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ORIGINAL PAPER

Vulnerability and adaptation to climate risks in Ontario agriculture

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Abstract A vulnerability approach to climate change adaptation research is employed to explore prospects of agricultural adaptation to climatic variability and change. The methodological approach focuses on the system of concern, in this case, farms in Perth County, Ontario. Twenty-five interviews and four focus groups with farmers were used to identify climate risks on farms, and to document farmers' responses to conditions and risks associated with climate and weather. The information collected describes a complex decision-making environment, with many forces both external and internal to the farm operation influencing management decisions. Within this environment, climate and weather are consistently referred to as a significant force influencing both farm operations and management decisions. Farmers have, however, developed a wide-range of anticipatory and reactive management strategies to manage climate risks. While these have potential to address future climate-related risks and opportunities, there are limits to adaptation, and an increase in the frequency of extreme events may exceed their adaptive capacities. Farmers are also generally unaware and/or unconcerned about future climate change, which could constrain opportunities to adopt long-term climate change adaptations.

Keywords Adaptive capacity · Agricultural adaptation · Climate change · Climate risk · Exposure · Farmers · Perception of climate · Vulnerability

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1 Introduction

As greenhouse gas emissions increase, models predict changes in climate, including increases in temperatures and changes in moisture and extreme conditions (IPCC 2001a). Climate change is expected to have impacts on agricultural production and farming communities in Canada and around the world (Downing et al. 1997; Risbey et al. 1999; Reilly et al. 2003; Liu et al. 2004; Wall et al. 2004; Motha and Baier 2005; Sivakumar et al. 2005). The vulnerability of agriculture to climate change is widely recognized in scientific and policy communities, as identified in international policy agreements. The United Nations Framework Convention on Climate Change acknowledges threats to food production as a key concern.

Internationally, many studies have attempted to estimate the manner and degree to which food production might be threatened by climate change (Rosenzweig and Parry 1994; Fischer et al. 1995; Parry et al. 2004). By the very nature of the relationship between the agriculture industry and climatic conditions that vary over space and time, food production is susceptible to climatic variations and farmers are required to adapt. However, in the Canadian agricultural sector, climate change has yet to become a high priority item, and there is little evidence of serious steps being taken to facilitate adaptation (Chiotti and Johnston 1995; Wall et al. 2004). This may reflect the way in which climate change has been presented to the agricultural community, as a warmer world many decades in the future, which is hardly the most pressing issue to Canadian farmers (Smit et al. 2000b). Further, there has been little research on and there is no generally accepted approach to assessing agricultural vulnerabilities and adaptation strategies to climate change in Canadian agriculture (Brklacich et al. 1998; Dolan et al. 2001). There are numerous studies of the implications of future climate change scenarios for crop yields and production in Canada (Arthur 1988; Smit et al. 1989; Singh and Stewart 1991; Brklacich and Stewart 1995; El Maayer et al. 1997; de Jong et al. 1999; Winkler et al. 2002; Neilsen et al. 2002) but there has been less research on how it will affect farm operations and the ways in which the agricultural sector might adapt to changing conditions (Bryant et al. 2000; Wall et al. 2004; Belliveau et al. 2006). The Canadian Senate recently identified adaptation as a key factor in determining the implications of climate change for Canadian agriculture (Standing Senate Committee on Agriculture and Forestry, 2003).

The need for research that will improve farm-level adaptation to climate change is well recognized (Chiotti and Johnston 1995; Brklacich et al. 1998; Smith et al. 1998; Leary 1999; Kandlikar and Risbey 2000; Smit et al. 2000a). To assist farmers in adapting to climate change it is necessary to understand farmers' perceptions of climate and climate change, how they are affected by climatic conditions, the adaptive strategies that are available to them, and the constraints and opportunities for enhancing their adaptive capacity (Smit and Pilifosova 2003; Yohe and Tol 2002; Belliveau et al. 2006). The research discussed in this paper aims to identify the vulnerabilities and adaptive capacities of agricultural producers in order to contribute to the development of effective strategies to assist farmers in adapting to climate change.

This paper focuses on farm-level perceptions of risks associated with climate variations and changes, and farm-level responses to deal with these conditions. It employs a version of the "bottom-up" or "vulnerability approach" in which insights are gained from the decision-makers (in this case farmers) on the climate-related conditions to which they are exposed and on their adaptive capacities and strategies to deal with those farmer-relevant exposures now and with changes in climate (Kelly and Adger 2000; Tol et al. 1998; Pittock and Jones 2000; Kasperson et al. 2001; Burton et al. 2002; Ford and Smit 2004). The first section of the paper describes the ways in which adaptation has been included in climate change research, particularly with respect to the vulnerability approach. An overview is provided of projected climate change and expected impacts on agriculture in Canada with a focus on the province of Ontario. The empirical methodology employed is outlined and the agricultural industry in the study area of Perth County, Ontario is described. The results of the research discuss the relevant farm-level exposures, including but not limited to climate, the adaptations to manage these conditions, producers' perceptions of climate change, and the implications these have for the future vulnerability of Ontario producers to climate variability and change.

2 Climate change impacts, vulnerabilities and adaptations

Agricultural adaptation to climate change involves adjustments in natural or human systems in response to climatic conditions or risks, to maintain, preserve, or enhance the viability of agricultural systems (IPCC 2001b; Smit et al.1999). Much of the research on climate change adaptation is concerned with estimating the degree to which adaptation may reduce the seriousness of climate change and identifying how and where adaptation might be undertaken in sectors to moderate losses or reduce risks (Burton 1997; Kelly and Adger 2000; Mendelsohn 2000; Yohe 2000; Smit and Wandel 2006). The most widely employed approach for understanding the relationship between climate and agriculture has been the climate impact assessments, which use models to estimate the impacts of future climate change scenarios (Carter et al. 1994). Studies of this nature are primarily intended to estimate the overall magnitude of the effects of long term climate change, often modeled as a change in average temperature and precipitation; these climatic variables, however, are not necessarily the conditions to which agricultural decision-makers are most sensitive (Antle et al. 2004; Burton and Lim 2005).

Most climate change impact assessments, particularly those dealing with agriculture and food production, now include some consideration of adaptation (e.g. Alexandrov and Hoogenboom 2000; Easterling et al. 2003). In some cases, the adaptations investigated refer to changes in the natural systems (i.e. the biophysical response of the crops) in light of changing agroclimatic conditions and increases in CO_2 levels (e.g. Easterling et al. 2001). Other studies incorporate assumed adjustments in the farm system, such as changing planting date or crop types, to estimate the degree to which negative impacts could be offset. This work has evolved from assuming farmers do not adapt to changed conditions to assuming a variety of adjustments that could hypothetically be undertaken in agriculture (Easterling et al. 1993; Fischer et al. 1995; El-Shaer et al. 1997; Reilly et al. 2003). These impact studies focus mainly on the effects to yields rather than farm management processes, and hence are not designed to identify and characterize the ways in which adaptations actually occur nor how they are likely to occur in the face of changes in climatic conditions (Chiotti et al. 1997; Kelly and Adger 2000; Smit and Skinner 2002; Tan and Reynolds 2003). Further, the roles of many non-climatic factors that interact with climatic stimuli in adaptive decision-making in agriculture are rarely analyzed substantively (Chiotti and Johnston 1995; Smit et al. 1996; Tol et al. 1998; Kandlikar and Risbey 2000; Schneider et al. 2000).

A complementary approach, vulnerability assessments, redirects the research starting point from specified future climates and their modeled effects to the agricultural system itself and its sensitivity to climatic conditions, including variations and extremes, and explicitly incorporates adaptation processes (Tol et al. 1998; Kelly and Adger 2000; Smit and Pilifosova 2001). The term vulnerability reflects broadly ''...the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes'' (IPCC 2001b, 21). The *vulnerability* (V) of an agricultural system may be described as a function of the *exposure-sensitivity* (E) of that system to environmental (climatic) changes, and the system's *adaptive capacity* (A) (modified from Smit and Pilifosova 2003). This can be presented generally as:

$$\mathrm{Vist} = f(\mathrm{Eist}, \mathrm{Aist})$$

where Vist is the vulnerability of a system i to climate stimulus s in time t, Eist is exposure-sensitivity of system i to climate stimulus s in time t, Aist is adaptive capacity of i to climate stimulus s in time t.

