242	(41)
479917000	2,460	.318	(43)	0.126	0.505	0.538	0.772	.485	(27)	.000	.140	.889	.007	.259	(38)	.281	.544	.199	.379	351	(27)
479914000	3,812	.312	(44)	0.205	0.632	0.370	0.637	.461	(34)	.000	.123	.939	.027	.272	(34)	.151	.380	.215	.326	268	(36)
479916000	2,869	.311	(45)	0.155	0.502	0.401	0.715	.443	(36)	.000	.053	.898	.018	.242	(41)	.175	.341	.189	.253	239	(42)
479909000	3,118	.305	(46)	0.200	0.404	0.453	0.711	.442	(37)	.000	.000	.833	.026	.215	(46)	.000	.179	.039	.165	096	(53)
460416000	921	.289	(47)	0.206	0.424	0.347	0.586	.391	(44)	.000	.122	.733	.030	.221	(45)	.301	.146	.235	.177	215	(45)
461001000	688	.276	(48)	0.233	0.345	0.470	0.885	.483	(28)	.000	.145	.073	.338	.139	(50)	.381	.065	.152	.074	168	(50)
485009000	1,268	.275	(49)	0.000	0.241	0.818	0.821	.470	(32)	.000	.195	.050	.062	.077	(52)	.456	.000	.479	.072	252	(37)
487018000	821	.273	(50)	0.053	0.169	0.649	0.897	.442	(38)	.000	.271	.631	.021	.231	(44)	.457	.182	.552	.097	322	(32)
486014000	904	.271	(51)	0.199	0.000	1.000	0.942	.535	(13)	.000	.177	.295	.055	.131	(51)	.353	.000	.467	.000	205	(46)
487017000	2,758	.260	(52)	0.110	0.306	0.748	0.881	.511	(18)	.000	.145	.772	.020	.234	(43)	.136	.160	.495	.195	247	(39)
461218000	1,534	.236	(53)	0.240	0.611	0.412	0.734	.499	(22)	.000	.044	.000	.071	.029	(53)	.140	.136	.179	.221	169	(49)

