Multiple Exposures and Dynamic Vulnerability: Evidence From the Grape Industry in the Okanagan Valley, Canada

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Multiple exposures and dynamic vulnerability: Evidence from the grape industry in the Okanagan Valley, Canada

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Abstract

This paper assesses the vulnerability of grape growers and winery operators in the Okanagan Valley, British Columbia to climate variability and change, in the context of other sources of risk. Through interviews and focus groups, producers identified the climatic and non-climatic risks relevant to them and the strategies employed to manage these risks. The results show that the presence of multiple exposures affects the way in which producers are vulnerable to climate change. Producers are vulnerable to conditions that not only affect crop yield, but also affect their ability to compete in or sell to the market. Their sensitivity to these conditions is influenced in part by institutional factors such as trade liberalization and a ''markup-free delivery'' policy. Producers' ability to adapt or cope with these risks varies depending on such factors as the availability of resources and technology, and access to government programmes. Producers will likely face challenges associated with the supply of water for irrigation due to a combination of climatic changes and changing demographics in the Okanagan Valley, which in turn affect their ability to adapt to climatic conditions. Finally, adaptations made by producers can change the nature of the operation and its vulnerability, demonstrating the dynamic nature of vulnerability.

Keywords: Climate change; Adaptation; Grapes; Wine; Multiple risks; Canadian agriculture; Vulnerability

1. Introduction

Climate change is expected to present both risks and opportunities for agricultural systems, and there is evidence that climate change effects are already being experienced (Chiotti, 1998; Scheraga and Grambsch, 1998; Gitay et al., 2001; Walther et al., 2002). In addition to a global rise in temperatures, it is projected that some extreme events will increase in frequency and severity as a result of a shift in mean conditions and/or a change in the natural variability of climate (Easterling et al., 2000; McCarthy et al., 2001). It is these extreme events and climatic variability that will likely be the most challenging for farmers and for societies in general (Burton, 1997; Adger, 1999; Bryant et al., 2000; Rosenzweig et al., 2001). Farmers have the ability to reduce the adverse effects of climate change or seize opportunities by adapting to the changing conditions (Easterling, 1996; Wheaton and MacIver, 1999; Bryant et al., 2000; Smit and Skinner, 2002). However, the process through which adaptation will occur, or indeed does occur presently, is not well understood (Brklacich et al., 2000; Bryant et al., 2000; Lemmen and Warren, 2004).

One obvious complication is the impact of non-climatic stimuli on adaptation decisions. Farmers work within an environment characterized by highly variable political, economic, institutional, and biophysical conditions (Fleisher, 1990; Brklacich et al., 1997; Kandlikar and Risbey, 2000; Wandel and Smit, 2000). These multiple exposures interact to influence farmers' decisions, or more precisely their management practices, and hence agricultural adaptations to climatic variability and change cannot be conceived via simple stress–response models (Risbey et al., 1999; Smit et al., 2000; Bradshaw et al., 2004; Adger et al., 2005). The interactive effect of multiple exposures has the potential to be experienced and responded to by individual farmers in highly variable ways, owing to differing personalities, farming systems, and circumstances (Smit et al., 1996; Kandlikar and Risbey, 2000).

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It follows that agriculture's vulnerability to climate change is related to multiple exposures and to the local and broad-scale conditions that facilitate or constrain adaptation (Holloway and Ilbery, 1997; Smithers and Smit, 1997; O'Brien et al., 2004a). The term vulnerability has been increasingly adopted by the climate change community, reflecting its inclusion in international agreements and documents authored by the likes of the UNFCCC and the IPCC (Klein et al., 1999; Handmer et al., 1999; Kasperson et al., 2001; Turner et al., 2003; Adger, 2006). System-based vulnerability assessments have emerged as a complement to traditional scenario-based impact assessments, particularly by giving more explicit treatment to the role of human agency (Chiotti and Johnston, 1995; Bryant et al., 2000; Burton et al., 2002; Ebi et al., 2004). The vulnerability approach draws on past and current experiences to understand how particular groups, communities or individuals experience and manage climatic risks, to identify the factors that facilitate or constrain this management, and to assess the prospects for improving this management capacity, especially in light of anticipated future risks (Klein and MacIver, 1999; Adger, 1999; Ford and Smit, 2004).

A particular strength of the vulnerability approach is its recognition of the role of non-climatic forces that contribute to vulnerability. These forces are commonly discussed in terms of how they influence the sensitivity and adaptive capacity of a system (Watts and Bohle, 1993; Blaikie et al., 1994; Cutter, 1996; Adger, 2003). However, in the climate change field, vulnerability analyses have tended to focus on particular stressors, including climate variability and change (Downing et al., 1997; Vásquez-León et al., 2003), floods (Pelling, 1997; Mustafa, 1998; Few, 2003), drought (Liverman, 1999; Wilhelmi and Wilhite, 2002), and extreme storms (Dorland et al., 1999; Clark et al., 1998; Adger, 1999). Some recent research (e.g. Pelling and Uitto, 2001; O'Brien et al., 2004b) has sought to broaden this focus, arguing that climate change occurs simultaneously with economic globalization, and may produce cumulative effects, a concept that O'Brien and Leichenko (2000) term "double exposure." Leichenko and O'Brien (2002) further argue that the environmental and socioeconomic contexts that influence vulnerability are in a state of continual change. Hence vulnerability is dynamic and should be seen as a process rather than a static state or snapshot in time (Handmer et al., 1999; Adger and Kelly, 1999; Turner et al., 2003; Smit and Pilifosova, 2003; O'Brien et al., 2004b).

In scenario-based studies, the researcher selects the stressors to be analysed. A recent strand of research has engaged stakeholders in the community of interest to identify the climatic and non-climatic stressors that are relevant to them. This work provides insights into the place of climate and climate change within individuals' decision-making frameworks (Defoer, 2002; Conde and Lonsdale, 2004; Sutherland et al., 2005; Wall and Smit, 2005). In this study, it is the agricultural producers who identify the relevant exposures and how adaptation to climate change might occur in the context of multiple risks. We also attempt to show that the dynamism of vulnerability includes feedbacks where adaptations made to climate and other risks can change the way in which the system is vulnerable to other stresses, a concept argued also by McLeman and Smit (2006).