In this equation, V is a positive function of E (increased exposure-sensitivity results in increased vulnerability) and an inverse or negative function of A (increased adaptive capacity results in decreased vulnerability) (Smit and Pilifisova 2003). *Exposure-sensitivity* refers to the susceptibility of the system to be affected by the stimulus (or stimuli) and reflects the interaction of the characteristics of the stimuli (e.g. climatic conditions) relative to the system (e.g. agriculture) (Kasperson et al. 2001; Smit and Wandel 2006). Climatic stimuli are not experienced by farmers in isolation from the local conditions of the farm nor from the broader economic, social, environmental and political processes and conditions (Smit et al. 1996; Chiotti et al. 1997; O'Brien and Leichenko 2000). Exposure-sensitivity can vary from farm to farm according to the conditions and characteristics of farms that make them more or less susceptible to particular types of climatic stresses.

Adaptive capacity (A) is the potential or ability of a system, region, or community to adapt to the effects or impacts of climate change' (Yohe and Tol 2002; Smit and Pilifosova 2003). In the case of agricultural systems, it may be influenced by a range of factors such as commodity prices, financial markets, available technologies, social networks, and institutional support. Individual farmers are also informed by the experience of others in the region. Literature from a number of scholarly fields offers insights for understanding a system's adaptive capacity, including resilience, risk assessment, risk management, farm-level decision-making and diffusion-of-innovation (Rogers and Shoemaker 1971; Ilbery 1985; Carter et al. 1994; Chiotti and Johnston 1995; Kandlikar and Risbey 2000; Wandel and Smit 2000). Table 1 summarizes some of the factors that may influence adaptive capacity, sometimes called ''determinants'' or ''drivers'' of adaptive capacity or adaptability. These determinants may facilitate or constrain adaptation initiatives.

Table 1 Determinants of adaptive capacity

Determinant	Description
Awareness	The ability to accurately identify the signals of change and their implications
Technology	The availability of and access to technological options for adaptation
Resources	The availability of resources for adapting (including financial capital and physical resources)
Institutions	The structure of critical institutions, including the allocation of decision-making authority
Human capital	The skills, education, experiences and general abilities of individuals
Social capital	The informal social networks and collective life of a community, as it influences the ability and willingness of residents to work together for common community goals
Risk management	The ability of a system to manage risks, including sharing the risk amongst the stakeholders
Information management	The ability of decision-makers to manage information; including the processes by which information is acquired and assessed

Sources: Yohe and Tol (2002) and Smit and Pilifosova(2001)

3 Climate change and agriculture in Canada

There has been considerable research on the potential impacts of climate change in agriculture internationally and in Canada, many employing scenario-based modeling methods, and most focusing on agro-climatic conditions and crop growth (Brklacich and Stewart 1995; Delcourt and van Kooten 1995; El Maayar et al. 1997; Singh et al. 1998; Smith et al. 1998; Williams and Wheaton 1998; McGinn et al. 1999; Belanger et al. 2002; Neilsen et al. 2002; Winkler et al. 2002). While there is little consensus about the impacts of climate change on Canadian agriculture, most regions in Canada are expected to have warmer temperatures, with longer frost-free seasons, increased evapo-transpiration rates, and increased moisture deficits (Wall et al. 2004). However, agro-climatic change is not expected to impact regions equally, with some regions expected to benefit, while others suffer (Smith et al. 1998; Lemmen and Warren 2002). For example, an extension of the growing season may be favorable to some apple and grape producers in the British Columbia interior, but this could be offset by risks of extreme heat events or an increased persistence of crop pests through milder winters. These fruit producers are also anticipated to face significant challenges with water supply and demand (Neilsen at al. 2002). Also, on the Canadian prairies, longer growing seasons may be beneficial for wheat production (McGinn et al. 1999), but the projected higher average temperatures may result in soil moisture deficits (Nyirfa and Harron 2002).

In Ontario, climate change models suggest warmer summers and winters, longer growing seasons, and more frequent extreme weather events and prolonged dry spells, although summers may be wetter closer to the Great Lakes (Koshida and Avis 1998; Andresen et al. 2000; DesJarlais et al. 2004). Possible impacts of elevated temperatures include increased crop yields, provided there is adequate moisture. Sorghum and corn yields in Ontario may benefit from warmer, wetter conditions, and some forage and fruit crops would benefit from longer, warmer growing seasons and less winter damage (Brklacich et al. 1998; Andresen et al. 2000). On the other hand, such conditions may lead to increased plant diseases and pest infestations (Lemmen and Warren 2002; Winkler et al. 2002; Kling et al. 2003). Increased evapo-transpiration from higher temperatures and reduced rainfall would increase crop stress and reduce crop yields. Drought conditions also reduce the effectiveness of herbicides and pesticides, increasing the potential for losses if accompanied by an increased number of pest infestations (Lemmen and Warren 2002). Increases in extreme weather events are possible, including heat waves, intense rain, and hailstorms, conditions to which Ontario crops are sensitive (Smith et al. 1998; Lemmen and Warren 2002).

Climatic changes may also impact the livestock sector, since livestock are also sensitive to temperature changes. High summer temperatures can cause heat stress, affecting milk production in dairy cows, suppressing weight gain, and causing fatalities, especially with poultry. Warmer weather may also increase the number of livestock pests and pathogens (Smith et al. 1998; Charron et al. 2003). Increased drought may affect the quantity of forage crops available for feeding livestock, while increased levels of carbon dioxide would increase grassland productivity. Increases in storms could result in a greater number of power outages, potentially devastating for dairy farms without back-up generators (Smith et al. 1998).

Farmers, however, have the ability to offset some of the negative impacts through adaptation. The adaptability of Ontario agriculture to climate change has been explored mainly via assumptions in impact assessments (e.g. Brklacich and Smit 1992; Brklacich and Stewart 1995; Reinsborough 2003) via inventories of possible adaptive strategies (Smit and Skinner 2002; Kurukulasuriya and Rosenthal 2003) and via analysis of producer responses to hypothetical future climate change (Brklacich et al. 1997; Holloway and Ilbery 1997). Climate change studies in Ontario have not traditionally investigated vulnerability from the perspective of the agricultural decision-makers, although this has been done elsewhere (Belliveau et al. 2006).

4 Research approach and methodology

This study was designed to identify those attributes of climate and other conditions to which farmers are vulnerable, to characterize the nature of those vulnerabilities, to identify existing adaptive strategies, and to consider possible adaptation options to deal with future climate risks. The aims and design of the study sought to build upon previous research into vulnerability to climate change and connect it with scholarship on farmer decision-making, which was achieved through the development of a conceptual framework.

4.1 Conceptual framework

The conceptual framework employed in this study (Fig. 1) starts by assuming that individual farms and farmers are exposed on an on-going basis to a range of conditions and stimuli exogenous to the farm which include variable climatic conditions. A variety of factors or determinants influence the ability of the farm or farmer to adapt to the conditions to which they are exposed. These conditions of exposure and the factors that influence adaptive capacity are perceived and experienced through the particular, endogenous characteristics of the individual farm or farmer. Decisions are made in light of these multiple forces over long term (strategic) and short term (tactical) time horizons. These decisions may include measures or strategies that represent adaptations to climatic conditions.