Table 3 (continued). Determinant averages and normalized indicator values

Census Division		Overall Adaptive Capacity Index (ranking in brackets)		Infrastructure				Institutions and Networks						Equity			
Census Division Code	Number of farms			Soil resource	Transportation network	Average (rank)		Informal operating arrangements	E-mail use	Internet access	Access to agricultural education institutions	Average (rank)		Employment opportunities	Access to health and social services	Average (rank)	
460803000	1,830	.524	(1)	1.000	.014	.507	(2)	.545	.360	.390	.834	.532	(28)	.750	.537	.643	(10)
482002000	3,329	.511	(2)	.014	.052	.033	(35)	.155	.743	.817	.885	.650	(10)	.625	.517	.571	(21)
460911000	170	.508	(3)	.048	1.000	.524	(1)	.547	.410	.427	1.000	.596	(14)	.500	.660	.580	(19)
482005000	2,875	.499	(4)	.082	.031	.057	(17)	.203	1.000	1.000	.838	.760	(3)	.750	.269	.510	(32)
460207000	1,246	.492	(5)	.042	.043	.043	(29)	.533	.516	.599	.981	.657	(8)	.625	.815	.720	(4)
460710000	455	.487	(6)	.193	.017	.105	(5)	.348	.872	.983	.940	.785	(2)	.750	.253	.501	(34)
460709000	739	.484	(7)	.150	.027	.088	(11)	.402	.393	.379	.847	.505	(35)	.625	1.000	.813	(1)
483006000	4,941	.459	(8)	.032	.223	.128	(3)	.608	.895	.913	.980	.849	(1)	.625	.269	.447	(39)
460902000	1,655	.458	(9)	.056	.053	.054	(21)	.265	.247	.251	.891	.414	(51)	.750	.524	.637	(11)
479911000	3,564	.450	(10)	.109	.026	.067	(13)	.813	.499	.520	.866	.675	(7)	.375	.754	.564	(22)
483003000	2,043	.443	(11)	.024	.057	.040	(31)	.403	.736	.766	.884	.697	(5)	.250	.641	.446	(40)
460804000	1,191	.443	(12)	.164	.014	.089	(10)	.766	.431	.430	.786	.603	(13)	.875	.451	.663	(7)
479906000	3,901	.432	(13)	.187	.022	.104	(6)	.900	.532	.597	.957	.746	(4)	.500	.533	.516	(31)
485008000	4,542	.426	(14)	.067	.073	.070	(12)	.637	.597	.600	.725	.640	(11)	.625	.459	.542	(28)
484007000	3,316	.426	(15)	.058	.035	.046	(25)	.634	.450	.465	.776	.581	(20)	.875	.234	.555	(24)
484110000	5,694	.421	(16)	.142	.051	.096	(8)	.799	.307	.304	.888	.574	(21)	.750	.438	.594	(17)
479907000	2,795	.420	(17)	.032	.012	.022	(47)	.799	.466	.503	.756	.631	(12)	.500	.659	.579	(20)
481001000	1,636	.417	(18)	.013	.031	.022	(46)	.000	.625	.671	.689	.496	(36)	.625	.413	.519	(30)
479908000	3,058	.416	(19)	.037	.000	.019	(49)	.366	.676	.754	.534	.583	(18)	.875	.336	.606	(14)
460708000	1,315	.408	(20)	.100	.007	.054	(22)	.703	.165	.169	.834	.468	(41)	.750	.692	.721	(3)
460105000	1,556	.400	(21)	.099	.016	.057	(15)	.670	.387	.427	.853	.584	(17)	.875	.521	.698	(6)
485011000	6,618	.400	(22)	.056	.153	.104	(7)	.740	.477	.478	.907	.651	(9)	.625	.480	.552	(26)
460315000	1,907	.392	(23)	.076	.012	.044	(27)	.736	.320	.323	.870	.562	(24)	.750	.574	.662	(8)
479912000	2,377	.389	(24)	.051	.014	.032	(36)	.579	.336	.405	.831	.538	(26)	.750	.375	.563	(23)
461114000	830	.387	(25)	.154	.037	.095	(9)	.803	.258	.260	.914	.559	(25)	.625	.436	.531	(29)
460912000	660	.386	(26)	.080	.049	.065	(14)	.849	.286	.316	.924	.594	(15)	.875	.556	.716	(5)
461113000	539	.386	(27)	.090	.148	.119	(4)	.741	.315	.288	.910	.564	(23)	.625	.681	.653	(9)
479903000	2,620	.381	(28)	.043	.004	.023	(44)	.834	.470	.509	.940	.688	(6)	1.000	.202	.601	(15)
479902000	2,692	.378	(29)	.043	.004	.023	(43)	.760	.387	.448	.777	.593	(16)	.875	.381	.628	(12)
479913000	2,744	.377	(30)	.053	.008	.030	(39)	.558	.408	.454	.634	.514	(32)	.750	.249	.500	(35)
460206000	892	.372	(31)	.056	.027	.042	(30)	.681	.197	.197	.852	.482	(37)	.625	.593	.609	(13)
479915000	4,382	.365	(32)	.101	.013	.057	(16)	.862	.226	.255	.768	.528	(29)	.250	.655	.453	(37)
481004000	1,487	.365	(33)	.011	.035	.023	(45)	.485	.589	.647	.540	.565	(22)	.875	.225	.550	(27)
479904000	1,790	.363	(34)	.010	.007	.008	(51)	.546	.457	.526	.566	.523	(30)	.875	.324	.599	(16)
479901000	2,651	.349	(35)	.089	.003	.046	(26)	.844	.270	.275	.662	.513	(33)	.875	.302	.588	(18)
487019000	3,531	.347	(36)	.050	.014	.032	(37)	.693	.440	.470	.122	.431	(48)	.500	.319	.410	(43)
479905000	3,231	.334	(37)	.100	.010	.055	(20)	.965	.216	.241	.907	.582	(19)	.500	.399	.450	(38)
479910000	2,534	.332	(38)	.110	.000	.055	(19)	.938	.223	.226	.745	.533	(27)	.500	.364	.432	(42)
486012000	2,830	.330	(39)	.014	.098	.056	(18)	.895	.149	.155	.667	.466	(42)	.500	.507	.504	(33)
460617000	1,812	.326	(40)	.027	.020	.023	(42)	.871	.000	.000	.700	.393	(52)	.500	.946	.723	(2)
486013000	4,921	.322	(41)	.032	.037	.034	(34)	.792	.246	.257	.786	.520	(31)	.500	.259	.379	(45)
460520000	885	.318	(42)	.011	.021	.016	(50)	.931	.186	.141	.624	.471	(40)	.375	.618	.497	(36)
479917000	2,460	.318	(43)	.038	.042	.040	(33)	.784	.152	.162	.720	.455	(45)	.250	.387	.319	(50)
479914000	3,812	.312	(44)	.092	.004	.048	(24)	.807	.204	.227	.496	.434	(46)	.375	.400	.387	(44)
479916000	2,869	.311	(45)	.076	.011	.043	(28)	.944	.090	.100	.702	.459	(43)	.250	.627	.439	(41)
479909000	3,118	.305	(46)	.090	.008	.049	(23)	1.000	.039	.047	.808	.474	(39)	.625	.483	.554	(25)
460416000	921	.289	(47)	.057	.007	.032	(38)	.898	.178	.196	.761	.508	(34)	.375	.355	.365	(48)
461001000	688	.276	(48)	.000	.080	.040	(32)	.918	.066	.042	.801	.457	(44)	.375	.358	.366	(46)
485009000	1,268	.275	(49)	.000	.016	.008	(52)	.765	.260	.253	.623	.475	(38)	.500	.232	.366	(47)
487018000	821	.273	(50)	.050	.002	.026	(40)	.776	.306	.334	.307	.431	(49)	.375	.000	.188	(53)
486014000	904	.271	(51)	.004	.003	.004	(53)	.687	.276	.280	.483	.432	(47)	.500	.138	.319	(49)
487017000	2,758	.260	(52)	.030	.013	.021	(48)	.822	.176	.168	.000	.291	(53)	.125	.390	.257	(52)
461218000	1,534	.236	(53)	.029	.018	.024	(41)	.919	.040	.020	.715	.424	(50)	.000	.539	.269	(51)

