Garnaut Climate Change Review

Viticulture, wine and climate change

Prepared by
Kym Anderson, Christopher Findlay, Sigfredo Fuentes and Stephen Tyerman, University of Adelaide

June 2008

Contents

1 Summary 2

2 Introduction 3

3 The wine and grape sector—structural change 4

4 Impacts of climate change 5
- 4.1 Background 5
- 4.2 Direct impacts of climate change 5
- 4.3 Indirect effects 8
- 4.4 Winery level impacts 9

5 Adaptation 10
- 5.1 Allow yield to go up to compensate for reduced quality 10
- 5.2 Shift viticultural areas further south combined with changes in varieties 10
- 5.3 Application of genetically modified materials 10
- 5.4 New varieties 10
- 5.5 Phylloxera strategies 10

6 Policy implications 11

7 Research agenda 12

8 Conclusions 13

9 Glossary 14

10 Acknowledgments 16

11 References 17

1 Summary

The winegrape and wine industry provides a set of forward indicators for all Australian agricultural industries as they confront climate change. This is because winegrapes are particularly challenged not only by the expected increased incidence of extreme weather-related events (heat, drought, frost, wind, hail, bushfires) but also by the expected higher temperatures in the growing season that will bring forward the harvest date to a hotter month. The temperature rise in the critical harvest month for winegrapes may therefore be two or three times greater than the expected temperature rise in the current harvest month.

While the industry is highly sensitive to the effects of climate change, it also has a track record of a high level of adaptability to shocks. There is scope for further adaptation, in terms of both the relocation of its activities and within existing locations. Options for adaptation at the vine, vineyard, winery and consumer levels need to be explored, and choosing the best ones will take time and require significant research and development expenditures.

The industry operates in a global market and the rest of the world will also be responding to climate change. It is important for the Australian industry to move quickly in that context, because shortening the time lags to adoption of its adaptive R&D findings boosts the returns to that investment. Some competitor supplier responses, in the EU in particular, are likely to be constrained by their regulatory environment while others (e.g., in the US, New Zealand and Chile) have the capacity and flexibility to be as rapid as Australia’s.

The efficiency of the adaptation depends also on national cross-sectoral policy. The industry has strong interests, in terms of designing its own responses and reaching efficient results, in the structure of national carbon trading arrangements, the design of national water policy, and the Australian approach to the use of GM material.

The national policy settings in which businesses in the industry plan their adaptations is very significant for another reason. The industry will be tested on its approach to mitigation through the market. By its location it will be associated with the national policy and that policy and its own responses will be assessed by international standards. Failure to meet expectations of wine consumers abroad could lead to a negative consumer response and new impediments to exports.

2 Introduction

The wine and viticulture sectors capture a wide range of impacts of climate change that will matter for all of the agricultural industries. On the supply side, for instance, the vine is extremely sensitive to the various shifts associated with climate change. The first aim of this paper is to illustrate the significance of these effects. The effects operate via a number of channels. Not all can be described here in detail, but a sufficient number are presented to demonstrate the complexity of the systems within which the industry operates, including the extent of its integration across stages of production, and their sensitivities.

The complexities of the grape-growing and wine-making system, and the stages of production involved, also open up a wide range of options for adaptation. The second aim of the paper is to illustrate some of these. It is not yet clear which of those options are the most efficient, partly because choices will be affected not only by policies applied in the Australian wine industry but also by responses in other sectors of the economy. The costs of various solutions in the wine industry depend on getting a wide range of national policy settings right.

With two-thirds of its production exported, the Australian wine industry operates in a global market. That context complicates the industry's responses to climate change. The third aim of the paper is to identify these links and the associated risks involved. Competitors to the Australian industry will also be responding to climate change, so the conditions in world markets will depend on the nature and extent of their responses. Likely scenarios in this respect are topics for further research, but some elements of the analysis are discussed here.

Consumers in Australia and the rest of the world will also be concerned about the nature of not only the Australian industry responses to climate change but also the national policy settings within which they take place. Anticipating this consumer interest, global retailers are already requesting details and reporting of industry strategy with respect to climate change. In this respect, too, wine is a forward indicator among Australian agricultural exporters.

3 The wine and grape sector—structural change

In 2006–07 the value of domestic wine sales reached $1.9 billion and the value of export sales $3.0B. Export volumes have increased five fold over the past decade, reaching 787m litres in 2006–07, while the export value has almost quadrupled. Meanwhile, domestic sales of Australian wine have grown 35% by volume over the same period (Figure 1).

In 2006–07, 1.4m tonnes of grapes were crushed in Australia, a reduction of 26.5% on the previous year. The Australian Wine and Brandy Corporation in February released a harvest update reporting that at 'just under half complete, the 2008 Australian winegrape harvest is expected to be in the range of 1.55 to 1.65 million tonnes. This is below the record 2005 harvest of 1.925 million tonnes but higher than the drought and frost affected 2007 harvest of 1.397 million tonnes. While yields per hectare in 2008 were below the long run average, the current higher production base of the Australian wine industry means this assessment will place 2008 in the top five harvests on record.'[1] The AWBC refers to the contribution of access to water through trading arrangements to this result.

Wine production in 2006–07 fell to less than 1m litres. ABS Census data indicate that direct employment in the grape growing and wine making industries exceeded 30,000 in 2001.

South Australia accounted for 43% of winegrape production in 2007, NSW for 29%, Victoria for 22% and WA for 5%.

Three varieties accounted for 54% of all production in Australia in the drought- and frost-affected 2006–07 season: Chardonnay (367,000 tonnes), Shiraz (284,000 tonnes) and Cabernet Sauvignon (183,000 tonnes) (ABS, 2008). Figure 2 shows the mix of output by variety over a longer period of time. AWBC reports a total vineyard area of 170,000 hectares.[2] Red grape varieties accounted for 58% of the total area of vines and 59% of the total bearing area (ABS, 2008).

The industry has experienced significant structural changes throughout its history. Since 1990–91 its size has increased by a factor of nearly five in terms of winegrape crush. The number of wineries has more than doubled in 10 years, to exceed 2100 in 2007: 70% have an annual crush of less than 100 tonnes.

Wine tourism has reported healthy growth. Between 2000 and 2006, the number of domestic overnight wine visitors increased at annual rate of 6% while domestic and international day visitors increased 5% and 8% respectively.

More recently, the industry has been adapting to changes in the availability and price of water supplies and to higher degrees of salinity in water. In the past year or so it has also had to deal with shocks such as frosts and bushfire smoke taint in wine.

On the demand side, it is responding to changes in distribution systems in its traditional markets, such as the rising role of the retailers, and to opportunities for growth in new markets at home and abroad. It is confronting a variety of regulatory issues in selling its products in all markets.

The unit value of exports was $3.66 per litre in 2006–07. While that is lower than the $3.82 achieved in the previous year, it follows a decade of steady rise. An industry target is to raise that value by moving to more premium and super-premium wines.

The industry has demonstrated its ability to learn and its adaptability in the past, a capacity that will need to be called upon yet again in response to climate change.

One piece of evidence of adaptability is the dramatic move away from sultana grapes and into popular winegrapes production (Figure 2 shows the data since 1990). Evidence of the ability to learn is the increasing specialisation of Australia's various wine regions since 2001 in growing the winegrape varieties most suited to the climate of their region (Figure 3).

