Future Climate Change Impacts on Australian Viticulture

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Abstract

The impact of projected global warming on the Australian wine industry was investigated using spatial modelling techniques. Expected shifts in annual average temperature between present day and the year 2030 will be in the order 0.2 to 1.2°C in many of the Australian viticulture areas. By 2050 the projected increase in annual average temperature in viticultural areas is 0.4 to 3.0°C. The study included a range of greenhouse gas emission scenarios, climate sensitivity levels and global and regional climate models.

The projected changes in phenology for Chardonnay and Cabernet Sauvignon in several representative Australian wine regions revealed a dual effect of climate change on the temperatures during grape maturation. In addition to the projected regional warming, the acceleration of vine phenology and earlier maturation, resulted in the ripening occuring in an earlier, warmer part of the annual climate cycle. Ripening may occur in the order of 15 days earlier by 2030, or 30 days earlier by 2050 depending on the region.

The potential impact of these higher ripening temperatures on grape quality was modelled for premium varieties grown in each wine region in Australia. Unique growing season temperature and grape quality relationships were developed using grape price as a surrogate for grape quality. These models indicated that the grape quality in Australia's warmer wine regions could be significantly affected by global warming.

The potential adaptation strategies for the Australian wine industry in the face of this projected global warming were considered in terms of management strategies, variety selection and geographic relocation. Adaptation to raised temperatures will depend on more detailed knowledge of vine response to elevated CO_2, particularly during extreme temperature episodes.

There are a broad range of *terroirs* on the Australian continent, many presently too cool for grape growing. These are potentially available for viticulture if reliable water supplies can be secured.

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The Australian wine industry is an important contributor to the Australian economy with wine exports being the third largest valued agricultural export commodity behind wheat and beef (ABARE, 2006). The grapevine-based industry currently occupies 160,000ha with grape production being affected by drought and frost in the 2006-07 season (Fletcher *et al.*, 2007). The wine industry is considered to be particularly vulnerable to climate change because of its special dependence on unique *terroirs* that are strongly climate related (Jones *et al.*, 2005; Seguin and de Cortazar, 2005).

Globally, increasing emissions of carbon dioxide and other greenhouse gases are altering the composition of the atmosphere, leading to global climate change. Eleven of the last twelve years (1995-2006) rank among the 12 warmest years in the instrumental record of global surface temperature (since 1850). Regardless of the actions that we take today, some degree of global warming is inevitable and there is now, according to the Intergovernmental Panel on Climate Change, very high confidence (at least a 90% chance of being correct) that some of this change is already here (IPCC 2007). In 2005, for instance, the Australian annual mean temperature was more than 1°C (1.09°C) above the 1961-1990 average with the monthly temperature anomaly for the grape ripening month of April a record 2.58°C higher than the long term average.

In 2030, annual average temperatures are projected to be 0.4 to 2.0°C higher over most of Australia, with slightly less warming (0.3 to 1.7°C) in southern coastal areas, including many of the viticulture areas. By 2070, annual average temperatures are projected to increase by 1.0 to 6.0°C over most of Australia with spatial variation across the continent similar to that for 2030 (CSIRO, 2001). Most model projections show that there will be more warming in central regions of Australia and less warming in coastal regions. The spatial variability of projected warming is shown for the year 2050 in Figure 1.

The impact of greenhouse gas induced climate change on wine grape production for the Australian wine industry was investigated using a spatial analyses of projected climate change across the wine regions of Australia (Webb, 2006). The study used a range of emission scenarios and climate models of differing sensitivity to generate a range of potential impacts (IPCC 2000; IPCC 2001). This method allowed for uncertainty of climate change projections to be incorporated in the impacts modelling (Whetton *et al.*, 2005) as well the specific future climates for particular wine regions to be assessed.

The experimental approach taken was to examine the impact of climate change on a range of viticultural parameters affected by climate in order to deal with the issue as comprehensively as possible, and also to show the synergy of impacts.