- economic resources (ranked 22nd);
- technology (ranked 53rd);
- information, skills and management (ranked 49th);
- infrastructure (ranked 41st);
- institutions and networks (ranked 50th); and
- equity (ranked 51st).

The results appear to show that while economic resources are not among the determinants contributing most to the low adaptive capacity ranking, the contributions from the other five determinants are approximately equal. The technology determinant however, did receive the lowest ranking overall in this respect. For this determinant, the indicator for computer technology was among the lowest of all CDs (as measured by the ratio of farms reporting computer use), as were technological flexibility (as measured by the ratio of tractors under 100 hp to all other equipment) and technological exposure (as measured by the ratio of technologically demanding to less-demanding farm types). The institutions and networks determinant of adaptive capacity was the next greatest contributor to the low overall adaptive capacity ranking for this CD. While this CD ranked relatively high in terms of the social capital proxy indicator (as measured by the ratio of informal partnerships) and the access to agricultural education indicator (as measured by proximity to regionally significant agricultural institution), it ranked among the lowest with respect to email and Internet use.

In Saskatchewan only one CD is in the lowest quintile (i.e., lowest 10). However, the overall trend holds true—the northernmost CDs in Saskatchewan's Prairie eco-zone are all within the next lowest quintile. The breakdown of determinants for the lowest-ranked CD in Saskatchewan (45th of 53 CDs) is as follows:

- economic resources (ranked 36th);
- technology (ranked 41st);
- information, skills and management (ranked 42nd);
- infrastructure (ranked 28th);
- institutions and networks (ranked 43rd); and
- equity (ranked 41st).

Based on these determinant rankings, economic resources and infrastructure appear to contribute the least to the CD's relatively low overall ranking.

The overall trend holds true in Alberta with the lowest-ranked CDs lining the northern and western extremities of the Prairie eco-zone. But curiously, there is one CD that exhibits a relatively average ranking for adaptive capacity (21st overall) in this northern area and surrounded by some of the lowest-ranked CDs in the Prairies. A key fact for this CD is that it includes the urban centre of Grand Prairie. The CD to the immediate north is ranked second lowest overall in terms of adaptive capacity, owing largely to the same determinants as the lowest-ranked CD in Manitoba, namely infrastructure via relatively low soil resources and transportation networks, and institutions and networks via considerable distance to agricultural education institutions and limited email and Internet use. The Grand Prairie-

centred CD ranked around average for all determinants, but received a boost in ranking from the equity determinant (ranked sixth overall).

Discussion

The spatial analysis of the adaptive capacity index and its determinants for the 53 Census Divisions within the Prairie eco-zone has given us a unique view of the ability of farm families and communities to potentially deal with climate shocks and stresses that will occur in the future due to climate change. To the best of our knowledge, this is the first use of census data to gain an understanding of adaptive capacity across the Prairies. But just how representative is this of the factors on the ground that agriculture producers cite as being most helpful to coping with and adapting to weather shocks and stresses?

As part of the Prairie Climate Resilience project, farm interviews were conducted at six study locations across the Prairie Provinces. Case study site locations were identified using a combination of historical climate data to describe climate exposure (E), and socio-economic data, which described adaptive capacity (A). First, an exposure map was generated based on a coefficients of variability calculated from average precipitation data (1960-2002). The data were compiled by Agriculture and Agri-food Canada. Field case study locations were identified by overlaying the exposure map (precipitation variability map) with the adaptive capacity indices map.

For Alberta, two study locations were identified that had similar exposure levels, but which differed with respect to adaptive capacity (relatively higher and lower): one study area was in the vicinity of Coaldale, located 12 km east of the city of Lethbridge in Southern Alberta; and the other situated near the town of Foremost, located 130 km southeast of Lethbridge and 100 km southwest of Medicine Hat. These interviews were conducted and reported by Medlock and McCoy (2008). In Saskatchewan, two study locations were identified with similar levels of climate exposure and different adaptive capacity rankings. The northern study location is situated northwest of Regina and encompasses the towns of Roleau, Pense, Abernathy and at its most northern boundary, Wynyard. The southern location is located southeast of Regina encompassing the towns of Estevan, Benson, Carlyle and Redvers. The Saskatchewan interviews were undertaken by Pearce (2009) as part of his Masters degree at the University of Manitoba's Natural Resource Institute. In Manitoba and similar to the Saskatchewan locations, two locations were identified having similar levels of adaptive capacity with differing levels of exposure—one location north of Brandon and south of Riding Mountain National Park and the other and southeast of Brandon at the Manitoba borders with Saskatchewan and the U.S.. These interviews were conducted by Myers (2007) as part of his Masters degree at the University of Manitoba's Natural Resource Institute.

