Understanding Canadian Winegrowers' Perceptions of Climate Change and Their Implications for Adaptation Behaviors

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General abstract

Climate change (CC) is currently impacting and will continue to affect the international and the Canadian wine industry in the future. Understanding how Canadian winegrowers perceive CC and address its consequences through adaptation can help support the grape and wine industry in the context of CC. The thesis aimed to understand how winegrowers perceive CC and the ways CC adaptation is occurring throughout Canada. Two studies were conducted in the provinces of Ontario, British Columbia, Québec and Nova Scotia. The first study of this thesis characterizes winegrowers with respect to their environmental values, CC knowledge and beliefs, and their perception of the consequences of CC on their winegrowing operations. The second study describes the present state of CC adaptation in the Canadian wine industry, as well as the adaptation strategies currently used and considered for future implementation to cope with specific weather events associated with CC. This study also investigates the attributes that drive CC adaptation throughout the country. Together, the two studies provide an overview of CC perception and adaptation in the main winegrowing provinces of Canada for the first time in literature. The thesis also contributes to the scholarly literature on CC perception and adaptation by highlighting the drivers that influence winegrowers' adoption – or lack thereof – of adaptation practices in their operations. It also offers practical information that can be used by stakeholders of the industry to communicate CC information and adopt new practices to address its effects.

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List of abbreviations

CC	Climate change
CWI	Canadian Wine Industry
IPCC	Intergovernmental Panel on Climate Change
NEP	New Ecological Paradigm
NS	Non-significant
SD	Standard deviation
Sig	Significant
WE(s)	Weather eve

Chapter One: General introduction

Introduction

Climate change (CC) is one of the greatest issues of our time (United Nations, 2016). In the 21st century, our planet has experienced many of the warmest years ever recorded, and the Intergovernmental Panel on Climate Change (IPCC) projects an increase of 1.5°C in global temperature between 2030 and 2052 at this present rate (2018). The modification of precipitation patterns and an increase in occurrence of extreme weather events are also anticipated to occur in the future. Greenhouse gas emissions associated with post-industrial anthropogenic activities are linked to these effects and, as a result, global and rapid actions are needed to lower climate-related risks for human and natural systems (IPCC 2018).

The wine industry is inherently connected to environmental conditions and is, therefore, directly impacted by CC (Battaglini et al 2009; Mozell and Thach 2014; Pickering et al. 2015; Shaw 2016). In fact, a compatibility between a regions' climate and grapevine cultivars is necessary to ensure the optimal grape and wine quality (Jones et al 2005; Tomassi et al. 2011). In the context of CC, the observed and projected climate alterations can severely impact the sustainability of wine regions. As a consequence, a rising interest in developing approaches to cope with the effects of CC on grape growing and winemaking is currently being observed globally (e.g. Battaglini et al. 2009; Zhu et al. 2016; Ollat et al. 2017).

The Canadian Wine Industry (CWI) is steadily growing and gaining international recognition (Canadian Vintners' Association, 2017). In Canada, commercial viticulture occurs close to the border with the United States, between the 41ºN parallel and the 50ºN (Table 1) (Wines of Canada 2016). The main winegrowing provinces are Ontario and British Columbia. In Ontario, three Appellations of Origin are established: The Niagara Peninsula, Prince-Edward County and Lake Erie North Shore (Vintners Quality Alliance Ontario 2018) (Figure 1). In addition to those main regions, the Ontario wine industry is expanding its territory to several emerging areas such as the Huron, Grey, Durham and Norfolk (Shaw 2016). In British Columbia, the main wine growing regions are the Okanagan Valley, Fraser Valley, Vancouver Island, Similkameen Valley and Gulf Islands and emerging wine regions include the Shuswap, Kootenays, Thomspson Valley and Lilloet. Those regions are designated as official Geographical Indication, which is a component of the appellation system that indicates the origin of the wines and attests to its quality (Wines of British Columbia 2018). In the provinces of Québec and Nova Scotia, the short growing season and extremely cold temperatures experienced in the winter do not typically allow for the production of quality wine grapes (Shaw 1999). However, sensibly selected cultivars have successfully grown in some regions, and winegrowers in those provinces continuously innovate to increase their share of the market every year (see Table 1) (Shaw 1999; Jones 2012; Canadian Vintners Association 2017). A Protected Geographical Indication was recently established in Québec, which encompasses a large proportion of the south-western territory of the province. This regulated appellation indicates that a product has certain characteristics specifics to its origin (Agriculture, Pêcheries et Alimentation Québec 2018). In Nova Scotia, wine production occurs throughout the province. Launched in 2012, Tidal Bay is the only Nova Scotian wine appellation (Wines of Nova Scotia 2018) (see Figure 1).

Table 1. Characteristics of the main Canadian winegrowing provinces

	British Columbia	*Ontario*	*Québec*	*Nova Scotia*
Economic impact (Billion $CAD)	2.8 (31%)	4.4 (49%)	1.1 (12%)	0.2 (0.2%)
Number of wineries	275	180	115	17
Number of grape growers	929	456	270	94
Wine grape acreage	10,260	18,383	1,684	658
Top planted varieties	Merlot Pinot Gris Pinot Noir Chardonnay	Vidal Blanc Chardonnay Riesling Cabernet Franc Merlot	Frontenac noir Vidal Seyval Blanc Maréchal Foch Sainte-Croix	L'Acadie Blanc Seyval Blanc Vidal Muscadet Lucy Kuhlman Baco Noir Maréchal Foch Léon Millot

Note. Data for Economic impact, Number of wineries, Number of grape growers, wine grape acreage from Frank, Rimerman + Co. LLP (2017), for Top planted varieties in British Columbia from Wines of British Columbia (2019), in Ontario from Grape Growers of Ontario (2017), in Québec from Conseil des vins du Québec (2017), in Nova Scotia from Wines of Nova Scotia (2019).

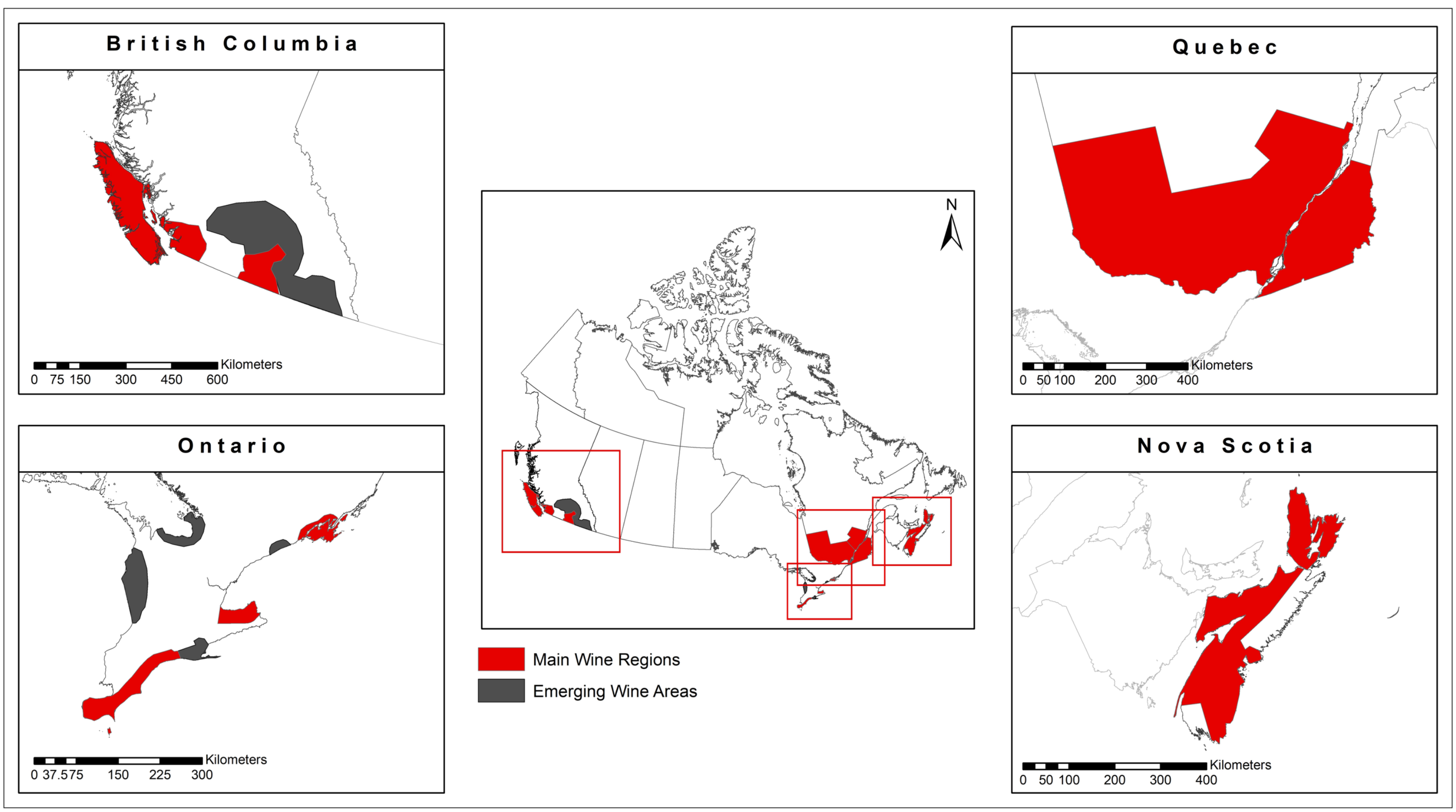

Figure 1. Map of Canadian main wine regions and emerging wine areas

Climate models predict a rise of the annual mean temperature, a change in frequency and magnitude of precipitations, as well as an increased occurrence of extreme weather events throughout Canada (Governement of Canada 2017). Combined, these variables influence *grape phenology* (Pickering et al. 2015; Shaw 2016), which refers to the relationship between climate and grapevines' life cycle events, and ultimately, has an impact on quality wine production (Jones and Davis 2000; Tomasi et al. 2011). Such changes could create opportunities for the CWI, but also pitfalls, that could generate important losses (Belliveau, Smit and Bradshaw 2006; Pickering et al. 2015).

As part of the global effort to address CC, the IPCC presents adaptation as a promising strategy that could help reduce the negative impacts of CC in both the short and long-term. As defined by the IPCC, *climate change adaptation* refers to, "the process of adjustment to actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities" (IPCC 2018 p. 542). By modifying components of a system of interest, such as an agricultural operation, CC adaptation is a response strategy to climate variabilities and their consequent impacts (Smit et al. 2000). *Adaptive capacity* or *adaptability* is, "the ability of systems, institutions, humans and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences" (IPCC 2018 p. 542). Thus, adaptations are demonstrations of adaptive capacity (Smit and Wandel 2006), and they involve the conversion of adaptive capacity into action (Adger, Arnell and Tompkins, 2005). Adaptive capacity is context-specific and several determinants and factors can either facilitate or undermine the adaptability of a system (Skinner et al. 2001). For example, in the CWI, the availability of financial resources can enable the acquisition of a costly piece of equipment that protects grapevines against frost, which in turn, would increase the adaptive capacity of a vineyard. Conversely, in the same situation, a lack of access to financial resources could be detrimental to the vineyard and therefore, lower the adaptive capacity of that system.

Similarly, in order to be successfully implemented, sensible adaptation needs to consider the distinctive sensitivities and vulnerabilities of a system (Smit et al. 2000). *Sensitivity* is defined as, “the degree to which a system is affected by, or responsive to, climate stimuli” (Smit et al. 2000 p. 238). A climate stimulus can affect two similar systems in different ways, depending on their respective sensitivities. *Vulnerability* refers to, “the degree to which a system is susceptible to injury, damage or harm” (Smit et al. 2000 p.238). Consequently, systems with the highest sensitivities to climate alterations are the most vulnerable and, therefore, the least adaptable (IPCC 1996).

Grapes are a highly climate-sensitive crops which makes the wine industry vulnerable to CC. For instance, grapevines are sensitive to high rainfall around the flowering period which can lower the yield and quality of the berries at harvest (Jackson and Lombard 1993). Hence, viticulture is vulnerable to such weather event, at this specific moment of the growing season. Similarly, grapevines are sensitive to temperatures over 30^{o}C which can negatively affect berry composition and in turn impacts the final wine, making the industry vulnerable to such an extreme weather event (Keller 2010). While the vulnerability of viticulture varies with biophysical and human factors, grapevines generally do better when specific climatic conditions are experiences throughout the year (Holland and Smit 2014). Therefore, when considering the multiple sensitivities of grapes as a crop, most wine regions are vulnerable to the effects of CC.

Smit et al. (2000) describe adaptation by addressing three questions: (i) adaptation to what? (ii) who or what adapts? and, (iii) how does adaptation occur. These questions are applied to this research in that the first question in the series refers to CC and its associated effects on viticulture and oenology. The answer to the second question represents the *unit of analysis,* defined by the characteristics of the system that needs to adapt (Smit et al. 2000). In the context of this research, the *unit of analysis* is the CWI, which is represented by winegrowers' vineyard and winery practices. The answer to the third question is informed by the two former answers and constitutes one of the main objectives of this research: which strategies are used and considered in the CWI to adapt to CC? In fact, the possible vineyard and winery adaptation options are diverse and can be described according to their types (Smit et al. 2000).

To better appreciate the complexity of the concept of adaptation, it is important to understand its different forms. Depending on the initiator, adaptation can be either public or private (Table 2). Actions implemented by governments and guided by collective needs are *public adaptations*. Conversely, *private adaptations* are initiated by individuals and private companies, which are generally started in those individual's or company's self-interests and are often focused on economic efficiency.

Table 2. Attributes that differentiate adaptation types (adapted from Smit et al. 1999)

Attributes	Adaptation Types		
Initiator	Private	←→	Public
Timing	Anticipatory	←→	Reactive
	Proactive	←→	Responsive
Intention	Autonomous	←→	Planned
	Spontaneous	←→	Purposeful
	Automatic	←→	Intentional
	Natural	←→	Policy
	Passive	←→	Active
Temporal Scope	Short Term	←→	Long Term
	Instantaneous	←→	Cumulative
Spatial Scope	Localized	←→	Widespread
Function/Effects	Retreat, Accommodate, Protect, Prevent, Tolerate, Change, Restore		
Form	Structural, Legal, Institutional, Regulatory, Financial, Technological		

In theory, adaptation can be reactive or anticipatory, depending on its timing (see Table 2) (Smit et al. 2000). *Reactive adaptation* refers to the adjustments brought to a system *after* the effects have been observed (IPCC 2001); it requires monitoring and the ability to quickly respond to climate variabilities (Nicholas and Durham 2012). *Anticipatory* or *proactive adaptation*, however, requires the knowledge and understanding of the expected outcomes of CC in order to address them *before* they affect a system (IPCC 2001). For example, the implementation of an irrigation protocol in a vineyard after a drought episode is a form of *reactive adaptation*. Conversely, the investment in the same irrigation system to prevent the damages an eventual drought episode would cause is considered a form of *anticipatory adaptation*. Both the private and public sector can adapt to observed and anticipated CC (Adger, Arnell and Tompkins 2005).

CC adaptation can also be either autonomous or planned (see Table 2). *Autonomous* or *spontaneous adaptation*, “does not constitute a conscious response to climatic stimuli but is triggered by ecological changes in natural systems and by market or welfare changes in human systems” (IPCC 2001 p. 982). *Planned adaptation* is commonly associated with public actions, and results from conscious interventions (Fankhauser, Smith and Tol 1999).

The IPCC (2001 p. 982) defines *planned adaptation* as, "the result of a deliberate policy decision, based on an awareness that conditions have changed or are about to change and that action is required to return to, maintain, or achieve a desired state". Autonomous adaptations, however, are generally reactive and mostly initiated by private individuals or companies, but they may not be adequate on their own to address CC. Planned adaptation can then be implemented as a complementary strategy to support or better inform autonomous adaptation (IPCC 2001).

Based on temporal scope, adaptation can also be short or long-term (see Table 2) (Smit et al. 2000). *Short-term adaptation* is more likely to be reactive, autonomous, and implemented by the private sector (IPCC 2001). It involves less uncertainty and more predictable short-term benefits than long-term adaptation (Stern 2007). *Long-term adaptation*, however, can be reactive or anticipatory and autonomous or planned, and instigated by either the private or public sector (IPCC 2001). While long-term adaptation generally results in lower long-term costs and more successful outcomes than short-term adaptation, it requires potentially 'risky' investments for the private sector. For this reason, the public sector often initiates, or supports such adaptations (Stern 2007). For instance, leaf removal during the growing season as well as the adjustment of spray regime could be a form of short-term autonomous adaptation to increase air flow in the grapevines' canopy during a wet year and lower pest pressure. Conversely, the replacement of existing grapevines by cultivars that can better tolerate wetter conditions could be a form of long-term, planned adaptation considered in the CWI to cope with the same climate stimulus and its impacts.

Much like temporal scope, adaptation also occurs within a spatial scope (see Table 2) (Smit et al. 1999). For instance, local observation of a climate stimulus is more likely to trigger reactive and autonomous adaptation, while climate variations experienced or expected over a larger area could initiate anticipatory and planned adaptation (Smit et al. 2000). Adaptations can have different functions and effects such as to retreat, accommodate, protect, tolerate, change, or restore a system or a part of it. Adaptation also takes different forms: it can be structural, legal, institutional, regulatory, financial, or technological (Smit et al. 1999). In practice, the distinction between private and public, reactive and anticipatory, or autonomous and planned adaptations can be unclear. Much like CC, adaptation occurs on a continuum of transformations on the short and long-term (Fankhauser, Smith and Tol 1999; Smit et al. 1999). For example, the diversification of crops by a winegrower could constitute a form of reactive and autonomous adaptation from the perspective of a government. Simultaneously, it could also constitute a form of anticipatory and planned adaptation by a winegrower (Fankhauser, Smith and Tol 1999).