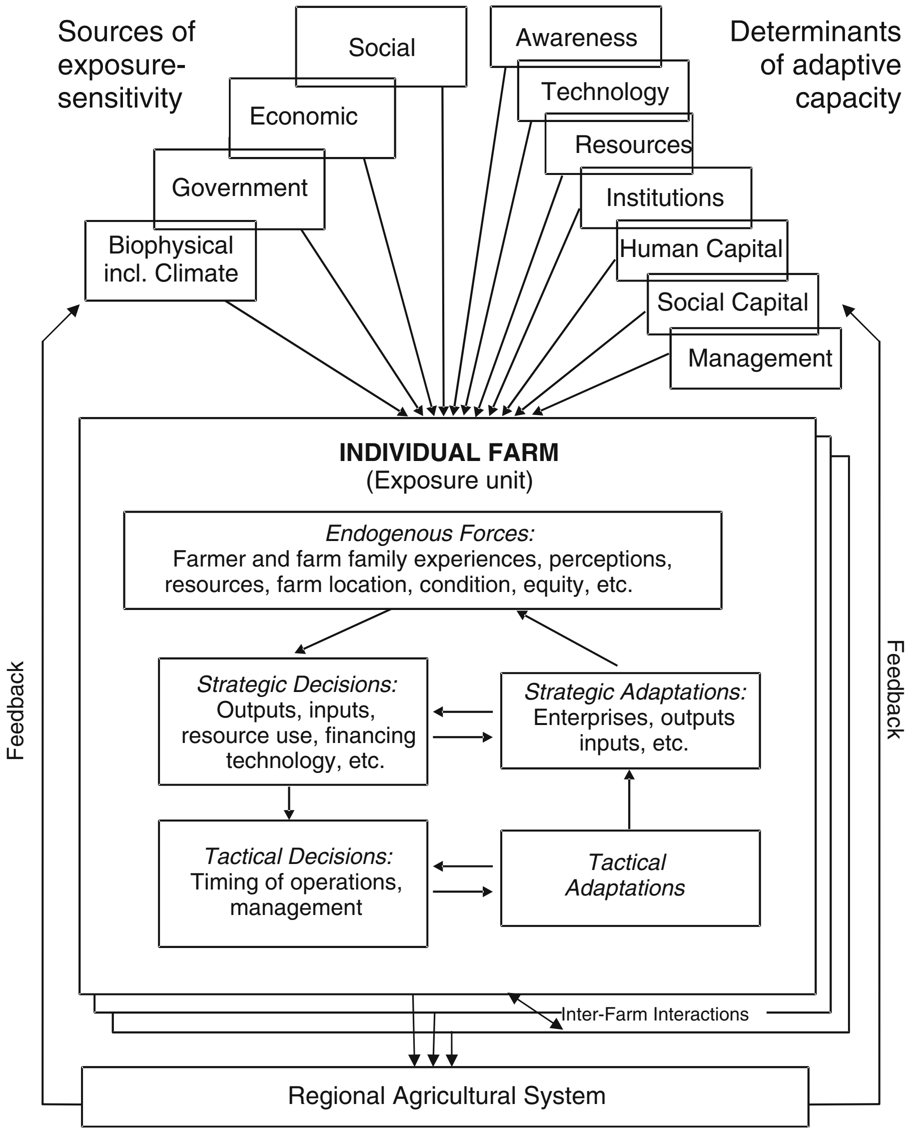


Fig. 1 Conceptual framework of agricultural adaptation to climatic variation

The farm is vulnerable to exposures to the degree that they are detrimental to the operation and to the degree that the farmer is unable to adapt, due to constraints to adaptation and/or adaptive capacity (Smit and Pilifosova 2003; Smit and Wandel 2006). While the external sources of exposure and the determinants of adaptive capacity may be common or similar among farms in a region, the location, farm characteristics and farmer attributes can vary greatly, resulting in differential vulnerabilities among farms over that region (Smithers and Smit 1997). Nonetheless, the vulnerability of a regional agricultural system will reflect the aggregation of the many farms in the region (Fig. 1). Decisions on one farm will also be informed by the experience of others, and decisions on farms and characteristics of the regional agricultural system will feed back to some of the sources of exposure and determinants of adaptive capacity.

4.2 Study area

Perth County was selected for this study because it is an example of an established intensive agricultural area in Ontario, it has a large farming population and it was already familiar to the field researcher. Perth County is a predominantly rural municipality in southwestern Ontario, with a population of approximately 38,000 (Fig. 2). It is a very productive agricultural area, with 90% of the land in the County classified as prime agricultural land according to the Canada Land Inventory, with soils commonly being clay and silty loams (Perth County 2003). Agriculture creates 29% of the county's employment, and farm gate sales total on average more than $400 million (Canada) annually (Cummings and Associates 2000). Perth County farmers have traditionally concentrated production on field crops, dairy, hogs, and to a lesser extent beef (Fig. 3). In the past decade, field crop operations have increased by 23%, while dairy and hogs have decreased by 25% and 21%, respectively (Statistics Canada 2001). While the number of animals in the county increased over the same period, livestock production has become increasingly concentrated on a smaller number of farms (Table 2).

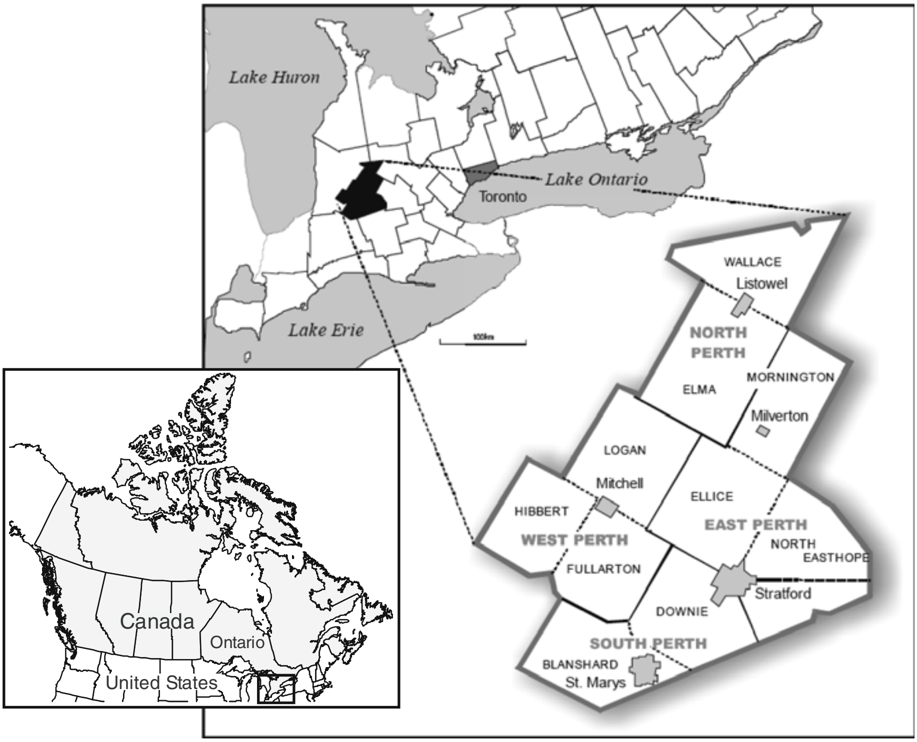


Fig. 2 Location of study area, Perth County Ontario

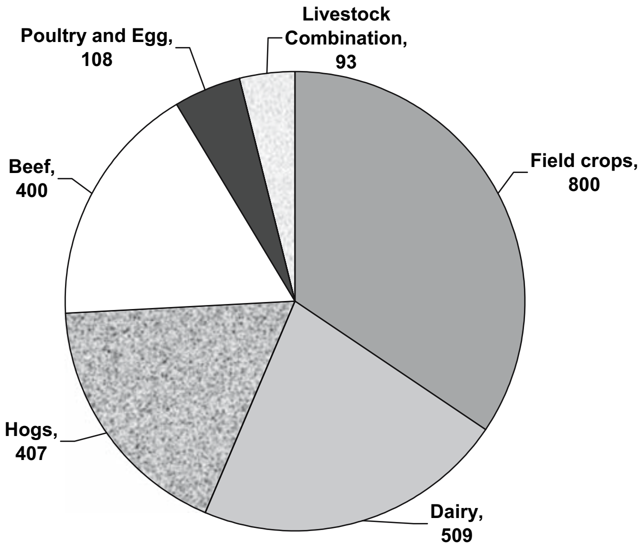


Fig. 3 Number of farms, by type, Perth County Ontario 2001. Source: Statistics Canada, 2001