Information on factors which aided the adaptive responses of producers was compiled during the interviews. These observations are summarized in Table 4 for each of the provinces. Table 5 categorizes these observed aids to adaptive responses according to the relevant indicator categories. The comparative results reveal that aids to adaptive responses observed from producer interviews matched 14 of 24 determinant aspects. The following is a brief synthesis of the comparisons for each of the determinants:

- *Economic resources determinant* – All four aspects were represented in the producer interviews with most observations matching aspects related to income generation.
- *Technology determinant* – The water access and technological flexibility aspects were represented in the producer interviews (aspects related to computer technology and technological exposure were not represented).
- *Information, skills and management* – All four aspects were represented in the observations from producer interviews. By a large margin, most of the observations related to the broader aspect of enterprise information management.
- *Infrastructure* – Only one of the four aspects in this determinant was detected in the producer interviews, and intuitively this was the aspect for surface water resources. It could be argued, however, that many of the observations categorized with sustainable soil resource management could alternatively be placed in this category as an acknowledgement of the importance of the soil resource base.
- *Institutions and networks* – Two of the four aspects for this determinant were detected in the producer interviews, namely: informal operating arrangements (i.e., a proxy for social capital) and the opportunity to access agriculture educational institutions. Email and Internet use were not mentioned as aids to adaptive responses.
- *Equity* – Only one of four aspects in this determinant could be detected from the producer interviews. The one example observed was related to the distribution of income, and more specifically, a change in irrigation water policy (equitable distribution).

The producer interviews across the Prairie Provinces appear to show that the six determinants are a good reflection of what aids adaptive responses in the field and approximately half of the aspects identified for the framework were reflected in these field observations. But just how reflective of these actual aids to adaptive responses were the specific indicators that were used? Table 6 provides a comparison in this regard, revealing that of the 14 representative aspects, only eight indicators were a reasonable reflection of what producers cited as important for adaptive capacity:

- *Economic resources determinant* – The indicators relating to income and employment opportunities appear to be reasonable proxies for what was observed from field interviews. The off-farm earnings indicator, however, was not representative of field data as the indicator reflected employment earnings, not earnings from government programs (as was observed from the producer interviews).
- *Technology determinant* – The water access aspect appears to be well represented by the indicator, but the technological flexibility indicator that was used did not reflect the diversity of aids to adaptive responses observed from the producer interviews.
- *Information, skills and management* – The indicator used to represent the enterprise information management aspect does not reflect the diversity of responses as observed from the producer interviews. The other three indicators do, however, appear to be a good representation of the aspects related to soil resources, environmental and human resources management, in light of the producer responses.

- *Infrastructure* – The indicator for the surface water resources aspect (Ratio of surface-water area to total land area) is a reasonable reflection of the observations from producer interviews.
- *Institutions and networks* – An important aspect for this determinant was the building of social capital to facilitate norms of reciprocity and the exchange of information. In a study in the U.S., Putnam (2001) identified informal operating arrangements as a proxy for social capital. Canada's Census of Agriculture includes data that allowed us to create an indicator describing the *ratio of total farms reporting formal agreements to total number of farms reporting sole proprietorships and partnerships without written agreement* (minus the miscellaneous category). The interview data from producers suggest that this indicator is a good approximation for what they cite as important in this regard. The indicator related to the *opportunity to access agriculture education institutions* obtained using spatial map data also appears to be a good approximation of this aspect, in light of the field data.
- *Equity* – The indicator used to detect equity in relation to the distribution of income among agriculture producers is not a good reflection of what was considered important by producers (e.g., equitable distribution of water rights).

Conclusions

Three broad conclusions have been drawn from this exercise to develop GIS-based indices of adaptive capacity to climate change across the Prairie region of Canada:

1. A new spatially explicit perspective can be gained from existing statistics in Canada to better understand the capacity of agriculture producers and agro-ecosystems to adapt to weather-related shocks and stresses;
2. The assessment of adaptive capacity requires multiple perspectives, such as economic resources, technology, information/skills/management, infrastructure, institutions and networks, and equity, as put forth by Smit *et al.* (2001); and
3. While statistics can be effective in better understanding adaptive capacity to weather-related shocks and stresses across the prairies, the design of policies to facilitate the capacity of producers to adapt to future climate change requires on-the-ground research.