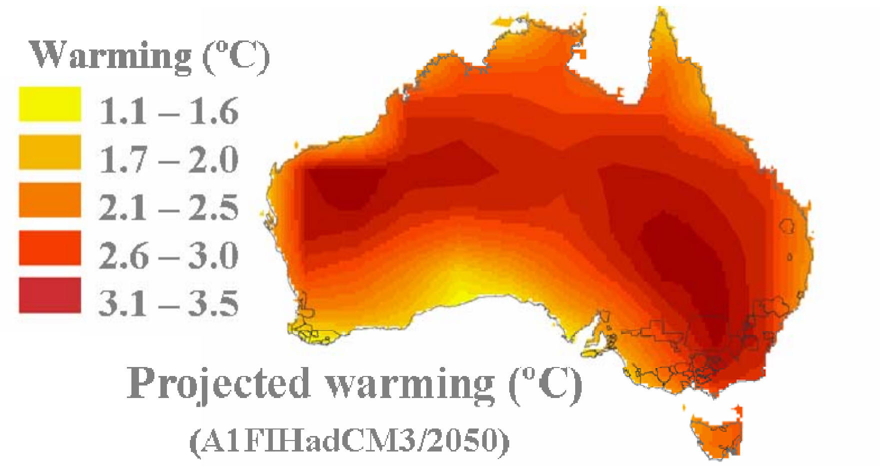

Figure 1. Results from one climate model projection showing average temperature change for January (°C). (Australian wine regions are superimposed on the map. Year 2050, A1FI greenhouse gas emission scenario, mid climate sensitivity, and HadleyCM3 climate model was used in this instance).

This article reports the on the results of an assessment into climate change impact, both on grapevine phenology (annual growth stages) and grape quality, focusing on the Australian wine industry.

I. Impact on grapevine phenology

The timing of phenological stages is fundamentally temperature driven so the impact of projected warming on phenology was investigated. The VineLOGIC vineyard performance simulator (developed by the CRC for Viticulture) was used to model phenology for the winegrowing regions in the study (Godwin *et al.*, 2002). Daily weather data from this model was perturbed with projected monthly temperature increases for the particular wine region to give quantitative estimates of the impact of future temperature change on grapevine phenology.

Results for four regions are presented here. The Coonawarra region is a cool climate region, the Clare Valley, a warm region, the Riverina is a hot region and the Margaret River has a maritime climate. The results illustrate the differential phenological responsiveness to warming for the different regions (Table 1).

Cabernet Sauvignon budburst in Coonawarra was found to occur earlier by 3 to 5 days in the year 2030, and 6 to 11 days by 2050 relative to modeled budburst dates in the current climate. Similar impacts to budburst exist for all the regions except in Margaret River where budburst is predicted to be later, because the chilling requirement may not be reached in coastal (maritime) regions like that of the Margaret River, where the winters are not particularly cold. Harvest was also found to be earlier in most cases. The Margaret River harvest dates were later with some projected warming scenarios, probably as a consequence of the later budburst dates carrying through to harvest. In the Riverina, Cabernet Sauvignon harvest may be six to twelve days earlier than currently by 2030 and between seven to fourteen days earlier than currently by 2050. It was found for all regions that the season duration (time from budburst to harvest) is compressed. This will have obvious impacts on vineyard management strategies and winery infrastructure.

Table 1. Simulated impacts of climate change on the different phenological events in 2030 and 2050 for two varieties and six grape growing regions, using the three models and three emission scenarios. Each impact is presented as a range (in days). Negative figures indicate earlier events and positive figures indicate later events.

