Impact on Australian Viticulture from Greenhouse Induced Temperature Change

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EXTENDED ABSTRACT

In Australia, projected shifts in annual average temperature between present day and the year 2030 will be in the order of 0.3 to 1.7°C in many of the viticulture areas. By 2070 the projected increase in annual average temperature in viticultural areas is 0.8 to 5.2°C (Figure 1) (Most major grape growing regions are found within the black ovals). The estimates take into account uncertainties associated with the range of future global warming (the greenhouse gas emissions scenarios (IPCC 2000)) and the range of regional climate model responses (IPCC 2001).

For this wine industry impact assessment we were interested in projected changes to average regional climate for all Australian wine-growing regions. Using GIS techniques, gridded climate data was extracted, for each wine region, from a range of climate maps. This climate data was then compared to various assigned or inherent estimators of regional grape quality.

Our analysis indicated that temperature increases will impact on grape production and grape quality within a region. Increasing temperature will have a negative impact on grape quality, given the grapes of a particular variety will ripen in the present day climate. Yield (tonnes/hectare) generally increased with temperature. From the yield (tonnes/hectare) and price ($/tonne) relationships, the income ($/ha) was derived, which was also related to temperature.

Using derived temperature sensitivity relationships, the impact of climate change was explored. Climate change projections were used to produce 'cost' impact models. Depending on the emissions scenario used in the model, and the grape growing region itself, by 2030 a cost of 0-25% to grape quality could be expected Viticulture-suitability maps in projected climates are shown and in general there is a southward shift of suitability.

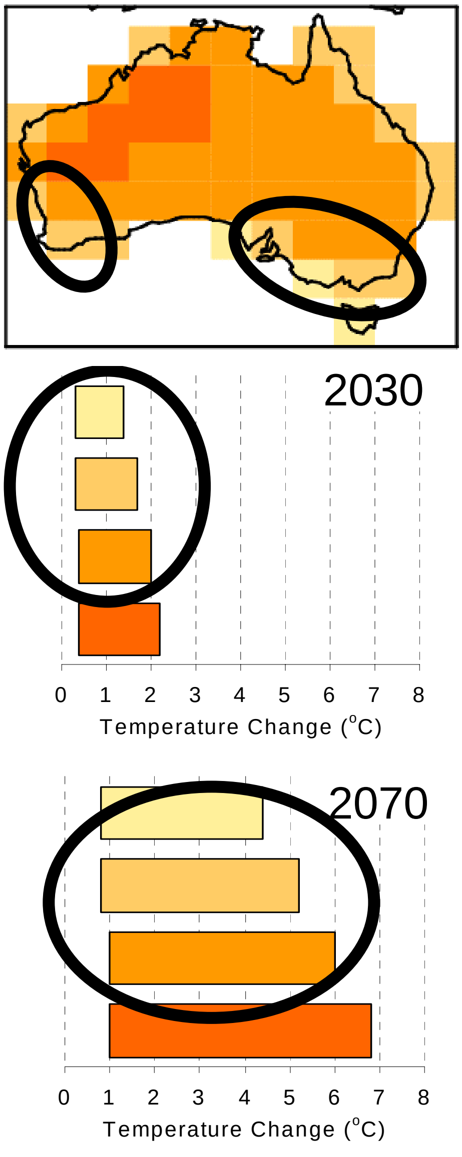

Figure 1 Average seasonal and annual warming ranges (°C) for around 2030 and 2070 relative to 1990. The coloured bars show ranges of change for corresponding coloured areas in the maps. (From (CSIRO 2001)).

1. INTRODUCTION

Global climate models project temperature increases due to an increase in the concentration of greenhouse gasses in the atmosphere (IPCC 2001). Past commentary on the impact of climate change on the Australian and European wine industries have been in the main qualitative (Boag et al. 1988; Dry 1988; Gladstones 1992; Kenny and Harrison 1992; Schultz 2000). Some European climate change impact studies have addressed spatial shifts of wine growing regions without addressing impact to grape quality (Kenny and Harrison 1992). An assessment was therefore conducted to determine the impact of projected greenhouse gas induced temperature change on the grape quality of a wine growing region and also spatial shifts of viticulture suitability.