New Perspectives and Understanding

The results of this study are helpful to policy design for climate change adaptation in several ways. First, the very exercise of researching current thinking on adaptive capacity and mining existing census data for relevant information has illuminated many aspects that can influence adaptive capacity on the Prairies (see Table 2). The aspects listed in Table 2 are a pragmatic guide for policy-makers at this early stage of policy analysis and development for climate change adaptation on the Prairies.

Second, spatial analysis of the adaptive capacity indices for Census Divisions across the Prairies revealed that adaptive capacity is likely to be positively correlated with proximity to urban centres. Proximity to urban centres brings with it positive benefits in the form of:

- off-farm earnings;
- diversity of employment opportunities;
- computer technology;
- use of computers in farm management;
- transportation networks;
- email/Internet use to keep abreast of current climate trends and innovative farming practices; and
- opportunities to access agricultural education institutions.

The implications for policy are twofold. First, policy interventions that facilitate any of the above in the more remote rural areas would be beneficial. For example, programs to facilitate high-speed Internet access and education in the use of computers for communication, information gathering and farm management are likely to help build adaptive capacity. Second, it implies that aspects that are less correlated with locations near urban centres should receive special policy attention. Such aspects include:

- ensuring agricultural commodity prices are fair;
- access to irrigation equipment (debatable);
- promoting sustainable soil-management practices;
- discouraging farming on marginal land; and
- use of farm equipment versatile to variable climate and land conditions.

Adaptive Capacity Requires Multiple Perspectives

All six of the determinants of adaptive capacity as put forth by Smit *et al.* (2001) were represented in comments obtained from agriculture producers. Additionally, 15 of the 24 aspects under these determinants, which were identified in this study based on the literature and on available statistics, were cited by agriculture producers as being important to aiding their adaptive responses. This highlights the importance of viewing adaptive capacity to climate change from multiple perspectives.

Importance of On-the-Ground Research

Of the 15 aspects developed in this study for adaptive capacity, only nine of these aspects were supported by indicators and data that were a good representation of what producers felt as important to them in aiding their adaptive responses. Listed below are the 15 reflective aspects with bold italics used to portray those in which the supporting indicator was a reasonable representation of field conditions. This reveals the importance of site visits to detect those aspects most important for facilitating the capacity of producers to adapt to climate change.

- Economic Resources
    - ***Income generation*** (relative to capital investment and summary expenses)
    - Off-farm earnings
    - ***Diversity of employment opportunities***
- Technology
    - ***Water-access technology***
    - Technological flexibility

- Information, Skills and Management
    - Enterprise information management
    - ***Sustainable soil-resource management practices***
    - ***Sustainable environmental management practices***
    - ***Human-resources management***
- Infrastructure
    - Surface water resources
    - ***Soil resources***[2]
- Institutions and Networks
    - ***Informal operating arrangements***
    - ***Opportunity to access agriculture education institutions***
- Equity
    - Distribution of income (agriculture)

[2] Not explicitly mentioned by producers as aiding adaptive capacity, but assumed as an important aspect given its fundamental role in agriculture production

Table 4. Factors aiding adaptive response

Manitoba[i]	**Saskatchewan**[ii]	**Alberta**[iii]
Experience and knowledge	Take the loss	Diverting water to higher-value crops
Flexible attitude, no delaying reaction	Crop insurance	Purchasing water rights
Neighbour's help	Zero/minimum-till	Change in irrigation water policy (equitable distribution)
Ability to outsource help	Hail insurance	Wait out extreme heat
Available technology	Multiple field locations	Pump water off of fields when excessive
Market opportunities, consumer response	Government payment (NISA)	Digging ditches when water excessive
Participation in organizations	Early harvest	Use of government aid programs
Government program aid	Delayed harvest	Altering crops to adapt to weather conditions
Affordability	Seed short season crop	Increase size of operation (mentioned larger, but smaller an option)
Border constraints, decreased value	Multiple year grain storage	Change in techniques of field work
On-farm buffer capacity, diversity	Use crop as feed	Change in equipment for field work
Employ opportunities	Ethanol	Change in type of output of operation depending on market
Good weather	Small land drainage	Change rotation to include chemical fallow
Experience and knowledge	Maintaining fertility program	Increase market research
Flex attitude, willing to experiment	Increased lending	Little or no change
Program aid	Marketing change	Increased acquisition of farm equipment and machinery
Available technology	Late seeding	Change in key farm management objectives
Affordability	Specialty crops	Spending more time to improve financial control of farm
Employ opportunities	Seed to hay	More programs and research on area-appropriate crops
Neighbour's help	New equipment purchase	More programs and research on area-appropriate farming techniques
Market opportunities	Modify equipment	Reduce inputs
Participation in organization	Irrigation	Mechanize to reduce need for (uncertain) labour
	Row covers	Use of government aid programs
	Increased spraying	*Change tillage practices (e.g., reduced/ no-till)*
	On-farm management	*Organic farming*
	Holistic ranching	*Change crop choices (more tolerant of extreme conditions)*
	Leave crop on field to retain snow	*Change crop rotation*
		Alter field work dates