While the adaptive capacity of a wine region is modulated by several determinants (Pickering et al. 2015), agricultural systems, including the wine industry are managed by humans and therefore, their perceptions, beliefs and attitudes can influence their propensity to be favorable to CC actions and policies (Skinner et al. 2001). For instance, conscious efforts to adapt to CC emerge from the acknowledgment that CC is real and threatening (IPCC 2001). Indeed, the belief about the existence of CC and the anthropogenic contribution to the phenomenon, as well as the degree of concern about the issue, have been found influence public and private sphere actions (Howden et al. 2007; Arbuckle, Morton and Hobbs, 2013; Mase, Gramig and Prokopy 2017). Similarly, scientific knowledge about CC can influence individuals express concern about CC and support climate policies (Stoutenborough and Vedlitz 2014). Moreover, skepticism and uncertainty about CC and its effects can also hinder one's ability and willingness to effectively address it (Rahmstorf 2004; Capstick et al. 2015; Hornsey et al. 2016). Individual's environmental value can also influence the desire to engage with pro-environmental behaviors (Dunlap et al. 2000; Whitmarsh 2008). One's trust in the media, governmental and non-governmental organizations, and educators can also shape people's perception of CC (Weber 2010). The type of information transmitted by different stakeholders and governance bodies also influences perceptions of environmental conditions and phenomenon (Jacobson and Price 1990). Such perceptions are also selective, and CC competes with many other stimuli for attention in people's minds. In their everyday lives, for example, people cannot invest their mental resources in every issue that they consider worthy: they must prioritize attending to the issues that are *most* important (Weber and Johnson 2009). In doing so, people's fundamental values and worldviews influence which phenomena and risks they attend to, and which they ignore or deny (Jacobson and Price 1990; Weber 2010). Consequently, other concerns, such as economic stability and health problems, might garner people's attention and mobilize them more efficiently than the statistical evidence of CC and its associated risks (Weber, 2010). Finally, perceptions of the consequences of CC can also influence the public's response to CC (Capstick et al. 2015; Weber 2006). In light of those considerations, understanding how winegrowers perceive CC and how they are currently prepared – or not prepared – to cope with its effects, appear to be logical first steps to support the sustainability of the wine industry.

Summary of knowledge voids

CC perception and adaptation in the wine industry have been the subject of limited study. In the international wine industry, Battaglini et al. (2009) investigated how French, German, and Italian winegrowers perceive CC and its impacts and how they adapt to its various manifestations. They found that winegrowers believe that potential CC required adaptive measures, especially with respect to water availability and pest and disease management. Also, a slim majority of winegrowers did not plan to modify grape varieties in case the weather in their region became unsuitable for the variety that they were currently growing. They also observed a discomfort with change and lack of information amongst winegrowers; in fact, most winegrowers did not know which alternative varieties they would plant and expressed their desire to learn more about CC and its multiple impacts on grapevine varieties.

In the CWI, Pickering et al. (2015) conceptualized a framework to assess the adaptive capacity of the Ontario wine industry. Among winegrowers, they found that perception, diversity, and knowledge were adaptive capacity determinants with the highest degree of capacity. In their study, *perception* referred to the perceived risk and ability of winegrowers to manage and adapt to CC; *diversity* represented the variety of options available for implementation; and *knowledge* referred to the availability and perceived value of local and scientific knowledge within the industry. Political and technological determinants showed the lowest degree of capacity. They also identify that winemakers' and grape growers' adaptive capacities differ, but both professions were interested in learning new skills and techniques that could help them better adapt to CC (Pickering et al. 2015).

Scholars have also examined the adaptation options used in vineyards and wineries operations in response to the effects of CC in the international wine industry (e.g. Alonso Ugaglia and Peres 2017; Battaglini et al. 2009; Alonso and O'Neill 2011; Nicholas and Durham 2012). In Canada, investigations of CC adaptation have exclusively studied specific regions and none have comprehensively examined the whole CWI. For instance, in the Okanagan Valley in British Columbia, Belliveau, Smit and Bradshaw (2006) characterized winegrowers' vulnerability to CC and the adaptation strategies they use to cope climatic and non-climatic risks. The winegrowers interviewed in their study identified several problematic factors for their operations such as the availability of water for irrigation and the risks associated with rainfall at bloom, for example. Likewise, in the region of Prince Edward County, Holland and Smit (2014) examined the current adaptation strategies used by winegrowers to manage climate-related conditions; they found that winegrowers learn about adaptive strategies from collaborative efforts with other winegrowers, and trial and error processes. They found that most adaptations are autonomous, reactive, and in the short-term, but could evolve to become anticipatory, long-term strategies (Holland and Smit 2014). Pickering et al. (2012) highlight opportunities for innovation and research that could facilitate the Ontario wine industry's adaptation to CC. Adaptation measures were mostly anticipatory and included both viticulture and oenology strategies.

To increase the industry's diversity and production capacity in the context of CC, studies have also suggested different adaptation strategies for the CWI, including the migration of wine production towards other regions, and the implementation of new grapevine varieties in established regions (Pickering et al. 2015; Shaw 2016; Roy et al.

2017). Additionally, the modification of current cultural practices and the use of technology could greatly help adaptation (Belliveau, Smit and Bradshaw 2006; Jones, 2012; Holland and Smit 2014). For example, the use of web-based warning systems and wind machines could lower the risk of frost damage, while the usage and installation of irrigation systems could lessen drought vulnerability (Belliveau, Smit and Bradshaw 2006; Pickering et al. 2015; Shaw 2016). The purchase of crop insurance could also be an interesting strategy to cope with less predictable weather events that could cause major crop loss (Pickering et al. 2015).

Finally, while the role of human agency in CC adaptation is recognized as important in the literature (e.g. Arbuckle, Morton and Hobbs 2013; Skinner et al. 2001), no studies have examined the influence of winegrowers' attributes on CC adaptation in the CWI. For instance, winegrowers' demographics, as well as their beliefs, attitudes, and knowledge of CC, have not been examined in relation to CC adaptation in the wine industry. Understanding what factors drive adaptation in Canadian vineyards and wineries could help support the adoption of protective measures in the context of CC. It could also illuminate what factors are most susceptible to encourage or discourage adaptation in the CWI.

Research aim and objectives

Considering the elements elaborated above, the aim of this research is to understand how Canadian winegrowers perceive CC and the ways CC adaptation is occurring in the CWI. Three objectives are associated with this overarching aim. Objective One is to assess and understand how CC is perceived. This is done by investigating winegrowers' environmental values, CC knowledge and beliefs, and their perceptions of the consequences of CC on their winegrowing operations. Consideration is further given to the main winegrowing provinces and different categories of winegrowers (Chapter two). Objective Two is to describe the present state of CC adaptation and the various adaptation strategies considered and used by winegrowers in response to specific weather-events (WE) associated with CC in the CWI (Chapter three). Finally, Objective Three is to investigate the attributes that drive CC adaptation in the CWI (Chapter three). The predictors – or drivers – investigated include demographic and psychological attributes such as education level, political affiliation, CC knowledge, CC skepticism and uncertainty, CC concern as well as years of experience in the wine industry, and vineyard size.

Structure of the thesis

The thesis is structured by manuscripts for publication. This opening chapter frames the overall research undertaking. Chapter two (Study one) addresses Objective One. This Chapter was published in the *International Journal of Wine Research* (Jobin-Poirier, Pickering and Plummer 2019). Chapter three (Study two) addresses Objective two and Objective three. Chapter three will be submitted for publication in *Regional Environmental Change*. The fourth and final chapter summarizes the main findings and conclusions of the thesis and provides an overview of the contribution of each study. It also emphasizes the need for further investigation to support the CWI in the context of CC and includes suggestions for future research.

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Chapter two: Doom, gloom or boom? Perceptions of climate change among Canadian winegrowers

Introduction

Global climate change (CC) poses a major threat to our society and puts ecosystems and humankind at risk. From the warming of temperatures to the occurrence of extreme weather events, the repercussions of CC on human systems are increasingly difficult to ignore, especially in sectors such as agriculture, in which climate variations are experienced on a daily basis (Intergovernmental Panel on Climate Change [IPCC] 2014). The wine industry is one of the agricultural sectors that could be most impacted by CC. In fact, since a precise climate range is required to produce quality wines, short-term and long-term climate variability put grapevines at a higher risk than other crops (Jones and Webb 2010; Mozell and Thach 2014). In the international wine industry, a need to understand, assess, and be able to adapt to the effects of CC on grape and wine production is of broad and current interest (Lavenworth 2017; Ollat et al. 2017; Ruell 2018). However, effectively addressing CC is a complex endeavor that requires a transdisciplinary approach involving a myriad of stakeholders (Hirsch et al. 2008). In Canada, winegrowers (winemakers and grape-growers) are at the forefront of decision making in the wine industry. As such, their perceptions are very likely to influence the relationship between CC manifestations and vineyard and winery practices.

Previous literature has demonstrated that perceptions can give insight into people's comprehension of CC and their responses to the phenomenon (Capstick et al. 2015). Understanding CC perceptions could also reveal the most salient barriers that prevent the adoption of best practices, and inform how to effectively communicate CC information

(Whitmarsh 2011; Bennett 2016). Therefore, understanding how winegrowers perceive CC should be part of the strategy to help the industry manage the issue.

A multitude of psychological factors and barriers can shape perceptions, and can either encourage or obstruct the adoption of solutions that would improve environmental sustainability (Gifford 2011). Prior research has shown that perceptions of CC, its impacts, and the participation of individuals in pro-environmental actions are influenced by existing values, beliefs, and knowledge. For instance, pro-environmental values have been positively associated with pro-environmental behavior in a number of studies (Dunlap et al. 2000; Whitmarsh 2008; Ziegler 2017), and a higher likelihood to endorse pro-environmental public policies (Dunlap et al. 2000; Ziegler 2017). Similarly, CC knowledge is a crucial component influencing CC perceptions and behaviour. According to the Knowledge Deficit Model, the general public lacks an expert's understanding of a phenomenon, which explains why they do not respond to it like scientific experts would (Simis et al. 2016). People with low scientific CC knowledge would therefore be less likely to support CC policies, be concerned about the issue, and appropriately address it (Stoutenborough and Vedlitz 2014). Hence, determining CC knowledge amongst winegrowers should inform how to better communicate CC information. Also, CC skepticism and uncertainty represent obstacles to mitigation efforts and willingness to adopt climate protection measures (Rahmstorf 2004; Capstick et al. 2015; Hornser et al 2016). For example, while CC awareness has been increasing internationally in the last few decades (Capstick et al. 2015), attribution skeptics – or people who believe that the Earth's climate is changing, but doubt the influence of anthropogenic activities on CC (Rhamstorf 2004) – still represent a significant segment of the population, despite the extraordinary scientific consensus regarding its reality (IPCC 2001; Capstick et al. 2015). Therefore, assessing individuals' environmental values, CC knowledge, and beliefs is important to understanding their perception and response – or lack thereof – to CC (Capstick et al. 2015).

Generating over $9 billion in national economic impact per year (Canadian Vintners Association, 2017), the Canadian wine industry (CWI) is booming and increasingly gaining international recognition (Montgomery 2013). During the last forty years, Canada has transformed from a marginal grower of native American grapes to a quality producer of acclaimed icewines and world class table wines (Statistics Canada 2009). Most Canadian wine regions are found in four main provinces: Ontario accounts for approximately 49% of the national economic impact of the CWI, British Columbia 31%, Québec 12% and Nova Scotia 0.2% (Canadian Vintners Association 2017). Across the country, wine producing areas are generally considered 'cool-climate' due to their relatively short growing seasons and their cold winters (Reynolds 2010; Shaw AB 2016). However, as the second largest country on Earth, Canada is home to a range of climates and topographies, which makes Canadian wines very diverse.

In the past few decades, the gradual shift towards warmer temperatures has allowed the ripening of cool climate *Vitis Vinifera* varieties in Canada, especially in Ontario and British Columbia (Jones 2012). For Canadian wine regions, this could bring both opportunities and losses in the future. A longer growing season, including an extended frost-free period, coupled with a rise in temperature during ripening could help growers plant commercially successful, less cold-tolerant grapevines. This could also allow for the development of new wine styles and wine regions, which were previously not suited to quality grape growing (Shaw 2016; Roy et al. 2017). Conversely, changing temperatures could also lessen the capacity of established wine regions to produce the cool-suited cultivars that currently thrive in those areas (Pickering et al. 2015; Shaw 2016). Similarly, icewine production could be compromised by the rise of temperatures created by climate change. Icewine is a unique dessert wine made by pressing frozen grapes that have to be harvested and processed at -8^{o}C, or below. Therefore, warmer winter temperatures could lower the number of days available for icewine harvest (Cyr and Shaw 2010).

Additionally, CC is altering precipitation patterns (IPCC 2012; Natural Resources Canada 2015) which could directly impact winegrowing in Canada (Shaw 2016). A sufficient amount of rainfall is required to ensure grapevines' growth and survival, but high rainfall is associated with lower quality, especially early in the season and close to harvest. In early spring, intense rainfalls can cause an increased pest pressure in vineyards, and can thus negatively affect bloom. During the growing season, rainfall can delay ripening, and interfere with the optimal berry maturation. During grape ripening, high rainfalls can cause the berries to swell, which dilutes their sugar and flavor and may result in berry splitting, fungal disease, and increased disease pressure (Jackson and Lombard 1993).

Moreover, extreme weather events related to climate change are hard to predict and can severely damage crops (IPCC 2012; Pickering et al. 2015; Shaw 2016). For instance, temperatures over 30^{o}C can alter grapevines' photosynthetic capacity, and thus lessen their performance and health (Mullins, Bouquet and Williams 1992), while cold-snaps during the winter can kill or deeply damage grapevines (Pickering et al. 2015; Roy et al. 2017). Also, episodes of drought can impact many vital aspects of viticulture, and can reduce yield, vine vigor, and ultimately reduce grapevines' potential for survival (Pickering et al. 2015).

In the international wine industry, little is known about CC perceptions. In Europe, Alonso and O'Neill (2011) found that Spanish winegrowers who identified the impacts of CC were more inclined to adjust their operations than those who did not acknowledged the consequences of CC. Also, research in both Europe (Battaglini et al. 2009) and Canada (Ontario) (Pickering et al. 2015) observed that perceptions of the impact of CC – both positive and negative – were linked with winegrowers' interest in adaptation.

In light of these considerations, this study seeks to describe Canadian winegrowers with respect to their environmental values, and CC beliefs and knowledge, as well as their perception of the consequences of CC on their winery and vineyards' operations. This information captures the 'state of the industry' regarding CC perceptions, and allow a comparison between provinces, groups of workers, and other populations. In addition, this study seeks to determine how the perceptions of CC impacts vary with values, beliefs, and knowledge. This information should reveal opportunities for knowledge transfer between stakeholders in the industry, and inform policymaking to help the industry thrive within the context of CC.

Material and methods

Recruitment of participants

Data were collected from July 2017 until January 2018, using an online bilingual survey hosted on Qualtrics® survey software. To reach as many participants as possible, winegrowers associations of British Columbia, Ontario, Québec, and Nova Scotia were contacted and asked to share the invitation with their members through email or their associations' newsletters. Approximately 1,860 winegrowers were sent a one-page invitation letter that stated the aim of the study as well as the inclusion criteria: that participants needed to i) be working in Canada as a winemaker, grape-grower, or winery owner, and ii) be 18 years old or older to participate. To access the survey, a secure URL address was included in the letter. Upon the completion of the survey, participants were eligible to enter a lottery for a $500 cash prize. The study has received ethics clearance through the Brock University Research Ethics Board (File #16-310).

Variables measured

The survey text is presented in Supplementary Material 1. Demographics of the participants were collected including gender, age and the education level. Characteristics specific to the vineyard or winery operated by participants were also documented, including the role of the respondent in the vineyard or winery (grape-grower, winemaker, owner, employee, or external consultant) and province of production.

A six-item New Environmental Paradigm scale (NEP) (Dunlap et al. 2000) adapted by Whitmarsh (2011) was used to measure environmental values (Supplementary Material 2). On a 5-point Likert scale, winegrowers were asked to rate their level of agreement with the statements. Responses were coded with numerical values (1=strongly disagree; 5=strongly agree) and reverse coding was applied for negatively worded questions (5=strongly disagree; 1=strongly agree). Individual NEP scores were then generated, where higher scores reflect greater pro-environmental values.

Climate change belief, as a variable, was deconstructed into two sub-variables for consideration. First, uncertainty and skepticism were measured using five attitudes statements adapted from Whitmarsh (2011) and Spence, Poortinga, and Pidgeon (2012). Using a 5-point Likert scale, participants were asked to rate their level of agreements with the statements. The responses to statements were coded numerically, and reverse coding was applied when necessary, then averaged to generate uncertainty and skepticism scores. Scores closer to '1' suggest a lower level of skepticism, while scores closer to '5' reflect a higher level of CC uncertainty and skepticism. Second, the same question Morris and Pickering (2019) asked to measure belief in anthropogenic CC was used. Participants were asked to select the circle they think represents the cause(s) of climate change. Response options were illustrated as pie charts presenting five different proportions of anthropogenic v*ersus* natural causes of CC.

Perceived and assessed knowledge of CC were both determined. Perceived knowledge was measured by asking participants to gauge how much they know about climate change by moving a slider on a horizontal line with two anchor phrases positioned at its extremes. *I know very little* was positioned under the rating of '1' at the left end of the line, and *I know a great deal* was positioned under '10' at the right end (Morris and Pickering 2019). The perceived knowledge average scores were then transformed to percentage values for comparison with the assessed knowledge values. Assessed CC knowledge was measured using Stoutenborough and Vedlitz's (2014) index, which is composed of a set of six true-or-false (T/F) type questions based on material extracted from the Intergovernmental Panel on Climate Change (IPCC 2001) and developed with climate scientists. Instead of being presented as a binary question, the additional choice to select the answer *I don't know* was provided in this study to prevent participants from guessing. An *assessed knowledge score* was created following a two-step method adapted from Liu, Stoutenborough, and Vedlitz (2017). First, the responses to the questions were coded using a 0/1 score (1 = *correct*; 0 = *incorrect* and *I don't know*). Second, the six answers were averaged and transformed into a value representing the percentage of correct responses, with 0% representing no correct responses and 100% representing all correct responses.

