COMPLETING THE SMOKE EFFECT PICTURE: Systems development to reduce the negative effects of smoke on grapes and wine

FINAL REPORT to
GRAPE AND WINE RESEARCH & DEVELOPMENT CORPORATION

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Abstract

Smoke taint in wine is an issue of increasing frequency and severity for the wine industry nationally. Grapevines exposed to smoke during sensitive periods of growth produce wines that can contain smoke-related aromas, flavours and compounds and be unpalatable. Development, implementation and communication of a national smoke taint reduction package for the wine industry is addressed in this project, which incorporates an understanding of smoke complexity, wine grape sensitivity, smoke detection and quantification, vineyard locations and grapevine growth stages. A web-based application that predicts the seasonal smoke taint risk to grapes has been developed.

Executive Summary

Smoke derived taint in grapes and wine has resulted in a decline of product quality and financial losses for many grape growers and wine producers within Australia. The issue of smoke taint in wine is increasing in Australia as climatic conditions change. This report details research that builds on our understanding of grapevine susceptibility to smoke uptake and further investigates smoke complexity (density, duration, plume distribution, composition) and smoke taint development in grapes with a view to reducing the incidence and severity of smoke taint in grapes and wine.

This project has developed and communicated a computer based system to predict the seasonal likelihood of smoke damage to grapes to assist with landscape management (prescribed burning) and smoke taint reduction strategies (e.g. winemaking techniques). This system is called the 'Smoke Taint Risk calculator' (STAR) and incorporates key knowledge gained from this study such as an understanding of smoke complexity, varietal susceptibility to smoke and smoke effects on key grapevine phenological stages. The STAR model is an interactive, user friendly web based tool that can predict seasonal smoke taint risk to grapes for any wine-producing location. The model assists landscape managers to determine the best times to schedule burns and assists vignerons to implement strategies to reduce the risk of smoke taint in grapes and wine. STAR operates by automatically simulating grape growth stages to predict a time series of likely smoke taint risk for key wine grape varieties. STAR uses real weather data from any weather station in Australia and can make predictions for future weather scenarios using simulated weather of any decile. STAR is a powerful communication tool in co-operative efforts to manage the risk of smoke taint at the vineyard level.

The susceptibility of different grapevine varieties to smoke is critical to the estimation of smoke taint risk. This study used chemical and sensory research to generate smoke taint risk factors for the four key wine grape varieties of Merlot, Cabernet Sauvignon, Chardonnay and Sauvignon Blanc. Results showed smoke taint risk factors to be highly variable between variety and grapevine growth stage. Cabernet Sauvignon shows a high risk probability (0.8) at berries pea size (E-L31) compared to Chardonnay (0.2), Sauvignon Blanc (0.3) and Merlot (0.4) at the same stage. In comparison, the Cabernet Sauvignon risk factor is lower at harvest (0.4) (E-L38) than that of Chardonnay (0.78), Sauvignon Blanc (0.76) and Merlot (0.7). Further research is being conducted to elucidate the timing of smoke effects to a wider range of grapevine varieties and stages.

This study revealed a relationship between the duration and density of smoke exposure and the accumulation of smoke-related compounds and sensory attributes in wines. Smoke exposure to grapevines that is of a high smoke density and/or for long durations was found to accentuate smoke-related chemical and sensory attributes in wine. This research has a further practical application for interpretation of smoke events in-field with vineyard based smoke detecting equipment (nephelometers) established in-field to quantify the density and duration of smoke exposure and as a smoke taint risk assessment tool. Field-based smoke detecting equipment (such as nephelometer equipment) located within grape producing regions can be used to detect the density and duration of smoke exposure. From our current research, smoke detection in-field is useful as a tool to understand whether the smoke event has been of significant duration and density to create potential smoke taint in wine. This work is currently in further development.

This study investigated the effect on grapes and wine of smoke derived from different hard wood, softwood and grass fuel types. Results showed that the lignin derived compounds that accumulate in wine do not reflect that of the vegetation source. Interestingly, results suggest additional compounds that are likely to contribute to smoke taint. Some of these compounds, such as syringyl derivatives, may be a better measure of smoke taint than the guaiacol and 4-methylguaiacol compounds. However the elevated levels of syringyl derivatives in wine suggest some mechanism of transformation that is being further investigated. Grapevine smoke exposure to any of the fuel sources was not found to elevate the concentration of metal elements in wine. This research also suggests that the uptake of smoke compounds by berries is likely to be more significant than the translocation through the foliage of grapevines.