[1] https://www.awbc.com.au/winefacts/data/free.asp?subcatid=235
[2] http://www.wineaustralia.com/australia/

4 Impacts of climate change

The following discussion of the impact of climate are based on work which assumes ‘business as usual’, that is no new national policy or other coordinated effort in Australia or the rest of the world to reduce emissions and ameliorate likely changes in climate.

4.1 Background[3]

The grapevine (*Vitis vinifera L*.) used for wine production in Australia is a woody deciduous perennial. In Australia there are approximately 94 varieties of *Vitis vinifera* and several clones of each variety. Out of this only 16 varieties have plantings greater than 1000 ha each (Dry, 2004).[4]

Grapevine phenology, quality and yield are very dependent on climate at a regional scale, a local scale (mesoclimate: altitude, slope aspect and nearness to water, wind) and a microclimate scale (influenced by vine spacing, reflectance of radiation from soil, and canopy management) (Gladstones, 2004). Regional climate has been the focus of assessments of climate change impacts. At the local level, the impact of site selection and management are increased, and these are important for potential adaptations to climate change.

Temperature has the most influence on grapevines. The sensitivity occurs through three interrelated effects of temperature on the vegetative and reproductive growth:

- timing of key events in the annual cycle of growth and reproduction (*phenology)*
- other reproductive effects
- photosynthesis, respiration and transport of assimilated carbon
- biochemistry and transport of flavour molecules and precursors in the berry.

The physiological and morphological differences between varieties (genotypes) enable wine grape production over a relatively large range of climates than otherwise would occur with a more restricted range of genotypes. However, there are many obstacles to establishing a new variety and obtaining consumer acceptance (Rose, 2008). For each variety it is possible to define climates for premium wine production (Jones, 2008). Each grape variety grows in a range of temperature ranges and for some the range is large, eg Riesling compared to Pinot Noir (Fig 4A). Figure 4B illustrates how wine quality might vary with changes in climate and illustrates the inverted U and optimum frequently observed in more detailed analysis (Webb 2006; Jones et al. 2005). Warming may increase quality or decrease quality depending on the variety and the region. Plasticity depends on variety and production techniques.

Viticulture regions tend to lie in the 12–22°C isotherm (Jones, 2007). Grapes can be grown outside this range, at some cost in terms of other valuable characteristics foregone. Chardonnay for example, classified by Jones as an ‘intermediate group’ grape between cool and warm (Fig. 4A), has 38% of total area cultivated in Australia in hot climates with a mean January temperature MJT >23 C (1998 data, Paterson, 2004). Profitability ultimately drives the selection of location and particular grapes may be grown in areas which are ‘too warm’ according to the analysis in Figure 4.

The difference between varieties is not stable over different regions and some varieties can show plasticity in their phenology, a feature of great interest in the context of climate change. Riesling can ripen earlier than Shiraz in warm regions, but later than Shiraz in cool regions (Dry 1984).

4.2 Direct impacts of climate change

Summarised in this section are the direct effects of climate change, including:

[3] For definitions of technical terms in what follows, please refer to the Glossary at the end of the paper.
[4] There are approximately 5000 varieties worldwide, most of which have arisen in Europe and central Asia.

- the earlier budburst, the earlier harvest and the shorter season (with variations by region and variety)
- the significance of harvesting in a warmer climate
- the compression of harvest dates among varieties
- the links between higher temperature and lower quality
- the links between higher temperature and higher yield
- the general reduction in gross returns and the degree of relocation required to maintain them
- the higher levels of aridity and the rising demand for irrigation water
- the negative effects of weather extremes
- the uncertain effects of higher levels of CO_2.

Webb et al. (2007) examined the effect of climate change in six regions with two varieties; Chardonnay (early season) and Cabernet Sauvignon (late season).Three climate models were used in order to capture the range in uncertainty in global warming using different climate sensitivities and different GHG emissions scenarios. VineLOGIC (Godwin et al. 2002) was used to determine the changes in the annual cycle of growth and reproduction (phenology) after confirming the model's predictive performance with past records. Budburst was predicted to be earlier in 5 regions with the range in uncertainty of timing overlapping for both varieties and regions. For Margaret River, budburst was predicted to be later due to insufficient chilling during winter, which would also cause erratic timing. Excluding Margaret River the other 5 regions had lower and upper bound average changes between 2030 and 2050 of: -3 to -10 days for budburst, -8 to -27 days for harvest, and -4 and -20 days for season duration.

Two important sets of findings from this work are worth emphasising. One is the 'dual warming impact', whereby the earlier harvest induced by the warming effects on phenology means that harvests will occur earlier, in a month that has a higher average temperature today. The temperature rise in the critical harvest month for winegrapes may therefore be two or three times greater than the expected temperature rise in the current harvest month. This could potentially reduce berry quality through greater loss of volatiles and greater water loss.

The second important finding is that differences in harvest dates between early and late-harvesting varieties will be compressed due to late varieties being more sensitive to warming than early varieties. This will put greater strain on the logistics of winery intake, and that impact will be compounded by increased volatility in future weather patterns.

The hot, dry conditions leading up to the 2008 vintage provided a natural experiment in dealing with both of these effects: the higher March temperatures in the cooler parts of South Australia brought forward harvest dates and compressed the difference across varieties in their optimal harvest date. As a result, harvesting labour and machines were in excess demand and wineries had difficulty sequencing their intakes optimally, so quality suffered.

Webb et al. (2008a) used the historical statistical (negatively sloped or inverted u-shaped) relationships between temperature and prices paid for grapes by variety to estimate the effects of climate change. Allowing for the mix of outputs in different regions and assuming that mix remained constant, the predicted percentage change in prices paid for wine grapes are large for most regions and particularly those with a high proportion of national production, eg Riverland (2030, -5 to -32%; 2050, -9 to -87%) and Riverina (2030, -9% to -73%; 2050, -16 to -100%). Even cooler climates were predicted to show significant reductions in prices, again because of lower quality (eg Tasmania: 2030, -2 to -8%; 2050, -3 to -19%). Amongst the predicted least affected (percentage cost less than -18% (2050)), but with relatively high national production, were the Coonawarra, McLaren Vale and Langhorne Creek. Taking into account the uncertainties in both climate predictions and temperature sensitivities, the national impact was predicted to be between -7 and -39% (2030) and -9 to -76% by 2050.

At the same time, yield tends to increase with increased temperature, assuming no effect on water supply. Webb (2006) estimated changes in gross returns (change in yield times change in price). Most of the large producing regions show significant reductions in gross return, but there are notable exceptions including McLaren Vale, and Langhorne Creek. The national impact for both 2030 and 2050 were negative.

The previous results assume locations of grape growing remain the same. Webb's (2006) estimates of the maxima in gross return at a particular temperature for each variety allowed a spatial projection on to future climate maps of Australia. A southward shift of 40 km by 2030 and 65 to 115 km by 2050 would maintain gross returns. Shifts to higher altitude can have the same effect. This shift could affect areas currently listed as nature reserves, and there may be impact from fire (smoke taint) when vineyards are closer to forested areas. Fire frequency may increase with increased warming and aridity (Hennessy et al. 2005).