Participants were asked if the consequences of CC on their operations were *mostly positive, mostly negative, positive and negative,* or *neutral (no consequence)*. Except for those who selected the latter choice, participants were then directed to a check-all-that-apply multiple-choice question with an open-ended option, which asked them what they perceive to be the major benefits and disadvantages from CC for the wine industry in their region. Participants who selected *mostly positive* or *positive and negative* were asked about the benefits, while those who selected *mostly negative* and *positive and negative* were asked about the disadvantages.

The specific benefits and disadvantages chosen for this question were based on Pickering et al. (2015) and from other literature on the commonly discussed effects of CC on the CWI (Jones et al. 2005; Jones 2012; Holland and Smit 2010; Shaw 2016; Roy et al. 2017). They represent direct impacts of weather events associated with CC on grape and wine production, with the exception of *extended growing season*, which is commonly referred to as a positive effect for cool-climate regions (Holland and Smit 2010; Jones 2012; Pickering et al. 2015; Shaw 2016; Roy et al. 2017). Since Canadian wine regions are mostly considered to be cool-climate, low temperatures are certainly recognized as one of the main problems for viticulture and winemaking (Heinricks 2001). Therefore, the potential benefits used in the multiple-choice question were all related to the predicted increase of annual temperatures. However, the warming of temperatures can also be a drawback for the industry, especially for regions that are currently successful with reliable production of cool-climate varieties and styles, which is reflected in the multiple choices

(Shaw 2016). While the effects of CC can vary from one region to another, the benefits and disadvantages listed are relatively general and not region-specific given the desire to survey a wide geographical distribution of the CWI. Finally, to capture as comprehensive a listing as possible of the perceived consequences of CC, an open-ended option allowed participants to list any other benefit(s) or disadvantage(s) they identified as important.

Data treatment and analysis: general approach

XLSTAT Version 2017.19.05.46974 (Addinsoft, NY, USA) was used to perform all data analysis. To assess potential differences in average NEP and skepticism scores between the provinces of Ontario, British Columbia, and Québec, and between categories of respondents (grape-growers, winemakers, and winemakers/grape-growers), one-way ANOVAs, followed by a Tukey's $HSD_{0.05}$ tests, were performed. Nova Scotian participants were excluded from the provincial comparisons because of the low number of respondents from this province (n = 9). Two-sample t-tests (α= 0.05) were conducted to compare owners' and non-owners' NEP and skepticism scores. A Shapiro-Wilk test for normality and a Levene's test for homogeneity were previously performed for each sample compared in the study. Cronbach's alpha was used to measure the internal consistency of the NEP and skepticism scales (Cronbach's α value higher than 0.7 demonstrated the reliability of the scales). Since the assessed CC knowledge distributions of participants did not follow normal distributions, knowledge scores were grouped into two categories – *low* and *high* – based on the median score of 50% correct. Contingency tables and chi-square (χ^2) tests of independence were then used to examine the potential relationships between knowledge and the different categories of workers and their province of work.

To investigate how ecological values, skepticism, and assessed knowledge relate to participants' perceptions of the impacts of CC, contingency tables were created, and χ^2 test of independence were performed. The non-parametric Fisher's exact test results were reported in instances where the *p* value of the χ^2 tests of independence was very close to significance. To improve statistical power, NEP, skepticism and uncertainty, and assessed knowledge scores were grouped into two categories – *low* and *high* – to create contingency tables. NEP scores from 1 to 3.99 were grouped in the *low* category, and scores from 4 to 5 in the *high* category. The median score of 2.20 was used to categorize the skepticism and uncertainty scores: results lower than 2.20 were characterized as *low*, and scores equal of higher than 2.20 were considered *high*. The median value of 50% correct responses was used to categorize the assessed knowledge scores. The perceived consequences of CC were classified into three of the four original categories of responses; i) *mostly positive*; ii) *mostly negative*; and iii) *positive and negative*. Due to the low number of respondents (n = 10) who selected the response *neutral (no consequence)* to the perception of impact question, this was removed from the analysis. The statistical tests used are described in Supplementary Material 3 and the detailed categories of responses for each variable are given in Supplementary Material 4.

Results

Description of participants

A total of 122 winegrowers completed the survey, which represents an approximate response rate of 6.5%. Participants who did not respond to all questions were excluded from the analysis, excepted for one participant who omitted to respond to 8% of the demographic questions. At the time they took the survey, 38% of respondents were working in Ontario, 33% in British Columbia, 22% in Québec, and 7% in Nova Scotia. A majority of respondents are male (73%), aged between 31 and 60 years old (77%), attended University (81%) and have worked in the wine industry for more than five years (89%). The sample is described in detail in Table 1 below.

Table 1: Sample description

Gender	
Female	27%
Male	73%
Age	
18-30	5%
31-40	27%
41-50	25%
51-60	25%
Over 60	18%
Highest level of Education	
No formal qualification	1%
High school diploma	4%
Apprenticeship or Trades Certificate or Diploma	4%
College, CÉGEP, or other non-University Certificate or Diploma	10%
University Certificate, Diploma or Degree below the Bachelor Level	12%
University Certificate, Diploma or Degree at the Bachelor Level	45%
University Graduate Degree	24%
Role in the winery/vineyard	
Winemaker	61%
Grape grower	66%
Winemaker and grape grower	39%
Owner	56%
External Consultant	4%
Years of work experience in the wine industry	
Less than 5 years	11%
5 to 10 years	26%
11 to 20 years	38%
Over 20 years	25%

Environmental values, beliefs, and knowledge

A NEP score of 3 is commonly considered as the cut-off for an anthropocentric worldview (lower than 3) and a pro-ecological worldview (higher than 3) (Ogunbode

2013). At the national level, the average NEP score was 3.84 (standard deviation (*SD*) = 0.66), which suggests that Canadian winegrowers have a more ecological than an anthropocentric worldview. The ANOVAs performed did not show a significant difference in NEP scores between provinces ($F = 2.03$; $p = 0.14$) or between winemakers, grape-growers, and winemakers/grape-growers ($F = 1.63$; $p = 0.20$). Similarly, the t-test did not show a significant difference between owners and non-owners; $t(120) = 1.58$, $p = 0.12$) (Table 2). The shortened (6-item) NEP scale used to measure environmental values was found to be internally consistent (Cronbach's α= 0.71).

Table 2. Average responses, for environmental values, climate change skepticism/uncertainty and assessed climate change knowledge for winegrowing provinces and categories of workers.

	NEP Scores			**Uncertainty and Skepticism scores**			**Assessed Knowledge (% of Correct Responses)**		
	Average	*SD*	*Sig*	*Average*	*SD*	*Sig*	*Average*	*SD*	*Sig*
*Provinces**									
Ontario (*n* = 46)	3.8	0.8	NS	2.3	0.9	NS	55.4	22.3	NS
British Columbia (*n* = 40)	3.8	0.6	NS	2.3	0.7	NS	52.9	24.6	NS
Québec (*n* = 27)	4.1	0.5	NS	2.1	0.6	NS	58.0	15.3	NS
*Role in the Winery/ Vineyard**									
Winemakers (*n* = 28)	4.0	0.6	NS	2.2	0.7	NS	59.5	18.6	NS
Grape-Growers (*n* = 33)	3.7	0.8	NS	2.4	0.8	Sig	51.0	25.3	NS
Winemakers/ Grape-Growers (*n* = 47)	3.9	0.7	NS	1.9	0.7	Sig	54.3	22.4	NS
*Owners/ Non-Owners***									
Owners (*n* = 68)	3.8	0.7	NS	2.6	0.7	NS	54.7	21.9	NS
Non-owners (*n* = 54)	3.9	0.6	NS	2.1	0.8	NS	56.2	21.6	NS

* One-way ANOVA was performed; Tukey (HSD) with a confidence interval of 95%
** Two-sample t-test was performed, with a confidence interval of 95%
Abbreviations: NEP, New ecological paradigm, SD, standard deviation; Sig, significant, NS, non-significant.

At the national level, the average uncertainty and skepticism score was 2.19 (SD = 0.73). The average uncertainty and skepticism score is significantly lower in individuals identified as winemakers/grape-growers than in those who work as grape-growers only ($F = 4.60$, $p = 0.01$). No significant difference was observed between provinces ($F = 0.80$, $p = 0.45$) or between owners and non-owners; $t(120) = 1.12$, $p = 0.267$ (Table 2). Total agreement and mean scores for the five skepticism statements are presented in Supplementary Material 5. The lowest agreement was for *The seriousness of climate change is exaggerated*; followed by *I am uncertain that climate change is really happening*; and *The media is too alarmist about climate change.* Approximately half of the participants agreed with the statement *It is uncertain what the effects of climate change will be.* The highest agreement was for *Most scientists agree that climate change is really happening.* A reliability analysis was conducted on the five statements, which showed internal consistency (Cronbach's $\alpha = 0.73$). Moreover, the majority of respondents (78%) believe CC is caused by a mix of natural and anthropogenic factors, while only 3% of respondents believe it is entirely caused by natural forces, and 19% attribute CC to human activities solely (see Supplementary Material 6 for full details).

The assessed knowledge score was measured in terms of the percentage of correct responses. Perceived knowledge was measured on a 10-point scale (1 to 10), and converted into a percentage value for comparison purposes with the assessed knowledge values. At the national level, the assessed knowledge mean score is 55.3% (*SD* = 21.8), while the perceived knowledge mean score is 7.0 (*SD* = 1.8), corresponding to 61.7% (*SD* = 23.0), which is higher than the assessed knowledge national value. A similar trend is observed for the different groups of workers and for Ontario and British Columbia; whereas in Québec, the assessed knowledge score is slightly higher than the perceived knowledge score (Supplementary Material 7 and 8).

Chi-square tests of independence were performed on contingency tables to examine the potential relationships between the level of assessed CC knowledge (*low* or *high*) and the role of the respondents in the winery (winemaker only, grape-grower/winemaker, and grape-grower), their ownership status (owner or non-owner), and their provinces of work (Ontario, British Columbia, or Québec). The tests showed that the level of knowledge is independent from participants' professional role in the winery (χ^2 (2, N = 108) = 0.367, p= 0.83); the ownership status (χ^2 (2, N =122) = 1.04, p = 0.31), and from their province of work (χ^2 (2, N =113) = 1.48, p = 0.48).

Perceived positive and negative consequences of climate change

As shown in Figure 1, the majority of Canadian winegrowers indicated that the consequences of CC on their operation are *both positive and negative*, an equal proportion of them stated that CC has *mostly negative* or *mostly positive* impacts, and a small proportion affirmed that CC has *no impact* on their operations. Similar to the national values, the majority of respondents in each province and in each group of workers indicated that the consequences of CC are *positive and negative*, while a small portion of respondents perceive the consequences of climate change to be *neutral* for the wine industry. The perceptions of CC consequences on the industry for the different categories of winegrowers are given in Supplementary Material 9.

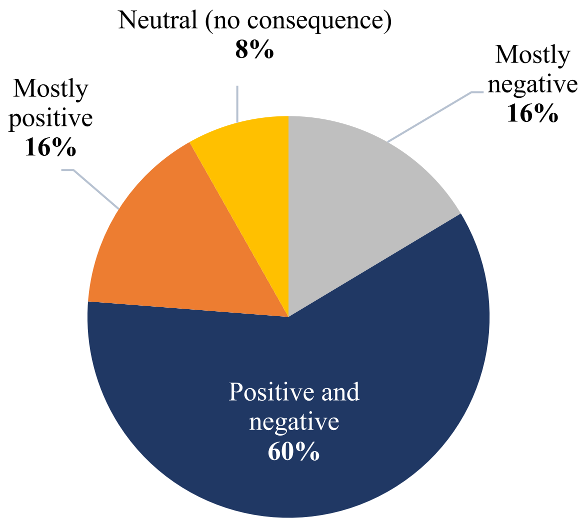

Figure 1. Consequences of climate change perceived by Canadian winegrowers

The selected benefits and disadvantages of CC for the CWI are illustrated in Figure 2 and 3, respectively. Other positive and negative consequences of CC described by respondents are presented in Supplementary Material 10. The most frequently cited responses in this 'other' category include the *uncertainty in predicting the weather*, the *inconsistent quality* and *the variability of yield*.

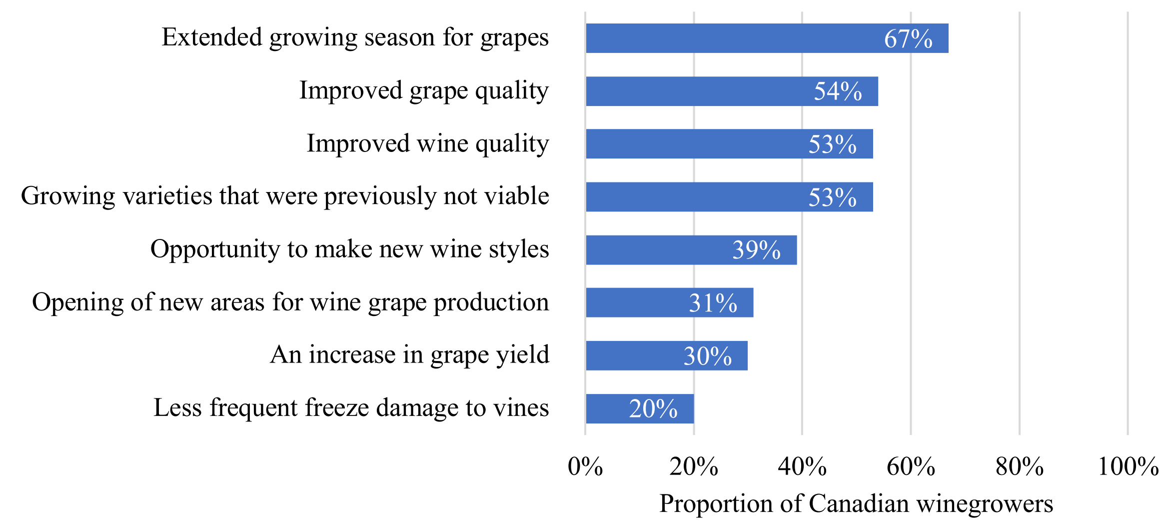

Figure 2. Perceived benefits of climate change for the wine industry.

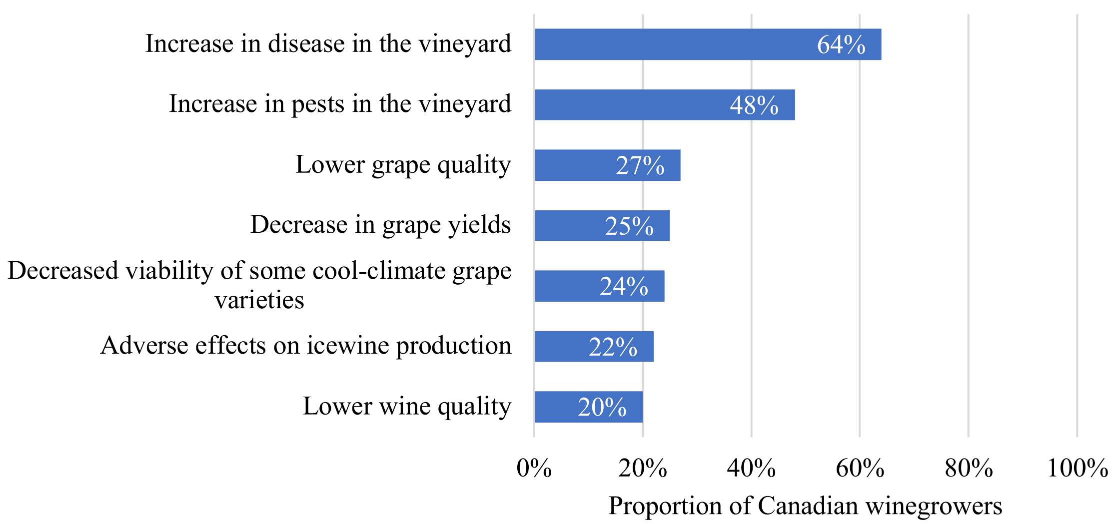

Figure 3. Perceived disadvantages of climate change for the wine industry.

Relationships between values, skepticism, knowledge, and perception of Impacts

The contingency table χ^2 result indicates no association between environmental values (NEP scores) and the perception of CC for the wine industry (χ^2 (2, N = 112) = 5.70,

p = 0.058). However, the Fisher's exact test indicates that respondents with a more anthropocentric worldview (low NEP scores) see CC as being *mostly positive*, while respondents with a more ecological worldview (high NEP scores) were less likely to see CC as being *mostly positive* for the CWI. Similarly, no association between the level of skepticism and the perception of CC consequences was observed (χ^2 (2, N = 112) = 2.25, p = 0.32), nor between level of assessed knowledge and the perception of CC consequences (χ^2 (2, N = 112) = 1.82, p = 0.40).

Discussion

Environmental values, beliefs, and knowledge

The revised NEP scale is widely used and has been extensively validated as an accurate measure of environmental values. In several previous studies, an ecological worldview – represented by a high NEP score – has been associated with pro-environmental intentions and behaviours. Conversely, an anti-ecological worldview – represented by a low NEP score – has been associated with low ecological support and actions (Dunlap et al. 2000; Whitmarsh 2008; Ziegler 2017). Much like the general Canadian population (Pickering 2015; Morris and Pickering 2019), winegrowers appear to have a more eco-centric than anthropocentric worldview. Furthermore, there was no significance difference in average NEP scores between provinces, ownership status, and roles in the winery. Therefore, the results suggest that Canadian winegrowers may be inclined to support and act in favor of the environment.