This project has compiled comprehensive and up-to-date maps and a database of wine grape vineyards in Western Australia. The information is held on the Client Resource Information System (CRIS) and shared with the Department of Environment and Conservation (DEC), local Shires, land managers and regional wine associations. This information improves decision making as to the timing of prescribed burns on public land and burn-off on private land by identifying the location of vineyards at risk to smoke exposure. Vineyard location information is provided to the DEC to overlay their Master Burn Planning (MBP). Various methods of vineyard mapping and data collection systems are also being piloted around Australia. DPI Victoria has developed the HIN Mapper application for iPad® to capture this information. Wine Tasmania has developed a web-based map of vineyard locations indicating the grape status (such as dormant, growing or ripening) in real time. The Phylloxera and Grape Industry Board of South Australia maintains a registry of wine grape vineyards in South Australia.

Vineyard maps and datasets generated in this project have provided multiple on-going benefits to the wine grape industry of WA. They assist to minimise the effect of smoke on grapes and wine, the response to smoke events in vineyards, to enhance public safety from wildfires, improvement of biosecurity surveillance and to facilitate extension of research and development. Statistical information gained from this study has assisted with lobbying state and local governments; providing information on the value of the wine industry and its contribution to regional communities; information on vineyard planting and variety trends and the capacity of the WA wine industry.

Research outlined in this report has been achieved in collaboration with Assoc. Prof. Michael Renton and Mike Airey from the University of Western Australia, Crawley, and David Kelly form Curtin University, Margaret River. This project was funded by the GWRDC in response to the heightened incidence and severity of smoke taint to grapes and wine nationally.

1. Background

As Australia is facing a warming climate with increasing bushfire incidences the issue of smoke taint in grapes and wine has become a regular occurrence. Smoke affected wines can exhibit ‘smoked meat’, ‘disinfectant’, ‘leather’, ‘burnt’, ‘smoky’, ‘salami’ and ‘ashtray’ aromas and flavours. Where significant smoke exposure occurs during sensitive periods of vine development the resultant wine can be unfit for purpose. Unsaleable wines result in financial losses for grape and wine producers with costs on-flowing from associated damage to wine brands, market presence and future wine sales.

To demonstrate the importance of this issue for the wine industry nationally, smoke taint has resulted in significant financial losses for vignerons in Western Australia (WA), Victoria and South-Eastern New South Wales (NSW). The financial loss to vignerons in WA was estimated to be $7.5 million in 2004 alone and in Victoria smoke taint has been reported to have cost wine grape growers more than $300 million over the past five years (ABC News 2010, Godwin 2011). Furthermore, isolated incidences of smoke taint damage are increasingly being reported in Australian wine producing regions. Due to climate change, an increase in fire events is occurring worldwide resulting in more frequent exposure of viticultural areas to smoke (Mira de Orduña 2010, Zybach et al. 2009).

Investigations into the nature and amelioration of smoke taint have been conducted by the Department of Agriculture and Food WA (DAFWA) and Curtin University proving the direct link between smoke exposure and the creation of smoke taint in wine, indicating a variation in smoke assimilation by grapes during the grapevine growth cycle (Kennison et al. 2007). From our initial investigations, there were gaps in our understanding of smoke taint including the effect of smoke distance, duration, density, plumes and composition on the creation of smoke taint in wine. We discovered no mechanism for relating smoke uptake potential to seasonal grapevine phenology and no available tools or early detection systems to assess the risk of smoke events at a vineyard level. Furthermore, national wine producer databases were scant, reducing the effectiveness of fire planning and smoke warning systems. This project endeavoured to fill these knowledge gaps, complete smoke taint research requirements and provide a smoke taint reduction and risk management package for the Australian wine industry.

This project focused on the comprehensive development, implementation and communication of a national smoke taint reduction package for the wine industry. This package builds on our previous research of grapevine susceptibility to smoke uptake and further investigates smoke complexity (density, duration, plume distribution, composition) on smoke taint development in grapes and wine. Vineyard based smoke detection equipment (nephelometers) were established in-field to quantify the presence of smoke and as a smoke taint risk assessment tool. A further understanding of smoke complexity enabled the production of a computer based system to predict the seasonal likelihood of smoke damage to grapes to assist with landscape management (prescribed burning) and smoke taint reduction strategies (e.g. winemaking techniques). This system was validated by the compilation and inclusion of vineyard site information (location, vine varieties and phenology) into the database and piloted in WA during the 2011/12 season. This project was funded by the GWRDC in response to the heightened incidence and severity of smoke taint to grapes and wine nationally.