This paper assesses the vulnerability of grape growers and winery operators in the Okanagan Valley, British Columbia, Canada to climatic variability and change, in the context of other sources of risk. It is well established that climate is a major factor influencing the distribution and flavour of grapes (Jackson and Schuster, 1981; Mullins, 1992; Gladstones, 1992; Happ, 1999). Grape and wine production has been the focus of several climate change impact studies, which tend to concentrate on the physical relationship between climate and grape development (e.g. Kenny and Harrison, 1992; Jones and Davis, 2000; Tate, 2001; Caprio and Quamme, 2002; Jones et al., 2004; Hayhoe et al., 2004; Wake, 2005). Using a selection of techniques, including scenario-based models, test plots, crop simulation models, or regression analyses, these studies analyse the impact of past and/or future climate change and enhanced carbon dioxide on grape growth, grape quality, crop water demand, and phenology (Bindi et al., 2000, 2001; Nemani et al., 2001; Winkler et al., 2002; Neilson et al., 2004a; Jones et al., 2005). However, there has been less consideration of multiple exposures, dynamic vulnerability, or adaptation.

This paper briefly synthesizes scholarship dealing with vulnerability and agricultural systems, highlighting similarities between the two fields. This synthesis is followed by a description of the study area and methods for the empirical investigation of farmers' vulnerability to climatic variability and change. The findings are discussed in terms of producers' current exposure and sensitivity to risks, including the interactive effects of these risks, and their current capacity to adapt. These findings on producers' vulnerability are extended into the future by incorporating information on future climate and possible adaptations.

2. Farm-level vulnerability

The concept of vulnerability is not unique to the climate change scholarship; it has roots in the natural hazards, food security, and political ecology literatures, where it has taken on various meanings and interpretations (Adger, 1996; Kelly and Adger, 2000; Brooks, 2003). Biophysical vulnerability usually relates to the likelihood of impacts from a natural hazard, focusing on the characteristics of the hazard, such as its magnitude, frequency, and areal extent (Burton et al., 1993; Adger, 1996; Hewitt, 1997). Social vulnerability usually refers to the state of a human system, shaped by political, economic, and social processes that can put people at risk and can also reduce their ability to avoid, withstand, or recover from harm (Watts and Bohle, 1993; Bohle et al., 1994; Adger, 1999; Cutter et al., 2003). Some commonly identified examples of such factors are poverty, inequitable food entitlements, or access to resources and power (Sen, 1981; Downing, 1991; Bohle et al., 1994; Adger and Kelly, 1999).

In the climate change field, conceptualizations of vulnerability combine natural and social factors, and it is generally viewed as a function of exposure, sensitivity, and adaptive capacity (McCarthy et al., 2001; Yohe and Tol, 2002; Fraser et al., 2003; Turner et al., 2003). The degree to which a system (e.g. household, community, or country) is vulnerable to an environmental stimulus is related to the system's propensity to be adversely affected, and the system's ability to deal with or recover from its adverse impacts (Blaikie et al., 1994; Kasperson et al., 2001; Leichenko and O'Brien, 2002; Smit and Pilofosova, 2003). The propensity to be affected by a stimulus is related to both the exposure and sensitivity of a system, where exposure is the condition of being subject to detrimental effect, and reflects the biophysical characteristics of the stimulus relative to the location and nature of the system (Hewitt, 1997; Ford and Smit, 2004). Sensitivity refers the degree to which a system is affected by or responsive to a stimulus, and is related to characteristics of the system and to broader non-climatic factors (e.g. land use, livelihood, infrastructure, government policy) (Ziervogel and Calder, 2003; Adger, 2006; Füssel and Klein, 2006). Exposure and sensitivity are intimately related concepts, with discussion of exposure typically implying a degree of sensitivity and vice versa (O'Brien et al., 2004b; Ford and Smit, 2004). If a system is not sensitive to a stimulus to which it is exposed then there would be no effect, and it would not be relevant to the system. Thus the two terms are discussed jointly.

The capacity of a system to adapt or recover, also known as adaptability, coping ability, or resilience, is influenced by such factors as the availability of financial, technological, and information resources, infrastructure, institutions, human capital, social networks, and risk perception; these factors are a reflection of both local characteristics of the system and broader external influences (Watts and Bohle, 1993; Wheaton and MacIver, 1999; Kelly and Adger, 2000; Smit and Wandel, 2006).

Vulnerability is a useful concept because it accounts for interconnected processes occurring at different scales. It reflects the dynamic characteristics of the system, as well as broader conditions or processes within which the system operates (Handmer et al., 1999; Wilbanks and Kates, 1999; O'Brien et al. 2004c). The concept of multi-scale factors influencing a system is also found in the scholarship on agricultural decision-making. In this field, the farm is considered the main decision-making unit, composed of three elements (land, labour, and capital) that are connected via management. The farm is viewed as a dynamic system that operates within and changes in response to external, interconnected systems (ecological, economic, social, and political) (Olmstead, 1970; Bowler, 1992; Bryant and Johnston, 1992). These external forces provide risks, opportunities, and constraints to the functioning of the farm, and influence producers' decision-making (Bryant and Johnston, 1992). It follows then that these external forces and local farm characteristics influence the farm system's exposure, sensitivity, and adaptive capacity, and hence its vulnerability.

Producers are exposed and sensitive to risks beyond climate and weather. Several types of risk for agriculture in the developed world have been identified, including production risk, price or market risk, institutional risk, financial risk, and personal risk (see Table 1). There are many examples of these risks that have prompted farmers to adjust their operations, including declining output prices, increasing input costs, inconsistent government support, more sophisticated technology, changing environmental conditions, increased urban pressures, increased environmental regulations, and increased competition for rural land resources (Marsden, 1998; Bradshaw and Smit, 1997; Winter, 2000; Smithers and Johnson, 2004). These risks represent potential exposures for the farm, and the adjustments made to reduce risk can influence the system's sensitivity.

The adaptive capacity of a farm is a function of the tools and resources available on the farm that relate to the elements land, labour and capital, including farm income, access to credit, equipment, and technology, and the capabilities of the farmer in terms of his/her skills, age, and perception of risk. Adaptive capacity is also shaped by external factors, such as the availability of government

Table 1
Types of risk in agriculture (From: Hardaker et al., 1997; Harwood et al., 1999; Kay et al., 2004)

Production or yield risk	chance of losses in output or yield as a result of events that are beyond the farmer's control, often related to weather, and/or related to technology.
Price or market risk	risk associated with changes in prices of outputs or inputs, which are seldom known when producers make choices about products and inputs; may include market access.
Institutional risk	risk related to changes in government policies and regulations; may impose unanticipated constraints on production practices, or new costs or taxes.
Financial risk	risk resulting from the way in which the farm's capital is obtained and financed; related to borrowing, uncertainty about future interest rates, the ability to meet debt payments, and lender's willingness to continue lending.
Human or personal risk	risk associated with the people who operate the farm, as when death, divorce, illness or injury, may result in disruption of farm production and profitability.

support programmes, the development of biotechnology, the market demand for crops that are suited to a changing climate, and the availability and accuracy of weather forecasts. This paper aims to identify the local and external elements of the farm system specific to Okanagan grape growers and winery operators that influence their vulnerability to climatic variability and change.