		Use of government programs
		Increased efficiency of irrigation technologies
		Implementation of GPS technology
		Building economies of scale
		Knowledge sharing
		Decreased inputs
		Reduced movement on land (i.e., no. Of field passes)
		Hiring labour at strategic times
		Relocation of livestock outside of impacted areas
		Live within financial means
		Alter field work dates
		Shelter belts
		Community water pipelines
		Continuous cropping
		New marketing programs to increase demand for output
		Changing crops to more economically valuable (increasing intensity)
		Increased skill in use of technology
		Local informal topical knowledge networks
		One pass field application for tilling, seeding and fertilizing
Notes: *[i] based on Myers (2008)* *[ii] based on Pearce (2009)* *[iii] based on Medlock and McCoy (2008)* *Italics denotes factors aiding adaptive responses over the longer-term*		

Table 5. Comparison of observed aids to adaptive responses and aspects of adaptive capacity used in identifying indicators

Indicator Framework		Aids to adaptive responses from producer interviews
Determinant	**Aspect**	
Economic resources	Income generation relative to capital investment	Affordability, decreased value, increase size of operation (mentioned larger, but smaller an option), building economies of scale, take the loss, increased lending
	Income generation relative to summary expenses	
	Off-farm earnings	Crop insurance, hail insurance, government payment (NISA), government program aid, use of government programs
	Diversity of employment opportunities	Employ opps
Technology	Water-access technology	Pump water off of fields when excessive, digging ditches when water excessive, increased efficiency of irrigation technologies, irrigation, community water pipelines
	Computer technology	
	Technological flexibility	Available technology, change in equipment for field work, change rotation to include chemical fallow, increased acquisition of farm equipment and machinery, implementation of GPS technology, one-pass field application for tilling, seeding and fertilizing, multiple year grain storage, modify equipment, new equipment purchase
	Technological exposure	
Information, skills and management	Enterprise information management	Experience and knowledge, flexible attitude, no delaying reaction, market opportunities, consumer response, on-farm buffering capacity, willing to experiment, diversity, diverting water to higher-value crops, wait out extreme heat, altering crops to adapt to weather conditions, change in techniques of field work, increase market research, little or no change, spending more time to improve financial control of farm, reduce inputs, change crop rotation, alter field work dates, decreased inputs, continuous cropping, relocation of livestock outside of impacted areas, changing crops to more economically valuable crop (increasing intensity), new marketing programs to increase demand for output, reduced movement on land (i.e., no. Of field passes), early harvest, delayed harvest, seed short season crop, use crop as feed, small land drainage, marketing change, maintaining fertility program, late seeding, specialty crops, seed to hay, increased spraying, on-farm management, ethanol, purchasing water rights, change in irrigation water policy (equitable distribution)
	Sustainable soil-resource management practices	Change tillage practices (e.g., reduced/no-till), zero/minimum-till, leave crop on field to retain snow, change in key farm management objectives (e.g., soil moisture conservation), shelterbelts,
	Sustainable environmental management practices	Organic farming, change crop choices (more tolerant of extreme conditions), decreased inputs
	Human-resources management	Ability to outsource help, hiring labour at strategic times, mechanize to reduce need for

		(uncertain) labour
Infrastructure	Surface water resources	Purchasing water rights, community water pipelines
	Groundwater resources	
	Soil resources	Change tillage practices (e.g., reduced/no-till)
	Transportation network	
Institutions and networks	Informal operating arrangements	Neighbours help, participation in organization, knowledge sharing, local informal topical knowledge networks
	Email use	
	Internet access	
	Opportunity to access agriculture education institutions	More programs and research on area-appropriate crops, more programs and research on area-appropriate farming techniques
Equity	Employment opportunities	
	Opportunity to access health and social services	
	Distribution of income (agriculture)	Change in irrigation water policy (equitable distribution)
	Distribution of income (general)	

Table 6. Comparison of observed aids to adaptive responses and the specific indicators of adaptive capacity