Region	Budburst		Harvest day		Season Duration	
	2030	2050	2030	2050	2030	2050
Riverina	-4 to -7	-5 to -12	-6 to -12	-7 to -14	-2 to -5	- 4 to -15
Clare Valley	- 4 to -9	-6 to -18	-8 to -15	-12 to -30	- 4 to -8	-5 to -15
Margaret River	+10 to +4	+6 to +26	-10 to+4	0 to -14	-1 to -20	-13 to -31
Coonawarra	- 4 to -8	-6 to -11	-15 to -23	-21 to -45	-10 to -21	-15 to -37

An important implication of these findings is the dual impacts of climate change on the temperature of the ripening period. In addition to the higher temperatures resulting from the projected climate changes, the accelerated phenology, which causes earlier maturation, results in ripening temperatures increasing even further. For example, in the Clare wine region, grapes are projected to be harvested earlier in the year 2030 relative to the harvest date in the current climate. Not only is the harvest earlier in the season (and therefore warmer), but it is in a warmer climate (Year 2030). Harvest temperature is not 0.5°C warmer as the climate projection indicates, but 1.8°C warmer (if the earlier harvest date is accounted for). By the year 2050 harvest is not only 1.0°C warmer (projected climate change), but 3.2°C warmer in the Clare Valley (climate change and earlier harvest). The implications of harvesting grapes in a warmer climate and earlier in the season were examined in the context of potential impacts on grape quality below.

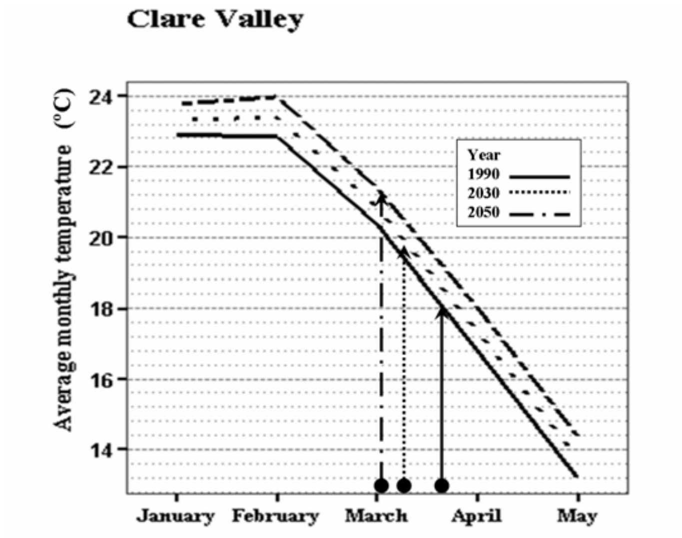

Figure 2. The current and projected modelled Cabernet Sauvignon harvest dates (arrows) and temperatures (°C) for the Clare Valley for the baseline year 1990 (solid line), and years 2030 (dotted line) and 2050 (dot/dash line) for the A1B GHG emission scenario and the CSIRO Mk 3 climate model. Projections of earlier harvest date as the climate warms from 1990 to 2050 causes harvest temperature to increase due to the greenhouse effect and also the 'earlier seasonal effect'.

II. Impact on grape quality

An essential pre-requisite to exploration of the potential impacts of climate change on wine quality is to establish a robust quantitative relationship between wine grape quality and climate. Relating regional quality measures with regional climate provides one possible means of quantifying the relationship between climate and quality. Grape quality can be estimated in various ways. Grape colour (anthocyanin concentration), glycosyl glucose concentration (a flavour aroma precursor) and price ($/tonne) can all be used as quality indicators. The relationship between climate and these quality indicators had to be determined before climate change impacts on grape quality could be quantified.

Regional average climate indices (various temperature and rainfall parameters) were compared to these regionally averaged wine-grape quality estimators. All of the quality indicators showed a significant correlation with Mean January Temperature (MJT), a well known viticultural climate indicator in Australia (Smart and Dry 1980). Price was chosen as the quality surrogate for temperature sensitivity studies because it was positively correlated with the biophysical quality estimators and also because the data for this indicator were available for most Australian wine regions. Temperature sensitivity curves were used to determine climate change impact on grape quality (as indicated by percent impact on grape price) for each variety, and the methodology is shown for the variety Cabernet Sauvignon (Figure 3).