The average winegrower's score for CC uncertainty and skepticism is relatively low. More specifically, most respondents seem to have a low level of uncertainty regarding the existence of CC, but their uncertainty with regards to the effects of CC is mixed. A multitude of reasons could explain this trend, but perhaps one of the main factors is the uncertain nature of CC itself. As a complex phenomenon, CC abounds with uncertainty (Weber 2010). In fact, understanding the impacts of CC not only requires a high level of scientific literacy, it also involves the mental process of transposing predicted changes into natural and human systems to fully appreciate the concrete implications for humans' daily lives. It also requires people's attention to and trust in the media providing CC information which, in turn, can convey conflicting messages (Weber 2010; Braman et al. 2012). All those factors combined can exacerbate the level of uncertainty about the effects of CC. Additionally, winegrowers arguably experience and are attentive to numerous climate variations which can impact their production. In this context, determining which specific effect is attributable to CC rather than to normal climate variability could be arduous and could, thereby, reinforce uncertainty. The results also show that only a minority of participants believe that *the seriousness of CC is exaggerated*, and that *the media is too alarmist about CC*. Those results are similar to those reported by Morris and Pickering (2019) for a representative sample of the adult Canadian population, and suggests that Canadian winegrowers understand the seriousness of the issue.

Respondents who identified as grape-growers trended toward a higher skepticism score than respondents who identified as both grape-growers and winemakers. This difference could be due to the more diverse experience of individuals who are responsible for grape growing as well as winemaking. Indeed, while grape-growers mostly witness the repercussions of climate variabilities in the vineyard, winemakers observe the effects in the grape must and the processed wine. The coupled experiences might reinforce the perception that CC is not only happening, but that it is serious, and its effects are evident; this, in turn, could decrease uncertainty and skepticism.

Our findings also show that almost all Canadian winegrowers (97%) recognize the effect of human activities on CC; this suggests that the prevalence of attribution skepticism is very low amongst winegrowers, similar to the general Canadian population (Morris and Pickering 2019). This is also consistent with prior studies that have indicated that only a small part of the population completely rejects the notion of anthropogenic CC (Whitmarsh 2011; Gifford 2011). However, this small group of people tend to be more vocal about their opinions than people who acknowledge the veracity of the issue (Gifford 2011), and may receive a disproportionate amount of attention from the media. In turn, this could perpetuate the misconception that they form a significant part of the population (Rhamstorf 2004), which may extend to how the CWI is perceived and represented on the issue of CC.

Knowledge of CC is a necessary precursor for CC perceptions, and can be either a barrier or a motivator to actions (Gifford 2011; Stoutenborough and Vedlitz 2014). Using Stoutenborough and Vedlitz's (2014) index, we determined that winegrowers have an average assessed knowledge score of 55.3%, which is significantly lower than that of experts (100%). This suggests that Canadian winegrowers may be less likely than experts to perceive CC risks, which might diminish their likelihood of appropriately understanding and addressing them. Furthermore, the results show that the level of assessed knowledge is independent from winegrowers' professional roles in the winery, their ownership status, and their provinces of work, suggesting that there is an opportunity for further CC knowledge transfer throughout the CWI.

Despite its popularity, the measure of self-assessed or perceived CC knowledge has been criticized in the past because it can be erroneous and shows little support for the Knowledge Deficit Model (Kellstedt, Zahran and Vedlitz 2008; Stoutenborough and Vedlitz 2014). Nevertheless, measuring perceived CC knowledge has value since it illustrates the extent to which people think they know an issue, which might inform their disposition and interest in increasing their CC literacy. Our results show that Canadian winegrowers have a higher level of perceived CC knowledge (6.6) than the general Canadian population (5.8), as assessed by Morris and Pickering (2019). This could be partly due to the nature of winegrowers' work, which is intrinsically linked to the environment and climate variabilities, thereby making them more likely than the rest of the population to know – or *think* they know – more about CC. Also, on average, winegrowers perceived their knowledge to be higher that their assessed CC knowledge. While the gap between scientific and perceived knowledge is modest (between 2% and 13%), it indicates a broad trend: Canadian winegrowers are prone to overestimate their CC knowledge. An overestimation of knowledge may lead to a lack of interest in learning more about CC (Stoutenborough and Vedlitz 2014). Consequently, while the results show that there is room for improvement in terms of scientific knowledge, winegrowers might not be as willing to use their resources to learn more about CC if they perceive that they already know enough about it.

Perceived positive and negative consequences of climate change

CC could provide opportunities for and cause damage to the CWI (Pickering et al. 2015; Shaw 2016). Much like the winegrowers of Ontario (Pickering et al. 2015), Italy, France and Germany (Battaglini et al. 2009), our results suggest that most Canadian winegrowers (92%) are aware that CC has consequences on their operations. Amongst the respondents who acknowledge the consequences of CC, a majority (60%) perceive them as both *positive and negative*, while the remainder perceive CC consequences as being either *mostly positive* (16%) or *mostly negative* (16%).

In this study, *extended growing season for grapes* was the most selected positive consequence of CC for vineyards and winery operations. This result is unsurprising, given that the potential for the industry to extend further into the vast northern regions of the country is largely limited by the inability of grapes to ripen there in the relatively short growing season (Reynolds 2010). In addition, our findings show that Canadian winegrowers are more likely to perceive CC as being favorable than detrimental for the quality of grapes and wines. As observed by Battaglini et al. (2009), who reported similar results amongst European winegrowers, this is due to the understanding amongst winegrowers that warmer temperatures – and possibly, more sunny days – are associated with higher grape and wine quality (Battaglini et al. 2009). In cool-climate and marginal grape-growing regions, this perspective can understandably seem promising for winegrowing, despite the potentially negative impacts of warmer temperatures outlined earlier.

On the other hand, the most frequently selected negative impact of CC is the *increase in disease in the vineyards*, followed by an *increase in pests in the vineyards*. Since those two consequences can potentially affect grapes and wine quantity and quality (Pickering et al. 2015; Shaw 2016), it is surprising that *lower grape quality*, *decrease in grape yields,* and *lower wine quality* were only selected by less than a third of participants.

This could indicate that winegrowers are confident in their capacity to handle more disease and pest pressure without compromising their production.

More than half of respondents selected the *opportunity to grow varieties that were previously not viable* as being a positive consequence of CC while, conversely, less than a third of them selected the *decreased viability of some cool-climate grape varieties* and the *adverse effects on icewine production*. This insinuates that winegrowers may think that CC will provide more opportunities than loss regarding the size and variety of their wine portfolio. Again, those perceptions might be, in part, attributable to the common belief that cold temperatures are the primary deterrent to quality grape growing and winemaking. Indeed, while some cool-climate grape varieties such as Riesling typically do well in Canada, winegrowers must often cope with the consequences of freeze damage and, consequently, may believe that the benefits of warmer temperatures outweigh the potential disadvantages associated with, for instance, a shorter window for icewine harvest. The industry currently relies heavily on icewine exports for its economic viability; indeed, Canada is the world's largest icewine producer per volume and this product accounts for almost a quarter of her wine exportation (Canadian Vintners Association 2017). Therefore, underestimating the impact of CC on icewine production could be risky for the sustainability of the CWI.

Limitations and further research

The main limitation of this study is the relatively small sample size. While most Canadian winegrowers' associations and wineries were contacted, a rather small percentage of the winemakers, grape growers, and owners completed the survey. This could be due to many factors, including the length of the survey. Also, participation bias may be a noteworthy limitation. Specifically, the topic of the study might have attracted more ‘environmentally conscious’ winegrowers and, as a result, the responses may not be as reflective of the whole industry as desired.

The success of the CWI relies on its ability to continuously produce quality wine and to be competitive in an aggressive international market. In the context of CC, the need to understand and appropriately respond to the present and future climate alterations is imperative. Hence, future research should take into account the importance of winegrowers’ opinions and perceptions of CC, which is reflective of their needs and, most likely, their willingness to embrace new technologies and methods. Also, determining the current state of CC adaptation in the CWI could provide an important benchmark, illuminate weaknesses, and help inform new policies and potential contributions from the various actors of the industry. Barriers other than perceptions, including financial resources and the availability of the required technologies to adjust existing operations, should also be part of the discussion around CC impacts and adaptation in the CWI.

Conclusion

This is the first study to characterize Canadian wine growers’ environmental values, CC knowledge and beliefs, and perceptions of the consequences of CC on the wine industry. Canadian winegrowers generally have a pro-environmental worldview, are moderately knowledgeable about CC, and have a low level of skepticism regarding the existence and seriousness of the phenomenon. Furthermore, they largely acknowledge that CC has positive as well as negative consequences for their industry. However, they are somewhat uncertain about the specific effects of CC in general and on their operations. Overall, our findings indicate the need to document and explain the effects of CC, rather than to reinforce the veracity of its existence and the anthropogenic contribution to its aggravation within the winegrower and grape-grower population in Canada. Indeed, the uncertainty of the consequences of CC can obstruct the development and implementation of effective adaptations strategies, which are much needed for the CWI. Moreover, uncertainty can restrain people from supporting climate policies, since their benefits are not well understood, or are not perceived as valuable. Therefore, an effective knowledge transfer and collaboration strategy involving all the relevant stakeholders of the industry – but especially between winegrowers and CC experts – is indicated to improve the capacity of the industry to develop and adjust to the consequences of CC.

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Supplementary Material

Supplementary Material 1: Survey Text

Age

What is your age?

- ◯ 18 to 30
- ◯ 31 to 40
- ◯ 41 to 50
- ◯ 51 to 60
- ◯ Over 60

Gender

Are you female or male?

- ◯ Female
- ◯ Male

Years of experience in the industry

How many years of experience in the winemaking/grape growing industry do you have?

- ◯ Less than 5 years
- ◯ 5 to 10 years
- ◯ 11 to 20 years
- ◯ Over 20 years

Province of production

In which province are you mostly working?

- ○ British Columbia
- ○ Ontario
- ○ Québec
- ○ Nova Scotia

Role in the winery/vineyard

What best describes your role in the vineyard/winery you work at? Check all that apply.

- ○ Winemaker
- ○ Grape Grower
- ○ Employee
- ○ External Consultant
- ○ Owner

Environmental values (modified NEP)

Please indicate your level of agreement with each statement.

	Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree
Humans have the right to modify the natural environment to suit their needs	○	○	○	○	○
Humans are severely abusing the environment	○	○	○	○	○
Plants and animals have the same rights as humans to exist	○	○	○	○	○
Nature is strong enough to cope with the impact of modern industrial nations	○	○	○	○	○
The balance of nature is very delicate and easily upset	○	○	○	○	○
Humans were meant to rule over the rest of nature	○	○	○	○	○

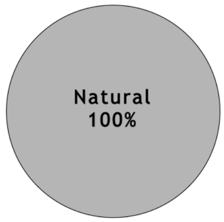
Uncertainty and skepticism

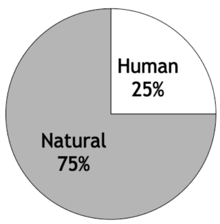
Please indicate your level of agreement with each statement.

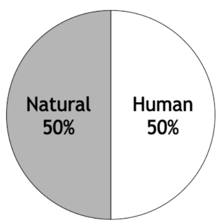
	Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree
I am uncertain that climate change is really happening	○	○	○	○	○
The seriousness of climate change is exaggerated	○	○	○	○	○
Most scientists agree that climate change is really happening	○	○	○	○	○
It is uncertain what the effects of climate change will be	○	○	○	○	○
The media is too alarmist about climate change	○	○	○	○	○

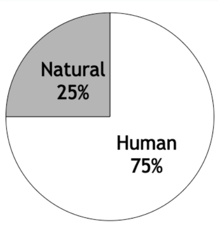
Belief in anthropogenic climate change

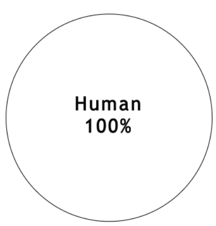
Please select the circle you think best represents the cause(s) of climate change.











Assessed climate change knowledge

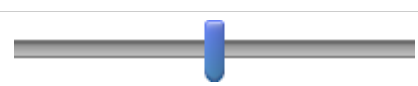
For each of the following statements about possible causes and effects of climate change, please indicate whether you think the statement is **true** or **false** or you **don't know.**

	True	False	Don't know
Nitrous oxide is a greenhouse gas. T	○	○	○
The major cause of increase atmospheric concentration of greenhouse gases is humans burning fossil fuels. T	○	○	○
Biological diversity will increase as global temperature increases. F	○	○	○
Aerosols are airborne particles that are known to contribute to the formation of clouds and precipitation. T	○	○	○
Scientifics agree that, as a result of climate change, the sea level will continue to rise for at least a century. T	○	○	○
There is a scientific consensus that there will be an increase in global precipitations as a result of global climate change. T	○	○	○

Perceived knowledge

How much do you know about climate change? Please move the slider to your answer.

I know very little								I know a great deal
1	2	3	4	5	7	8	9	10



Perceptions of the consequences of climate change on the wine industry

Taken overall, the consequences of climate change on your operations are:

- ○ Mostly positive
- ○ Mostly negative
- ○ Positive and negative
- ○ Neutral (no consequence)

Perceived benefits from climate change for the wine industry

What do you perceive to be the major benefits from climate change for the wine industry in your region? Check all that apply.

- ○ Extended growing season for grapes
- ○ New varieties can be grown that were previously not viable
- ○ Less frequent freeze damage to vine
- ○ An increase in grape yield
- ○ The opening of new areas for wine grape production
- ○ Improved wine quality
- ○ Improved grape quality
- ○ Opportunity to make new wine styles
- ○ Other(s) (please list)

Perceived disadvantages from climate change for the wine industry

What do you perceive to be the major disadvantages from climate change for the wine industry in your region? Check all that apply.

- ○ Increase in pests in the vineyard
- ○ Increase in disease in the vineyard
- ○ Decrease in grape yields
- ○ Decreased viability of some cool-climate grape varieties
- ○ Adverse effects on icewine production
- ○ Lower wine quality
- ○ Lower grape quality
- ○ Other(s) (please list)

Supplementary Material 2: The revised New Environmental Paradigm (Dunlap 2000) shortened by Whitmarsh (2011)

NEP Statements used in the survey
Humans have the right to modify the natural environment to suit their needs (NEP #2)
Humans are severely abusing the environment (NEP #5)
Plants and animals have the same rights as humans to exist (NEP #7)
Nature is strong enough to cope with the impact of modern industrial nations (NEP #8)
The balance of nature is very delicate and easily upset (NEP #13)
Humans were meant to rule over the rest of nature (NEP #12)

Supplementary Material 3: Description of the statistical tests performed

1. **One-way ANOVA (One-way Analysis of variance)**

   A method used to test "the equality of three or more population means by analyzing samples variances. One-way ANOVA is used with data categorized with one factor, so there is only one characteristic used to separate the sample data into different categories" (Triola 2014, p. 639).

2. **Tukey's HDS$_{0.05}$ (Tukey's honestly significant difference test)**

   A test used to identify which means are different after performing an ANOVA at the 0.05 significance level (95% confidence interval) (Triola 2014).

3. **Two sample T-test**

   A test used to compare the means of two samples (Triola 2014).

4. **Shapiro-Wilk test**

   A test used to assess the normality of the distribution, which is an assumption of the one-way ANOVA (Statistics Solutions, 2019).

5. **Levene's test**

   A method used to test if samples have equal variances (homogeneity of variance), which is an assumption of the one-way ANOVA (Statistics Solutions, 2019).

6. **Cronbach's alpha**

   A test used to estimate the internal consistency (or reliability) of a composite score (Statistics Solutions, 2019).

7. **Contingency tables and chi-square (χ^2) tests of independence or Fisher's exact test**

   Methods used to test the association between two qualitative variables. Test the null hypothesis (H_o): the two qualitative variables are independent.

   - *Chi-square (χ^2) tests of independence*: "is based on the computation of a chi-square statistic which reflects the distance between the real data and theoretical data if the null hypothesis were true" (XLSTAT, 2017).

   - *Fisher exact test*: less reliable that the Chi-square (χ^2) tests of independence – "it computes the probability of having the observed data as well as the probabilities of getting all of the more extreme possible datasets under the null hypothesis. These probabilities are used to compute Fisher's exact test p-value" (XLSTAT, 2017).