Webb (2006) also defined 'suitability bands' for high quality wine production using temperature ranges for different varieties, based on the historical relationships between temperature and price which were then superimposed on to maps of Australia, taking into account projected changes in MJT in to the future. Webb concluded that by 2030 there may be additional areas for growing some varieties. However, overall there will be a reduction in suitable areas by 2050 (between 27%, mid warming and 44%, high warming) (Webb et al., 2008c). Shiraz showed a reduction in suitable area of between about 15–25% and Chardonnay showed a reduction in suitable area of between about 40% and 60%. Note that this scenario assumes that the wines produced are aimed at above commercial grade. It is possible, given no constraints on water supply, to have varieties grown outside the optimum temperature range if the desired end point is commercial grade wine. The production of Chardonnay in hot regions in Australia is a case in point (Paterson, 2004).

CSIRO climate models have predicted that despite changes in rainfall patterns there will be an increase in potential evaporation by up to 30% increase by 2070. Webb (2006) investigated the impact of GHG induced changes in hydrological balance on viticulture over different regions. Vineyard water demand was estimated using the McCarthy et al. (1992) aridity index. Impact on water storage from winter rainfall was not assessed. The same three climate models as used in the above analyses were used.

Growing season rainfall was predicted to decrease or increase depending upon region. Areas of large current production such as the Riverina, Murray Valley, and Coonawarra have predicted declines in rainfall. Margaret River which is already often experiencing water shortages is predicted to have a large reduction in growing season rainfall by 2050. The aridity index is predicted to increase in all regions in 2030 and 2050. The Hunter Valley is the only region where the range in uncertainty encompasses the possibility of less aridity. Generally these predictions require that water demand be reduced through increased water use efficiency, or that supply is increased. Webb uses projected changes in aridity index as a preliminary indication of greater water demand for viticulture. Riverina and Murray Valley demand for water for irrigation increases by between 2 and 33%. The occurrence of extreme events and more frequent droughts will add further pressure and in this respect it is difficult to predict when the industry will approach any catastrophic or dangerous conditions, especially since it has already coped with some quite extreme variations from season to season over the last 50 years (Hayman et al. 2008).

Another important channel of effect could be via weather extremes. Extreme heat days could be significant. From a study relevant to the USA, White et al (2006) showed that predictions based on average increase alone are likely to considerably underestimate the impact of climate change on viticulture. The differences in reduction in suitable area between using average temperature increase and increased frequency of extreme heat days are very substantial (60% versus 81% reduction in area). The studies by Webb reviewed above did not take into account the impact of increasing frequency of extreme heat days. This is currently being researched via GWRDC funding by South Australian Research and Development Institute and collaborators (Soar et al., 2008).

Rising carbon dioxide will have a significant stimulatory effect on vegetative and fruit yield of grapevines (Bindi et al., 2001) through its influence as the source of carbon for photosynthesis. The predicted changes in carbon dioxide and temperature have only once been factored in to models to predict vine performance, relevant to Italy (Bindi et al. 2001). The CO_2 effect strongly interacts with temperature (Morison and Lawlor, 1999) and nutrition (McKee and Woodward, 1994). For example for yield in soybean the negative effects of rising temperature are largely offset by the fertiliser effect of high carbon dioxide (Long et al. 2006). Higher carbon dioxide also increases transpiration efficiency, a component of crop water use efficiency (Kimball et al. 2002). There are also species-dependent secondary affects of high carbon dioxide for which we have no knowledge of for grapevines. These can include effects on phenology and growth patterns. It is unlikely that high CO_2 will have major effects on the phenology of grapevines because of the dominant effect of temperature, but based on effects observed in other woody deciduous plants it is likely that shoot branching and leaf morphology may be altered (Hättenschwiler et al. 1997) and this has implications for vine management and adaptation to climate change.[5]

To summarise the key direct effects:

- higher temperatures across the growing season will bring forward the winegrape harvest date to a hotter month, so the warming effect of climate change will have a double impact in lowering the quality of winegrapes
- differences in harvest dates between early and late-harvesting varieties will be compressed due to late varieties being more sensitive to warming than early varieties, which will strain the logistics of harvesting and winery intake
- that impact on the logistics of harvesting and winery intake will be compounded by greater volatility in future weather patterns
- quality of grapes will suffer as a consequence and, despite higher potential yields, gross margins in most areas are expected to fall
- re-locating vineyards to cooler locations (to lower latitudes and higher altitudes) could help but overall there will be a reduction in suitable areas for growing quality winegrapes in Australia
- an increased frequency of extreme heat days and greater constraints on water supplies in the wake of more-frequent droughts will exacerbate the above trends.

4.3 Indirect effects

Soil also influences yield and quality and in some cases can largely define a region, such as the Coonawarra. The water and nutrients derived from the soil by the vine, combined with the climate, can strongly influence the ratio of vegetative to reproductive growth (vine balance), and it is this that the viticulturist is largely trying to manage to achieve the optimum for fruit quality and yield (Dry et al. 2005). Most Australian viticulture requires irrigation and nutrient additions, and these can be used through judicious timing of application to attain optima in yield and quality, as well as achieve high crop water use efficiency. There will be non-linear effects of climate change caused by interactions between soil, climate and nutrition, in part dependent on adaptation in vine management.

With increased aridity often comes decline in soil structure and increased salinity (Clarke et al. 2002; Richards et al., 2008). Soil structure decline and increased sodicity can occur when saline water is used for summer irrigation and then subsequently the soil receives high quality rainwater during winter (Clarke et al., 2002). Decreased flows in the Murray Darling system will result in increased salinity of the irrigation water in many viticulture regions. Increased pressure to restrict irrigation can result in increasing rootzone salinity to the detriment of wine quality. This may not be mitigated by winter

---

[5] There can also be surprising effects of other gasses linked to industrialisation. Ozone has a severe growth depressing effect on plants and ozone clouds can extend many hundreds of kilometres from industrial areas to affect plant productivity (Reich, 1987). Ozone distribution has been investigated in Australia and it is possible for some important wine regions to be affected by this gas.

rainfall flushing, since winter rainfall is predicted to decline (McInnes et al. 2003). Salinity and soil degradation is likely to be a major indirect effect of climate change on viticulture.

Pest and disease pressure is likely to increase and also shift to new areas further south with warmer winters and warmer night temperatures. This is suggested by international experience. For example, Pierce's disease is predicted to move to Oregon and Washington wine regions where it is currently not present due to lower winter temperatures (Tate, 2001). In Italy, Downey mildew is predicted to increase disease pressure due to increasing temperatures (Salinari et al. 2006). Virus-vector nematodes are also predicted to spread at a rate of 160–200 km per 1°C in Great Britain aided by man (Neilson and Boag, 1996)

There is an increased risk of phylloxera spread based on the increased rate of emergence of the insect from the soil with warming, and making the spread of the insect more probable (Dr Kevin Powell, DPI Victoria, Pers. Com.). Also after a drought event or when water allocation to vines is reduced this results in more obvious phylloxera (visually) stress on the vine, more rapid decline and increased population abundance (*ibid*). This presents a high risk for Australian grapevine zones, since quarantine is the main management option currently used (National Vine Health Steering Committee, 2003).