The wine industry is Australia's fastest growing rural industry with an annual gross value of more than $5 billion. This includes $2.7 billion in export earnings. The grapevine-based industries are rapidly expanding, high value activities currently occupying 111,000ha. Vineyards have a life ranging from thirty to more than one hundred years so when selecting vineyard sites, or when managing existing vineyards, consideration of the changing climate is prudent.

Projected greenhouse gas induced temperature increases are not uniform across the continent of Australia (CSIRO 2001). There will be more warming in the central regions of the continent and less warming in the coastal areas. For this reason regional variation in the projected temperature change needs to be considered.

That temperature has an effect on wine-grape quality is not in question (Jackson and Lombard 1993). Quantification of the relationship between temperature and grape quality was the first aim of this study. This relationship was modelled with a set of regression equations for all the premium grape varieties, showing their respective sensitivities to temperature (Webb Submitted thesis 2005).

The regional impact to grape quality was quantified using temperature sensitivity regression equations. This was done for each variety in each region. The model also incorporated a weighting of the 'cost to quality' by the proportions of varieties grown in a region. This is because sensitivity to temperature varies among varieties.

Determination of how each region would be affected by climate change can be important to the future planning in the wine industry. The projected regional cost to wine-grape quality in Australia, indicating relative impacts, where some regions are impacted more than others is depicted. Further to this, identification of zones of viticulture suitability and future suitability given projected warming are shown.

2. THE TEMPERATURE SENSITIVITY MODEL

2.1. Grape quality surrogates

The Australian Wine industry is divided into distinct geographical regions[1]. Economic quality surrogates and bio-physical quality surrogates inter-regionally were compared to identify a suitable quality estimator.

Wine-grape crush surveys produce annual grape crush data for each region. Prices paid for grapes (**weighted average weighbridge price ($/tonne))**, variety by variety and region by region were available for the years 1999-2003 (http://www.awbc.com.au/ ARWCS/default.asp)

Biophysical estimators of grape quality available in a dataset provided to me by the Australian Wine Research Institute (http://www.awri.com.au) were 'Total soluble solids (TSS) (degree brix)'(Iland 2000), 'pH', 'total glycosyl-glucose' (Francis et al. 1999) and colour (Anthocyanins mg/g).

The quality surrogates were all categorised by Geographical Indicator (GI) region. These data were then analysed using a Pearson Correlation in order to determine whether there was a relationship between the regional averages of the biophysical quality estimators and the economic estimators.

Table 1 Pearson correlation comparing the biophysical quality surrogates and the economic quality surrogates.

	$/tonne	Glycosyl Glucose	Colour(mg/g)
$/tonne	1	.717**	.623**
Glycosyl Glucose	.717**	1	.854**
Colour(mg/g)	.623**	.854**	1

**. Correlation is significant at the 0.01 level (2-tailed).
Pricing data is average 1999-2003.
Colour and GG Data limited to: (TSS> 20) AND (TSS< 24) collected during the period 1996-2003 (µmol/g fw)

[1] A Geographical Indication (GI) is an official description of an Australian wine zone, region or sub-region. It takes the form of a textual description (i.e. a list of grid references, map coordinates, roads and natural landmarks which can be traced to outline the regional boundary) along with a map. (http://www.awbc.com.au)

Given that all the biophysical and economic quality surrogates were significantly correlated ($P<0.01$) and that the pricing ($/tonne) information was readily and nationally available, it made sense to use weighted average weighbridge price ($/tonne) as the chosen surrogate for quality.