3. Study area and methods

The Okanagan Valley is located in the southern interior of British Columbia, stretching 250 km north–south to the border of the state of Washington, United States (Fig. 1). The long, narrow 8200 km^2 valley is flanked by mountain ranges and incised by a system of oblong lakes, of which the Okanagan Lake is the largest (Taylor and Barton, 2004). The combination of the rain shadow effects from the mountains and the moderating effects of the lakes creates a mild, dry, continental climate, the hottest and driest in British Columbia, but which varies along the length of the basin. The average annual precipitation ranges from 300 to 750 mm, with precipitation increasing to the north of the valley, as well as with higher elevations (Wilson, 1996; Neilson et al., 2001). Conversely, air temperatures decrease northward. Soil types also vary, with well-drained, sandy soils found in the south and darker, richer, clay and loam soils to the north and on benchlands (Wilson, 1996). The high latitude and continental climate of the valley is distinct from other traditional wine growing regions of the world, like the temperate regions of western France, northwestern California, and Australia (Jackson and Schuster, 1981). Fig. 2 compares the monthly degree days (above 10 °C) for the respective growing seasons of these four regions. In the peak summer months (July and August) Okanagan temperatures match those of other regions; however, the overall growing season is shorter, with significantly fewer degree days in the spring and fall. The valley is pushing the geographic limits of where premium grapes can be grown.

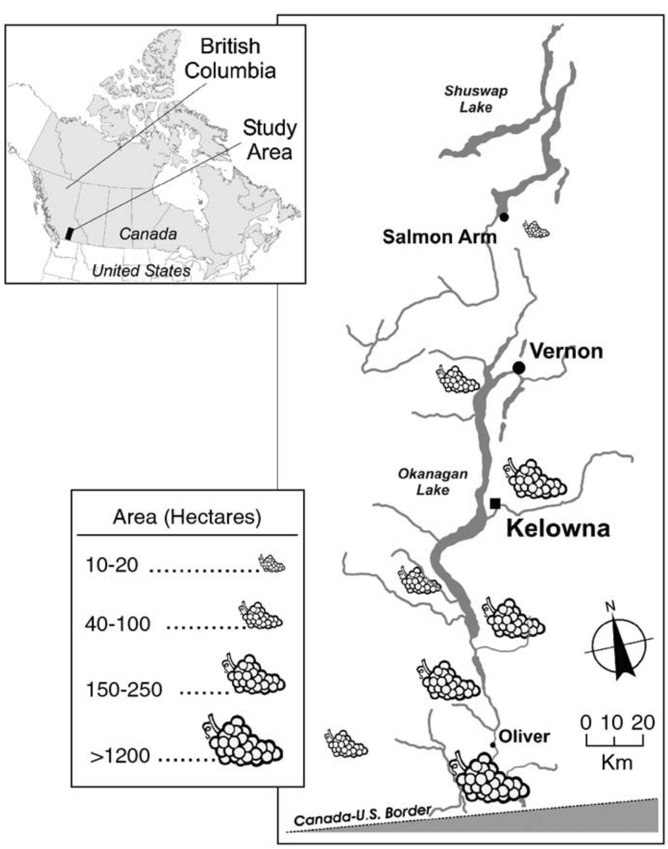

Fig. 1. Area and distribution of planted grapes in the Okanagan valley, BC, Canada, 2004 (Data source: MKWS, 2004).

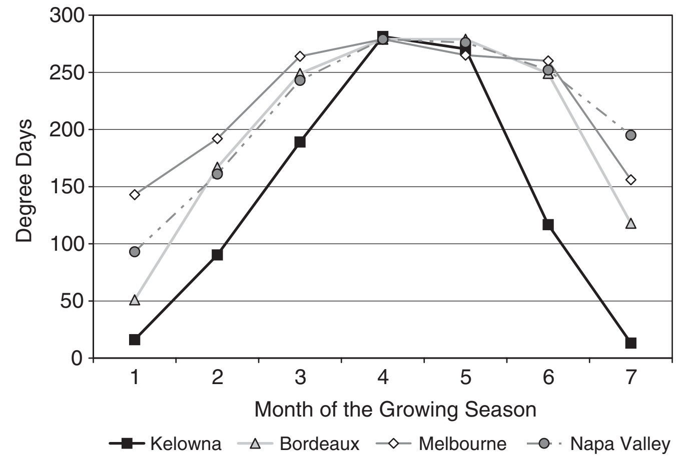

Fig. 2. Average monthly degree days above 10 °C for the growing seasons of four wine growing regions (Kelowna, British Columbia, Canada; Bordeaux, France; Melbourne, Victoria, Australia; Napa Valley, California, United States).
Data for Kelowna are based on climate normals from 1971 to 2000 obtained from Environment Canada; data for other regions are based on normals from 1960 to 1990 from Gladstone (1992).

Throughout the 1960s to the 1980s, grape growers in the valley planted mainly low-quality French and American hybrid grapes. The two primary reasons the industry was sustained for this period was because the local, 'unsophisticated' market demanded the sweet red wines made from these grapes (Schreiner, 2004) and because provincial legislation protected it from external competition (Heien and Sims, 2000). Following the signing of the Canada–United States Free Trade Agreement (FTA) in 1989, the industry underwent major transformation as local producers were unable to compete with the premium foreign wines that flooded the market (Schreiner, 2004). The government sponsored a CAN$28 million pullout program to remove the inferior grapes and, if desired, replant them with premium European varieties (Schreiner, 1996, 2004). Since the pullout, the area of planted grapes has rapidly increased from less than 530 ha to nearly 2200 ha in 15 years, with the greatest expansion occurring in the south where the valley experiences the hottest, driest, near-desert conditions (Fig. 1). Wine is now the second highest grossing commodity in the Okanagan Valley, after apples (BCMAFF, 2002).

To understand the conditions that are relevant to grape growers and their ability to adapt, a bottom-up vulnerability approach was adopted. Analyses aiming to quantitatively rank vulnerability of communities or regions have used scores to estimate surrogates for vulnerability and its components (Schimmelpfennig and Yohe, 1999; Alwang et al., 2001; Wilhelmi and Wilhite, 2002; Yohe and Tol, 2002; Luers et al., 2003; Sygna et al., 2004). The purpose of this study, however, is not to quantify or rank vulnerability based, but rather to understand the nature of vulnerability based on the experience of producer stakeholders. This type of study is broadly consistent with the UNDP's Adaptation Policy Framework (Lim and Spanger-Siegfried, 2004) and has been employed by Adger (1999), Vásquez-León et al. (2003), Ford and Smit (2004) and Sutherland et al. (2005). These studies have applied various combinations of participatory and ethnographic techniques such as interviews, surveying, focus groups, and participant observation to attempt to gain this understanding.

The method adopted here has two main stages of analysis: assessing current vulnerability and projecting future vulnerability. The first stage involves documenting the past and current risks (and opportunities) to which an individual or community has been exposed and is sensitive, and identifying the adaptive strategies employed to manage these risks. In this study, 22 semi-structured interviews and three focus group meetings were completed with independent grape growers and winery operators in summer 2004, to get an in-depth understanding of the complex behaviours and motivations behind farmer decision-making (Dunn, 2000; Cameron, 2000). The participants were selected through a combination of snowball and typical case sampling to obtain a sample of producers that is illustrative of the operations within the valley (Bradshaw and Stratford, 2000).

Producers were asked to describe their experiences over the last 10 years and prospects for the future, including their characterization of past good or bad years, the farm management practices employed to respond to these conditions, and the effectiveness of the responses. Initially, questions were left open to invite discussion on various types of risks, rather than prompting or limiting the focus to climatic variables. By identifying the forces that are important to producers in an unbiased way, the role of climate can be put into the context of producer's broader decision-making environment. Subsequently, producers were prompted to comment on the influence of specific drivers (e.g. market, government, environment, and climate). Responses in the individual interviews and the focus groups were analysed through latent content analysis, a procedure that aims to identify themes and meanings from the data (Dunn, 2000); data were coded based on the themes of adaptive capacity and exposures to which producers are sensitive.

The second stage of the vulnerability approach, projecting future vulnerability, incorporates data on potential change in the conditions that were identified as problematic, respondents' potential to manage those risks, and areas where capacity is constrained. The study utilized data from climate change scenarios for the southern interior region of British Columbia supplied by the Canadian Institute for Climate Studies (CICS) and an assessment of the future water supply in the Okanagan Valley by Cohen et al. (2004), which includes projections of changes in climate and hydrology for the valley.

4. Okanagan valley grape growers' vulnerability

4.1. Exposure and sensitivity

Producers' characterizations of past good and bad years revealed that climate-related conditions are indeed important for their operations; without prompting, over three-quarters of respondents identified at least one climatic condition as influential (Table 2). In good years, favourable conditions include a hot and dry summer with a long growing season and early spring. In addition to climatic conditions, half of the producers noted that good years were those where there was an increase in sales or an improvement in the quality of the product as a result of the producer's or winemaker's enhancement of skills through experience and learning. Since vulnerability denotes a susceptibility to harm, the focus in the remainder of this section is on conditions that are deemed problematic by producers. Fig. 3 illustrates the complex interaction of multiple local and broad-scale conditions that affect exposure, sensitivity and adaptive capacity, as they are discussed in the following sections.

In characterizing bad years, the climatic conditions that were repeatedly identified as problematic were those in which the growing season experienced lower temperatures and greater rainfall than normal. In these seasons, fewer heat units are available to grow and mature grapes in an already restricted climate and the vines are more prone to

Table 2
Types of risk that characterize bad years

Type of risk	Problematic conditions	Respondents (%)
Climate and weather	Cold and wet growing season	77
	Rain at bloom and harvest	
	Spring and fall frost	
	Severe winter	
	Extreme heat	
Market	Fewer tourists (from forest fires, SARS outbreak, "9/11," fuel prices)	36
	Market prices for table grapes	
Pests and diseases	Cutworm, leafhopper	18
	Powdery mildew	
Other	Rising input costs	9
	Technology failure	

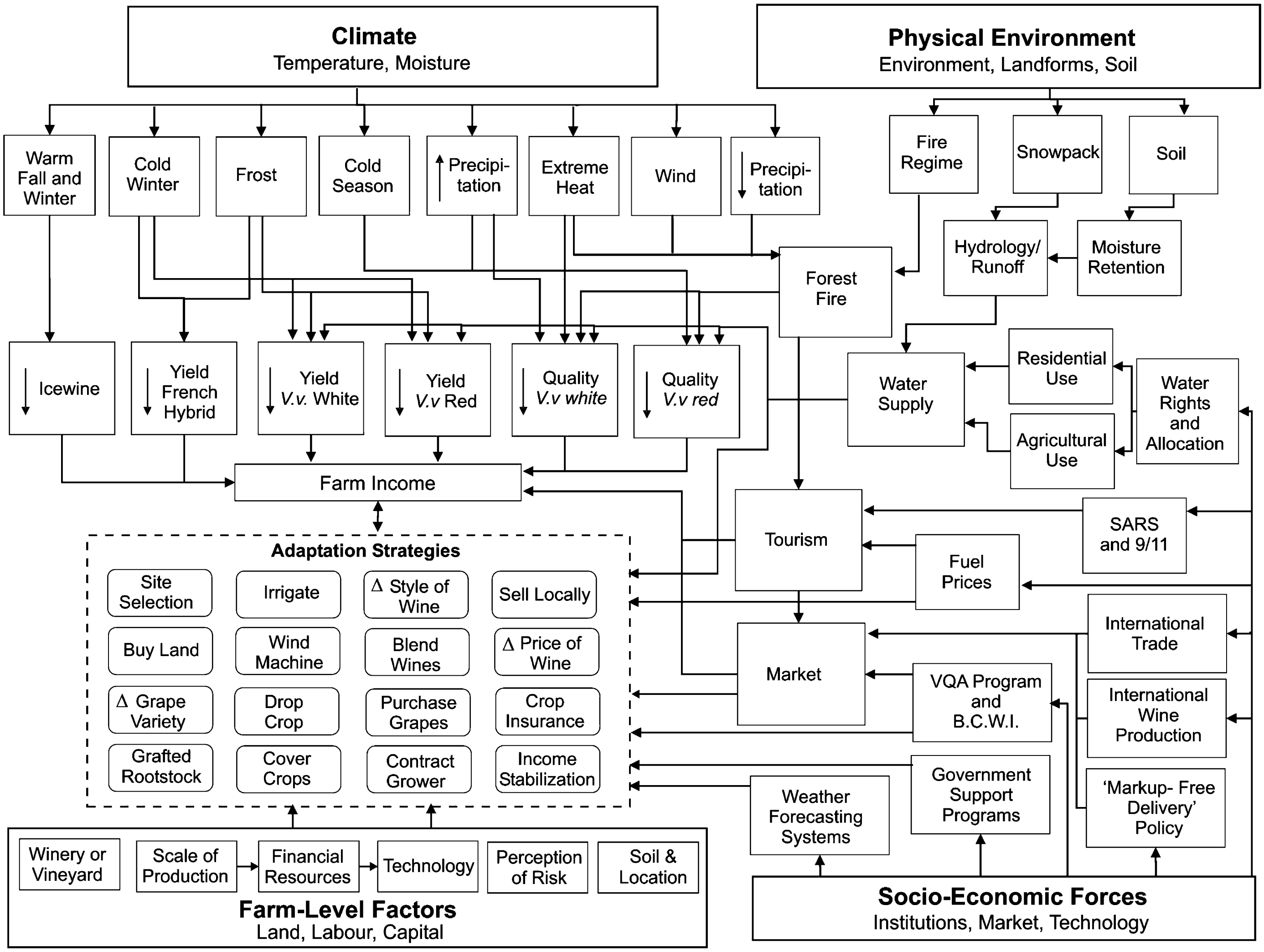

Fig. 3. Multi-scale factors influencing the farm-level vulnerability of Okanagan grape growers and winery operators.

mildew outbreaks. Excessive rain at bloom and harvest were especially disadvantageous because the former hampers pollination, or fruit set, and the latter causes the grape to swell, which dilutes the end flavour of the wine. All of the flavours and colours are found in the skin of the grape and so a small berry with a high skin to juice ratio yields a more concentrated, fruitier, stronger wine than would a large, plump grape.

Producers were also concerned with temperature extremes in the winter (less than $-23\,^{\circ}$C) and in the summer (more than $35\,^{\circ}$C) and spring and fall frosts (less than $-4\,^{\circ}$C). Winter temperatures below $18\,^{\circ}$C can cause minor injury to buds and shoots, but extreme winter temperatures for a period of 4 days or more can kill the vine; if vines are replanted it takes 5 years before they come into full production. Extreme heat in the summer is problematic for white grape varieties in particular because it causes the stomata on the leaves to close, thereby halting photosynthesis and berry development for a period of a few days to a few weeks. If the vine shuts down, maturation is then delayed in an already short season, increasing the risk of fall frost damage and reducing the chances of getting a fully matured crop; if photosynthesis does not properly resume, then flavour development may be impaired and the desired acid levels may decline, leaving a bitter tasting product. Fall frost is problematic because it can burn the leaves off the vine, inhibiting the plant from producing additional energy to mature the grape, or it can prevent the plant from building enough carbohydrates to prepare it for winter, making it more sensitive to low temperatures. In the spring, a frost can kill the buds or damage the vine, limiting crop production for that season. The exposure to frost varies throughout the valley and by operation, as producers can select frost-free sites or level out depressions in the vineyard where cold air can pool. In addition, operations in the south end of the valley are generally more exposed to frost because they do not experience the moderating effects of the lake.

Climate and weather, however, are not the only risks that concern producers. Producers also identified risks associated with their costs of production, pest and disease outbreaks, changing government policies, interest rates, failures in technology, and, especially, risks associated with the market, including the loss of the tourist market, competition from other wineries and wine growing regions, and losing consumer acceptance of the product (Fig. 3). Over one-third of producers had identified bad years in which local and non-local events (a large forest fire in Kelowna, the SARS outbreak, and the September 11 attacks in the United States) disrupted tourism, significantly reducing on-site sales at the wineries. While this affected winery operators more directly, independent grape growers noted a trickle down effect where wineries were likely to purchase fewer grapes from growers in order to cut costs.

Producers' identification of these non-climatic risks shows that farmers work within a multi-risk environment. Furthermore, it is the presence and interaction of these various risks that influences producers' exposures, sensitivities, and responses. The climate and the market are two types of risk that are intimately related. For example, the cold and wet seasons that producers repeatedly cited as problematic, as well as rain at harvest and extreme heat, do not damage the vine or reduce yield, but they affect the vine's ability to mature the grapes fully and hence influence the end flavour, or quality, of the product. A reduction in quality, in turn, reduces a winery's price premium or may even limit sales entirely. Thus, in this case, producers are not vulnerable to the climatic stress itself, but rather to the expression of the climate stress as a market risk.

Furthermore, this emphasis on quality is in part a result of the larger process of trade liberalization, which has allowed foreign wines to enter the Canadian market without additional import duties, reducing the market for lower quality domestic wines (Heien and Sims, 2000). Producers then have more incentive to produce a high-quality product in order to compete with other wine growing regions, many of which have lower costs of production. This expands upon the double exposure concept in that not only can global economic forces exacerbate or dampen existing vulnerabilities, but these forces may also influence the way in which communities are vulnerable to climate change.

The interconnectedness of the multiple risks and the dynamic nature of vulnerability are also apparent when adaptations occur within the system. Following the North American Free Trade Agreement, grape producers replaced the low quality, but winter hardy French hybrid grape varieties with the tender *Vitis vinifera* varieties, an adaptation that was facilitated by government aid. This change enhanced the wine industry's domestic and international competitiveness, thereby reducing market risks, but simultaneously increased its sensitivity to winter injury. However, the adaptation also means that there is a greater emphasis on producing a quality product, in order to be competitive, and hence producers are now more sensitive to the climatic conditions that affect quality as well. This

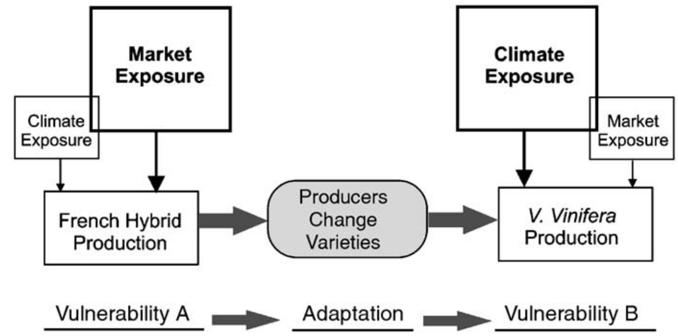

Fig. 4. Dynamic nature of exposure. The relative sensitivity of the system to each type of risk exposure is represented by the size of the box, illustrating that following an adaptation, the nature of the system, and hence its sensitivity, is changed.

example suggests that the market is a fundamental driver to which producers are vulnerable and to which they adapt. This adaptation, switching varieties, changes the nature of the system to make it better adapted to the market but more vulnerable to climatic stresses to which it was previously less sensitive (Fig. 4). At the same time, secondary adaptations to moderate the increased sensitivity to climatic stresses may enhance market risks. To minimize frost risks, producers use overhead irrigation to wet the berries so that as temperatures reach 0°C, the water on the berries freezes, transferring latent heat into the berry. The extra water from irrigation, however, can dilute the flavour in the grapes, reducing quality and increasing market risks; the moist conditions may also increase disease pressure and the risk of a mildew outbreak, a production and market risk.

The synergistic and dynamic effects of multiple risks are not limited to climate and market. Government policies can influence producers' exposure, both indirectly, such as via trade policies, and more directly. The wine industry in the Okanagan is an agri-tourism-based industry, which is encouraged by a policy referred to as 'markup-free delivery.' On all wine products there is a 100% markup included in the sale price of the product. With this policy in place, sales through the government-owned Liquor Distribution Branch (LDB), result in the markup being captured by the government, leaving little profit for the wineries (Strachan, 2005, pers. comm.). However, for sales that occur on-site at the winery, the winery is able to keep this markup as profit. This policy means that wineries, small wineries in particular, are reliant on these on-site sales to retain enough profit to stay in business; larger wineries have the economies of scale to sell through the LDB and other market channels to spread the risk. The reliance on on-site sales, in turn, means that producers are vulnerable to fluctuations in tourism. Tourism can be affected by exposures like long-rainy periods or large-scale climate-related events, such as forest fires. Thus while this government policy is generally opportune for producers, it concurrently puts them in a position in which they are sensitive to particular market and climatic risks.

4.2. Adaptive capacity

While producers are exposed to a variety of condition, the degree to which they are vulnerable depends on their ability to cope or adapt. This is complicated because climate is not the only condition to which producers adapt, and an adaptation to one stress may increase exposure to another, as shown above in the example of switching varieties. However, when grape growers were asked how they managed the risks in good and bad years, they more readily identified adaptations to manage climate-related risks than other risks, and these adaptations varied by timing (anticipatory or reactive) and duration (tactical or strategic) (Table 3).

Tactical adaptations, which are short-term strategies undertaken within the growing season to deal with a problem (Smithers and Smit, 1997; Risbey et al., 1999), were more commonly employed in response to daily weather variability. Some tactical adaptations were anticipatory, such as using irrigation to minimize frost risk in order to prevent the vines from shutting down in times of extreme heat and to raise the moisture level in the root zone following harvest, which reduces the potential for root damage as winter temperatures fall below zero. Other practices were in reaction to poor weather, such as fruit thinning (referred to as 'dropping crop') in cold and wet seasons. A vine has the ability to mature a limited amount of fruit, an amount that varies by the type of grape and the availability of heat units. By reducing the cropload, more energy is available to the remaining fruit, allowing it not only to mature, but also to achieve a higher quality. Thus this practice may also be considered an anticipatory adaptation to reduce exposure to market risks.

Table 3
Types of adaptations employed to manage risks Identified in bad years

Type of adaptation	Source of risk	Example of adaptation
Tactical, reactive	Cold, wet season	Fruit thinning or 'dropping crop' Lighten canopy to dry Make sparkling wines Drop the price of the wine
	Frost Winter	Claim crop insurance
	Smoke damage (forest fires)	Claim crop insurance Reverse osmosis
	Low tourism	Sell more aggressively in other market channels
Tactical, anticipatory	Frost	Turn on windmachines Irrigate the vineyard
	Winter Extreme heat	Irrigate the vineyard
	Powdery mildew	Routine sprays of sulphur
Strategic, reactive	Technology failure	Replace manual water pump with automatic pump
Strategic, anticipatory	Frost	Selection of early maturing variety Site selection Purchase crop insurance
	Winter	Purchase crop insurance
	Pests	Integrated pest management Plant varieties on grafted rootstock

The strategic, long-term adaptations that were cited were primarily anticipatory management practices, some of which occur at the time of the vineyard establishment. Producers reduced frost risk through site selection and changing topography, by avoiding or removing frost pockets in the vineyard, or choosing to plant a variety that matures earlier in the season. The selection of varieties, however, was not a decision based solely on climate; producers need to strike a balance between a variety that is suited to the climate and one that is marketable. Other strategic adaptations occurred in good years, when the farmer had the finances to invest in more efficient or risk-reducing technologies, such as wind machines. This is an example of a strategic adaptation adopted in response to opportunistic conditions to deal with problematic exposures.

The variety of adaptations cited by producers partly reflects the heterogeneity of individuals' decision-making options, but it also indicates the differential capacity of producers to adapt. This capacity varies by the type (winery vs. independent grower) and size of operation, and by the risks being adapted to. It is also a function of several determinants, including the availability of financial resources, technology, and government policies (Fig. 3). In cold and wet seasons, for example, while fruit thinning is a practice that is employed by virtually all producers, wineries have additional options during the processing of the fruit, including making a different style of wine or blending different juices together to compensate for poor quality. Wineries also have the option of charging a price for the wine that is reflective of the quality, or of marketing the wine differently to consumers. Larger wineries have the capital to be able to purchase additional parcels of land or to contract independent growers in different locations. Since the climate in the valley varies considerably from one end to the other, having vineyards in different locations minimizes some risk in that there is a greater chance that one region will sufficiently mature the grapes; the lower quality grapes from one location can sometimes be blended with the fully matured grapes to create a product of sufficient quality to be marketable.

Contracting growers also enhances a winery's ability to adapt to market risks associated with reductions in tourism because the next season they can cut contracts to reduce costs. In this sense, a winery's adaptation becomes an exposure for an independent grape grower. However, in general there are few options to cope with reductions in tourism. A few wineries noted that they tried to be more aggressive in sales through other market channels, such as government liquor stores. However, provincial listing requirements (the provincial liquor board must first buy and 'list' the product) restrict the ability of small wineries to enter this channel. Generally it is the larger wineries that get their products listed due to their high production capacity. In fact, the majority of their product is sold through the Liquor Distribution Branch (LDB), so disruptions in tourism do not have as serious implications for large wineries as they do for smaller operations.

Producers' capacities to manage frost and severe winter events, which can vary between operations, is influenced by the availability of technologies, access to water, and government programmes and policies. To minimize frost risk, most producers use overhead irrigation. However, producers' access to water is limited by the water allocation system in British Columbia. This system is based on the two principles of prior appropriation and beneficial use. This means that the right to use water is given the earliest license holders, and to those users who demonstrate a priority of purpose; the Water Act ranks the purposes in priority order, with domestic use being the highest (Shepherd et al., 2004). In times of water shortages, residential use gets priority over agriculture, leading to restricted use of irrigation. A few operations can avoid this conflict and minimize frost risk with wind machines that pull down warm air from above when there is a temperature inversion, raising the temperature in the vineyard by a couple of degrees. Wind machines, however, are very expensive and are only economical on a very few large operations.