The relationship between 'quality' and temperature varies considerably with variety, with some varieties more sensitive (with regard to quality) to temperature differences than others. Pinot Noir was the variety displaying the greatest sensitivity to temperature, and both Chardonnay and Shiraz were less responsive.

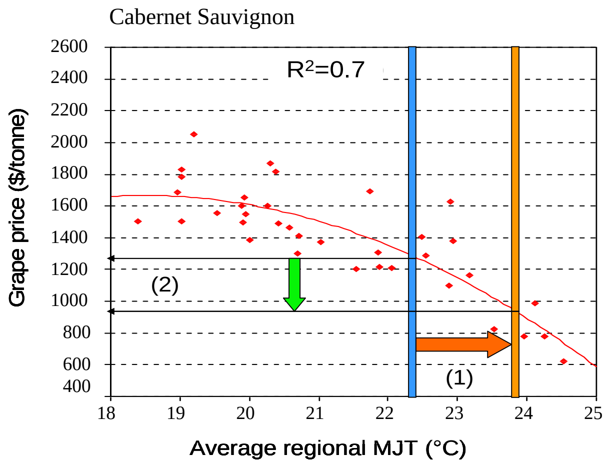

Figure 3. The relationships between Cabernet Sauvignon winegrape price (1999-2003) and the regional MJT (°C) for Australia Each point (red dot) represents a region. Price sensitivity (2) to temperature change (1) is illustrated on this diagram. The red arrow (1) depicts one possible projected GHG-induced temperature increase. This will vary depending on the region, climate model and GHG emission scenario used to calculate the projected temperature change. The green arrow (2) represents the projected impact of the temperature increase on the quality surrogate price. Note that if the temperature for a region was different to start with (blue line) the impact of the same temperature increment would be different.

Given information on future regional changes in temperature, these varietal temperature sensitivity relationships can be used to determine the regional cost of climate change to quality. Because the different varieties respond with varying sensitivity to temperature changes, the regional climate change impact was calculated by weighting varietal impact by the proportion of the varieties crushed in a region.

The impact of the climate change projections on different grape growing regions in Australia for the year 2030 revealed a reduction in quality for the Riverina, Hunter Valley, Yarra Valley, Margaret River and Coonawarra wine regions of 16%, 5%, 4%, 3% and 1.2% respectively under a low impact scenario (less warming) and 52%, 17%, 10%, 7%, and 4% respectively under a high impact scenario (more warming) (Figure 4).

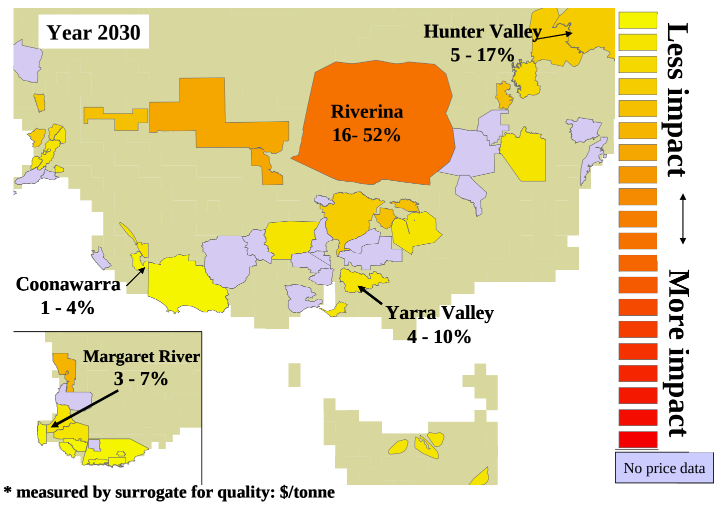

Figure 4. Range of projected regional cost to quality for Australian wine regions by the year 2030. Purple areas denote no pricing data available.