High CO_2 may increase vine canopy size and density, resulting in higher biomass, nutritional quality and favourable microclimate for disease proliferation (Manning and Vontiedemann, 1995).

4.4 Winery level impacts

The major impact to wine quality and production with change in climate will be largely the result of impacts on the grapevine. Winemaking in theory may be undertaken in a variety of climates without a significant impact on the resulting wine, though costs may differ across climates related to refrigeration and requirements. Carbon offsets will be larger for wineries in warmer climates, though there are ways of increasing efficiency of wine production by reducing refrigeration costs (Pearce, 2008).

There are also adjustments required in the wine making process that result from the particular climate from which grapes are sourced. One notable example of this is the addition of tartaric acid to address the imbalance of acidity caused by warm/hot climates that decrease acidity in grape berries. The current cost of tartaric acid addition to wine in Australia is substantial at current output, and this demand would increase with increasing warming. DeBolt et al. 2006 discovered one of the key enzymes controlling the synthesis of tartaric acid in the berry. It would be possible through genetic modification to alter the expression of the gene in order to increase tartaric content of berries in warming climates, thereby maintaining optimal acid/sugar balance.

Another aspect is the difficulty of fermentation to dryness with high sugar concentrations. In association with warming trends during the last 20 years, the maturity (21.8 °Brix) of Chardonnay, Cabernet Sauvignon and Shiraz from commercial crops across Australia has advanced at a rate between 0.5 and 3 days per year (Petrie and Sadras 2007). Faster maturity has been fully compensated by early harvest in Chardonnay, but not in Cabernet Sauvignon and Shiraz, which are therefore being harvested with higher sugar concentrations. This is consistent with the time trends in the composition of Australian wines reported by Godden and Gishen (2005). For red wine, they showed an increase in alcohol content at approximately 1% per decade. Also in red wines, there has been a trend for an increasing concentration of residual sugars. Remediation of high alcohol in the winery will require new yeasts that can ferment sugar but without creating alcohol, this could be done relatively easily by genetic modification of the yeast or by using adaptive evolution to rapidly select strains of yeast that have the desired characteristics (Thornton, 1985; McBryde et al. 2006). The alternative engineering solution is reverse osmosis procedures to de-alcoholise wine, but this can also take out flavour compounds.

5 Adaptation

The previous section shows a wide range of potential impacts of climate change at the vine, vineyard and winery levels. In this section we note some options for adaptation to these changes.

5.1 Allow yield to go up to compensate for reduced quality

Higher yield would also require an increase in water supply for irrigation (not accounting for increased water use efficiency afforded by high CO_2 concentration which would tend to reduce demand for water). This is a scenario that does not complement the predictions of greater aridity and lower irrigation supplies with poorer water quality.

5.2 Shift viticultural areas further south combined with changes in varieties

This option requires that the new areas, eg south-western Victoria and south eastern SA have suitable soils and do not have increased frost risk or disease pressure. However there is a predicted total loss in area suitable for quality wine production. The Australian industry could increase the proportion of quality wines produced compared to current proportions of quality/commercial wines. This could enable increased income from wine exports, despite reduced volume of export. This scenario also would be complemented by greater water use efficiency. This scenario would depend on changes in global markets (most of the largest wine companies in Australia are global companies). It is possible that the shift from unsuitable regions could occur across national boundaries.

5.3 Application of genetically modified materials

Adaptation in viticulture using new technology and potentially genetically modified vines and yeast will allow for some compensation for higher sugar (high alcohol) and reduced acid in grapes. Also reduced quality of water and salinity may be partially offset by genetically modifying rootstocks, possibly without the need to modify the scion.

5.4 New varieties

Trials could be undertaken of new varieties for Australia with higher MJT requirement or growing season temperature range. The time for building up expertise and market, based on the experience with Chardonnay (Paterson, 2004) and Viognier (Rose, 2008), is likely to be of the order of 20–30 years. So this adaptation requires concerted action now.

5.5 Phylloxera strategies

In response, to concern about pests and diseases, new plantings should occur on phylloxera resistant rootstocks. However, there have been reports of potential breakdown in rootstock resistance to phylloxera in Europe (Porten and Huber, 2003) and USA (Granett et al. 2001). Therefore, alternative management options are required to be investigated (Powell et al. 2007).

Uncertainties about the nature of climate change impacts remain and in a later section we note some research priorities.

6 Policy implications

There are several linkages between the likely success of wine industry adaptation and national policies beyond wine. Several examples illustrate this point.

- Water policy: Securing water property rights and allowing market forces to influence water prices would go a long way towards improving the efficiency of water use not only nationally but also within the wine industry.
- GMO policy: State as well as federal government action is required to allow more freedom for producers to use genetic engineering in R&D. Doing so could reduce consumers' negative impression of that technology and open up more avenues and faster means of adaptive research in agriculture generally, including in the wine industry.
- Greenhouse emission policy: The more globally responsible is Australia's greenhouse emission policy, the less likely are governments and consumers abroad likely to turn against Australian products via nontariff import barriers and consumer boycotts.
- Carbon footprint reporting; Generating better and more-comprehensive data on the carbon footprint of each rural industry, including that for wine, would help meet market expectations, provide opportunities for winemakers to adjust production to vary their footprint and provide comparisons with the rest of the world. A tool has been developed for this purpose by Adelaide-based Provisor Pty Ltd and Yalumba Wines and it can be further refined.[6]

[6] http://www.wfa.org.au/PDF/GHG_Users_Guide_(15%20pages).pdf

7 Research agenda

The research agenda includes the following items:

- modelling changes in frost risk and finding ways of better predicting events and designing ameliorative management options
- modelling impacts of high temperature extremes
- development of GM yeasts and root stocks
- further investigation of soil degradation under reduced irrigation and low quality water.
- work on impacts of CO_2 alongside changes in temperature
- trialling new varieties
- impact of climate change on pests and diseases, particularly of those already established in Australia (eg Phylloxera)
- modelling regional impacts, including climate change impact on other crops that compete for land and water that grapegrowers might otherwise use
- modelling of impact on adaptation in Australia and in the rest of the world, including, the impact of spillovers of new technologies to help adapt/mitigate (from or to Australia).

These investments in R&D have to be prioritised and that in itself is a research project of interest. Also work in some of these areas is in progress (eg soil degradation and modelling regional impacts). The research projects will have a higher payoff the sooner they are undertaken, given the long lead times involved and the likely similar but possibly slower responses abroad (first-mover advantage). Arguably this is a time when government co-funding of rural R&D could be increased, either by providing more than one dollar per dollar of producer levy funds and/or by raising the ceiling above 0.5% of the gross value of production (which has been a low amount in recent years because of drought).

8 Conclusions

Grape production is highly sensitive to climate change. The key channels of influence in wine and viticulture are through temperature, water, weather extremes and possibly CO_2 itself. The range of effects in this sector helps identify a portfolio of topics for attention for all Australian agriculture.

The adaptability of the vine and the stages to the final product offer several options for adaptation, at the levels of the vine, the vineyard and the winery, including within existing regions and including relocation between regions. It is not yet clear which of those will be taken but from a national point of view it will be important to provide the industry with the right signals that lead to efficient choices, especially with respect to carbon emissions and water use.