2.2 Climate drivers

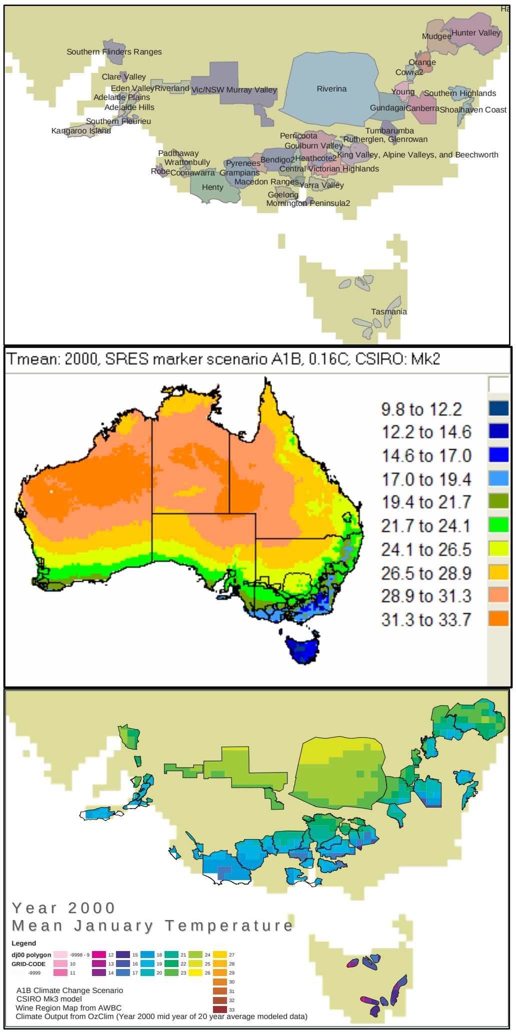

Figure 2 A sequence of maps illustrating the ArcGIS climate data extraction in South-eastern Australian grape growing regions. Wine region maps are used to intersect the climate maps. Climate data can then be analysed region by region (third map).

A literature review was conducted to identify climate indicators that were likely associated with grapevine growth and/or grape quality. Potential climate indicators included the following:

Heat degree days (HDD) (Amerine and Winkler 1944); annual rainfall; mean January temperature (MJT)(Dry and Smart 1988); latitude temperature index (LTI) (Jackson and Cherry 1988); winter minimum temperature (June to August); harvest maximum temperature (Average of December to March) (Happ 1999); rainfall (summer) (Nicholas et al. 1994); diurnal range (January maximum temperature minus January minimum temperature); continentality (January mean minus July mean) (Gladstones 1992).

Climate data were obtained in gridded format from OzClim climate change generator software. OzClim has been developed at CSIRO Atmospheric Research by the Climate Impact Group in collaboration with the International Global Change Institute (IGCI), New Zealand (http://www.dar.csiro.au/publications/ozclim.html) OzClim's observed base climatology is spatially interpolated from station data of the Bureau of Meteorology. Year 2000 gridded climate data were used to create the baseline climate.

The climate data were imported into the ArcGIS format as ascii text files, then converted through grid files to coverage files, and then the data were extracted using overlay techniques. Finally, an area weighted averaged climate was calculated for each region. Figure 2 illustrates the climate extraction for south east Australian grape growing regions.

2.3 Linking Climate and Quality.

The average climate (for all of the indices explored) was compared to the weighted average price paid per tonne for wine grapes (the chosen quality surrogate). It was found that there was a significant negative correlation between the price ($/tonne) and the climate descriptors HDD, MJT, Harvest maximum temperature and the LTI. As MJT is a well used viticultural climate estimator this was the chosen climate descriptor to use in modelling temperature sensitivity of wine grape quality.

Figure 3 shows the relationship between MJT and average regional 'weighted average weighbridge price paid per tonne', for Cabernet Sauvignon. A quadratic equation was chosen in the case of Cabernet Sauvignon as this best describes the bio-physiological response of grape ripening profiles. Cool climates will not ripen some varieties to their best potential (Gladstones 1992). Under-ripe characters probably reduce the desirability of Cabernet Sauvignon grapes from the coolest areas and hence result in lower prices being paid. The price per tonne for Cabernet Sauvignon reaches a peak when the MJT is about 20°C. Climates represented by this MJT could be said to produce Cabernet Sauvignon grapes at the best of their potential. As the climate (represented by the MJT value) becomes warmer the quality is reduced.