Perth County is characterized by warm, reasonably wet summers and cold, snowy winters. Average daily temperatures range from a low of –7°C in January to a high of 20°C in July. There is, however, considerable variability around these averages. For example, a daily high of 14°C was recorded on January 14, 1995, while on January 4, 1981, the recorded daily high temperature was –32°C. Similarly, daily highs in July have ranged from 36°C to 4°C (Environment Canada 2005). Precipitation averages over 100 mm monthly from November through the end of January, while during the May to September growing season monthly precipitation averages between 80 mm and 100 mm. Again, variability in precipitation patterns occurs, with both dry spells and extreme precipitation events being possible; a single day storm event on July 28, 1983 brought 137 mm of rain to the area (Environment Canada 2005). Long term trends in agro-climatic variables recorded at the London weather station in neighboring Middlesex County illustrate the interannual variability and show a century long trend of increasing crop heat units and lengthening growing seasons (Fig. 4a–d).

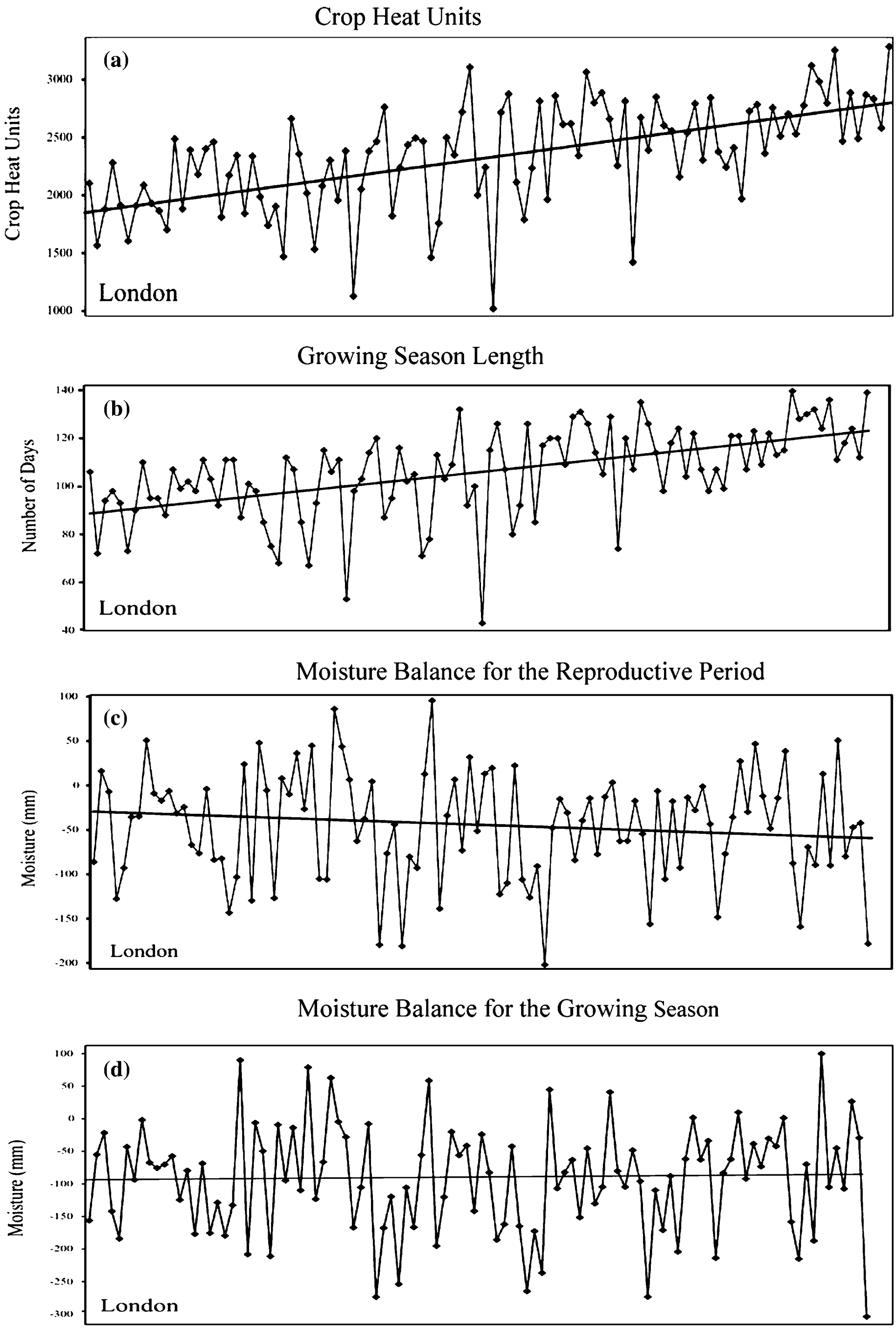
Table 2 Trends in Perth County farm and livestock numbers

	Year	Field crops	Dairy	Beef[a]	Hogs	Poultry and egg[b]	Livestock combination
Number of Farms	1991	612	676	523	589	90	164
	1996	730	608	397	464	108	167
	2001	800	509	400	407	108	93
Number of Animals	1991	N/A	30,634	117,071	417,090	2,019,731	N/A
	1996		28,809	112,188	460,468	2,352,342	
	2001		29,897	117,672	570,399	4,028,579	

[a] Includes beef, cattle and calves

[b] Includes hens, chickens and turkeys

Source: Statistics Canada (2001)


Crop Heat Units
(a)
Crop Heat Units
3000
2500
2000
1500
1000
London
Growing Season Length
(b)
Number of Days
140
120
100
80
60
40
London
Moisture Balance for the Reproductive Period
(c)
Moisture (mm)
100
50
0
-50
-100
-150
-200
London
Moisture Balance for the Growing Season
(d)
Moisture (mm)
100
50
0
-50
-100
-150
-200
-250
-300
London

◀ **Fig. 4** Trends and variations in agro-climatic variables 1895–1997, London, Ont. station (source: Adamson 2002). Note to Figures: Definitions of agro-climatic variables (from Adamson 2002) Crop Heat Units (CHU): is a measure of the accumulated heat available for crop growth over the growing season. CHUs are accumulated from the last day of three consecutive days having a daily mean temperature of 12.8°C or higher, *and* after the date the 30-year average daily mean air temperature reached 10°C. CHUs are accumulated until the earlier date of *either* when the 30 year average daily minimum temperature is less than or equal to 6.5°C (which is the estimate of 10% probability of a killing frost of—2°C) or the first occurrence of a minimum temperature equal to/or less than 2°C. Growing Season Length (GSL): is the number of days in the growing season, representing the days during which the CHU are accumulated. Moisture Balance: represents the supply of water (precipitation and base moisture in the soil) minus evapotranspiration. Moisture Balance for the Growing Season (MBS): is the surplus or deficit of the supply of water produced over the entire growing season. Moisture Balance for the Reproductive Period (MBR): is calculated for the period between the start of the growing season and the date that 70% of the CHUs have been accumulated, representing the period when plant growth when crops are more sensitive to available moisture

Over the same period, moisture balance during the growing period has remained stable, but has declined slightly for the reproductive period, when plants are more sensitive to moisture availability.