Indicator Framework		Aids to adaptive responses from producer interviews	Indicators of Adaptive Capacity
Determinant	**Aspect**		
Economic Resources	Income generation relative to capital investment	Affordability, decreased value, increase size of operation (mentioned larger, but smaller an option), building economies of scale, take the loss, increased lending	Ratio of gross farm receipts to total capital investment. Higher is better
	Income generation relative to summary expenses		Ratio of income to expenses. Higher is better
	Off-farm earnings	Crop insurance, hail insurance, government payment (NISA), government program aid, use of government programs	Off-farm earnings as a per cent of total family income where families have at least one farm operator. Higher is better
	Diversity of employment opportunities	Employ opporunities	Ratio of employment in agriculture to employment in other industries within CD. Lower is better
Technology	Water-access technology	Pump water off of fields when excessive, digging ditches when water excessive, increased efficiency of irrigation technologies, irrigation	Ratio of value of irrigation equipment to value of all other farm equipment. Higher is better.
	Technological flexibility	Available technology, change in equipment for field work, change rotation to include chemical fallow, increased acquisition of farm equipment and machinery, implementation of GPS technology, one-pass field application (for tilling, seeding and fertilizing), multiple year grain storage, modify equipment, new equipment purchase	Ratio of value in tractors under 100 hp to total value of all other tractors. Lower is better
Information, skills and management	Enterprise information management	Experience and knowledge, flexible attitude, no delaying reaction, market opportunities, consumer response, on-farm buffering capacity, willing to experiment, diversity, diverting water to higher-value crops, wait out extreme heat, altering crops to adapt to weather conditions, change in techniques of field work, increase market research, little or no change, spending more time to improve financial control of farm, reduce inputs, change crop rotation, alter field work dates, decreased inputs, continuous cropping, , relocation of livestock outside of impacted areas, changing crops to more economically valuable crops (increasing intensity), new marketing programs to increase demand for output, reduced	Ratio of farms reporting computer livestock and crop record keeping to all other farms. Higher is better

		movement on land (i.e., no. Of field passes), early harvest, delayed harvest, seed short season crop, use crop as feed, small land drainage, marketing change, maintaining fertility program, late seeding, specialty crops, seed to hay, increased spraying, on-farm management, , ethanol	
	Sustainable soil resource management practices	Change tillage practices (e.g., reduced/no-till), zero/minimum-till, leave crop on field to retain snow, change in key farm management objectives (e.g., soil moisture conservation), shelterbelts,	Ratio of area of no-till or zero-till seeding to tilled area. Higher is better
	Sustainable environmental management practices	Organic farming, change crop choices (more tolerant of extreme conditions), decreased inputs	Ratio of farms reporting windbreaks and shelterbelts to all other farms Higher is better
	Human resources management	Ability to outsource help, hiring labour at strategic times, mechanize to reduce need for (uncertain) labour	Ratio of total farms reporting paid agricultural labour to all other farms. Higher is better
Infrastructure	Surface water resources	Purchasing water rights, community water pipelines	No data available
	Soil resources	Change tillage practices (e.g., reduced/no-till)	Proportion of area in dependable agricultural land. Higher is better
Institutions and networks	Informal operating arrangements	Neighbours help, participation in organization, knowledge sharing, local informal topical knowledge networks	Ratio of total farms reporting formal agreements to total number of farms reporting sole proprietorships and partnerships without written agreement minus miscellaneous category. Lower is better.
	Opportunity to access agriculture education institutions	More programs and research on area-appropriate crops, more programs and research on area-appropriate farming techniques	Distance between centroids of each Census Division and the nearest regionally significant agricultural education institution. Lower is better
Equity	Distribution of income (agriculture)	Change in irrigation water policy (equitable distribution)	Ratio of farms reporting sales in excess of $250,000 to all other farms. Lower is better.

References

Agriculture and Agri-food Canada. 2008. *Exports—Agri-Food for January to December 2005*. Agriculture and Agri-food Canada, Ottawa. Available at: http://www.ats.agr.gc.ca/stats/4470-eng.htm accessed July 2009.

Agriculture and Agri-food Canada. 2005. *An overview of the Canadian agriculture and agri-food system.* Agriculture and Agri-Food Canada. May, p. 61. Available at: http://dsp-psd.pwgsc.gc.ca/Collection/A38-1-1-2005E.pdf, accessed March 2007.

Arthur, L. and B. Chorney. 1989. Impact of the 1988 drought on recreation/tourism-Sasktachewan and Manitoba. In *Environmental and economic impacts of the 1988 drought: With emphasis on Saskatchewan and Manitoba.* Vol. 1. Saskatchewan Research Council, Saskatoon.

Gan, T.Y. 2000. Reducing vulnerability of water resources of Canadian Prairies to potential droughts and possible climate warming. *Water Resources Management* 14: 111–135.

Goodwin, R.B. 1986. Drought: A surface water perspective. In *Drought: The impending crisis?* Proceedings of the Canadian Hydrology Symposium #16, Regina, Saskatchewan, pp. 27–43.

Gray, J.H. 1967. *Men against the desert.* Fifth House Publishers, Calgary.

Herrington, R., Johnston, B. and Hunter, F. 1997. *Responding to global climate change in the Prairies.* Vol. III of the Canada Country Study: Climate Impacts and Adaptation, Environment Canada.