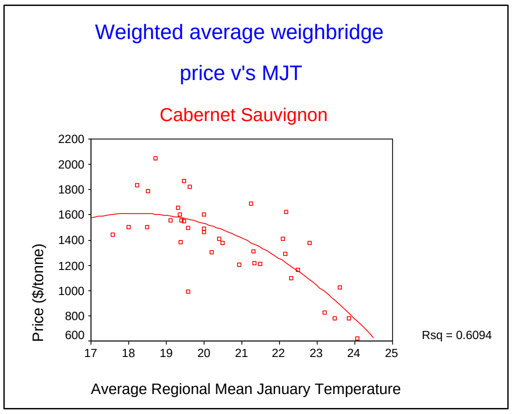

Figure 3 Scatterplot of Weighted average weighbridge price per tonne (1999-2003) for Cabernet Sauvignon compared to the Average regional Mean January temperature.

The temperature sensitivity relationship was defined for all the premium wine grape varieties of Australia (with some of the varieties the relationship was linear). Regression equations were used to explore the impact of projected greenhouse induced climate change on the Australian wine industry.

3.0 CLIMATE CHANGE IMPACT

OzClim climate change generator software produces gridded output of projections of temperature change for Australia. These climate projections were modelled using a wide range of demographic, economic and technological driving forces of future greenhouse gas and sulphur emissions (IPCC 2000). Projected climate change into the future includes some uncertainty.

GIS techniques were used to extract the regional climate **change** data from the OzClim maps for this impact analysis, as was done with the creation of the temperature sensitivity model. Regression equations describing the relationship between temperature and quality (developed as in Figure 3) were used to determine average **regional** impact to quality. Using these equations, the shift in quality was calculated for the given regional shift in temperature.

All of the components of the model: temperature sensitivity of grape quality; variation in regional warming; and variation in regional variety proportions, were incorporated to produce a **regional cost to quality**.

The range of impacts to grape quality (% impact to cost) for all Australian wine regions (including Western Australia) is given in Table 2. This describes two outlook periods, 2030 and 2050, and the two greenhouse gas emission scenarios.

Table 2 Ranges of impact of greenhouse gas induced climate change to grape quality in Australia (assume no adaptive measures).

Greenhouse gas emission Scenario	2030	2050
A1B	0% to -20%*	-5% to -50%
A1FI	0% to -25%	-10% to -60%

***Range indicates regional variation**

The projected percent impact to quality is depicted in Figure 4 and Figure 5. Mid range and high range emissions scenarios are used in the modelling and shown in the separate maps.

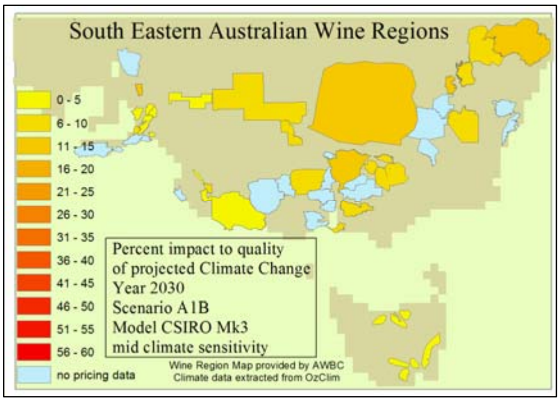

Figure 4 Ranges of percent impact to grape quality of greenhouse gas induced climate change (Time slice 2030, emission scenario A1B, Climate model CSIRO Mk 3, mid temperature sensitivity).

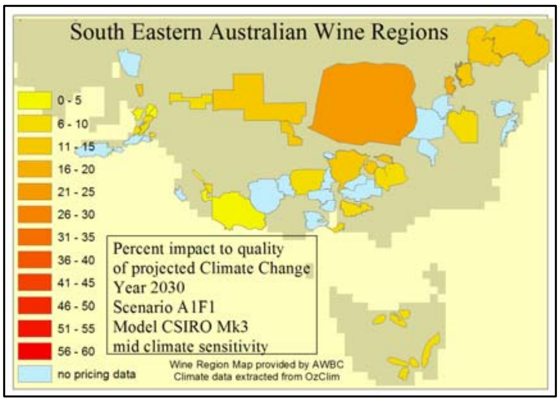

Figure 5 Ranges of percent impact to grape quality of greenhouse gas induced climate change (Time slice 2030, emission scenario A1FI, Climate model CSIRO Mk 3, high temperature sensitivity).