Several options for adaptation can already be identified but the detail and extent of others can only be clarified by further research. That investment is a priority for the industry. Examples are work on new varieties, work on the impact of CO_2, options for the application of genetically modified materials (yeasts and rootstocks) and the determination of the key decision-making parameters—through modelling of world markets for the impacts of climate change and of the policy and commercial responses to it.

The effects of climate change are particularly acute in relation to new targets set by the industry for its own development. It has for instance set itself the target of ‘new levels of expectation and awareness for Australia’s regionally distinct and fine wines.’ Climate change in the absence of any other action will make it more difficult to maintain attributes of grapes that contribute to quality. Another challenge for the industry in this new environment will be remediation of high alcohol in the winery.

It will be important to allay concerns of consumers and meet retailer expectations of its response to climate change. Without this success there are real risks not simply of loss of sales but of discriminatory trade-related measures taken against Australian exports. The degree of sensitivity of this industry’s sales to these concerns is higher than that of any other agricultural exporter. Consumer/retailer assessments will be based on international standards and will take into account the national policy within which the industry is operating. The industry has a strong interest in national policy for this reason as well, not just because of the signals it will receive concerning carbon and water pricing for example but also because national policy can demonstrate Australia’s commitments to responding to climate change.

9 Glossary

Adaptive evolution: a non-recombinant (non genetic modification) means of strain improvement. The technique involves the organism being subjected to serial or continuous cultivation for many generations under conditions to which it is not optimally adapted. An increase in fitter variants occurs because of natural selection.

Aridity index: measure of the irrigation requirement of a vineyard taking into account the evaporation and rainfall. Calculated as monthly totals of rainfall (mm) minus 50% of the evaporation (mm) from a Class A Pan, summed over the growing season (October to March).

Assimilated carbon: carbon processed by photosynthesis whereby the energy available in the resultant molecules has been increased.

Brix: a measurement of the mass ratio of dissolved sugar to water in a liquid.

Budburst: when 50% of the buds have the leaf tips visible.

Clone: a vine that has been vegetatively propagated from a parent plant such that it has the identical genotype of the parent vine. There are difference clones within a variety, for example Shiraz clone BVCR12, Chardonnay clone I10V1.

Crop water use efficiency: A measure of how well crop/horticultural plants produce yield relative to the amount of water used. This takes into account the harvest index (amount of crop yield produced per unit mass of plant), the transpiration efficiency, and the amount of water applied that is used in transpiration (water flow through plants to the atmosphere).

Deciduous perennial: A plant that has a life cycle greater than three years and which looses its leaves and goes into a dormant phase during the winter.

Downey mildew: Fungal infection of leaves or fruit caused by *Plasmopara viticola*.

Genetic modification: The direct manipulation of an organism's genes using recombinant DNA technology.

Genotype: the genetic code (the genome) of an organism as distinct from the *phenotype*, which is the physical and physiological manifestation of the genotype.

GHG: green house gas.

Isotherm: geographical locations that can be drawn as lines on a map of the same temperature. The temperature could be an average for a particular month or growing season etc.

Mesoclimate: local distance scale of climate influenced by location, altitude and topography. Scale can be tens of metres to kilometres.

Microclimate: smallest distance scale of climate, eg local conditions between vines on in a vine canopy.

MJT: Mean January temperature (Southern Hemisphere), in the Northern Hemisphere the mean July temperature is used.

Phenology, description of timing of events in an a organism's development, ie for grapevines it would describe the time of budburst, flowering, berry softening etc.

Photosynthesis: The process by which carbohydrates are formed from water and carbon dioxide in the chlorophyll-containing tissues of plants using light energy. Results in the consumption of carbon dioxide and water and the release of oxygen.

Phylloxera: **'**a yellow aphid (type of insect), which feeds on vine roots and leaves. The feeding causes galls to form on the developing leaves or roots. The aphids live on the surface of root galls and inside the leaf galls.' Phylloxera and Grape Industry Board of South Australia (PGIBSA) http://www.phylloxera.com.au/phylloxera/about/

Pierces's disease: Disease of grapevines caused by the bacterium *Xylella fastidiosa*, that is spread by xylem feeding leafhoppers known as sharpshooters.

Plasticity: ability to change; thus plasticity in phenology means that cardinal dates for budburst and flowering may change depending upon environmental conditions. Some varieties show more plasticity than others, thus it can be a feature of a variety.

Residual sugars: sugars in wine that remain after fermentation has stopped.

Respiration: oxidation of assimilated carbon (carbohydrate) coupled with the production of energy. Results in the consumption of oxygen and the release of carbon dioxide and water.

Scion: shoot part containing buds that is grafted on to the root system of a related plant to form a whole plant.

Sodicity: degree of sodium absorption in a soil, defined as the amount that is exchangeable (measured as sodium absorption ratio, *SAR*, relative to calcium and magnesium). Friability and permeability of soil is influenced by sodium content. If high, clay will disperse and block water flow through soil pores.

Transpiration efficiency: A measure of how well plants use available water in photosynthesis at the physiological scale. Measured as net photosynthetic rate (moles of CO_2 taken up) divided by the transpiration rate (moles of water lost) in a unit of time times 100%.

Variety: vine that has distinct characteristics and is uniform and stable in its characteristics when clonally propagated. Synonymous with cultivar. Article 2.1 of the *International Code of Nomenclature for Cultivated Plants*: 'an assemblage of plants that has been selected for a particular attribute or combination of attributes, and that is clearly distinct, uniform and stable in its characteristics and that, when propagated by appropriate means, retains those characteristics'

Virus-vector nematodes: nematodes (roundworms) usually confined to the soil that carry viral diseases of plants.

10 Acknowledgments

The authors thank participants in an Australian Wine 2030 workshop on the topic of the paper held on 15 February 2008. Australian Wine 2030 is a coalition of research groups at the University of Adelaide pursuing a linked series of research projects designed to respond to the challenges facing the wine industry to 2030.

11 References

Anderson, K. (2008), 'Terroir Rising in the New World? Varietal and Quality Distinctiveness of Australia's Wine Regions', paper for the European Association of Wine Economists' 2008 Annual Conference, 29–31 May, Collioure, France.

Australian Bureau of Statistics (2008), Australian Wine and Grape Industry 2007, Cat no. 1329, ABS, Canberra.

Bindi M, Fibbi L, Miglietta F. (2001) Free Air CO_2 Enrichment (FACE) of grapevine (*Vitis vinifera* L.): II. Growth and quality of grape and wine in response to elevated CO_2 concentrations. European Journal of Agronomy. 14 (2): 145–155

Clark LR, Fitzpatrick RW, Murray RS, McCarthy MG (2002) Vineyard soil degradation following irrigation with saline groundwater for twenty years. 17th World Congress of Soil Science; Bangkok, Thailand.

DeBolt S, Cook DR, Ford CM (2006) l-Tartaric acid synthesis from vitamin C in higher plants. PNAS 103: 5608–5613.

Delves TR, Weedon M, Louis JP (2008) Modelling winery refrigeration efficiency. In: Proceedings of the 13th AWITC eds Rae Blair, Pat Williams, Sakkie Pretorius. pp306.

Dry PR, Iland PG, Ristic R (2005) What is vine balance? In: Proceedings of the 12th AWITC eds Rae Blair, Pat Williams, Sakkie Pretorius. pp 68–74.