4.3 Data collection

The conceptual framework shows the categories of exogenous and endogenous conditions that may affect the vulnerability of farms. The empirical research was designed not to predetermine factors or bias responses, but to document the decisions, forces and processes that influence decisions, and to identify those that represent measures or strategies to adapt to climate risks. Interviews and focus groups were used to document farmers' management decisions and the forces and pressures that motivate or underlie them. Farmers were selected using a purposive snowball sampling approach to seek research participants to broadly represent the main types of Perth County farms and farmers with regards to farm size, farm type and location (Palys 1997; Flick 1998). Similar methods have been successfully employed in other studies of decision-making under changing conditions, including studies of adaptation to climate change in Canadian agriculture (Brklacich et al. 1997; Chiotti et al. 1997; Belliveau et al. 2006).

Twenty-five in-depth interviews were undertaken with Perth County farmers at their farms. The research was introduced to interviewees as a study 'exploring the risks and opportunities facing agriculture'. No reference was made to weather or climate upon introduction, in order to avoid biasing respondents to focus on climatic conditions. Rather, interview questions were open-ended and were structured to allow interviewees to identify those forces to which they were exposed, not limited to climate, and those that influenced their capacity to adapt. Interviews began by gathering information on the nature of the interviewee's farm operation. Interviewees were asked to describe those conditions of the past 10 years that were problematic and beneficial for them, and to indicate ways in which they managed or adapted to the conditions. Interviewees were then asked to suggest future risks and opportunities they might face, and how they might respond. Only in the final stage of the interview did the investigator raise the question of climate change specifically, asking interviewees what it meant to them, if they had experienced changes in conditions relevant to their farm, and how they managed them. Farmers were then given a list of specific adaptations based on Smit and Skinner's (2002) typology, and asked if these were employed to manage climatic risks.

Four focus groups were then held with different sets of Perth County farmers who had not been interviewed previously. As with the interviews, farmers were told the focus group was to explore the risks and opportunities facing agriculture, with no reference to weather or climate in the introductory invitation. Focus groups are seen as an opportunity to generate additional information through their dynamic information exchanges and dialogue among participants (Bedford and Burgess 2001; Wilkinson 2004). The format of the focus groups followed a similar outline to the interviews, asking about current and future risks and opportunities and farm management strategies. An open-coding process was used to organize and assist interpretation of the information gathered from the interviews and focus groups (Flick 1998). For each section of the interview or focus group discussion, responses were coded and categorized, with illustrative quotations retained to characterize the described exposure, adaptive response or risk management strategy.

5 Farmers' vulnerabilities

The following discussion reports on the results of the interviews and focus groups. It is divided into four sections, corresponding roughly to the vulnerability model, discussing the farm-level exposure-sensitivities, farm-level adaptations, perceptions of climate variability and change, and the implications for Perth County farmers' vulnerability to climate change.

5.1 Farm-level exposure-sensitivity

Perth County farmers described a complex socio-political environment within which they make management decisions. They identified a number of forces that affect their operations, including climate, environment, economic and market conditions, and government programs and policies that are summarized in Tables 3–5. These forces do not happen separately or independently, as farmers are exposed to a combination of forces in any given year.

Climatic conditions, which farmers more often refer to as weather, were the most frequently cited conditions by participants without any prompting (Table 3).

Table 3 Climatic and environmental forces affecting Perth County farms

Type of condition	Initial effects	Positive (+) or negative (–)
Warm weather, timely precipitation	Yield	+
Excessive precipitation	Yield	–
Drought conditions	Yield	–
Wet spring, difficulty planting crop	Yield	–
Insufficient heat during growing season	Yield	–
Wet fall, crop does not dry	Yield	–
Good conditions elsewhere in the world	Price	–
Disease (e.g. fusarium)	Yield, price	–
Crop pest outbreaks (aphids)	Yield	+/–
Livestock diseases	Livestock, income	–

Table 4 Market and economic forces affecting Perth County farms

Type of condition	Initial effects	Positive (+) or negative (–)
Interest rates (low, stable rates have positive effect, high or unstable rates have negative effect)	Income	+/–
Commodity prices (direction of effect depends on direction of prices)	Income	+/–
Rising land prices	Income when exiting farming	+
Availability of affordable farmland	Limits expansion	+/–
Changes in input costs (e.g. feed)	Income	+/–
Value of Canadian currency (direction of effect depends on whether production is for export; origin of inputs)	Income	+/–
Futures market moderates price fluctuations	Income	+
Increase of global commodity production	Income	–

Favourable weather was considered to be a combination of heat, sun and moisture at 'the right time', which resulted in increased crop yields. The timing and amount of rain throughout the season were emphasized as particularly important factors distinguishing good and bad years. Rain is required when corn is tasseling to produce a good crop; cold, wet springs can delay planting, thereby shortening the growing season; and wet falls affect the quality of the crop and the ability to harvest. Bad years were often characterized by moisture extremes (drought or excessive rain), with prolonged periods of wet weather or prolonged dry periods reducing crop yields or quality.

In most cases, climatic stresses were identified due to their impact to the crops, since 92% of the interviewees produced some amount of crops. However, the effect varied among operations depending on the type of operation. Cash crop operations are more sensitive to decreases in crop yield or quality since they accounts for a greater portion of their income. For operations that had a combination of livestock and crops, climatic conditions determine the quality and amount of feed produced, and hence whether additional feed had to be purchased. These mixed operation farmers did, however, identify climatic variables that affected the livestock as well, noting that heat stress can negatively affect chickens and reduce conception rates in hogs, and wet seasons can slow calf growth.

Producers also identified environmental conditions that are often related to or influence producers' sensitivity to climatic risks. In 2001, there was an outbreak of soybean aphids that was associated with the drought conditions at the time. The combination of drought and pests caused some producers to lose half or more of their soybean crops. The disease fusarium was problematic for wheat crops during wet or humid conditions when the wheat is flowering, which reduces the quality of wheat to feed grade and hence reduces the price received for it. Livestock diseases were also identified, such as the hog disease Porcine Reproductive and Respiratory Syndrome (PRRS), although these were not necessarily linked to climate. Producers' exposure-sensitivity to such livestock diseases can be influenced by the operations' location relative to their neighbors. One producer explained: "One of the reasons we located here, there are not any hog farms nearby—closest is a mile and half. That is a good thing—less disease traveled by land or birds." Soil types also influence the

Table 5 Government programs and policies affecting Perth County farms

Force	Type of condition	Effects	Positive (+) or negative (–)
Municipal by-laws	Restrictions on farm buildings, location of operations	Expansion/diversification opportunities	–
Provincial programs	Income stability programs	Income	+
	Market revenue insurance	Income	+
	Assistance to young farmers	Assists entry of new farmers	+
	Farm relief programs	Income	+
	Farm improvement grants	Yield, income	+
	Crop insurance	Income	+
	Reductions in extension support, increased paperwork	Yield, income	–
	Unwieldy program requirements or limits on access	Income	–
Federal/foreign policy	Protection of supply managed production (e.g. dairy, egg)	Income	+
	Reducing international trade restrictions	Income	+
	Farm subsidies, policies in USA	Income, market access	–

operations' exposure-sensitivity to climatic conditions, as well-drained, sandy soils are more prone to drought conditions, for example. Producers noted that they aim to maintain healthy soils because it enhances their ability to produce a good crop under a range of climatic conditions, thereby reducing their vulnerability.

Market and economic conditions are a constant influence on all farms, but this influence is not felt equally from one operation to the next (Table 4). Variable commodity prices were an exposure of great concern to the majority of producers. Beef, hog and cash crop operators are particularly sensitive to price fluctuations because these commodities are sold in a world market where prices are in constant flux; hence their income is variable and uncertain from year to year. The dairy and poultry operations, on the other hand, are in supply-managed, quota systems where price, and income, is more stable. For them, higher crop prices can be a negative influence because it raises the price of feed. Other economic forces that influence the farm operation include changes in interest rates, the value of the Canadian dollar, input costs, and land values, all of which influence producers bottom line.