Intergovernmental Panel on Climate Change (IPCC). 2001. *Summary for policy makers. Intergovernmental Panel on Climate Change, Third Assessment Report.* Available at: http://www.ipcc.ch/pdf/climate-changes-2001/synthesis-spm/synthesis-spm-en.pdf, accessed March 2007.

Krajnc, D. and P. Glavic. 2005a. A model for integrated assessment of sustainable development. *Resources Conservation and Recycling* 43: 189–208.

Krajnc, D. and P. Glavic. 2005b. How to compare companies on relevant dimensions of sustainability. *Ecological Economics* 55(4): 551–563.

Lemmen, D.S., R.E. Vance, S.A. Wolfe and W.M. Last. 1997. Impacts of future climate change on the southern Canadian Prairies: A paleoenvironmental perspective. *Geoscience Canada* 24(3): 121–133.

Medlock, J. and A. McCoy (2008). Farmer Coping and Adaptation Responses to Weather Shocks and Stresses in Southern Alberta. Working paper prepared for the International Institute for Sustainable Development. Retrieved from: http://www.iisd.org/climate/vulnerability/resilience.asp.

Morse, S. 2004. *Indices and indicators in development: An unhealthy obsession with numbers*. Earthscan Publications, Stirling, Virginia, USA, pp. 88–89.

Myers, P. (2008). *Farmer Responses to Weather Shocks and Stresses in Manitoba: A Resilience Approach*. Master of Natural Resources Thesis, Natural Resources Institute, University of Manitoba. Retrieved from: http://umanitoba.ca/institutes/natural_resources/pdf/Myers.Masters%20Thesis.Feb%2009.pdf.

National Atlas of the United States. 2005. Available at: www.nationalatlas.gov.

O'Brien, K., *et al.* 2003. Mapping vulnerability to multiple stressors: Climate change and globalization in India. Submitted to *Global Environmental Change*.

O'Brien, K. 2004. Mapping vulnerability to multiple stressors: Climate change and globalization in India. *Global Environmental Change* 14: 303–313.

Pearce, K. (2009). How Prairie Farmers Deal with Increasing Weather Variability. Forthcoming Master of Natural Resources Thesis, Natural Resources Institute, University of Manitoba.

Prairie Farm Rehabilitation Administration (PFRA). 2000. *Prairie agricultural landscapes: A land resource review*. Prairie Farm Rehabilitation Administration, Regina.

Polsky, C. and W. Easterling. 2001. Adaptation to climate variability in the US Great Plains: A multi-scale analysis of Ricardian climate sensitivities. *Agriculture, Ecosystems and Environment* 85: 133–144.

Putnam, R. 2000. *Bowling alone: The collapse and revival of American community*. Simon and Schuster, New York.

Putnam, R. 2001. Social capital: Measurement and consequences. *ISUMA – Canadian Journal of Policy Research* 2(1).

Ripley, E.A. 1988. *Drought prediction of the Canadian Prairies*. Canadian Climate Centre, Report #88-4. National Hydrology Research Centre, Saskatoon, p. 137.

Schindler, D.W. and W.F. Donahue. 2006. An impending water crisis in Canada's western Prairie Provinces. In *Proceedings of the National Academy of Sciences of the United States*. doi:10.1073/pnas.0601568103. Available at: www.pnas.org/cgi/reprint/0601568103v1, accessed March 2007.

Smit, B. and O. Pilifosova. 2003. From adaptation to adaptive capacity and vulnerability reduction. In J.B. Smith, R.J.T. Klein and S. Huq, eds., *Climate change, adaptive capacity and development*. Imperial College Press, London.

Smit, B. and M. Skinner. 2002. Adaptation options in agriculture to climate change: A typology. *Mitigation and Adaptation Strategies for Global Change* 7: 85–114.

Smit, B., *et al.* 2001. Adaptation to climate change in the context of sustainable development and equity. In J.J. McCarthy and O.F. Canziani, eds., *Climate Change 2001: Impacts, adaptation and vulnerability*. Contribution of Working Group III to the 3rd Assessment Report of the Intergovernmental Panel on Climate Change.

Spry, I. 1968. *The papers of the Palliser Expedition 1857–1860*. The Champlain Society, Toronto.

Statistics Canada. 2001. *Total area of farms, land tenure and land in crops, by province (1981–2001 Censuses of Agriculture).* Available at: www.statcan.ca/english/freepub/95F0355XIE/quality.htm, accessed November 2, 2006.

Statistics Canada. 2004. Mapping the socio-economic diversity of rural Canada. *Rural and Small Town Analysis Bulletin,* Allesandro Alasia, Vol. 5, No. 2. March. Catelogue no. 21-006-XIE.

Wheaton, E., *et al.* 2005. *Lessons learned from the Canadian drought years of 2001and 2002: Synthesis report for Agriculture and Agri-Food Canada.* Saskatchewan Research Council, Saskatoon. SRC Publication No. 11602-46E03.