Some of the uncertainty in the projections was addressed here by including two different greenhouse gas emission scenarios (IPCC 2000). A1B is a mid range greenhouse gas emission scenario where balanced use of fossil fuels and renewable energy technologies are implemented in the future, and the A1FI greenhouse gas emission scenario assumes high fossil fuel usage. CSIRO Mark 3 climate models have been used. Temperature increases projected by the CSIRO mark 3 model fall in the middle of the range of variation projected by different global models (Webb Submitted thesis 2005).

4.0 CROP VALUE

Yield also varies with temperature. In warmer climates it is possible to ripen larger crops (tonnes/hectare) as there is more photosynthetic potential (Howell 2001).

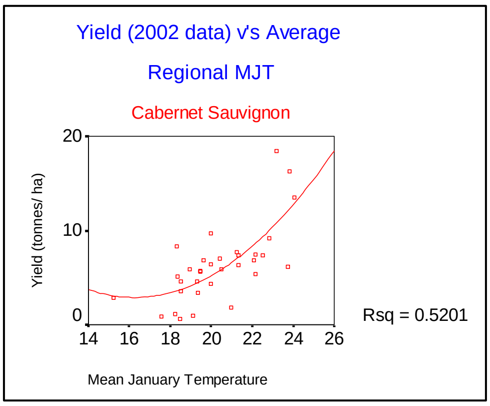

Figure 6 Yield (tonnes per hectare) for Cabernet Sauvignon as it varies with MJT.

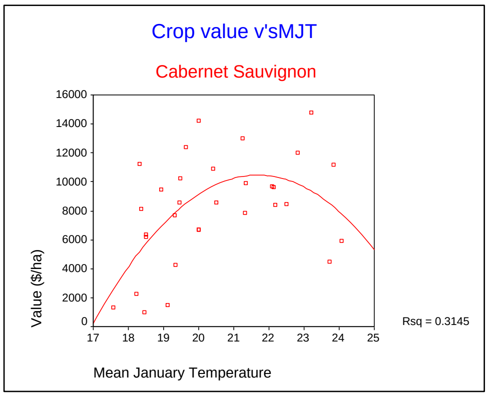

Figure 7 Value ($/tonne) for Cabernet Sauvignon as it varies with MJT.

Yield data (ABS 2002) were used to determine the relationship between yield and MJT. For all premium varieties, the yield was higher in the warmer climates. Figure 6 shows the relationship between the average yield (tonnes/hectare) and the average regional MJT for Cabernet Sauvignon. Yield (tonnes per hectare) as it varies with MJT (Figure 6), was multiplied by price per hectare as it varies with MJT (see Figure 3), to determine a value ($/hectare). Value as it varies with MJT is plotted for Cabernet Sauvignon (Figure 7).

These data were used to develop a regression model describing the relationship between grape value (per hectare) and MJT. This has been done for all varieties (Webb Submitted thesis 2005). A derivative of the regression equation of the value vs. MJT will give the MJT for which 'value' is at a peak (gradient = zero). This peak value for all premium varieties ranges between 21°C and 23°C (Figure 7 shows relationship for Cabernet Sauvignon).

Using GIS to extract this range of climate data from a baseline climate map, this 21–23°C zone of climate can be highlighted on a map of Australia where wine regions are also shown (Figure 8).

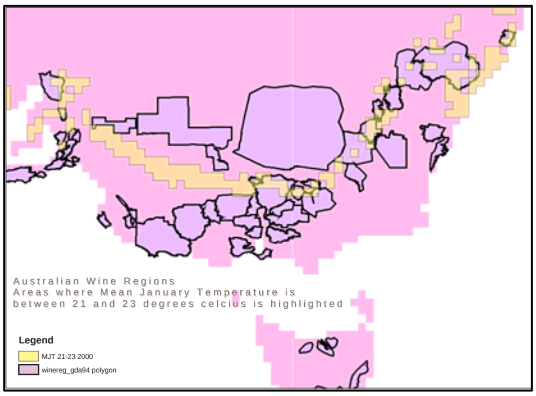

Figure 8 Areas where MJT is between 21°C and 23°C highlighted in gold, overlaying Australian wine regions (South Eastern Australia).