Dry, P. (2004). Grapevine Varieties. In: Viticulture Volume 1- Resources, Dry, P. and B. G. Coombe, eds., Winetitles, Adelaide, South Australia, 132–149

Dry, P. R. (1984). Recent advances in Australian Viticulture. Eds. T. Lee and C.Somers, 29 Nov–1 Dec, 1983.

Gladstones, J. (2004). Climate and Australian Viticulture. In: Viticulture Volume 1-Recources, Dry, P. and B. G. Coombe, eds., Winetitles, Adelaide, South Australia

Godden P.W. and M. Gishen (2005) Trends in the composition of Australian wine 1984–2004. Australian New Zealand Wine Industry Journal 20, 21–46.

Godwin, D. C., R. J. G. White, K. J. Sommer, R. R. Walker, I. Goodwin, and P. R. Clingeleffer. (2002). VineLOGIC- a model of grapevine growth, development and water use. In: Managing Water, Dundon, C., R. Hamilton, R. Johnstone, and S. Partridge, eds., Australian Society of Viticulture and Oenology Inc., Adelaide, 46–50

Granett J, Walker MA, Kocsis L, Omer AD (2001) Biology and management of grape phylloxera. Ann. Rev. Entomol. 46, 387–412.

Hättenschwiler S, Miglietta F, Raschi A, Körner C (1997) Morphological adjustments of mature Quercus ilex trees to elevated CO_2 Acta Oecologica 18(3): 361–365

Hayman PT, McCarthy MJ, Sadras VO, Soar CJ (2008) Can we identify dangerous climate change fro Australian viticulture. In: Proceedings of the 13th AWITC eds Rae Blair, Pat Williams, Sakkie Pretorius.pp 14–22.

Hennessy K, Lucas C, Nicholls N, Bathols J, Suppiah R, Ricketts J. (2005) Climate change impacts on fire-weather in south-east Australia. http://www.cmar.csiro.au/e-print/open/hennessykj_2005b.pdf ISBN 1 921061 10 3

Jones GV (2007) Climate change: observations, projections, and general implications for viticulture and wine production. In: Economics Department Working Paper No. 7 (Whitman College) Eds Eden Essick, Peter Griffin, Ben Keefer, Stacy Miller, Karl Storchmann.ISSN. 1933–8147.

Jones GV (2008) Climate change and the global wine industry. In Proceedings of the 13th AWITC eds Rae Blair, Pat Williams, Sakkie Pretorius. Pp 91–98.

Jones GV; White MA; Cooper OR; Storchmann K (2005) Climate change and global wine quality. Climatic Change. 73(3): 319–343.

Kimball BA, Zhu J, Cheng L, Kobayashi K, Bindi M. (2002) Responses of agricultural crops of free-air CO_2 enrichment. Ying Yong Sheng Tai Xue Bao. 13(10):1323–38

Long SP, Ainsworth EA, Leakey ADB,Nö;sberger J, Ort DR (2006) Food for Thought: Lower-Than-Expected Crop Yield Stimulation with Rising CO2 Concentrations. Science (312) 5782: 1918–1921.

Manning WJ, Vontiedemann A (1995) Climate-change—potential effects of increased atmospheric carbon-dioxide (CO_2), ozone (O-3), and ultraviolet-b (uv-b) radiation on plant-diseases. Environmental Pollution 88: 219–245.

McBryde C, Gardner JM,de Barros Lopes M, Jiranek V (2006) Generation of novel wine yeast strains by adaptive evolution. Am. J. Enol. Vitic. 57: 423–430.

McCarthy, M. G., L. D. Jones, and G. Due. (1992). Irrigation-Principles and Practices. In: Viticulture Volume 2: Practices, Coombe, B. G. and P. R. Dry, eds.,Winetitles, Adelaide, 104–128

McInnes KL, Whetton PH, Webb L, Hennessey KJ (2003) Climate change projections for Australian viticultural regions. Aust. Grapegrower Winemaker 469: 42–47.

McKee IF, Woodward FI (1994) CO_2 enrichment responses of wheat: interactions with temperature, nitrate and phosphate. New Phytologist 127 (3), 447–453.

Morison JIL, Lawlor DW (1999) Interactions between increasing CO_2 concentrations and temperature on plant growth. Plant, Cell and Environment. 22: 659–682.

National Vine Health Steering Committee, 2003. National Phylloxera ManagementProtocols. http://www.gwrdc.com.au/nvhscphylloxera.htm.

Neilson R, Boag B (1996) The predicted impact of possible climatic change on virus-vector nematodes in Great Britain. European Journal of Plant Pathology 102: 193–199.

Paterson T. (2004) Australian Chardonnay: past, present and future. Journal of Wine Research Journal of Wine Research, 15:2, 135–169

Pearce D (2008) Case study: becoming the world’s first CarboNZero® winery. In: Proceedings of the 13th AWITC eds Rae Blair, Pat Williams, Sakkie Pretorius. pp106–109.

Petrie P.R. and V.O. Sadras (2007) Advancement of grapevine maturity in Australia between 1993 and 2006: putative causes, magnitude of trends and viticultural consequences. European Journal of Agronomy (in Press).

Porten M, Huber L (2003) An assessment method for the quantification of *Daktulosphaira vitifoliae* (Fitch) (Hem., Phylloxeridae) populations in the field. J. Appl. Entomol. 127, 157–162.

Powell KS, Burns A, Norng S, Granett J, McGourty G. (2007) Influence of composted green waste on the population dynamics and dispersal of grapevine phylloxera *Daktulosphaira vitifoliae*. Agriculture, Ecosystems and Environment 119: 33–38

Reich P.B. 1987. Quantifying plant response to ozone: a unifying theory. Tree Physiology 3, 63–91.

Richards AL, Hutson JL, McCarthy MG (2008) Monitoring and modelling transient rootzone salinity in drip irrigated viticulture. In: Proceedings of the 13th AWITC eds Rae Blair, Pat Williams, Sakkie Pretorius. pp 212–217.

Rose, L (2008) Creating our future—new varieties and styles. In Proceedings of the 13th AWITC eds Rae Blair, Pat Williams, Sakkie Pretorius. Pp 134–141.

Salinari FS, Giosue FN, Tubiello A, Rettori V, Rossi F, Spannas C, Rosenzweig IG, Gullino ML (2006) Downy mildew (*Plasmopara viticola*) epidemics on grapevine under climate change. Global Change Biology 12: 1299–1307.

Schultz HR (2008) European challenges. In: Proceedings of the 13th AWITC eds Rae Blair, Pat Williams, Sakkie Pretorius. pp 33–36.

Soar CJ, Collins MJ, Sadras VO (2008) A comparison of experimental systems for increasing grapevine canopy and bunch temperature. In: Proceedings of the 13th AWITC eds Rae Blair, Pat Williams, Sakkie Pretorius.pp 297.

Tate AB (2001) Global Warming's Impact on Wine. Journal of Wine Research, 12:2, 95–109.

Thornton RJ (1985) The introduction of flocculation into a homothallic wine yeast. a practical example of the modification of winemaking properties by the use of genetic techniques. Am. J. Enol. Vitic. 36: 47–49

Webb LB (2006) The impact of projected greenhouse gas-induced climate change on the Australian wine industry. PhD Thesis. University of Melbourne.277p

Webb, LB, Whetton, PH, Barlow EWR (2007) Modelled impact of future climate change on the phenology of winegrapes in Australia. Australian Journal of Grape and Wine Research 13:165–175.