These regional impacts were scaled up to the national level by summing the production-weighted cost to quality across each region. Overall, projected greenhouse gas induced climate change could have a potential negative impact for the Australian wine industry with grape quality estimated to decrease by 7 to 23 percent by 2030 and 12 to 57 percent by 2050. It must be emphasized that these potential impacts assume that no adaptive strategies are implemented.

This analysis indicates the potentially very serious threat that climate change poses to the Australian grape industry, which for the most part is already situated on the warm side of the climate range for wine grape species. It provides a firm basis for grape growers to make a quantitative assessment of their own situation in relation to their vineyard location, varietal mix and market position. It also challenges researchers to investigate the potential for adaptive management strategies to be developed for individual varieties and regions.

III. Adaptive challenges

The wine industry will need to evaluate a number of adaptation strategies to reduce the impact of climate change. The industry has a few options. It may choose to preserve its current wine styles, based on particular well known varieties grown in particular climates, and so adapt by moving to present day cooler regions. Alternatively, the industry may choose to preserve its current infrastructure and change to varieties better adapted to warmer climates. Here we consider implications of the shifting of viticulture suitability.

The appellation system that exists in France and Italy, whereby regions produce wine from a restricted variety list, is not used in Australia. Many varieties are grown in each region producing different styles of wine from a variety, depending on the climate. However, it is noted that if the temperature range in which all the grapes are grown in Australia is split into categories there exists a preference of production of a particular variety within a temperature category (Table 2).

The temperature categories related to variety groupings were mapped by creating map layers corresponding to the MJT categories in present day and projected climates (Figure 5). The predicted suitability zones for the variety groups are shown for the south-east region of Australia for the current climate and projected climates. The temperature zones where varieties such as Pinot Noir, Chardonnay and Sauvignon Blanc are preferentially produced are found in the most southern part of the continent and also through the northern part of Tasmania. A suitability zone for Group 2 varieties (where production of Cabernet Sauvignon, Merlot and Cabernet Franc is preferred) is found throughout South Australia and the Coonawarra, and the central part of Victoria including Bendigo and the Pyrenees. Suitability for producing grapes from the Group 6 varieties; Ruby Cabernet, Chenin Blanc and Colombard is found in the Riverina Swan Valley and Victorian and NSW Murray Valley.

Table 2. Normalised proportion of grapes crushed in each temperature category compared to that crushed nationally. Temperature is represented by the mean January temperature (°C) index here. Grey shading indicates highest proportion nationally.

CATEGORY	**1**	**2**	**3**	**4**	**5**	**6**	National Crush
Number of regions represented	5	4	4	5	4	4	
6 categories of MJT(°C)	15.8-19.1	19.1-20.1	20.2-20.6	20.7-22.2	22.3-23.3	23.4-24.8	
Cabernet Sauvignon	0.8	1.8	1.4	0.9	0.7	0.9	1.0
Malbec	0.9	1.4	1.9	0.9	2.2	0.7	1.0
Merlot	0.7	1.3	0.9	0.7	0.6	1.1	1.0
Pinot Noir	9.7	3.4	1.2	0.9	1.1	0.3	1.0
Shiraz	0.7	0.8	1.2	1.4	0.9	1.0	1.0
Chardonnay	1.5	0.7	0.7	0.6	1.3	1.1	1.0
Chenin Blanc	0.2	0.0	0.6	1.1	0.3	1.3	1.0
Colombard	0.0	0.0	0.0	0.0	0.1	1.5	1.0
Riesling	1.2	1.5	1.8	1.8	2.2	0.6	1.0
Sauvignon Blanc	2.8	2.6	1.5	1.3	1.0	0.6	1.0
Semillon	0.1	0.3	0.6	1.7	1.6	1.0	1.0
Cabernet Franc	1.8	2.9	2.1	2.5	2.7	0.2	1.0
Muscadelle (Tokay)	0.0	0.0	0.6	4.7	2.7	0.6	1.0
Traminer	0.3	0.3	0.7	0.5	1.7	1.2	1.0
Verdelho	0.1	0.6	0.8	0.3	3.8	0.9	1.0
Ruby Cabernet	0.0	0.0	0.0	0.0	0.1	1.5	1.0