Supplementary Material 4: Detailed categories of variables tested with contingency tables and Chi-square tests of independence and respective frequencies

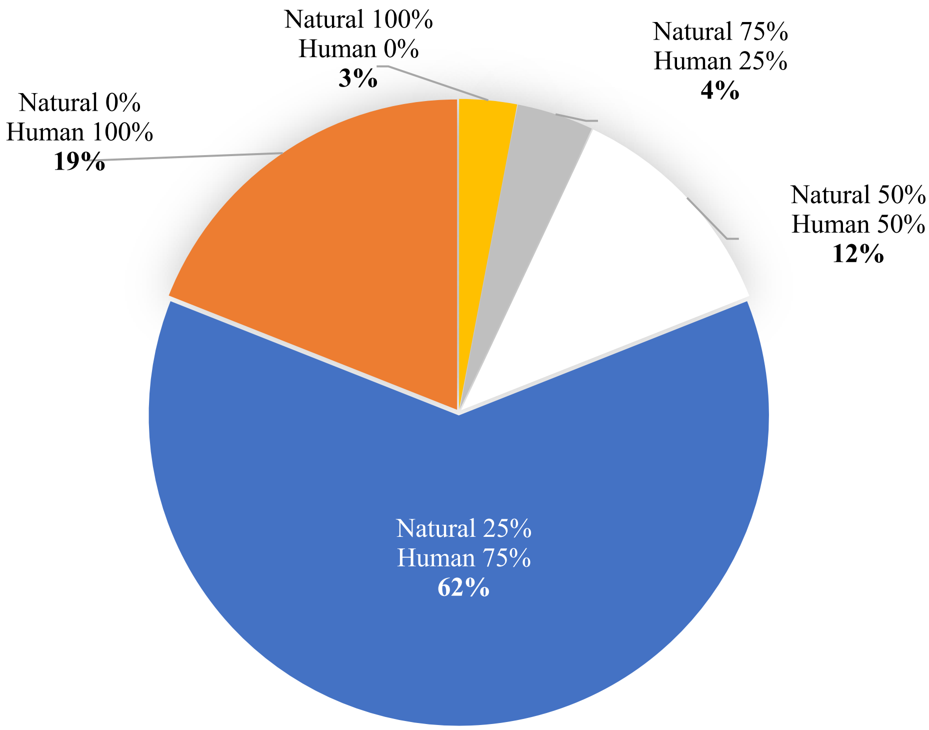
Variables measured	Categories	Scores	Frequencies
New ecological paradigm score	Low	1 to 3.99	55
	High	4 to 5	57
Skepticism and uncertainty	Low	1 to 2.19	59
	High	2.20 to 5	63
Assessed climate change knowledge	Low	0% to 50%	66
	High	51 to 100%	56
Perception of climate change consequences on the wine industry	Mostly positive	-	19
	Mostly negative	-	20
	Positive and negative	-	73

Supplementary Material 5: Total agreement and mean score for skepticism statements

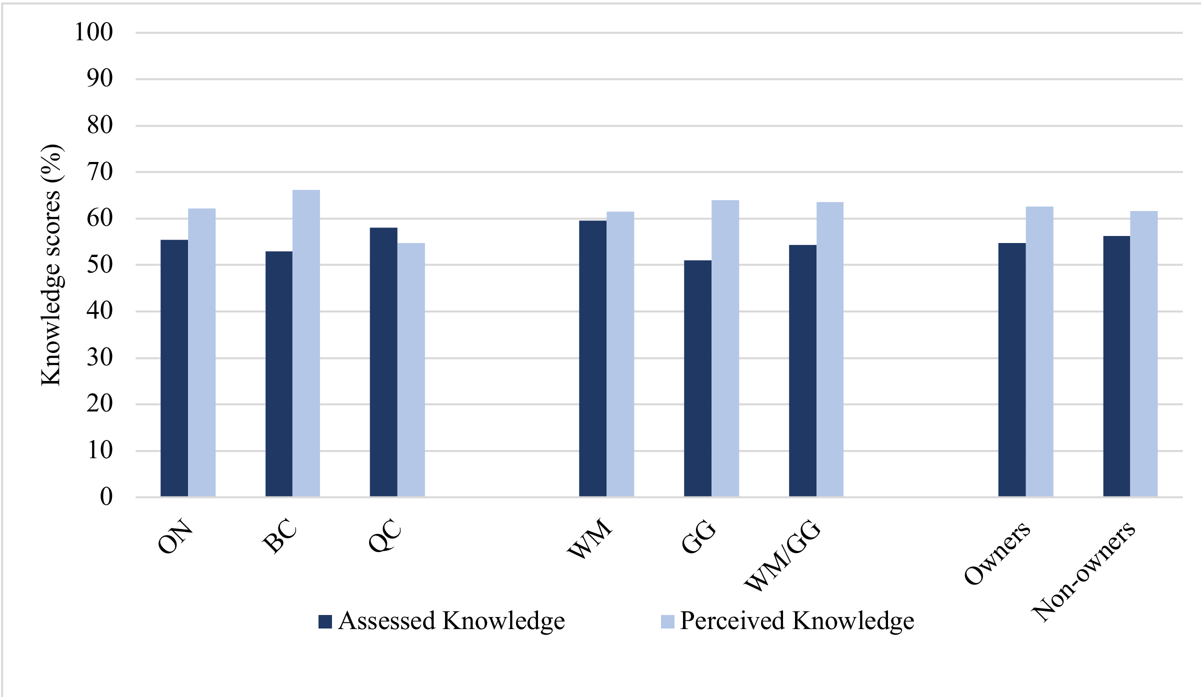
Skepticism Statements	Total Agreement[1] (%)	Mean Score[2]	SD
Most scientists agree that climate change is really happening	89.3	1.6	0.9
It is uncertain what the effects of climate change will be	51.6	3.2	1.1
The media is too alarmist about climate change	14.8	2.4	1.1
I am uncertain that climate change is really happening	13.9	1.9	1.2
The seriousness of climate change is exaggerated	9.0	1.9	1.0

[1]Total agreement represents the percentage of respondent who selected the option 'Strongly agree' and 'agree'. [2] Five-point Likert scale responses were coded numerically (1=strongly disagree; 5=strongly agree) and averaged (reverse coding was applied when necessary).

Supplementary Material 6: Perceived causes of climate change



Supplementary Material 7: Comparison of assessed and perceived knowledge scores between the main provinces, the different groups of winegrowers and between owners and non-owners.



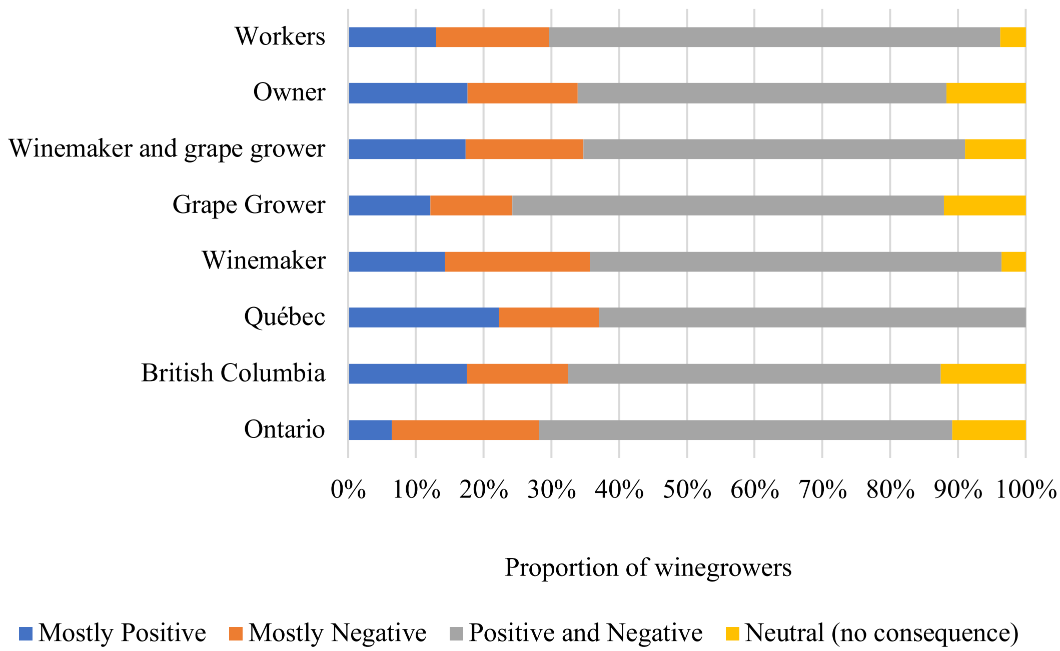
Abbreviations: ON, Ontario; BC, British Columbia; QC, Québec; NS, Nova-Scotia; WM, winemaker; GG, grape grower; WM/GG, winemaker and grape grower.

Supplementary Material 8: Perceived knowledge: original average values, corresponding normalized values, and respective standard deviations

	Measured on a 1 to 10 scale*		Normalized average values (0-100%)**	
Provinces	*Mean*	*SD*	*%*	*SD*
Ontario (n=46)	7.0	1.8	66.2	3.0
British Columbia (n=40)	6.6	2.1	61.9	3.7
Québec (n=27)	5.9	2.0	54.7	4.4
Role in the winery/vineyard				
Winemaker (n=28)	6.5	2.1	61.5	23.5
Grape Grower (n=33)	6.8	1.9	64.0	20.7
Winemaker and grape grower (n=47)	6.7	2.1	63.6	22.9
Owners/non-owners				
Owners (n=68)	6.6	2.1	62.6	22.8
Non-owners (n=54)	6.5	2.1	61.7	23.0

*Where: 1= '*I know very little*' and 10= '*I know a great deal*'
**Where: 0= '*I know very little*' and 100= '*I know a great deal*'
Abbreviation: SD, standard deviation

Supplementary Material 9: Perceived consequences of climate change on the Canadian wine industry for different categories of winegrowers



Supplementary Material 10: Other benefits and disadvantages of climate change listed by winegrowers in open-ended question

Benefits	**Frequency**
Marketing advantages and more southern seeking land for grape growing	1
Dryer growing period	1
Later arrival of fall rains combined with earlier ripening should reduce disease pressure at harvest time	1
Disadvantages	
Uncertainty in predicting weather	6
Inconsistent quality year to year	3
Greater variability in yields	2
Winter bud survival due to extreme temperatures	1
Cooler temperatures will reduce viability of the wine industry in Niagara	1
Higher risk due to variability in weather	1
Harder to harvest Icewine	1
Excessive rains and excessive drought needing correction	1
Risk of wildfire/smoke taint	1
Extreme weather such as early frosts result in vine damage and crop loss	1
Water stress issues for vineyards which are dry-farmed	1
The difficulty to start a vineyard and make it financially viable	1
Increase in frequency of crop devastating events	1

Chapter three: Climate Change Adaptation in the Canadian Wine Industry: Strategies and Drivers

Introduction

Climate change (CC) is affecting the international wine industry and has the potential to transform existing wine regions (Jones et al. 2005; Battaglini et al. 2009; Hannah et al. 2013; Jones 2016; Ollat et al. 2017). While climate variability has always been a challenging part of viticulture and oenology (Jones 2015), the changes to climate expected are unprecedented in the history of modern agriculture (Salinger 2005; Intergovernmental Panel on Climate Change [IPCC] 2018). Examples of observed and expected climate alterations associated with CC include warmer temperatures, shifts in precipitation patterns, and a greater frequency of extreme weather events (WE). Grapes, as a highly climate-sensitive crop, are especially threatened.

Canada is home to several established and emerging wine regions which are largely located in four provinces: Ontario, British Columbia, Québec and Nova Scotia (Canadian Vintners' Association, 2017) (Figure 1). While considered a small producer by international standards, the steadily growing Canadian wine industry (CWI) generates billions of dollars in economic activities and provides employment to thousands of workers across the country (Agriculture and Agri-Food Canada 2016; Canadian Vintners' Association 2017). Canadian wine regions are located at high-latitude and often rely on the tempering effects of large bodies of water or advantageous topography to grow quality wines. In this way Canada is similar to most wine producing countries as grape growing regions tend to be located in narrow climatic areas, and thus, will be impacted by CC (Jones et al. 2005). Adapting to CC is paramount to the sustainability and continued success of the CWI.

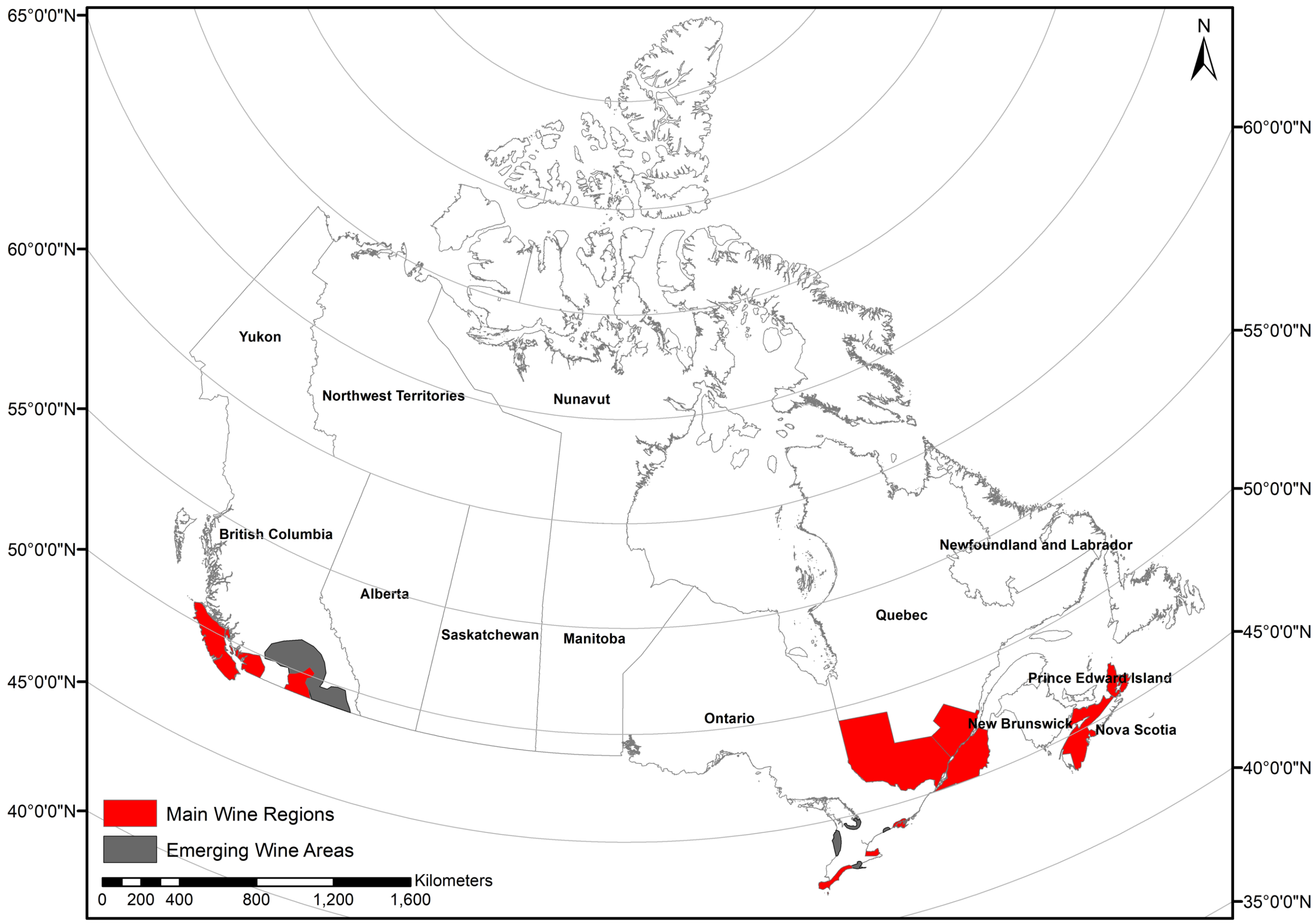


Figure 1. Map of the main Canadian wine regions and emerging wine areas

According to the Intergovernmental Panel on Climate Change (IPCC), *climate change adaptation* refers to the "adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities" (IPCC 2001 p.982). In reducing the vulnerability of a system of interest, CC adaptation contributes to the sustainability of agricultural productions, economies, and communities (Skinner et al. 2001). Depending on its intent, CC adaptation can be *planned* or *autonomous*. In agriculture, *planned adaptation* is generally a policy-based response to CC (Smit et al. 2000); however, specific farm-level adaptations largely depend on farmers, who are the most salient decision-makers of their industry (Smit and Skinner 2002). While they can be *planned*, private adaptations are often *autonomous* because they can be part of the vineyard's regular operation management, and thus, are not a conscious response to CC (Smit et al. 2000; IPCC 2001).

Smit et al. (2000) temporally categorize the climatic conditions or stimuli to which a system adapts into three types: shifts in long-term trends (such as the rise of annual mean temperatures associated with CC), change in norms over time (such as increased climatic irregularity), and the occurrence of extreme WE (such as droughts or floods). Those climatic stimuli, or WE, are all part of the global CC phenomenon, but it is worth examining them separately because they could be associated with different adaptation strategies (Smit et al. 2000). General climatic trends are expected to increase and intensify in most wine regions of Canada (Government of Canada 2017) and correspondingly affect the CWI.

For instance, the expected increase in average temperatures can alter several indicators of interest for grape growing across the country (Shaw 2016; Government of Canada 2017; Roy et al. 2017). Among others, the length of the frost season, the increased temperature during grape ripening, and the number of ice-wine picking days are all important variables that are likely to be affected by warmer temperatures (Shaw 2016). In addition, the increased occurrence of consecutive hot days – when the temperature reaches over 30°C – can have deleterious impacts on grape and wine quantity, as well as quality (Keller 2010; Pickering et al. 2015). Furthermore, the negative effects that warm temperatures exert on grapevines' hardiness during the fall season also contribute to lowering the cold resistance of vineyards (Bélanger et al. 2001). In this context, the occurrence of freeze-thaw episodes in the winter can severely injure grapevines that have started the deacclimation process (Willwerth et al. 2014; Shaw 2016). Finally, the potential reduction of snow precipitation would remove a protective cover that is sometimes essential during the frost season, particularly in colder regions (Bélanger et al. 2001; British Columbia Agriculture & Food Climate Action Initiative [BCAFCAI] 2016; Roy et al. 2017).

Future climate scenarios also indicate a shift of precipitation patterns. In general, an increase in rainfall is expected (Environment and Climate Change Canada 2017), but periods of drought are also anticipated in some regions such as the Okanagan Valley in British Columbia (BCAFCAI 2016; Environment and Climate Change Canada 2017). Rainfall impacts many important aspects of grape phenology and viticultural practice; thus, either too much or too little rain during specific periods of the year can greatly influence yield and wine quality (Jackson and Lombard, 1993; Pickering et al. 2015; Shaw 2016). For instance, heavy rainfall and humidity can increase pest and disease pressure in the vineyard, which can negatively affect bloom in the spring and reduce grape quantity and quality throughout the growing season. Moreover, heavy rain episodes close to harvest in late summer and early fall can cause excessive water uptake by the ripening berries, which can dilute the desirable molecules essential to the quality of the final product (Jackson and Lombard, 1993). Conversely, droughts are often considered 'extreme weather events' and can damage grapevines that struggle to grow and ripen when those conditions extend for a long period (Chaves et al. 2010; Pickering et al. 2015). Prolonged dry periods and episodes of droughts can also inflict permanent injuries to grapevines that can impair their integrity and vigor (Chaves et al. 2010).