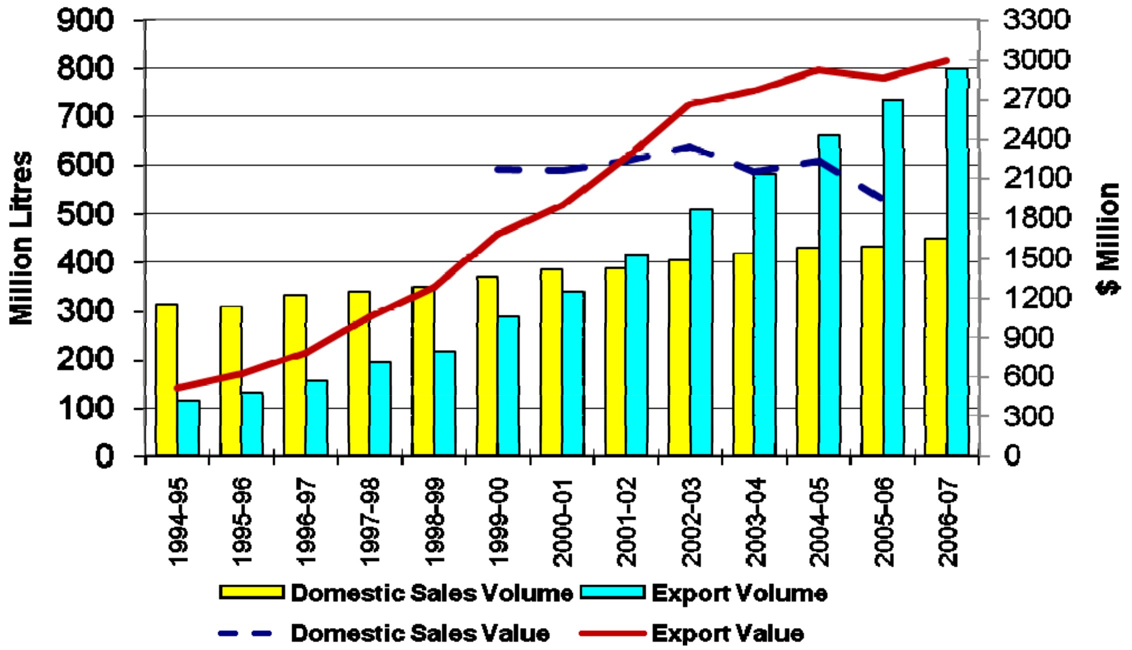
Webb, LB, Whetton, PH, Barlow EWR (2008a) Winegrape price; winegrape quality, and climate in Australia. (in Press)

Webb, LB, Whetton, PH, Barlow EWR (2008b) Climate change and winegrape quality in Australia. (in Press)

Webb, LB, Whetton, PH, Barlow EWR (2008c) Climate change impacts on Australian viticulture. In: Proceedings of the 13th AWITC eds Rae Blair, Pat Williams, Sakkie Pretorius.pp99–105.

White, M. A., N. S. Diffenbaugh, G. V. Jones, J. S. Pal, and F. Giorgi. (2006). Extreme heat reduces and shifts United States premium wine production in the 21st Century. *Proceedings of the National Academy of Sciences* 103(30): 11217–11222.

Figure 1 Domestic sales of Australian wine and wine exports



Note: Domestic Sales and Export Sales values are 2006–07 real prices
Sources: ABS Catalogue No: 8504.0 Sales of Australian Wine and Brandy by Winemakers and Catalogue No: 1329.0 Australian Wine and Grape Industry, AWBC Wine Export Approval Report via WINEFACTS Statistics

Figure 2 Grape output by variety, Australia, 1981 to 2005

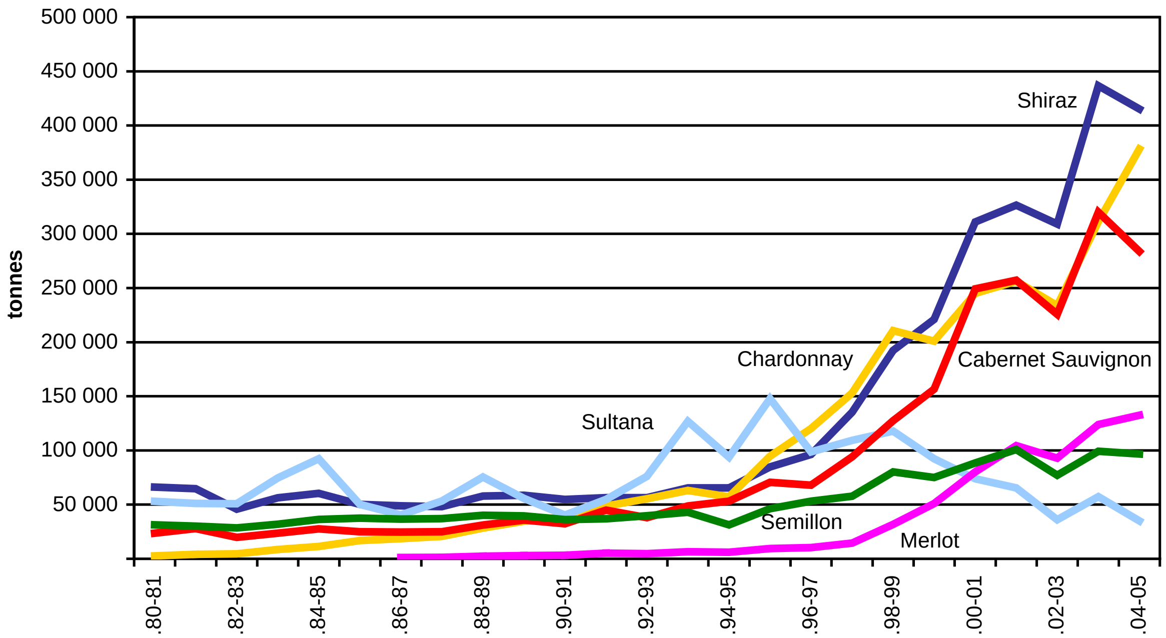
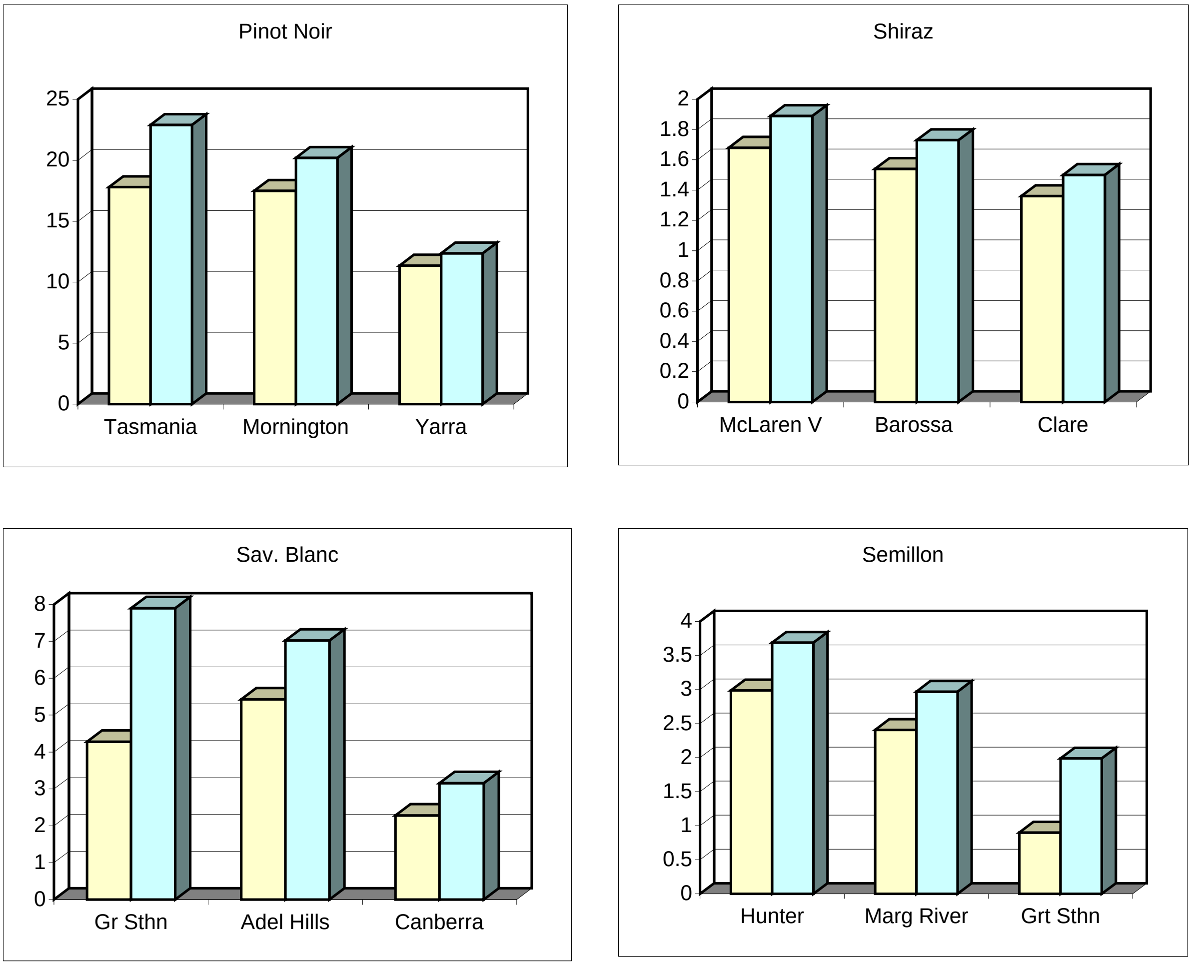