2. Project Aims and Performance Targets

As detailed in the original application to GWRDC the overall project objectives concentrated on the development of a smoke taint reduction and risk management package. This package incorporates:

1. Investigation of the effect of smoke distance, composition, concentration and duration on entry into the vine and development of subsequent smoke taint in grapes and wine;
2. Determine the sensory smoke taint effect of wine made from grapes exposed to various durations and densities of smoke;
3. Development and implementation of vineyard based nephelometer equipment to monitor smoke presence, density and duration as an indicator of smoke taint damage;
4. Development of a model to predict seasonal vine phenological stage of development (preferably web based to enable easy updates and user friendly) and associated susceptibility to smoke uptake as a decision making tool for prescribed burning activity;
5. Communication of information on smoke plume distribution and composition to incorporate into a risk assessment and early warning system for implementing smoke taint reduction strategies;
6. National pilot of comprehensive mapping and information collected from Western Australian and Victorian vineyards (such as vineyard location, varieties and phenology) as a standalone database to incorporate into a risk analysis model for smoke taint susceptibility;
7. Improve communication between wine industry and forest managers and better integration of planning systems for viticulture production and prescribed burns to reduce risk of smoke taint damage in grapes and wine; and
8. Development and communication of a comprehensive smoke taint reduction package containing tools that directly reduce the incidence of smoke uptake at the vineyard level.

The project outputs and activities as stated in the project agreement are:

Year 1	Output	Due Date mm/yy	Activities
A	Field trial, sensory and mapping database information captured and first stage of early warning and modelling system developed.	06/10	Hire staff, obtain equipment for field operations and develop early warning and modelling systems. Establishment of field-based trials and collection of database information and modelling.
B	Publish articles in industry press.	06/10	Compile information and write articles.
C	Trial report for year 1.	06/10	Analysis and summary of all data and developments of project to date.

Year 2	Output	Due Date mm/yy	Activities
A	Field trial information and knowledge of smoke plume distribution and composition captured for incorporation into the model and tools.	06/11	Conduct field based trials and collect knowledge on smoke plumes and composition.
B	Model and early warning system developed and first stage of decision making and risk assessment tool developed.	06/11	Model and systems development.
C	Vineyard mapping and database information captured.	06/11	Continue collection and verification of database information.
D	Publish articles in industry press.	06/11	Compile information and write articles.
E	Trial report for year 2.	06/11	Analysis and summary of all data and developments of project to date.
F	Trial of decision making and risk assessment tool by forest management agencies.	06/11	Key growers provide seasonal phenology information incorporated into database model and used for consideration in planning prescribed burns.

Year 3	Output	Due Date mm/yy	Activities
A	Early warning system, model and decision making and risk assessment tools developed.	06/12	Test and verify systems in the field.
B	Vineyard mapping and database information captured and integrated with forest burn plans and management systems.	06/12	Complete collection and verification of mapping and database information.
C	Knowledge and information captured in an extension package for presentation to industry.	06/12	Collate information and develop extension materials with collaborators for presentation of project results to industry nationally.
D	Publish articles in industry press.	06/12	Compile information and write article.
E	Smoke reduction toolkit produced. Phenology information incorporated into database. Up to 75% of vignerons in smoke susceptible areas access toolkit for risk assessment of grape susceptibility to smoke.	06/12	Assemble software and information into package. Up to 60% of vignerons in smoke susceptible areas access database to incorporate grape phenology information. Demonstrate toolkit nationally to industry at workshops. Demonstrate use of toolkit nationally; provide e-mail links and updates to vignerons.
F	Final project report.	06/12	Analysis and summary of all data and developments of project to date.

3. Method

To address the specified project aims and performance targets for this project a number of methodologies were employed. These methodologies are detailed in their following respective areas.

3.1 Smoke Application to Field-Grown Grapevines

Throughout this research, a number of trials were conducted to provide additional information to support the accurate development of the smoke taint risk reduction package. