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Rapidly changing climatic conditions for wine grape growing in the Okanagan Valley region of British Columbia, Canada

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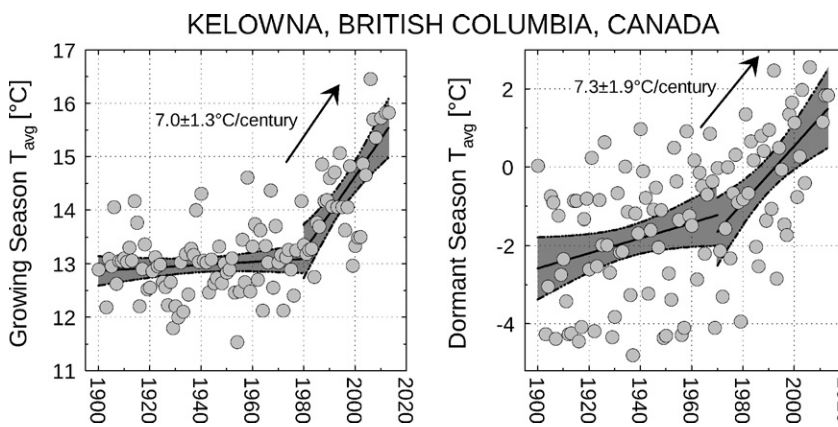
HIGHLIGHTS

- Long-term climate changes examined for sites around Okanagan Lake, British Columbia, Canada
- Average wine grape growing season temperatures increasing rapidly since 1980s
- Dormant season temperatures also rising quickly in post-1970 period
- Large increases in growing degree days over past few decades
- Formerly cool-climate viticulture regions now moving into intermediate classification

GRAPHICAL ABSTRACT



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ABSTRACT

A statistical analysis was conducted on long-term climate records for sites bordering Okanagan Lake in the Okanagan Valley viticultural region of British Columbia, Canada. Average wine grape growing season temperatures are increasing rapidly in the area over the post-1980 period at rates upwards of 7.0 ± 1.3 °C/century. Similar increases in the average dormant season temperature are evident. These temperature changes are likely some of the most extreme observed among the world's wine producing areas during the past few decades. Growing degree day base 10 °C (GDD_{10}) has increased by nearly 50% at some locations since the 1970s, resulting in major impacts on the corresponding climate classification for viticulture. If current climate trends continue, the southern and central portions of the region will likely enter Winkler region II within the next few decades, placing them in the same category as well-established warmer wine regions from France, Spain, Italy, and Australia. The large dormant season temperature increases over the last several decades have resulted in the area no longer being a cold season outlier when compared to most other cool-climate viticultural areas. Based on average growing season temperatures, the southern end of Okanagan Lake has moved out of the cool-climate viticultural classification and into the intermediate zone, while the central and northern regions are now at the cool/intermediate viticulture interface, similar to the historical positions of the Rhine Valley in Germany, northern Oregon in the United States, and the Loire Valley, Burgundy-Cote, Burgundy-Beaujolais, and Champagne appelations of France. The corresponding suitable grape species for the area have evolved into warmer region varietals during this time frame, having substantial economic impacts on producers. Increased temperatures are

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also expected to bring greater threats from agricultural pests, notably Pierce's disease from the bacterium *Xylella fastidiosa*.

1. Introduction

Concerns over global climate change have led to a critical examination of its potential impacts on wine production during the past several decades. The majority of the world's high quality wine producing regions have seen growing season average temperature increases of about 2 °C over the past century (Jones, 2004), with average winter and summer temperatures increasing 1.3 and 1.5 °C, respectively, between 1950 and 2000 (Fraga et al., 2012; Jones et al., 2005a, 2005b; Schultz and Jones, 2010). The warming trends in recent decades have resulted in wine grapes maturing more rapidly in North America, Europe, and Australia (Duchêne and Schneider, 2005; Duchne et al., 2010; Etien et al., 2008; Jones and Davis, 2000a; Petrie and Sadras, 2008; Sadras and Petrie, 2011; Wolfe et al., 2004). A study of climate and observed changes in European wine grape phenology (Jones et al., 2005a) showed that growing season average temperatures increased by 1.7 °C, maximum temperatures increased by 1.8 °C, minimum temperatures increased by 1.9 °C, with more warming in the spring and summer, and an average increase in growing degree day base 10 °C (GDD_{10}) of 264 across all stations. Between 1972 and 2002, average annual temperatures increased 1.8 °C in the Alsace region of France, where warming trends were highest during the grape ripening phase resulting in 33 more days above 10 °C and harvest dates occurring two weeks earlier (Duchêne and Schneider, 2005). Other work from the Bordeaux region of France found harvest dates were 13 days earlier in 1997 than in 1952 due to regional warming trends (Holland and Smit, 2010; Jones and Davis, 2000a). During the late 1990s and 2000s, mean annual temperatures in the area around Baden, Germany were 1.2 °C higher than the 1961–1990 average, leading to the advancement of maturation by 3 weeks between 1976 and 2006. Similarly, average temperatures increased 1.2 °C from 1970 to 2005 in the Palatinate region of Germany, concommitant with the harvest date moving forward by 2 weeks (Mira de Orduña, 2010).