The availability of crop insurance and income stabilization programmes enables producers to bear the loss and recover from these events, albeit with some difficulty. In this case, more established wineries or operations will be more likely to recover than new wineries with high levels of indebtedness. Independent growers have a higher capacity in this regard because they are eligible for income stabilization programmes, while wineries are not. Also, independent growers have lower overhead costs and, if they lose a crop, insurance will cover 60% of the value of the crop; wineries receive the same percentage, but it does not cover the value of the wine. Wineries have the ability to use the insurance money to purchase grapes from other vineyards, but due to particular government regulations and licensing parameters, small- and medium-sized wineries may only use grapes that originate within the Okanagan Valley. However, if a winter event was severe enough to kill one vineyard's grapevines, it is likely that similar damage occurred on vineyards elsewhere in the valley, limiting the supply of grapes these smaller wineries can purchase. The four largest wineries in the valley have the highest capacity to cope because they are able to buy bulk juice imported from other countries and label it 'Product of British Columbia,' rather than the Vintners Quality Alliance (VQA) label, giving them a buffer while their vines are being replanted. The VQA designation is similar to France's *Appellation d'Origine Contrôlée* (AOC); it signifies that the product is made of 100% British Columbia grown grapes and that it meets or exceeds a minimum standard of quality.

These findings suggest that adaptation can indeed reduce the negative effects of climate-related risks, and will be important for reducing the negative effects of climate change. In general it seems that grape growers currently have a higher capacity to cope with, or lower vulnerability to, risks that affect the quantity of a crop yield (frost and winter) than those conditions that affect quality (cool season and extreme heat), and hence the ability to compete in the market. Producers' vulnerability, however, will vary between operations due to the way that each is exposed to particular stresses and to the different resources, technologies, and government programmes that are available that influence their ability to adapt.

4.3. *Future vulnerability*

Drawing on this assessment of current vulnerability, what can be said of the future vulnerability of Okanagan grape/wine producers to anticipated changes in climate? To assess future exposure, potential data sources include scenarios of future climate, trend analyses, probabilities of change, and insights from interviewees about potential risks. Ideally the data would pertain to the climate-related variables that respondents identified as relevant, which in this case are those listed in Table 2. This analysis aims to extract insights from existing climate scenarios for the southern interior of British Columbia (CICS, 2004; Cohen et al., 2004), which estimate changes in variables found in traditional climate studies, such as average temperature and precipitation, as well as changes in hydrologic variables, degree days, and frost free days. These data are summarized in Table 4 and are used to make inferences about grape growers' future vulnerability.

The data indicate that with climate change, there may be a warming of 1.5–4.0 °C by 2050, with the greatest warming occurring in the spring. The higher temperatures would mean an increase in the number of degree day units available to mature grapes and more frost-free days, thereby extending the growing season. The warming is projected to be accompanied by an increase in precipitation in all seasons except for the summer, with the greatest increase occurring in the fall. However, while there may be an increase in precipitation, both studies found that a smaller percentage of this precipitation (between 35% and 75% less) will be in the form of snow, which represents a change that will be particularly pronounced in the spring and fall months. This change in the form of precipitation would mean a reduction in annual snowpack, a hastened rate of snowmelt, earlier peak streamflows, and an exacerbation of flow shortages later in the season (Merritt and Alila, 2004).

According to these data, climate change may bring both opportunities and risks to growers. Producers identified long, hot growing seasons as beneficial, and so the higher temperatures and increased availability of heat units from

Table 4
Projections of climate change in the Okanagan valley for 2050 by source (Parentheses indicate a negative change or decrease)

Climatic variable	Data source	
	CICS (2005)	Cohen et al. (2004)
Temperature (Δ in °C)		
Winter	2.2	1.5–4.0
Spring	3.0	
Summer	2.2	1.9–4.1
Fall	1.8	
Precipitation (%Δ)		
Winter	4	5–25
Spring	2	
Summer	(4)	(0–35)
Fall	11	
Frost-free days (%Δ)	7 [32 days]	
Degree days (%Δ)	16 [453 degree days]	
Precipitation days <0 °C (snow days) (%Δ)	(47)	(35–75)
Peak streamflows		Earlier onset of maximum peak flow

climate change represents a potential opportunity for growers. It may increase their ability to mature their *V. vinifera* crops fully, and to achieve higher quality on a more consistent basis, both of which are findings that are consistent with other studies on the grape and wine industry (Caprio and Quamme, 2002; Barton et al., 2004; Jones et al., 2004). It may also potentially reduce producers' exposure to cold and wet seasons, and allow producers to seize market opportunity more consistently. In addition, the lengthening of the growing season, and the increase in frost free days and winter temperatures may reduce the exposure to frost or winter events and the subsequent vine damage.

Such climatic changes may also increase risk exposure. The estimated changes in precipitation have negative implications for producers. For one, the reduced snow pack in the mountains would decrease the amount of water available for irrigation, a significant challenge considering 75% of irrigation systems in the valley are gravity-pressured systems using mountain runoff and only 25% are pumped from lakes and streams (Neilson et al., 2004a). The earlier peak flows coupled with a decline of precipitation in the summer would make water shortages particularly pronounced late in the season when it is the hottest and when water is required most. Since irrigation is used to cool down the vineyard during extreme heat events, the reduced water supply would reduce producers' capacity to adapt, particularly if such events become more frequent. The capacity to manage frost and winter risks would also be compromised as irrigation was cited as an adaptation to both risks.

Changes in temperature and precipitation may have indirect effects, such as increasing forest fire frequency. The frequently cited 2003 Kelowna forest fire occurred in a record hot and dry summer, and was preceded by a winter of low snowpack (Taylor and Barton, 2004). Since the scenarios project a reduced snowpack and hotter, drier summers, the probability of such forest fires is likely to increase, thereby exposing producers to market risks associated with fluctuations in tourism. The modelled increases in precipitation in the spring and fall, if they coincide with bloom and harvest, could reduce the quantity or quality of production, thereby creating a market risk.

There are limitations with relying on climate projections for insight into future vulnerability. Although they capture many of the climatic conditions identified as significant by producers, particularly with respect to climatic variability and extremes, certain vulnerabilities can be overlooked. For example, variability and extremes occurring at the beginning or end of the growing season means that the chance of frost damage is not necessarily decreased. If the season begins earlier in the spring, bud break will also occur earlier, at which time grapevines are actually more sensitive to frost. A temperature of only −2 °C can kill the primary buds and the crop will be reduced or eliminated because the vine will then be dependent on secondary buds, which produce a later crop and lower tonnage (Strachan, 2005, pers. comm.). Also, an increase in the risk of extreme heat events can negatively affect grape quality and put higher demands on water. More variable weather could also imply that the likelihood of cold and wet periods will not necessarily be reduced with climate change.