While these economic forces represent exposures that affect the farm directly, their importance extends beyond that, influencing producers' vulnerability to climatic conditions as well. Firstly, variable market prices have the ability to enhance or dampen the effect of climatic conditions. Producers characterized really bad years as ones with low yield and low price. Thus farmers are in a position where they may be 'double exposed' to risks and are in a sense 'double losers' (O'Brien and Leichenko 2000). High prices, on the other hand, can compensate for climate-induced yield losses, resulting in more average income years. Economic conditions also affect farmers' adaptive capacity. Shrinking profit margins due to high input costs and low prices limit an operations' ability to withstand repeated years of crop losses without financial debt or stress, it limits their ability to purchase crop insurance or risk-reducing technologies, and prompts farmers to reduce their inputs and input costs, such as fertilizer and sprays, which in turn increases their vulnerability.

Municipal, provincial and federal government policies influence the market, business, and overall decision-making environment within which farms operate within, as well as the ability to manage climatic risks (Table 5). Farmers reported being affected by local regulations, such as minimum distance separation requirements between livestock operations and neighboring land uses, by provincial nutrient-management legislation, and at the federal level through agricultural and foreign policies, such as the supply-management system in Canada. International trade agreements have opened up commodity markets and caused the increased volatility of commodity prices, which is now a significant exposure for Canadian producers. In Ontario, there used to be extension officers who would visit farms and provide information on the tools and techniques available to manage environmental risks, but this program has been phased out. In its place the Ministry of Agriculture provides information on various risks and risk management strategies to producers, but the service is provided through the internet which may limit access to older and/or less technologically inclined farmers. Government support programs can increase producers' capacity to cope with climate- and market-related risks through programs such as crop insurance, income stabilization, and disaster relief. However, these programs are often changing, which can become an exposure in itself, as described by a producer:

> "It took 10 years to develop Market Revenue and GRIP program, to a spot where it was workable, and now the new government comes in and changes it all – not necessarily for the better... When the government flip flops on policy it's difficult to adapt."

While the majority of risk exposures are forces that are external to the farm, the way in which they are experienced may be influenced by factors relating to the farm itself. Throughout the research, farmers described how relationships with family members or business partners, the health and well being of family members and unexpected crises like fires or farm accidents have important influences on their operations. Many farmers noted that their children's interest in becoming part of the business was a key factor in decisions made to increase farm size or expand their operations into new business areas, decisions that in turn affect farm success. For those farmers nearing retirement and without children wanting to take over the business, there is little incentive to invest in long-term risk management strategies, such as implementing strategic adaptations to anticipated climate change.

It is clear that Perth County farms and farmers are exposed and sensitive to a range of climatic and non-climatic forces that do not act in isolation of each other. Climatic conditions were consistently cited as an important factor affecting farm success each year, not only because of direct effects on crop yields, but also indirect effects on pest outbreaks and livestock stress, and the resulting effect to farm income. However, even with the best growing conditions, overall income in a year is also influenced by commodity prices and input costs, which in turn reflect processes and policies occurring at a broader international scale. These findings indicate that climatic stresses are often expressed in economic terms by farmers, which are simultaneously influenced by non-climatic forces; these external forces present risks to the farm itself, but in turn influence the degree and way in which producers are vulnerable to climatic stresses.

5.2 Farm-level adaptations to climate risks

To develop an understanding of an agricultural system's *adaptive capacity* it is helpful to identify the types and forms of adaptation that are possible, who implements these actions, and under what conditions. Perth County farmers identified a wide range of risk management strategies for responding to various climatic risks, as summarized in Table 6. Short-term, tactical responses farm production practices were the most common strategies employed. In years where there was a shortage of hay, due to insufficient or excess moisture, producers could supplement feed either with other crops that they grew (grain, corn), with feed stored in good crop years, or with purchased feed. In wet seasons, when the corn or soybean crop is of poor quality, it is used for feed rather than being sold to the market, an option that is especially effective for farmers with both crops and livestock. To avoid heat stress in summers, livestock are kept in the barn where it is cooler or other shaded areas. Farmers also sprayed to prevent or respond to pest outbreaks; the outbreak of aphids in 2001, however, was a problem that they had not previously encountered and were unprepared for.

Strategic practices are also employed to manage risk over the long-term. Some of these are technological responses, such as improving ventilation in poultry barns to reduce the harm caused by excessively hot summers. A strategic adaptation that received general consensus as being effective for dealing with moisture-related risks was to tile drain the land. The majority of the interviewees have systematically tiled most of their land, although it is a gradual process as it is a costly adaptation. Farmers have found that the tiled land improved crop yields in both wet and dry years, and is thus worth the investment. These strategic adaptations increase producers' capacities to manage extreme heat and moisture-related risks.

Farmers have different levels of control or influence over particular adaptations, with some available for implementation at the decision of a single operator, others being shaped by multiple stakeholders in farming, government and elsewhere. Adaptations can also be distinguished based on their timing, whether adaptations are taken in anticipation of a potential risk, during the realization of the risk or in reaction to it; although given the dynamic nature of climate, climate change, and farmer decision-making, these distinctions are not always clear. Table 7 organizes farmers' adaptive responses based on Wandel and Smit's (2000) categorization according to the timing and the level of farmer control. Farmers appear to make anticipatory adaptations to climatic risks on an on-going basis through practices such as crop rotation to break disease cycles and maintain healthy soils, planting a range of crop varieties, no-till practices, and investing in equipment or biotechnology. Forty percent of interviewees acknowledged their use of Roundup Ready® soybeans or *Bt*-corn, either in the past or currently, with reasons for use including increased yields from reduced pest damage, reduced pesticide and herbicide costs, and drought tolerance. On the other hand, reasons for non-adoption were that producers did not agree with the use of biotechnology and the share of profits that went to the seed companies, they felt that crop rotation was a cheaper, more beneficial pest management strategy, or they could receive premiums for identity preserved (non-GMO) commodities. This shows that climate, let-alone climate change, is not the only force to which producers respond, and adaptations to manage climate-related need to balance other considerations.

Table 6 Examples of climatic exposures, impacts and corresponding farm-level adaptations

Climatic exposures	Impact on farms	Farm-level adaptation
Good weather (hot sunny weather with timely rains)	Improved crop yields, reduce feed costs if livestock farmer	• Stockpile hay • Make improvements to operation • Pay down debt, buy more land
Hot summers	High heat units	• Plant longer day corn, beans
	Beef cattle weight gain slows down	• Ensure shade is available • Keep cattle cooler in barn, where it is cooler
	Too hot in chicken barn	• Increased ventilation
	Heat reduces hogs conception rate, semen quality reduced	• More diligent pregnancy checks • More artificial insemination • Air conditioner for barn • Overbreed hogs
Drought	Aphids on soybeans, lost half the yield	• New problem, no response • Crop insurance • In future, would spray
	Weeds do not respond to herbicide	• Round-up is safer in drought years • Use different sprays or none at all: if drop is filled in and weeds under control, don't have to spray
	Hay does not grow back, reduced hay harvest	• Only get first and second cut • Do not sell hay • Buy grain
Wet growing season	Trouble making hay	• Pasture cattle on hay field • Just waited • Did not cut at all • Kept hay from previous year • Tile drained field
	Rust in grain	• No response
Wet fall	Lost bean crop	• Used for feed • Stopped growing beans • Tiled fields
	Poor corn	• Crop insurance claim • Plowed it under • Increased storage capacity to • Stockpile feed from good years • Made cob meal. Corn silage gives more leeway, can harvest earlier before it is dry
Heavy rains, flooding fields	No specific impact	• Good management practices • Tile fields; repair tiles • No-till, protect soil • Take hollows in fields out of production (plant grass)
	Standing water in field, crop rotted	• No response
	Flattened soybean field	• Put in a berm to slow water, reduce erosion
	Soil erosion	• No response

Table 6 continued

Climatic exposures	Impact on farms	Farm-level adaptation
	Low heat units	• Plant different maturing varieties of corn, spread out risk
Combination of cold and wet weather	Poor quality crops	• Crop insurance • Bought feed
	Corn rust Corn would not dry down	• Insured corn the following year • Planted lower heat units following year • Used corn for feed
	Trouble making hay	• Neighbours gave them hay • Sold land following year
	Scouring problem with beef calves	• No response
	Hog feed consumption is higher	• Increase feed
Colder winter, no snow	Lost winter wheat	• Crop insurance claim
Warm winters	Possibility of insect problems	• Watch for insects (precaution)
	Risk of alfalfa being damaged	• No response

Some anticipatory adaptations are prompted by, or in reaction to, recent experiences with climatic conditions, blurring the distinction between anticipatory and reactive actions. Some producers, for example, planted corn with lower heat units following cold growing seasons or took up additional crop insurance. Others were prompted to tile drain additional land following a wet season. These responses, while not critical to the immediate operation of the farm, make use of hindsight to reduce exposure to similar conditions in the future.