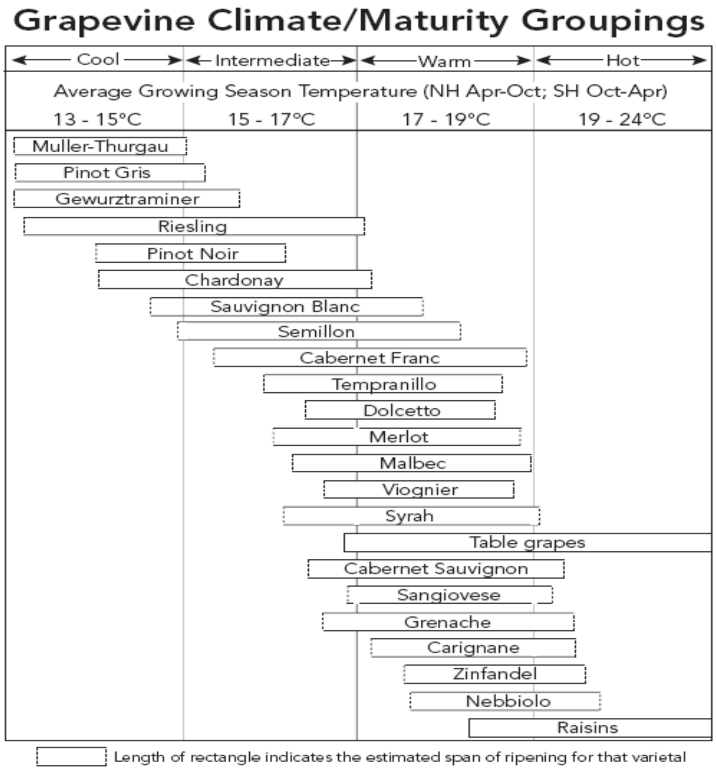
Figure 3 Varietal share of winegrape production in a region relative to the national average share of that variety, Australia, 2006



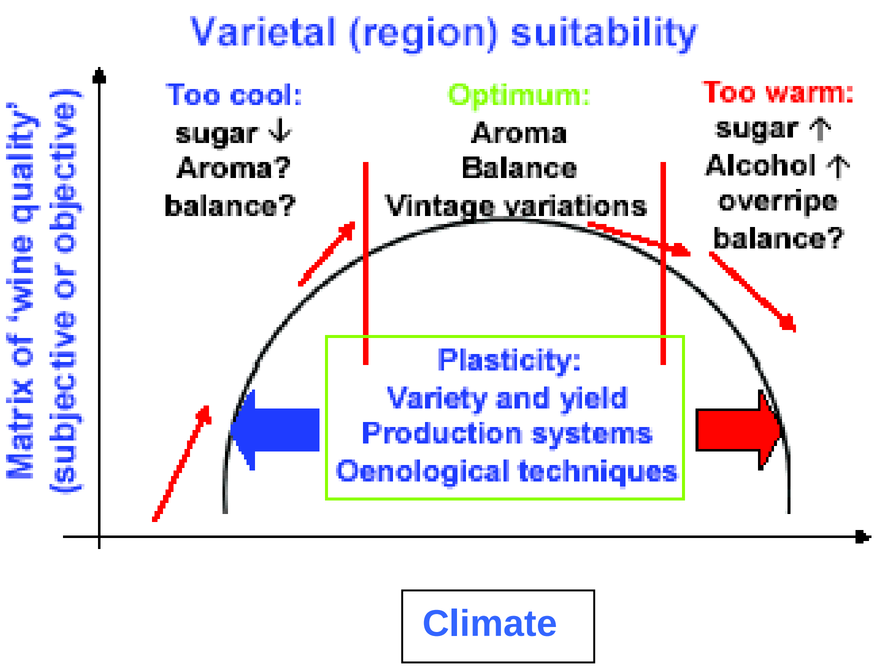
Source: Anderson (2008).

Figure 4 Grapevines and climate

(A)



(B)



Notes: (A) Groupings of climate-maturity based on phenological requirements for berry development to produce high to premium quality wine. This is based on examination of production in benchmark regions for each variety. (From Jones 2008). (B) Boundaries of suitable climates for wine production illustrating the 'inverse U' curve that defines optimum temperatures for production of quality wine. Note that present climates may be above or below the optimum so that warming may increase quality in some regions and decrease quality in others. There is also plasticity dependent on variety (see A) and on variation in production techniques. (From Schultz 2008: permissions pending).