In the CWI, *winegrowers* – who comprise of winemakers and/or grape growers – are analogous to farmers in general agriculture when considering their influence on vineyard- and winery- level CC adaptation. As such, their beliefs, knowledge, and attitudes towards CC might drive adaptation in the CWI. Here, we use the term *driver* to encapsulate the diverse factors that can hinder or motivate the adoption of CC adaptation strategies. For instance, CC beliefs, knowledge, and concerns can influence the engagement of individuals in CC adaptation. More specifically, a high level of uncertainty and skepticism about CC and its consequences may represent a considerable obstacle to addressing it, since it can provide a justification to maintain the status quo instead of investing resources for protective measures (Gifford 2011; Spence et al. 2012). In addition, an individual's level of scientific knowledge about CC could similarly influence willingness to engage in adaptation, since the understanding of an issue is often required to rationalize the need to address it (O'Connor et al. 1999; Gifford 2011; Stoutenborough and Vedlitz 2014). Concerns about the effects of CC on farm operations have also been found to predict support for adaptation in farmers (Howden et al. 2007; Arbuckle, Morton and Hobbs, 2013; Mase, Gramig and Prokopy 2017).

The socio-demographic characteristics of the decision-makers – winegrowers, in the present case – could also drive the adoption of CC adaptation strategies. Earlier studies demonstrate that education level (Mase, Gramig and Prokopy 2017) and political affiliations (Botzen et al. 2016) can impact adaptation. At the farm operation level, the size of the operation (Jørgensen and Termansen 2016) and the years of experience of farmers (Yegbemey et al. 2013) can also both influence the decision to adapt vineyards and winery operations to cope with CC effects. Hence, examining the relationship between the potential drivers of CC adaptation and the prevalence of adaptation could help understand the factors responsible for the adoption of vineyard and winery protective measures in the CWI.

Studies have examined adaptation strategies used in vineyards and wineries in response to CC in different regions of the world (e.g. Battaglini et al. 2009; Alonso and O'Neill 2011; Nicholas and Durham 2012; Alonso Ugaglia and Peres 2017) and in some wine regions of Canada (Belliveau, Smit and Bradshaw 2006; Holland and Smit 2014; Pickering et al. 2015). However, to our knowledge, a void exists as to the vineyard and winery practices that winegrowers currently use and plan to implement in response to CC in many Canadian wine regions. Furthermore, scholars have not investigated the potential drivers of CC adaptation in the CWI. Since the sustainability of the CWI largely relies on its ability to adapt to the impacts of CC, assessing *if* and *how* winegrowers adapt to specific CC-related WE and what drives their adaptation – or, lack therefore – could provide the information needed to support the development of a better-adapted industry.

In response to the above considerations, this study aims to assess and improve understanding of CC adaptation in Canadian wine regions. Specifically, it seeks to: 1) describe the current state of CC adaptation to several WE of interest to winegrowing in Canada as well as the adaptation strategies considered and used by winegrowers; and 2) explain what drives CC adaptations of winegrowers working in the CWI.

Materials and Methods

Recruitment of Winegrowers

We administered an online bilingual survey hosted on the Qualtrics® platform to winegrowers in Canada from the summer of 2017 until early in the winter of 2018.

Participants were recruited directly via email, phone calls, or through professional associations of winegrowers in their province of work. Close to 1,860 winegrowers received an invitation letter, which provided details about the objectives of the research and a secure URL with which to access the questionnaire. All participants were required to be 18 years old or older and to be working as a winemaker, grape grower, or to own a winery or a vineyard in Canada. As an incentive, we offered winegrowers the option to enter a lottery draw for a $500 cash prize upon completion of the questionnaire. The Brock University Research Ethics Board granted ethics clearance to this study (File #16-310).

Data Collection

Supplementary Material 1 displays the survey questions used in this study. To document CC adaptation, the survey asked participants to select the response that best described their level of experience with winegrowing-relevant WE that are plausible current or future manifestations of the climate in most wine regions of Canada. The WE chosen were extracted from pertinent literature about the possible changes that could affect the CWI in the future (Holland and Smit, 2014; Pickering et al. 2015; Shaw 2016; Roy et al. 2017), in addition to documents retrieved from government and scientific organizations' websites (Climate Change Nova Scotia 2014; BCAFCA 2016; Government of Canada 2017; Ouranos 2017).

Subsequently, the survey asked participants to express their level of concern for their operations for those events. Then, depending upon their experience with each WE, respondents were directed to a question that asked them to describe their plan to adjust their operation to moderate, avoid harm, or exploit beneficial opportunities – ergo, adapt – in response to each WE (see Supplementary Material 2). To select multiple relevant production practices that participants could nominate for coping with each WE, Drs Andrew G. Reynolds and Jim Willwerth – both viticulture experts from the Cool Climate Oenology and Viticulture Institute at Brock University – were consulted. The option to describe any other strategy used was also available to survey respondents.

Participants' CC knowledge was assessed using Stoutenborough and Vedlitz's (2014) index, which is composed of six true-or-false (T/F) type questions created in collaboration with climate scientists and information from the IPCC reports (2001). The option to select *I don't know* as an answer was also provided. Following Liu et al. (2017) method, an individual knowledge score was subsequently generated by coding the responses numerically (1 = *correct*; 0 = *incorrect* and *I don't know*) and averaging them. The calculated scores were then transformed into a percentage value, with 0% reflecting no correct responses and 100% reflecting a perfect score. We also used attitude statements adapted from Whitmarsh (2011) and Spence et al. (2012) to measure winegrowers' uncertainty and skepticism regarding CC. The question asked participants to rate their level of agreement with the five statements using a 5-point Likert scale. Responses were then numerically coded (1 to 5), and we generated an average score for each participant. Higher scores reflect a greater level of skepticism and uncertainty.

Finally, participants were asked to provide demographic details including their age, gender, highest education level achieved, and political affiliations. Information on the size of the winery or vineyard they operate, the number of years they have been working in the wine industry, their role in the vineyard or winery, and the province in which they currently work was also collected. To ensure the data collected is truly representative of the views of the leaders of the industry, we also determined the level of power/influence on the operations of the respondents (Supplementary Material 1).

Data treatment and analysis: an overview

XLSTAT Version 2017.19.05.46974 (Addinsoft, NY, USA) was used for data analysis. Among the 14 winegrowing-relevant WEs associated with CC used in the survey to assess CC adaptation, nine were retained for analysis. The WEs that were not considered further were selected by less than 80 winegrowers, which was considered too few to conduct the analysis. Thereafter, we performed nine multinomial regression analyses with *adaptation status* as an outcome variable for each of the WE related to CC. Table 1 describes the models. The outcome variables were collapsed into three instead of the original four responses categories to improve statistical power. Similarly, independent variables were collapsed into fewer, larger categories to aid with analysis (Online Resource 3). *Concern* was expressed as a percentage and treated as a continuous variable. The XLSTAT stepwise backward model selection function was used to determine which independent variables should be included in the final models. Multicollinearity was examined for the independent variables.

Table 1: Variables used in the regression models

Independent variables	*Dependent variable* Adaptation status to specific weather events	 Weather events
Education level	<u>*Multinomial response categories*</u>: **Adapted:** - *My operations have already been adjusted* - *I have already adjusted my operations and am considering adjusting them further* **Plan to adapt:** - *I have not adjusted my operations but I am considering doing so* **Not adapted:** - *I have not adjusted my operations and do not plan to adjust them*	More frequent and/or intensive rainfall in the spring
		More frequent and/or intensive rainfall during the growing season
Political affiliation		More frequent and/or intensive rainfall at harvest
Climate change knowledge		Decrease of winter snowfall
Climate change skepticism and uncertainty		Consecutive hot days (>30°C)
Vineyard size (acre)		Increase in average temperatures
Years of experience In the wine industry		Increased weather variability from year to year
		More frequent and extended dry periods and drought
Concern about weather events associated to climate change for winery/vineyard operations		Increased frequency of freeze-thaw cycles in the winter

Results

Description Respondents

Overall, a small percentage (6.5%) of the winegrowers who were contacted participated in the survey, which represents 122 respondents. All of them completed the entire survey, except for one individual who responded to 88% of the questions. 38% of winegrowers reported working in the province of Ontario, with the remaining 33% in British Columbia, 22% in Québec, and 7% in Nova Scotia. On average, their level of power or influence on their operation was 86%, which indicates that most participants have a preponderant role in the decision-making process of the vineyard and winery practices. Table 2 displays a detailed description of the respondents.

Table 2: Description of the respondents*

Attributes	*Proportions %*
Gender	
Male	73
Female	27
Age	
18-40	32
41-60	50
Over 60	18
Education level	
Below the bachelor level	38
Bachelor level or higher	83
Federal Political Affiliations	
Conservative Party	17
Liberal Party	29
New Democratic Party	4
Green Party	10
Bloc Québécois	0
None/would not vote	29
Other	12
Role in the winery/vineyard	
Grape grower	66
Winemaker	61
Both winemaker and grape grower	39
Owner	56
External Consultant	4
Years of work experience in the wine industry	
10 years or less	37
11 to 20 years	38
Over 20 years	25
Size of the vineyard/winery operated	
0 to 20 acres	57
20.1 to 50 acres	33
Over 50 acres	32

*Values in each category may not add up to 100% because of rounding

Climate change adaptation status and strategies

Figure 2 illustrates winegrowers' adaptation status for each WE. Overall, less than half of the participants surveyed have already adapted to the WEs presented. The WEs for which respondents have already adjusted their operations, or plan to adjust them the most, relate to rainfall (at harvest, during the growing season, and in the spring) and drought. Conversely, more than half of participants have not adapted and do not plan to adapt their operations to cope with the decrease in winter snowfall and the increase in number of consecutive hot days. Figure 3 displays the adaptation strategies implemented and considered for future implementation most frequently selected by winegrowers. Supplementary Material 4 presents the other strategies provided by participants. Winegrowers both use and plan to use a variety of different adaptation strategies in response to the WEs presented in the survey. However, for each WE, no single strategy is used by more than 33% of respondents, and no strategy is considered for implementation by more than 26% of winegrowers.

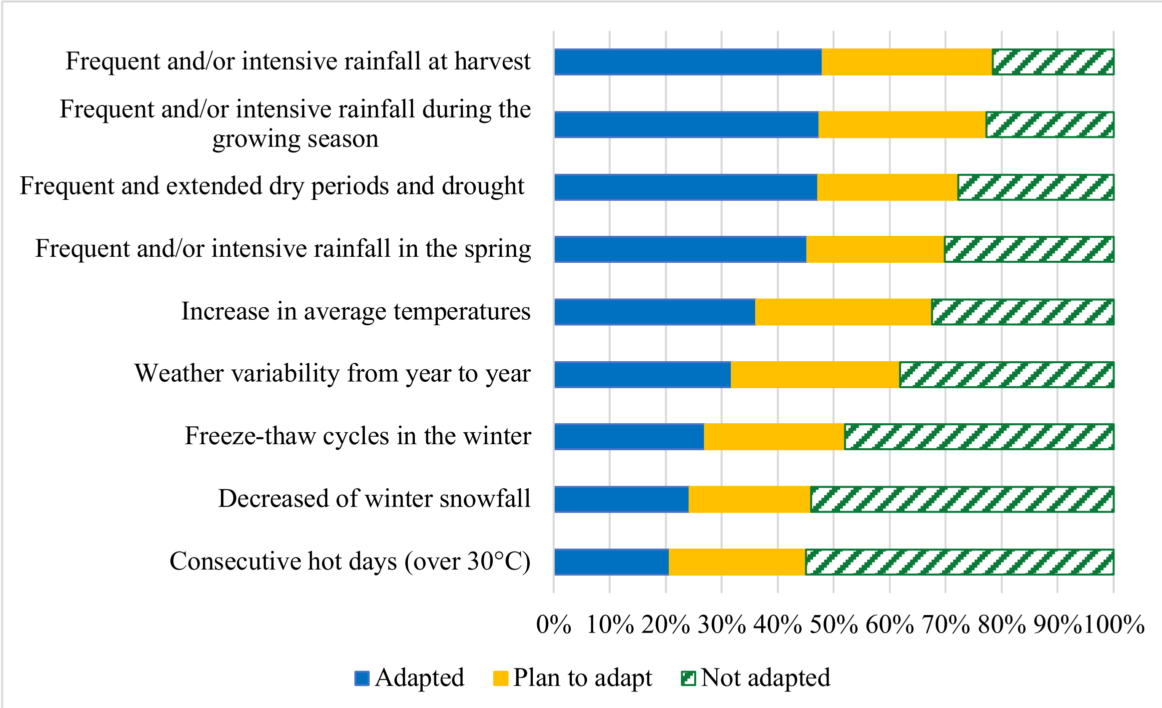


Figure 2. Adaptation status of winegrowers who have experienced or expected to experience various weather events

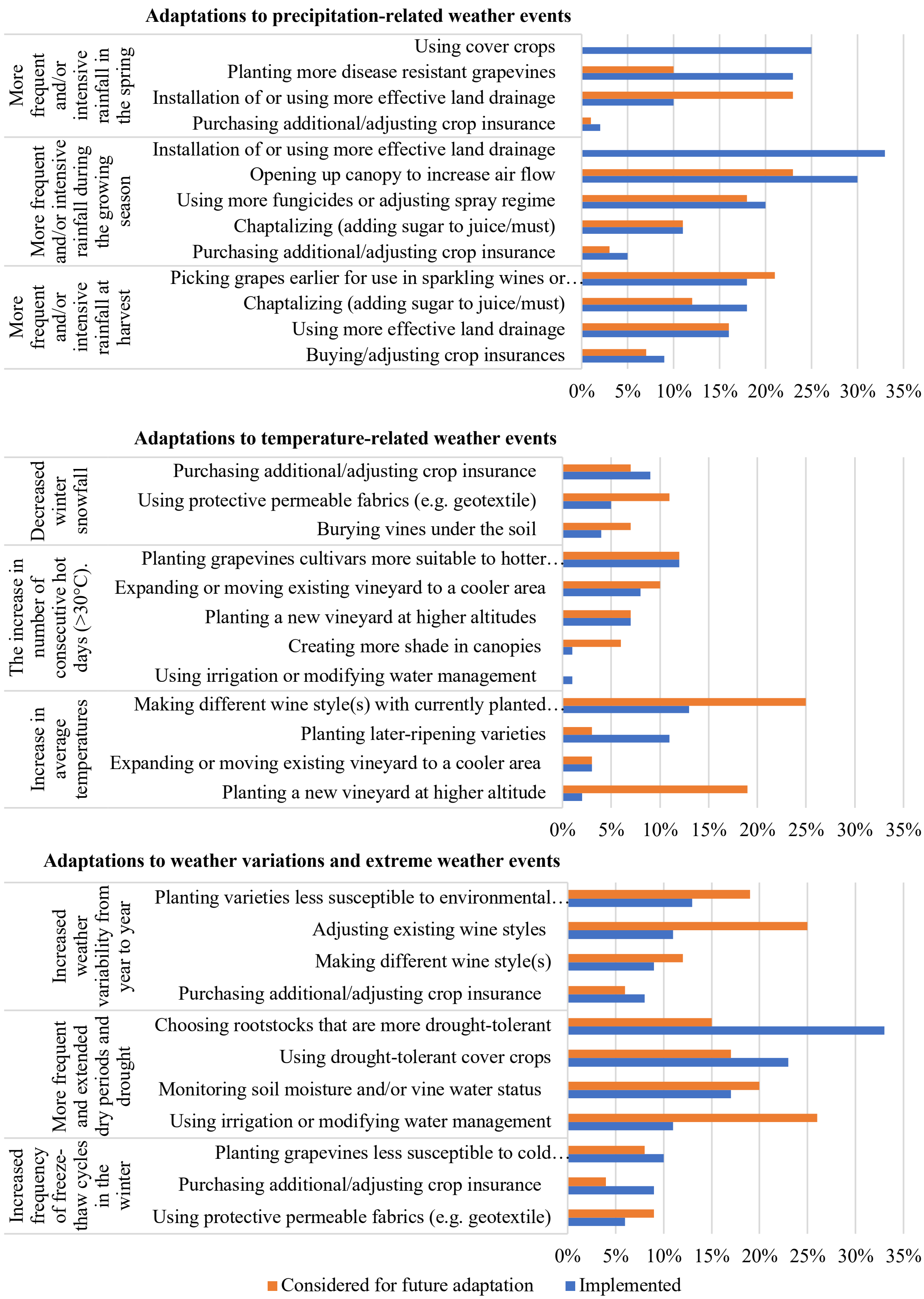


Figure 3: Adaptation strategies used to cope with various climate change related weather events and proportion of winegrowers who implemented them or consider them for future implementation

Climate change knowledge, concern, uncertainty and skepticism

The average CC knowledge score (in percentage of correct responses) is 55.3% (*SD* = 21.8), suggesting that participants are moderately knowledgeable about CC. Winegrowers' level of concern for their operations about the CC-related WEs they experienced or anticipate experiencing is on average 61.1% (*SD* = 24.6), which indicates a moderate level of concern. Finally, the mean uncertainty and skepticism score measured is 2.19 (*SD* = 0.73), which is relatively low.