Actions are also taken during (or shortly after) the occurrence of certain climatic conditions. In wet springs, farmers may plant seed directly into the moisture or delay planting until the soil dries. The later farmers wait, however, the higher the risk of not maturing a crop even if they switch to lower heat unit corn. Risks can also be transferred to other parties through the involvement in government safety-net programs; 70% of producers with crops purchased crop insurance, the majority of whom tended to insure at 80–90% coverage. Participation in these safety-net programs enhance producers' capacity to deal with climate-related risks that result in significant crop losses, including the aphid outbreak. However, there are limits to crop insurance; each claim filed results in a rise in the next year's insurance premiums and a decrease in the average yield upon which payments are based, thereby decreasing the payout for a claim occurring in the next five years. Thus there is a limited capacity to manage repeated years of losses. Other adaptive responses that involve more than individual farmers include renting out land for share-cropping, forward contracting to lock in a given crop price, although these practices are more driven by market-related risks than by climate.

The documentation of adaptation strategies shows that farmers currently have the capacity to deal with certain climatic exposures identified in the previous section. The severity of moisture extremes, for example, is reduced through actions such as tile drainage, no-till, and maintaining healthy soils. Technologies are available to

Table 7 Perth County farmers' adaptations to climate risks

Timing of management (with respect to hazard)		Levels of farmer control	
		Primarily individual	Primarily multi-stakeholder
Pre-risk (Anticipatory)	Risk reduction	Diversification of farm enterprise *Adding another farm enterprise; Custom work* Diversification of cropping system *Change crop hybrids; Plant a range of corn varieties with differing heat unit requirements* Soil conditioning *Crop Rotation Schedule; Applying manure to fields; Use red clover as a cover crop; No-till* Technological innovations *Investing in larger equipment improves efficiency, biotechnology* Improve drainage *Add drainage tiles* Off-farm income Change timing of farm practices *Breed cattle in spring to avoid hot weather*	Share-cropping
Pre-risk or during risk	Risk hedging	Carrying feed reserves *Maintain hay inventory; increase storage capacity* Alternative uses for poor crops *Feed poor quality cash crops; Pasture cattle on wet hay field; Make haylage and corn silage* Use pesticides for insect infestations Change timing of operations *Plant seed to moisture; Wait until it is dry to plant; Replant crop if seedlings drown; Harvest crop according to weather* Livestock husbandry responses for hot summer weather *Overbreed pigs to compensate for low conception rate in summer heat; Keep pigs watered down on hot days; Run water over barn roof to lower temperature in chicken barn*	Forward contracting

Table 7 continued

Timing of management (with respect to hazard)		Levels of farmer control	
		Primarily individual	Primarily multi-stakeholder
	Risk Transfer		Crop insurance Government safety-net programs
Post-risk (Reactive)	Risk mitigation	Buy feed for livestock when crop fails Engineer structures to prevent crop loss *Build berm around field to reduce erosion following heavy rains* Stop growing sensitive crops Respond to growing season conditions the next year *Planted lower heat unit corn after a cool year; insured corn after a poor year* Keep livestock out of hot sun *Add ventilating fans; build shelter; keep animals in barn*	Government safety-net programs

enhance farmers' capacities, although their adoption is influenced by other non-climatic forces or constrained by financial resources. There are limits to the effectiveness of some management practices, however, and crop losses do occur nonetheless. In such cases, government safety-nets provide a buffer, reducing producers' vulnerability. This discussion also shows that adaptive capacity is dynamic, as producers change their practices in response to climatic events in order to enhance their capacity to deal with similar events in the future.

5.3 Perceptions of climate change

The likelihood that an individual will adapt is in large part dependent on their perception of risk; if the stimulus is not viewed as a threat then adaptation is less likely (Hewitt 1997). Perceptions of risk are influenced by the way it is communicated and by whom (scientists, media, public agencies, leaders), and the way the information is processed or filtered by the individual (Kasperson and Kasperson 2005). In light of this, farmers in this study were asked broadly about what they see as future risks for their operation and later about their views of climate change. The future risks they identified include financial uncertainty, possible government policy and legislative changes, changes to the agricultural community, urbanization pressures and weather. Six of twenty-five farmers interviewed identified weather as a risk for the future, and of these only two made specific reference to climate change, indicating that it is not an issue that is on their minds. This is reinforced by a statement made by a dairy farmer:

> "[Worrying about climate change] doesn't keep me up at night. In the short term, I would be more concerned about interest rates. I am not concerned about climate change."

Participants were then asked specifically about future climate risks and opportunities, still not mentioning climate change specifically. They identified potential benefits, including the ability to grow higher heat units varieties, so long as there is adequate precipitation, cold winters being better for animal health, and adequate spring moisture. Potential risks identified were increasingly unpredictable weather, wet and cold conditions, longer heat waves, and repeated drought, which might increase crop insurance claims, subsequently increasing premiums. Late springs were also identified as a threat as they inhibit spring planting, while warmer winters would lead to increased and new insect and pest problems, and make livestock more susceptible to disease. Thus while it did not appear previously that climate change was on their minds, there is an indication of an awareness of climate change related issues.

Farmers were then asked specifically about their views and concerns about climate change. The most commonly held perception by 62% of the respondents is that it is a long-term warming trend, more often referring to it as global warming or the greenhouse effect. One cash cropper noted:

> "Right now we are in a good transition part [of climate change]. We used to live south of London [Ontario, a city to the south of Perth County]. Winters there when I was growing up are like they are now here. [Climate change] is impacting that area now. It is going to keep moving. I believe that climate change is a trend that has always been, but we have really sped it up."

Only 17% associated climate change with a change in variability and extremes, including more frequent droughts, and it was these respondents who expressed the greatest degree of concern for climate change. Twenty-one percent of producers were entirely skeptical about the issue, stating that the changes were due to natural climate cycles. Just over half of interviewees expressed some degree of concern with climate change, particularly with respect to drought, unpredictable weather, or what it would mean for their children. Forty-two percent of interviewees, however, were entirely unconcerned with climate change. This indifference may be fuelled in part by the way it is viewed as long-term trend—an event that may happen in the distant future and that will not be experienced until their children or grandchildren are farming. "*It will be so far down the road that I will be long forgotten.*" Thus, some producers do not feel that it will affect them and instead are worried about the more pressing issues that they must deal with.

The nature of Perth County farmers' perceptions of climate change is a fundamental feature affecting their vulnerability. It demonstrates how the characteristics of the farm system influence the way in which stimuli such as climate are felt, which together represent exposure-sensitivity. Farmers dependent on cash crops, which are more directly sensitive to climate and weather, expressed the greatest level of concern about climatic change, while it was primarily the hog farmers and some dairy farmers who expressed no concerns about climate change. Their perceptions may also influence their adaptive capacity, as those who are more concerned and aware of the climate change risks are more likely to make efforts to prepare and to take anticipatory actions to reduce risks than those who are less concerned or skeptical.