4.1 Viticulture Suitability zones in projected climates

In projected climate maps, these suitable climate zones can also be selected. The zones of greatest value grape crops can be shown on the same map and the 'movement' of potential viticulture suitability can be visualized (Figure 9). A south ward movement in potential highest value climates is apparent.

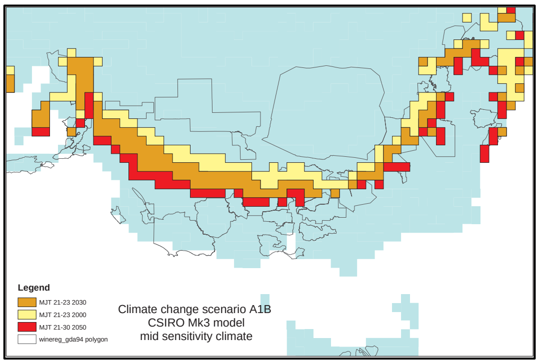

Figure 9 Map of South Eastern Australia where the MJT of between 21°C and 23°C is highlighted for the years 2000, 2030 and 2050. (For the projected climates the A1B mid range greenhouse gas emission scenario is used and the CSIRO Mk3 climate model).

5.0 DISCUSSION

GIS techniques were used to extract climate data to produce a regionally averaged database of the climate variables. Spatial interpolation of this data had not before been summarised in this way for the Australian wine regions.

Now that these data are available, exploration of the relationships between the extracted regionally averaged climate variables and the regional quality data was made. Using this inter-regional comparison, a link between climate and grape quality was found. It was also found that this relationship varies from one variety to another. Prior to this analysis, this was understood qualitatively but not quantitatively.

Extrapolating these data and the regression relationship for all of the premium grape varieties, cost impacts of projected greenhouse induced climate change (regionally averaged) were determined here for the first time. Calculations of the cost to regional quality were negative in all cases (given the variety can ripen in the region in present day climates). The Australian Wine Industry must make provision for adaptation to maintain grape quality in a competitive global market.

Viticulture suitability zones indicate a shifting of suitability of zones to the cooler southerly sites is likely to occur in response to continued climate change. This analysis resembles work done previously in Europe (Kenny and Harrison 1992).

For this analysis no adaptive strategies were included when calculating ‘cost’. What is implied is the need to consider possible adaptive strategies, the efficacy of which may be a profitable area of future research. For example, variety substitution could be seen as an adaptive strategy, especially in cooler climates, where a positive impact of climate change for some varieties could be realized. Viticultural management techniques such as canopy manipulation or vineyard orientation can be modified. Watering regimes are flexible (to a point) and could be used to manage some of the hot extreme weather. Shifting of vineyard sites completely or opening up of new areas previously too cool for cultivation of grapevines will be possible.

The amount of effort required to facilitate these adaptation strategies and their benefit to the wine industry remains to be seen. By highlighting the potential impact and risk to the wine industry of climate change, the current study highlights the urgency of considering such adaptive responses.

Future work will include regional risk assessment, especially regarding increased frequency of extreme events.

6.0 CONCLUSION

Temperatures in the wine growing regions of Australia are projected to rise in the range of 0.3 to 1.7°C by 2030 and 0.8 to 5.2°C by 2070. Increased temperatures are likely to have a negative impact on grape quality in a given region.

Increased temperatures may have a positive or negative effect on the ‘crop value’ of a given region, the value increasing in the more southerly regions in general and decreasing in the more inland areas.

Addressing the impact of greenhouse gas induced climate change on grape quality, yield, and value will allow the Australian wine Industry to determine some of the adaptive strategies that could be useful for the planning of future vineyard development. 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.

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