The potential shift of the variety suitability bands under projected greenhouse gas-induced temperature change is to more coastal areas of south-east Victoria, into the highlands of the Great Dividing Range, and more around to the south-east part of Tasmania. Suitability reduces in parts of south-western Victoria and mid NSW by 2030. Group 2 varieties are still suited to South Australia and suitability increases in the mid part of the Victorian grape growing regions. Suitability zones for group 6 varieties (e.g. Chenin Blanc, Ruby Cabernet and Colombard) are found in the southern part of the Riverina and Victorian and NSW Murray Valley by 2030. Under the high warming scenario for 2050 the shift is magnified.

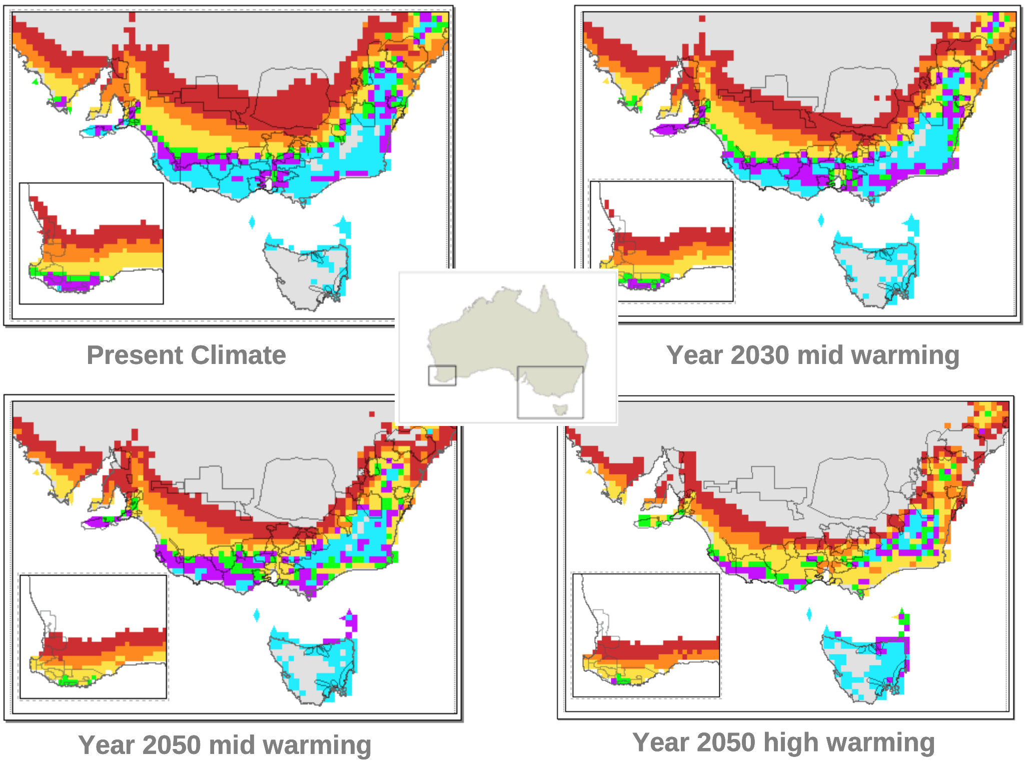

Figure 5. Suitability for growing grapevines in Australia (see key map in the centre) as defined by categories of temperature where particular grapevines are preferentially crushed in the present day (Red band indicates varieties suited to warmer climates, through orange, yellow, green purple, with the blue area being the climate zone suited to cooler climate varieties). Colour code matches that given in Table 2. The maps indicate the projected shifting of suitability zones by 2030 and 2050 with a mid climate warming (CSIRO Mk3 climate model and an A1B greenhouse gas emission scenario and mid climate sensitivity), and also a 2050 result from a high warming scenario (projected temperature was determined using the HADCM3 climate model and an A1FI greenhouse gas emission scenario and a high climate sensitivity).