5.4 Future vulnerability to climate-related risks

Perth County farmers are very aware of existing climate-related risks that affect their operations. However, they are generally unaware of or, in many cases, unconcerned about the potential effects of climate change. In part this likely reflects the conventional description of climate change in the sector—small increases in average temperature over several decades. However, lack of concern regarding climate change does not necessarily increase farmers' vulnerability to future climate risks. Farmers are continually responding to inter-annual climatic variability and employing adaptations to reduce their vulnerability to climate risks; a capacity to adapt to current climatic variability offers a certain level of preparedness for future climate changes. The capacity can be further enhanced by identifying and overcoming factors that constrain adaptation. Table 8 summarizes some of the factors facilitating and constraining adaptation as they relate to the broad determinants of adaptive capacity identified earlier.

The climatic conditions to which farmers will be vulnerable in the future are those to which they are currently most exposed-sensitive and to which they possess the least ability to adapt to, or that will change in such a way that exceeds their current adaptive capacity. For example, as outlined in Sect. 3, heat waves may become more frequent or intense, which would negatively impact livestock. Currently, some farmers have been able to install air conditioning systems to deal with the problem, but these are expensive and with farmers' net incomes decreasing due to market volatility, this adaptation may be constrained. Warmer winters may also lead to new

Table 8 Perth County farmers' adaptive capacity to climate change and risks

Determinants of adaptive capacity	Benefits to incorporating adaptive practices	Barriers to incorporating adaptive practices
Awareness	• Farmers refer to weather as a very important condition influencing any year • Type of farm seems to influence perception (i.e. Cash crop farmers are more concerned about climate change than farmers with mixed farms, or livestock only)	• Farmers are unaware/unconcerned about climate change • Farmers have more immediate concerns • Farmers are confident with their own adaptive abilities • Farmers are generally accepting of their own limitations in the face of extreme weather conditions • Perth County farmers are confident in the local conditions
Technology	• Larger machinery increases efficiency & allows farmers to optimize good weather • New seed varieties more resilient to weather, pests • No-till improves soil conditioning	• Informed decisions require extensive research • New cropping and livestock machinery is often complicated, means a steep learning curve once it is acquired • High cost of new technology • Other factors to consider in the adoption of biotechnology • Sometimes technological response is not available to address climate conditions
Resources	• Farmers who are growing their operations can incorporate new technology • Sustained low interest rates permit growth • Access to capital available • Owning equipment allows farmer to optimize timing of field work	• Ontario net farm income declining • Farmers retiring soon not likely to invest in changes • Small farms have less access to capital for new technology • Volatile commodity prices increase financial risk, cause producers to cut costs (e.g. input costs) • Farmers who rely on custom operators have less control of timing of field work
Institutions	• Some regulations indirectly encourage adaptation • Provide safety nets to manage climate-related crop losses and income variability	• Governments do not yet perceive climate change as a risk to producers • Lack of communication from government regarding climate change impacts and adaptation • Some regulations indirectly restrict adaptation • Changes in safety net programs can negatively affect producers • Canadian subsidies not equal to US and EU subsidies, puts Canadian farmers at a disadvantage
Human capital	• Perth County farming community is skilled, innovative, experienced and knowledgeable • Farmers who are early innovators are motivated to stay current with new practices and technologies	• Some farmers are late innovators, and wait until technology is proven before incorporating it • Inexperience dealing with new risks (e.g. pests) limits response

Table 8 continued

Determinants of adaptive capacity	Benefits to incorporating adaptive practices	Barriers to incorporating adaptive practices
	• Farmer's children joining operation brings growth and new vision	• Knowledge, experience, and ability to learn influences the use of technologies
	• Repeated experience with risks allows farmers to improve risk management ability	• If farmer's children do not join farm business growth is often restricted, which can restrict incorporating new practices
		• Some farmers choose to stay small, restricts incorporating new technologies
Social capital	• Perth County has an established agricultural industry	• Farms are increasing in size: competition from large farms threatens smaller operations
	• Established social network, including several agricultural organizations	• Young people are not becoming farmers
	• Established agricultural infrastructure and supply system	
Risk spreading	• History of government safety net programs	• Safety net programs are being revised, and are uncertain at present (not necessarily a barrier)
	• Some farmers have diversified operations	• Modernization of agriculture has encouraged specialization, some farmers are reluctant to diversify
	• Livestock farmers can feed poor crops	• Agriculture is vulnerable to failure in food safety systems
	• Some farmers have off-farm income	
Information management	• Perth County farmers have many well-established adaptation options to climatic variability	• Limited extension services to communicate climate change impacts and adaptation
	• Internet improves farmers' access to information	• New weather-related problems catch farmers without a response (i.e. aphids)
	• Seed companies inform farmers about weather-tolerant varieties	

or more pest outbreaks. As producers experienced, they have a low capacity to adapt to unexpected pest outbreaks; aphids destroyed the soybean crops because farmers did not have experience dealing with this pest previously. For this incident, they had to take out crop insurance, but farmers might have a greater adaptive capacity in a subsequent exposure by knowing which sprays to use and when. While crop insurance provides a safety net for single events, its effectiveness will decrease with repeated exposures because with each claim the next year's premium rises and the next payout falls. With a potential increase in the frequency and severity of droughts, farmers are particularly vulnerable to repeated drought years.

Adaptive capacity, however, is not static. Farmers have shown a confidence in particular in advancements in technology, such as improved machinery and pest-resistant seed varieties, as improving their adaptive capacity. One focus group observed that several management tools and technologies presently available to farmers to respond to poor weather conditions, such as tile drainage, improved crop genetics, and internet access to weather forecasts, were not available to previous generations of farmers. Some constraints on continued use of technology to enhance adaptive capacity are the affordability, the need to divert time from other aspects of the farm business to research new opportunities, and farmers' views of biotechnology. Furthermore, as farmers have to deal with other immediate issues like fluctuating commodity prices, which cause net incomes to vary from year to year, farmers may opt to save money and reduce costs rather than purchasing additional climate-risk saving technologies.

6 Conclusion

This study has shown that a participatory, stakeholder-based approach can provide insights into the vulnerability of an agricultural system to climate change, including climate variability and extremes. It identifies various attributes of climate and climate change that are problematic or present opportunities for farmers. To farmers in this region, average temperatures are of less concern than other climate variables, notably moisture extremes, availability of sufficient heat units in the growing season, pest outbreaks, and climate extremes like heat waves. While many farmers do not associate these with climate change, the science community has concluded that these variations and extremes may be altered with climate change (IPCC 2001a).

These results show the need for assessments of the probabilities of change in climatic characteristics that are important to stakeholders, in this case farmers. It shows that climatic stimuli are experienced together with numerous non-climatic forces, including the broader economic, institutional and social forces, and local characteristics of the farm and farm family that influence an operations' vulnerability to certain stimuli. While the external forces represent risks independent of climate, they also influence the severity of climate exposures and the ability of producers to adapt. The immediate importance of these non-climatic risks, particularly commodity price fluctuations, also serves to detract from longer-term issues such as climate change, potentially constraining anticipatory adaptations. Farmers, however, are continually managing for climatic risks either in anticipation of, during, or in reaction to the risks. As farmers learn from past experiences, they often implement long-term, strategic adaptations that enhance their capacity to manage future risks. Some of these strategic adaptations, however, are costly and may be constrained in part because of the variable net incomes they receive due to variable market, economic, and climatic conditions.

Despite the uncertainty of spatial and temporal patterns of future climate, farmers in Perth County are aware of those climatic or weather conditions that most greatly affect their operations, although in many cases they are unconcerned with future climate change. While farmers in Perth County have considerable capacity to deal with current risks, some changes in climate, such as new pest outbreaks or increased frequency or severity of droughts, would severely test their adaptive capacity. Enhancement of the region's ability to deal with climate change would likely require action beyond the control of individual producers to include public agencies, initiatives in awareness raising, policy review, insurance programs, and technological developments. Initiatives that enhance their capacity to manage a greater range of climatic conditions in the present would in turn reduce their future vulnerability and sidestep the barrier imposed by their perceptions of and lack of concern for climate change.

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