Drivers of climate change adaptation

We used multinomial logistic regressions to model the relationships between a series of predictors and winegrowers' adaptation status – adapted, plan to adapt, or not adapted – for nine specific CC-related WEs (Table 3). Seven out of the nine final models are significant overall ($p \leq 0.05$) and include significant predictors ($p \leq 0.05$). The model used to predict the adaptation status of the WE *more frequent and/or intensive rainfall in the spring* is significant ($p < 0.001$), but none of the predictors included in the analysis approach significance. Also, the WE *more frequent and/or intensive rainfall during the growing season*' was not significant ($p = 0.077$). This suggests that the independent variables used in these two models are not useful in explaining the adaptation outcome of those WEs. In the seven significant models, winegrowers' education level, years of experience in the wine industry, and CC knowledge did not associate with adaptation status. Conversely, winegrowers' concern about CC for their operations, vineyard acreage, political affiliation, and CC uncertainty and skepticism made significant contribution to the adaptation status in at least one of the models (Table 3).

Table 3: Results of the multinomial regression models for each weather event. Reference category is 'no adaptation'

Weather events	*Responses included in analysis*	*Significance of the model*	*Nagelkerke R^2*	*Significant predictor(s)*	*Odds Ratio*	*Confidence Interval (95%)*
Frequent and/or intensive rainfall in the spring	Adapted=45 Not adapted=31 Plan to adapt=24	**<0.001**	0.219	-	-	-
Frequent and/or intensive rainfall during the growing season	Adapted=42 Not adapted=22 Plan to adapt=27	0.077	0.316	-	-	-
Frequent and/or intensive rainfall at harvest	Adapted=46 Not adapted= 21 Plan to adapt=27	**0.050**	0.254	***Adapted***		
				Concern*	1.03	1.00-1.06
				Plan to adapt		
				Concern*	1.03	1.00-1.06
Decrease of winter snowfall	Adapted=23 Not adapted=56 Plan to adapt=21	**0.005**	0.258	***Adapted***		
				Concern*	1.04	1.01-1.07
				Acreage (med)**	0.10	0.02-0.51
				Political affiliation (other)*	3.81	1.05-13.84
Consecutive hot days (>30°C)	Adapted=21 Not adapted=41 Plan to adapt=19	**<0.001**	0.397	***Adapted***		
				Concern*	1.04	1.01-1.08
				Acreage (low)**	0.09	0.02-0.48
				Plan to adapt		
				Acreage (low)**	0.08	0.02-0.42
Increase in average temperatures	Adapted=35 Not adapted=33 Plan to adapt=31	**0.003**	0.319	***Adapted***		
				Acreage (low)**	0.11	0.03-0.48
				Plan to adapt		
				Concern**	1.04	1.01-1.06
Increased weather variability from year to year	Adapted=34 Not adapted=39 Plan to adapt=30	**< 0.0001**	0.401	***Adapted***		
				Concern*	1.04	1.01-1.06
				Skepticism and Uncertainty (low)*	3.35	1.05-10.75
				Plan to adapt		
				Acreage (low)*	0.20	0.05-0.75
				Skepticism and Uncertainty (low)*	4.47	1.35-14.81
Frequent and extended dry periods and drought	Adapted=45 Not adapted=27 Plan to adapt=27	**0.006**	0.279	***Adapted***		
				Acreage (low)**	0.09	0.02-0.46
				Plan to adapt		
				Concern*	1.04	1.01-1.07
Freeze-thaw cycles in the winter	Adapted=26 Not adapted=47 Plan to adapt=21	**0.024**	0.279	***Plan to adapt***		
				Concern*	1.04	1.01-1.08
				Acreage (med)**	0.08	0.01-0.51

*p ≤ 0.05, **p ≤ 0.01

Across all models, the most frequent predictor of CC adaptation is winegrowers' concern about the WEs associated with CC. More specifically, a higher level of concern about the effect of WEs on operations associates positively with a higher likelihood of *being adapted* (compared to *not being adapted*) to four WEs - frequent and intensive rainfall at harvest (OR = 1.03), decrease of winter snowfall (OR = 1.04), yearly weather variability (OR = 1.04), and consecutive hot days (OR = 1.04) (Table 3). Similarly, compared to the *not adapted* category, a higher level of concern about CC effects on winegrowing operations associates positively with a modestly greater likelihood of *planning to adapt* to frequent and intensive rainfall at harvest (OR = 1.03), frequent and extended dry periods and drought (OR = 1.04), freeze-thaw cycles in the winter (OR = 1.04), and increase in average temperature (OR = 1.04).

Winegrowers working in operations with low vineyard acreage (<20 acres) are approx.10 times less likely to be *adapted* (compared to *not being adapted*) to frequent and intensive rainfall at harvest (OR = 0.09), increase in temperatures (OR = 0.11), and episodes of consecutive hot days (OR = 0.09). Also, winegrowers with low vineyard acreage are 5 times less likely to belong to the *plan to adapt* category for weather variability from year-to-year (OR = 0.20) and 12.5 times less likely to be *planning to adapt* to consecutive hot days (OR = 0.08) (compared to *not being adapted*). In addition and compared to *not being adapted*, winegrowers who operate a medium sized vineyard (20 to 50 acres) are 10 times less likely to be *adapted* to decrease of winter snowfall (OR=0.10), and 12.5 times less likely to *plan adaptation* for freeze-thaw cycles in the winter (OR=0.08).

A low level of CC uncertainty and skepticism is associated with a 3.4 times greater likelihood of being *adapted* to and 4.5 times greater likelihood of *planning to adapt* to the increased weather variability from year to year. Finally, winegrowers without any political affiliation or those who would not vote were 3.8 times more likely to be *adapted* to decrease in winter snowfall than *not adapted.*

Discussion

Climate change adaptation status and strategies

Our results show that the weather events that winegrowers are the most *adapted* to relate to precipitation. Using more fungicides and adjusting spray regimes, in addition to opening canopy to increase air flow were the most frequently identified strategies implemented to deal with frequent or excessive rainfall during the growing season. These autonomous adaptation measures are typical farm practices winegrowers likely engage in regularly; hence, their implementation may not require major investment and infrastructural change. However, they most certainly necessitate the close monitoring of the vineyard and weather, as well as the flexibility of workers and operations. The use of cover crops was the most popular strategy cited to cope with high rainfall in the spring. Close to harvest, picking grapes earlier and using land drainage helped them cope with high or frequent rainfall was the most used strategy. As opposed to previously mentioned adaptations, those options are likely costlier (e.g., drainage) or require more flexibility (e.g., adjusting harvest dates) – and hence could be more difficult to implement.

Despite being the WEs to which winegrowers are most *adapted* to, the majority of participants have not implemented any adaptation strategy yet to deal with WEs associated to precipitations. In turn, many operations are vulnerable to frequent and intensive rainfall at key stages of berry development (Jackson and Lombard 1993), which may result in potential losses if CC exacerbates those events in the future and winegrowers do not implement measures to moderate or avoid harm. On the positive side, close to one-third of winegrowers plan to adapt to those WEs, which indicates that they are aware that those events could potentially threaten their operations, and that they must make adjustments to ensure better protection.

Frequent and extended dry periods and drought episodes are other WEs to which winegrowers were the most *adapted*. While droughts do not affect all wine regions of the country, some regions are already experiencing long dry periods and (sometimes) drought (Canadian Broadcasting Corporation [CBC] 2015; BCAFCA 2016). Dry conditions are sometimes beneficial during the growing season and close to harvest because they can be favourable to optimal berry maturation (Avery 2008; Holland and Smit 2014). However, certain grape varieties are more tolerant to dry spells than others, and the consequent lack of water supply for an extended period can severely damage grapevines (Chaves et al. 2010) and affect grape and wine quality (Avery 2008; Pickering et al. 2015). Our data suggests that almost half of winegrowers have already implemented adaptation strategies to cope with dry periods and drought. The most frequently selected adaptation is the use of irrigation and the adjustment of water management, which one-third of participants use. Interestingly, over a quarter of participants plan to use irrigation in the future in response to dry conditions. Investing in an irrigation system is costly, and might not be justified in some wine regions of Canada where rain is more abundant. This might explain why some winegrowers have not implemented this strategy and are not considering doing so.

Experts expect an increase in annual temperature to occur throughout the country (Government of Canada 2017). Our results show that a majority of winegrowers have already adjusted their operations or plan to adjust their operations in response to the warming of temperatures. Among the adaptations already implemented and considered for the future, making different wines with currently planted varieties and planting later-ripening varieties were the most frequently selected strategies. While both require technical and scientific knowledge, making different styles with existing varieties could be more cost-effective, at least in the short-term. Conversely, planting new, later-ripening cultivars requires significant investment that might be justified in the longer-term, especially if new varieties are more commercially successful than those currently planted (Mozell and Thach 2014). On the contrary, over one-third of respondent have not adjusted and do not plan to adjust their operations to cope with warmer weather. This could partly be linked to the nature of the generally cold continental Canadian climate, and its impact on quality grape growing. Indeed, the increase of temperature is seen as by many Canadian winegrowers as a benefit for their industry (Jobin-Poirier, Pickering and Plummer 2019). Hence, some might not consider adaptation as a necessary investment – for now.

Variabilities and uncertainties are inherent in agriculture in general – and therefore, to grape growing and winemaking. CC is expected to increase climatic variability, hence, the capacity of wineries' and vineyards' operations to adjust to year-to-year variations could partly influence their potential to adapt to future CC (Smit et al. 2000; Crane et al. 2011; Holland and Smit 2014). Over one-third of winegrowers have already adapted their operations to cope with weather variabilities. Adjusting existing wine styles was the most frequently selected measure used and considered for future implementation to deal with such variability. In fact, several oenological manipulations, including chaptalization[1] and

[1] *Chaptalization* is the addition of sugar to grape juice prior to or during fermentation to increase the alcohol level in the resulting wine.

adjusting blending proportions, often do not require as much investment as viticulture practices, and are already widely used as short-term strategies in the CWI.

Close to half of participants have not adapted and do not plan to adapt to freeze-thaw cycles in the winter, decreased winter snowfall, and consecutive hot days. This could be due to several factors, but perhaps a large proportion of winegrowers do not anticipate those events occurring, or do not think that they would have an impact on their operations. In fact, the cost of adaptation must be measured against the perceived risk of a WE for the operations: if winegrowers perceive that a WE might occur, but they remain uncertain about the magnitude and importance of the resulting impact(s), using resources to adapt might not be justifiable compared to other necessary investments (Howden et al. 2007).

Finally, similar to observations by Holland and Smit (2014) in Prince Edward County, we found that Canadian winegrowers used several adaptation strategies to cope with the WEs associated with CC. Also, a single strategy may be used to deal with several WEs. For instance, making different wine style can be a short-term strategy in response to weather variability from year to year, and a long-term approach to cope with the warming of temperature. Since winegrowers largely tend to learn from one another (Holland and Smit 2014; Pickering et al. 2015) the adaptation strategies presented in this paper can serve as a knowledge-transfer tool for winegrowers across the country.

Drivers of climate change adaptation

Our results show that winegrowers working in smaller operations (<20 acres) are less likely to be *adapted* to the extended dry periods and episodes of drought, the increase in temperature, and the occurrence of consecutive hot days. This finding is different from the observations Jørgensen and Termansen (2016) made; they found that Danish farmers with smaller operations are more easily persuaded to engage in adaptation actions. However, our finding may be explained by the nature of the strategies potentially used in the CWI to deal with the WEs in questions. In fact, the installation of an irrigation system and the replacing of existing varieties are long-term strategies that require much investment, which might not be cost-effective for small operations.

Our results also suggest that winegrowers' level of concern for their operations is positively associated with a higher likelihood of being *adapted* and *planning to adapt* to CC for some WEs. Those relationships were marginally positive, but they are similar to those observed in previous studies involving farmers. For instance, Arbuckle, Morton and Hobbs (2013) found that concern about CC for farm operations was a predictor of adaptation with Iowa farmers. Mase, Gramig and Prokopy (2017) also found that the level of concern for on-farm risks, such as extreme WEs, was the most important factor positively influencing crop farmers' adaptation behaviors in the Midwest United States. CC concern relates to perceived vulnerability: if farmers do not believe that their operations are susceptible to a WE, they would be less likely to adapt to them, and vice-versa (Howden et al. 2007). Therefore, it seems that when Canadian winegrowers are conscious that a WE associated with CC poses a risk to their operations, they acknowledge that adaptation is necessary.

Conclusion

This study describes the CC adaptation status and strategies currently used and considered by winegrowers across Canada for the first time in literature. It also illuminates some of the drivers of CC adaptation behavior in the CWI. Overall, we found that less than half of the participants surveyed have already adapted to the WEs presented. Our results also show that Canadian winegrowers are more adapted to rainfall-related WEs and drought, but less adapted to some extreme WEs, such as consecutive hot days and freeze-thaw cycles. Moreover, several adaptation strategies are currently used and considered for future implementation in response to those WEs. We also found that winegrowers' concern exerts a small but positive effect on both CC adaptation and the desire to adapt in the future. In addition, smaller operations are less likely to be adapted to several WEs associated with CC. Overall, this study provides important information and perspectives that industry stakeholders can use to support the implementation of context-specific adaptations. Lastly, a collaboration between winegrowers and the other relevant industry stakeholders is key to developing appropriate solutions to protect vineyard and winery operations from present and future climate alterations. Indeed, the sustainability of the CWI relies on its ability to continuously adapt to CC – and this transition necessitates the concerted work of many leaders of the industry.

It is important to mention that this work does not attempt to recommend adaptations and does not evaluate the benefit of specific adaptation strategies. Indeed, the implementation of effective adaptation options should be context-specific and take into account the particularities of a system of interest (Skinner et al. 2001). The CWI is distributed across four main provinces in Canada, and thus local variations are expected to affect adaptation. Therefore, adaptation strategies and priorities may – and probably should – differ from one province or region to another. Hence, future studies should address regional and sub-regional differences, and the results from this study provide an appropriate entry point for such an inquiry. Longitudinal work tracking adaptation behaviors and the effectiveness of the strategies used in the specific context of each wine sub-regions is also required. This work mainly considered the adjustment of wineries' and vineyards' operations as adaptation forms. However, non-production strategies could also be implemented to build adaptive capacity in the CWI. Indeed, as argued by Pickering et al. (2015), the adaptive capacity of the wine industry is also driven by several operational and strategic drivers, including political support, the availability of technology, and technical knowledge about the practices of adaptation. Therefore, the other forces that hinder or facilitate the transition to a more adapted CWI should also be investigated in the future.

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Supplementary Material

***Supplementary Material 1*:** Survey Text

Assessed climate change knowledge

For each of the following statements about possible causes and effects of climate change, please indicate whether you think the statement is **true** or **false** or you **don't know.**

	True	False	Don't know
Nitrous oxide is a greenhouse gas.	○	○	○
The major cause of increase atmospheric concentration of greenhouse gases is humans burning fossil fuels.	○	○	○
Biological diversity will increase as global temperature increases.	○	○	○
Aerosols are airborne particles that are known to contribute to the formation of clouds and precipitation.	○	○	○
Scientifics agree that, as a result of climate change, the sea level will continue to rise for at least a century.	○	○	○
There is a scientific consensus that there will be an increase in global precipitations as a result of global climate change.	○	○	○

Climate change uncertainty and skepticism

Please indicate your level of agreement with each statement.

	Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree
I am uncertain that climate change is really happening					
The seriousness of climate change is exaggerated					
Most scientists agree that climate change is really happening					
It is uncertain what the effects of climate change will be					
The media is too alarmist about climate change					

Concern

To what extent are you concerned for your operations about the weather events you experienced or anticipate experiencing? Please move the slider to indicate your level of concern.

Not Concerned At all — Extremely Concerned

0 10 20 30 40 50 60 70 80 90 100

Age

What is your age?

- ○ 18 to 30
- ○ 31 to 40
- ○ 41 to 50
- ○ 51 to 60
- ○ Over 60

Gender

Are you female or male?

- ○ Female
- ○ Male

Years of experience in the industry

How many years of experience in the winemaking/grape growing industry do you have?

- ○ Less than 5 years
- ○ 5 to 10 years
- ○ 11 to 20 years
- ○ Over 20 years

Province of production

In which province are you mostly working?

- ○ British Columbia
- ○ Ontario
- ○ Québec
- ○ Nova Scotia

Role in the winery/vineyard

What best describes your role in the vineyard/winery you work at? Check all that apply.

- ○ Winemaker
- ○ Grape Grower
- ○ Employee
- ○ External Consultant
- ○ Owner

Political affiliation

What is your political affiliation?