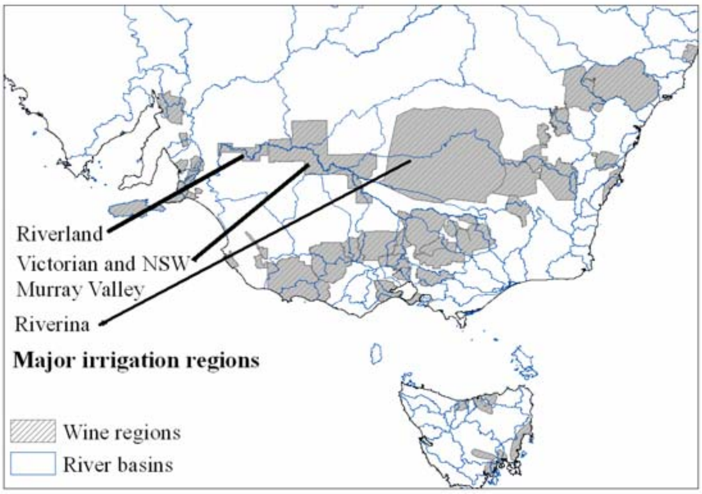

Figure 6. Southeast Australian winegrowing regions. Three regions: Riverland, Victorian and NSW Murray Valley and the Riverina, have access to major irrigation sources.

Availability of water will be a strong incentive for growing grapevines in the traditional irrigation districts (Figure 6) (already very warm regions) even with the suitability for viticulture production shifting away from these major substantial irrigation sources. By sourcing grapevine varieties adapted to the warmer climate of these sites the industry may still be able to produce good quality grapes for winemaking. These varieties will have to be sourced from sites now successfully managing them in climates equivalent to our projected future warmer climate. Possible new varieties from some hotter grape-growing regions of the world, for instance, those grown in southern Spain, Portugal, southern Italy or northern Africa could be considered. Examples of these varieties may include Aglianico and Fiano (from Campania, near Napoli).

Conclusion

Addressing the impact of GHG-induced climate change on grape phenology and quality will allow the wine industry to determine some of the adaptive strategies that could be useful for the planning of future vineyard development. The amount of effort that will be required to implement these adaptation strategies and their benefit to the wine industry remains to be seen. By quantifying the potential impact and risk to the wine industry of climate change, the current study highlights the urgency of considering such adaptive responses. With the huge infrastructure investment that goes into any vineyard and winery establishment, industry is engaging enthusiastically with this scientific study to incorporate the findings into their planning documents.

Global climate change will challenge wine production in all wine regions of the world in both a viticultural and regulatory sense. For example wine law in major European winegrowing regions allows for only certain grape varieties to be grown in certain regions for the resultant wines to be awarded the regional quality classification. Australian wine law does not have variety restrictions, which may enable the industry to be more flexible in adjusting to the effects of climate change.

The Australian wine industry has achieved phenomenal growth in the past two decades on the back of excellent innovation in both the vineyard and winery to produce fruit driven wines of consistently high quality at very affordable prices. This first detailed spatial analysis of the potential impacts future climate change has outlined the challenge to the Australian industry to develop suitable adaptation strategies to ensure its international competitiveness is maintained and even enhanced. The key to reducing the impact of climate change will be early recognition and action by the industry and researchers alike.

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