From 1951 to 1997, the wine grape producing regions of coastal California experienced an annual average temperature increase of 1.1 °C which advanced the start of the growing season by 18–24 days (Nemani et al., 2001). In the Veneto region of Italy, average growing season temperatures increased 2.3 °C between 1964 and 2009, with bloom, veraison, and harvest dates moving forward from 13 to 19 days (Tomasi et al., 2011). An eight day earlier harvest was associated with a 1 °C warmer vintage. South Africa's wine regions have also seen significant warming trends throughout the year, on the order of 1 °C from 1967 to 2000 and 0.6 to 1.8 °C between the 1960s/1970s and 1990s/2000s, depending on region and timeframe considered, and an increase in growing season mean temperature for the Stellenbosch district of 0.8 °C from 1967 to 2010 (Vink et al., 2012). Maturation dates advanced eight days per decade between 1985 and 2009 in southern Australia and between 1972 and 2004 in France, as well as four days per decade in Geisenheim, Germany over the period from 1955 to 2004 (Webb et al., 2011, 2012). In the Rheingau region of Germany, harvest dates are now two to three weeks earlier than during the late 18th century through the early 20th century (Stock et al., 2005). For the Chateauneuf du Pape and Tavel regions of southern France, harvest dates moved forwards 18–21 days between 1945 and 2000 (Mira de Orduña, 2010).

Warmer temperatures are leading to higher sugar accumulations in the berry over the course of the growing season, which translates into higher alcohol concentrations in the finished wine after fermentation. Approximately half of the increased alcohol contents in wines from Alsace (France), Australia, and the Napa Valley (California, USA) has been attributed to climate change (Jones, 2007). Over the period from 1980 to 2001, grape potential alcohol near harvest date increased substantially in southern France, with corresponding decreases in acidity and a higher grape pH (Mira de Orduña, 2010). Maturity normalized for sugar advanced between one-half day up to more than three days per year between 1993 and 2006 in Australia. (Petrie and Sadras, 2008). Asymmetric warming (at night and during the spring), leading to reduced frost occurrence, a longer growing season, and more rapid and advanced spring growth, has been linked to increased yields and quality in California. Average spring-time warming is occurring at twice the rate seen over the rest of the year in this region (Nemani et al., 2001). In general, grapevine phenological timing in Europe over the past 50 years is occurring earlier and with more significant changes being observed in later events than in earlier events. Strong correlations between grapevine phenology and climate parameters were observed, with maximum temperatures being more important for early season events (i.e., budbreak and bloom), and average temperatures and GDD_{10} being more important for later season events (i.e., veraison and harvest) (Jones, 2005a). Vintage ratings over the past 50 years in most of the world's best wine regions have increased, which has been found to be correlated to increases in growing season temperatures (Jones, 2005b).

In the United States, extreme heat impacts may reduce premium grape production by up to 80% in the late 21st century. These heat accumulation increases are predicted to shift production towards warmer climate varieties and/or lower-quality wines while reducing the impacts of frost damage, but the increase in extreme hot days (>35 °C) may eliminate wine grape production across much of the United States (White et al., 2006). A study of the impacts of climate change on the industry in California showed that grape ripening is predicted to occur one to two months earlier and at higher temperatures by the year 2100 (Hayhoe et al., 2004). More recent work suggests that, at the global scale, climate change under the higher RCP 8.5 greenhouse gas concentration pathway will result in a 25 to 73% decline in the area suitable for viticulture, and a 19 to 62% decline under the lower RCP 4.5 pathway, within the major wine producing regions (Hannah et al., 2013). Furthermore, problems with earlier harvest dates brought on by climate change, assuming that grape development has still maintained a balance between sugar, acidity, and flavor, include hot and desiccated fruit if greater irrigation inputs are not applied (Jones, 2005b). Since many of the world's grape growing regions are located in semi-arid environments where water scarcity is a major scientific and political issue, increases in irrigation demand to offset the harvesting of hot, desiccated fruit may not be possible.

Within this global context, work has only begun to examine the potential climate change effects on viticulture for the emerging wine grape regions in the Canadian province of British Columbia (Belliveau et al., 2006). The economic importance of the Okanagan Valley wine industry to the regional and provincial economy is now valued at several billion dollars per annum, and the region is located within the current effective northern limits of *Vitis vinifera* wine grape production. Herein we report that portions of this region have undergone – and continue to experience – rapid climatic change over the past several decades at rates likely exceeding those of most other viticultural regions worldwide.

2. Regional description

The Okanagan Valley is located in south-central British Columbia, Canada, approximately 300 km east of the Pacific Ocean. The valley is long and narrow and runs northward for 160 km from the US border at 49 to 50°N latitude (Fig. 1). The region lies in a rain shadow between two north-south trending mountain ranges, resulting in low annual