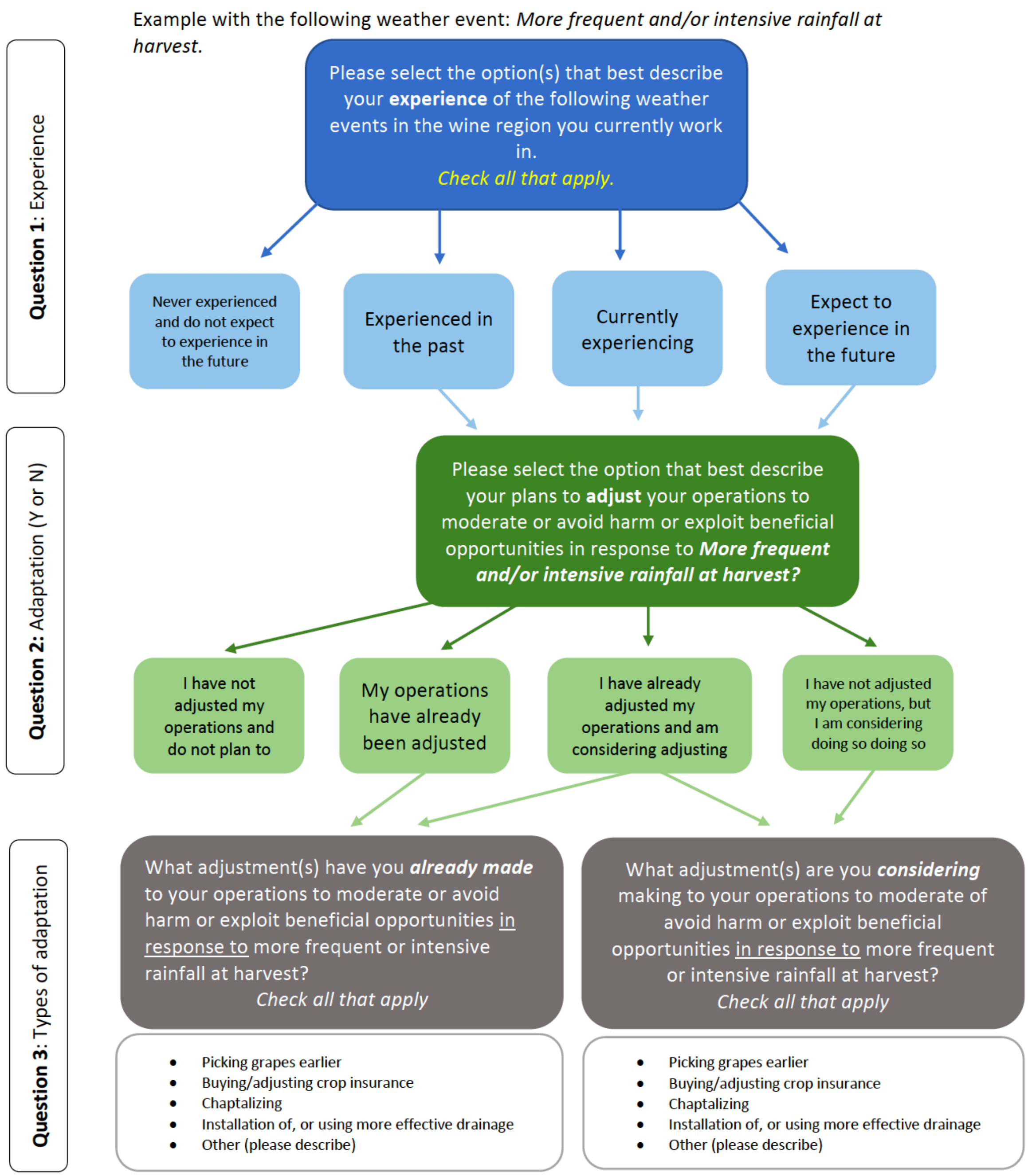
- ◯ Conservative Party
- ◯ Green Party
- ◯ Le Bloc Québécois
- ◯ Liberal Party
- ◯ New Democratic Party
- ◯ None/Would not vote
- ◯ Other

Highest education level achieved

What is your highest education level?

- ◯ No formal qualification
- ◯ High School Diploma
- ◯ Apprenticeship or Trades Certificate or Diploma
- ◯ College, CÉGEP, or other non-University Certificate or Diploma
- ◯ University Certificate, Diploma or Degree below the Bachelor Level
- ◯ University Certificate, Diploma or Degree at the Bachelor Level
- ◯ University Graduate Degree

Supplementary Material 2: Flow chart of the experience and adaptation questions



Supplementary Material 3**:** Detailed categories of independent variables used to build the multinomial regression models

Variables measured	*Categories*	*Values*
Education level	Low	Below the bachelor level
	High	Above the bachelor level
Political affiliation (federal)	Left leaning	Green Party, Liberal Party, New Democratic Party, Bloc Québécois
	Right-leaning	Conservative Party
	Other	None/would not vote, Other
Vineyard size (acres)	Low	0 to 20 acres
	Medium	21 to 50 acres
	High	Over 50 acres
Skepticism and uncertainty (scores)	Low	1 to 2.19
	High	2.20 to 5
Assessed climate change knowledge (% of correct response)	Low	0%, 16.66%, 33.33%
	Medium	50%
	High	66.66%, 83.33%
Years of experience in the wine industry	Low	0 to 10 years
	Medium	11 to 20 years
	High	Over 20 years

Supplementary Material 4: Other adaptation strategies described by winegrowers in response to specific weather events

Frequent or intensive rainfall at harvest		
Adaptations measures	Frequency of citation	
	Already implemented	Considered for future implementation
Adjusting spray schedule/regimen	2	3
Modify harvest dates	1	4
Modify leaf removal practices	4	-
Modify grape varieties	-	4
Blowing air in canopy post rain	2	1
Fruit thinning to achieve ripeness	2	-
Process faster/machine harvest	2	-
Using cover crops	1	1
Change to drip irrigation (irrigate less)	1	1
Reduce soil cultivation/no till	1	1
Diversifying to apple cider production	1	-
More canopy management	1	-
More aggressive vineyard practices	1	-
Rigorous berry sorting	1	-
Using winemaking technologies (enzymes, tannins, thermovinification, micro-ox)	-	1
Adjusting the quality standards	-	1
Frequent and/or intensive rainfall during the growing season		

Adaptations measures	Frequency of citation	
	Already implemented	Considered for future implementation
Adjusting spray schedule/regimen	2	2
Using cover crops	2	-
Using moisture monitoring equipment	2	-
Improving weed removal practices	1	1
Produce sparkling wines	1	1
Change to drip irrigation (irrigate less)	1	-
Improving timing of cultural practices	1	-
Optimizing the harvest date	1	-
Modify leaf removal practices	1	-
Choosing grapes varieties that are more resistant to mildew	-	1
Frequent and extended dry periods and drought episodes during the summer		
Adaptations measures	Frequency of citation	
	Already implemented	Considered for future implementation
Increase organic matter in soil	1	2
Using different training system (bush vine, gobelet training)	1	2
Increasing space between grapevines in the vineyard	1	2
Canopy and fruit thinning	2	-
Changing canopy management techniques	-	2
Growing more drought tolerant varieties	1	-
Reducing leaf thinning to slow down ripening	1	-
Return to overhead irrigation	-	1
Zero till practice	-	1
Soil and cover crop management	-	1
Frequent and/or intensive rain in the Spring		
Adaptations measures	Frequency of citation	
	Already implemented	Considered for future implementation
Adjusting spray program	7	3
Less irrigation	1	-
Considering abandoning organic practices	-	1
Growing more disease tolerant varieties	1	-
Switch to apple cider production	-	1
Improving canopy management	1	-
Monitoring soil moisture	1	-
Fruit thinning	1	-
Pumping excessive water out of soil's surface	1	-
Delaying soil labor to reduce erosion	-	1
Using cover crops earlier	-	1
Increase in average temperature		
Adaptations measures	Frequency of citation	
	Already implemented	Considered for future implementation
Reducing leaf removal	4	1
Adjusting canopy management	3	1
Harvesting earlier	2	2
Increasing irrigation (increase foliage/shade)	2	1
Adjust winemaking practices	1	1

Adjust crop load	1	1
Mechanically harvesting icewine (faster)	1	-
Planting more reds (less cold hardy varieties)	1	-
Planting in non-traditional aspect	-	1
Weather variability from year to year		
Adaptations measures	Frequency of citation	
	Already implemented	Considered for future implementation
Appropriate canopy management	4	-
Remove grapes and plant crops that are more resistant to variabilities	1	2
Closely monitor vineyard/weather	1	1
Being flexible with harvest dates	1	1
Planting many different grape varieties to lower risks	1	1
Use geotextile to moderate and lengthen growing season	1	-
Invest in irrigation system	1	-
Use drainage	1	-
Use wind machines	1	-
Hire well educated people in vineyard and winery management	1	-
Freeze-thaw events in the winter		
Adaptations measures	Frequency of citation	
	Already implemented	Considered for future implementation
Use of wind machines	3	1
Hilling up vines	-	2
Produce less icewine	1	1
Limiting crop load and irrigation in the Fall to stimulate earlier dormancy and better winter hardiness	1	-
Perform more frequent cold hardiness tests before winter pruning	-	1
Decrease of winter snowfalls		
Adaptations measures	Frequency of citation	
	Already implemented	Considered for future implementation
Hilling up vines	1	3
Modifying pruning schedule	1	1
Improving geotextile anchoring	-	2
Using mechanical harvester to harvest icewine earlier	1	-
Trial root treatments to improve winter hardiness	1	-
Switching from drip irrigation to overhead	1	-
Using snow fences to retain snow	1	-
Planting cold tolerant varieties	1	-
Changing training system	1	-
Using heaters	1	-
Using wind machines	-	1
Installing irrigation	-	1
Irrigate earlier to accommodate vines' needs	-	1
Protecting vines with mulch and compost	-	1
Adjusting cultural practices	-	1
Consecutive hot days		
Adaptations measures	Frequency of citation	
	Already implemented	Considered for future implementation

Producing more late-ripening varieties (Cabernet Franc)	1	-
Crop loading	1	-
Diversifying wine profile	-	1
Adjusting blending	-	1

Chapter four: General conclusion and recommendations for future research

Thesis summary and discussion

The effects associated with CC represent a challenge for all agricultural systems (Skinner et al. 2001). The wine industry is one of the most sensitive sectors to climate conditions and is therefore vulnerable to the impacts of CC (Skinner et al. 2001; Jones 2016). In Canada, CC represents a threat to existing wine regions, but it could also provide opportunities (Belliveau, Smit & Bradshaw 2006; Pickering et al. 2015; Shaw 2016; Roy et al. 2017). In both cases, the implementation of adaptation measures is necessary to, on the one hand, minimize the negative impacts of the changing climate on vineyard and winery operations; and on the other hand, seize the profitable occasions that could result from CC (IPCC 2001). In agriculture, the adoption of CC adaptation measures largely depends on farmers, who are the most salient decision maker for their operations (Smit and Skinner 2002; Arbuckle, Morton and Hobbs 2013). Therefore, this research sought to understand winegrowers' CC perceptions, CC adaptation efforts and their relationship in the CWI.

Study one (Chapter two), measured and described Canadian winegrowers' environmental values, CC knowledge and beliefs and their perceptions of CC impacts for their industry. It also investigated how values, beliefs and knowledge vary between the main winegrowing provinces and different categories of winegrowers. Furthermore, it examined the relationships between CC perceptions and CC knowledge, beliefs and environmental values. The results of this study show that winegrowers have a more ecocentric as opposed to anthropogenic worldview, which has been associated with pro-environmental intentions and the support of pro-environmental policies (Dunlap et al. 2000; Whitmarsh 2008; Ziegler 2017). Results also indicate that winegrowers are moderately knowledgeable about CC, which suggests that they might not perceive CC-risk and might not address the issue as experts would (Stoutenborough and Vedlitz 2014). With respect to their beliefs about CC, a great majority of winegrowers acknowledge the contributions of anthropogenic and natural causes to CC. Also, CC uncertainty and skepticism was low amongst respondents, but more specific results show that winegrowers are relatively unsure about the effects of CC. Furthermore, the results indicate that winegrowers generally perceive the consequences of CC on the wine industry to be both negative and positive. Those findings suggest that winegrowers might need more information about the effects of CC in general and on their operations. Indeed, CC uncertainty might hinder their willingness to implement protective measures to cope with the potential effects of CC and might negatively affect their interest in CC policies. An extended growing season for grapes was the most cited benefit associated to CC, followed by an improvement in grape quality, an improvement in wine quality, and the possibility to grow grape varieties that were not previously viable. Conversely, the mostly identified disadvantage of CC for vineyard and winery operations was an increase in disease in the vineyard, follow by an increase in pest in the vineyard. Finally, no association was found between CC perceptions and CC beliefs, knowledge or environmental values. This work is published in the *International Journal of Wine Science* (Jobin-Poirier, Pickering and Plummer 2019).

Study two (Chapter three) provides an overview of the present state of CC adaptation in the CWI. It also describes the various adaptation strategies used and considered for future implementation to cope with the potential effects of CC in wine regions throughout the country. Moreover, this study investigated the drivers that influence CC adaptation in the CWI. Findings of Study two indicate that less than half of winegrowers have already adapted to the CC-related WEs presented. The WEs for which winegrowers are adapted the most are related to more frequent or intense rainfall at key periods of the growing season, and drought episodes. Conversely, the climate stimuli for which winegrowers are the least adapted include: the freeze-thaw cycles in the winter, the decrease of winter snowfall and the occurrence of consecutive hot days (over 30ºC). Also, approximately a third of participants plan to adapt in the future to all the WEs presented. Overall, those results suggest that winegrowers are likely vulnerable to the occurrence of several WEs associated to CC. Indeed, while some of them plan to adapt in the future, the current prevalence of adaptation is relatively low in the CWI, for the WEs presented. Results of Study two also reveal that winegrowers' concern about the impacts of CC on their operations is positively associated with being adapted and planning to adapt – as opposed to not being adapted – to several CC-related WEs. Plus, winegrowers working in smaller operations (<20 acres) were more likely to belong to the *not adapted* category than the *adapted* and the *plan to adapt* categories. This study will be submitted for publication in *Regional Environmental Change*.

This thesis contributes new knowledge to scholarship and practice about CC perceptions and adaptations in the context of the wine industry. In terms of scholarly contributions, it provides the first overview of CC perception and adaptation across the four main winegrowing provinces of Canada. More specifically, Study one documents winegrowers' environmental values, CC knowledge and beliefs using established tools. This information allows for future comparisons with similar or different populations. In Study two, the adaptation status of Canadian winegrowers' to CC-related WEs is also assessed for the first time. Moreover, current strategies used, as well as options considered for future implementation in the CWI are documented for the first time in the literature. Furthermore, this work also investigates the drivers of CC adaptation behavior in the CWI. The models used to assess which variable influence winegrowers' adaptation status can be replicated in the future with populations of winegrowers in Canada or internationally.

From a practical stand point, the information provided in both studies can be used by the leaders of the industry to improve the adaptive capacity of the CWI. For instance, Study one reveals the need to clarify the effects of CC for winegrowers. This information could be used by winery organizations and educators to communicate the likely impacts of CC for specific regions to winegrowers. Study two also provides relevant information regarding the adaptation options used and considered by winegrowers across the country. Since Canadian winegrowers tend to learn from their peers about the strategies used to manage WEs (Holland and Smit 2014; Pickering et al. 2015), this information is a pertinent knowledge-transfer tool for the CWI. Moreover, Study two shows that concern exerts a positive influence on the adoption of adaptation strategies in the CWI; therefore, communicating the risk of CC-related WEs might help reinforce the importance of adaptation. Furthermore, the results also illuminate that many vineyard and winery operations are likely going to suffer from the impacts of CC since they have not and do not plan to implement adaptation strategies. Finally, this research also highlights the importance of considering winegrowers' attitudes and perceptions towards CC and its effects. In fact, winegrowers' ability and willingness to engage in adaptation is a fundamental component of the sustainability of the CWI, because they are the main actors involved in vineyard and winery management.

Conclusions and recommendations

The international and CWI will continue to face challenges associated with CC in the coming years. Understanding how CC will affect the CWI and also how the industry will adapt to those changes will certainly be a process that requires a transdisciplinary efforts involving numerous stakeholders (Hirsch et al. 2008; Ollat et al. 2017). Based on the assumption that winegrowers' perception of the CC, as well as their actions are important elements to assess in order to support the industry's sustainability, this thesis provides an overview of Canadian winegrowers' perceptions and adaptation to CC. Overall, the results obtained in this research reveals that the industry as a whole could benefit from better knowledge transfer opportunities, especially between climate scientists and winegrowers. Indeed, it seems that the specific effects of CC are not well understood, and as a result, the corresponding adaptations might not be implemented when needed.

The results presented in the conducted studies reflect the CWI as a whole, and therefore, it is recommended that specific impact assessments be performed to establish which adaptation measures would better suit different wine regions (Smit et al. 2000). In fact, while general climatic trends are expected to occur throughout the country (Government of Canada 2017), climate scenarios contain uncertainties at the regional scale, and thus need to be downscaled to provide better accuracy. Using historical data and climate models to build realistic climate scenarios, experts can present the probable manifestations of CC for a region in the future. For example, in the Niagara Peninsula, such efforts have demonstrated that the region will likely experience an increase in average temperature of 3-4°C by the 2050's (Penney 2012). While those scenarios are not exact predictions of the future, they provide a clearer picture of how the climate is changing in this specific region and what CC impacts are expected in the coming years. In turn, understanding the potential climate alterations in each region is key to both anticipate shifts in phenological indicators and to select appropriate adaptive measures in the short and long-term, and should be included in future research. Also, since this work does not intend to make recommendations regarding adaptation and does not evaluate any single measure's effectiveness, future work could examine the suitability of the different adaptation strategies for a system of interest. Indeed, since the impacts of CC vary from one region to another, CC adaptation measures likely differ from one region to another (Smit et al. 2000).

While this research focused on private adaptations at the operational level (vineyards and wineries), future research should consider other adaptation options and processes to improve the adaptive capacity of the CWI (Skinner et al. 2001; Pickering et al. 2015). For instance, farm financial management options as well as the diversification of winegrowers' income can help protect operations from the potential deleterious effects of CC (Skinner et al. 2001). Also, the adaptive capacity of a wine region relies on a myriad of other determinants that can influence the vulnerability of each system of interest (Skinner et al. 2001; Pickering et al. 2015). Therefore, in drawing upon the conducted studies, it is recommended other operational and strategic determinants be included in future studies. Nevertheless, the planning and implementation of adaptation can be lengthy and should not be delayed until the consequences of CC are experiences (Klein and

MacIver 1999). There are a number of strategies that can be used now and that will be beneficial on the short and long term. For example, many autonomous adaptations already used to cope with climate variabilities in the CWI can be implemented now to minimize the deleterious effects of future CC consequences (IPCC 2014).

Finally, it is important to note that CC is uncertain by nature, and its effects will vary from one geographical location to another (IPCC 2014). Along with providing region specific information, working with winegrowers to develop effective adaptation strategies and encouraging the collaboration of the industry across provincial borders could reinforce the ability of the CWI to adapt to CC. In fact, past as well as current practices and experiences can provide lessons to address climate variability and WEs in agriculture. Using this knowledge can improve the capability to respond to CC consequences in the short and long term (Klein and MacIver 1999).

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