Further, one cannot rely solely on these projections because the non-climatic conditions found to influence vulnerability will also change in the future. Although this section has addressed the potential changes in climatic conditions due to the climate change focus of the paper, changing market, government, economic, technological, and farm-level factors may have an equally important influence on grape producers' future vulnerability. For example, the population in the Okangan Valley is projected to increase by 60% by 2050, which could exacerbate water shortages and intensify competition for water resources with urban users (Neilson et al., 2004b). Some scenarios project world fuel prices to increase over the long-term (Page and Kavelec, 2005); high fuel prices can lead to reductions in tourism to wineries and can increase input costs. The industry will also be affected by changing market demands as consumer preferences vary, changes in trade barriers occur, and the global supply of wine increases (Anderson and Wittner, 2001). Although world wine consumption has been increasing in the last decade, the per capita consumption and the market share per country have fluctuated and will likely continue to do so (Anderson, 2001). Finally, farm-level adaptations made in light of climate change or other risks can influence future vulnerability, and may be a result of the development of new technologies or changes in government support programmes.

While the inferences drawn here on future vulnerability face limitations, they demonstrate the importance of considering of multiple risks and the dynamic nature of vulnerability in analyses of the implications of climate change. Information on how the interactions of multiple exposures have made producers susceptible to particular climatic stresses can be used to estimate how the relevant exposures and sensitivities may change in the future. Adaptive capacity is also dynamic and may be modified under climate change, for example through the decreased supply of water for irrigation. Characterization of future vulnerabilities can guide the development of adaptations.

5. Conclusions

This paper has sought to characterize the nature of Okanagan Valley grape growers' and winery operators' vulnerability to climate variability and change, in the context of multiple exposures. The bottom-up vulnerability approach employed here provides a different perspective on the potential implications of climate change compared to scenario-based impact assessments. In particular this approach provides insights into the conditions that are pertinent to producers, the adaptive responses employed by producers, factors that facilitate or constrain their responses, and the prospects for adaptations to manage risks in the future. By beginning with open-ended questions to allow producers to self-identify relevant risks, some conditions are identified that are consistent with other climate change studies relating to the grape and wine industry, but others are identified that are not generally considered in studies where the variables are pre-selected. Producers in this study, for example, identified long, hot growing seasons without the incidence of damaging frost as favourable conditions that allow for the production of a quality product, a finding which is similar to studies that have correlated past climatic data with grape production or quality ratings (Jones and Davis, 2000; Nemani et al., 2001; Caprio and Quamme, 2002; Jones et al., 2004).

This study also found that a challenge associated with climate change for Okanagan grape growers will be the availability of water for irrigation at critical times in the season, a finding consistent with Cohen et al. (2004). Changes in hydrology, in crop water demand, in urban water demand, and in institutional arrangements regarding water allocation will affect producers' access to water. The use of water for managing risks associated with extreme heat, frost, and winter events will place additional pressure on a stressed resource. Restricted access to water reduces producers' adaptive capacity, and increases their vulnerability to these climatic risks. Vulnerability associated with a water deficiency will be more pronounced on operations in the south end of the valley where soils are sandy and well-drained, and where there is less precipitation. This will be especially true on small operations that do not have water-saving technologies like moisture reading devices, drip irrigation, and wind machines.

Producers identified a number of climatic and non-climatic factors that are problematic for their operation and that are rarely considered in climate change scenario studies. These factors include climate-related risks that affect crop production (rain at bloom, frost, winter), the quality of wine (cold and wet season, rain at harvest, extreme heat, mildew outbreaks), the overall business (e.g. forest fires, excessive rain), or the ability to adapt (e.g. availability of water for irrigation). Other conditions that influence operations include market demand, fluctuations in tourism, government policies and programmes, technology access or failure, and economics (e.g. interest rates, input costs). This study showed that the presence of multiple risks or exposures influences the nature of producers' vulnerability to climate variability and change. It also shows that vulnerability is a dynamic process of interacting external forces, local characteristics, and management capabilities, realities of vulnerability that are not well captured in indices.

A climatic stimulus may not pose an obvious threat to producers or perhaps may pose only a moderate risk, but when viewed in the context of other stresses, may constitute a significant vulnerability. A forest fire may not pose a direct threat to operations that are far from the hazard. However, an indirect effect of the fire, its influence on tourism, can be considered a significant vulnerability for wineries. Reductions in tourism negatively impact wineries due to the 'markup free delivery' policy, an institutional arrangement that enables wineries to capture sizeable profits from on-site sales. The effects are more serious for small wineries because government policies restrict their ability to sell through the Liquor Distribution Branch, and so small wineries are more reliant on the on-site sales.

The presence of government support programmes like crop insurance and income stabilization reduce producers' vulnerability to the climatic extremes that are most damaging to the vine and reduce crop yields, but they leave producers vulnerable to uninsurable climatic risks that affect quality and hence a producers' ability to compete in, or to sell to, the market. This situation means that the climate change impacts on grape growers and wineries will not necessarily be beneficial as is often assumed. If the incidences of extreme heat events and forest fires increase, and if the availability of water for irrigation decreases, then the ability of wineries to produce a quality product and to manage other climatic risks may be challenged. Moreover, the emphasis on quality is reflective of broader economic processes and an international market. Hence, the vulnerability of Okanagan producers will be influenced by the broader economic changes in wine supply and demand occurring in conjunction with climate change.

Finally, exposure, sensitivity, and adaptive capacity are dynamic concepts. Vulnerability should be seen as a process shaped by economic, technological, social, environmental, and institutional forces that are in a constant state of flux (Adger and Kelly, 1999; Handmer et al., 1999;

Leichenko and O'Brien, 2002; O'Brien et al., 2004 a,b,c). In British Columbia, economic processes of globalization, changing government policies and support, and advances in technology have all influenced decisions made at the farm level. As adaptations are made, the nature of the system is changed, which in turn affects the way producers are sensitive or exposed to risk. In some cases, an adaptation may be made to address one risk, but which then exposes producers to other risks that either were not present before or to which producers were less sensitive. This is exemplified by the industry's adaptation to market forces following trade liberalization in which the industry was replanted to tender varieties, which in turn increased vulnerability to severe winter conditions. This study demonstrates the need to consider both the climatic and non-climatic conditions that are important to the sector or industry, and to incorporate adaptations into existing management practices; climate change is not the only stressor affecting farmers and adaptations will be made in the context of these other risks.

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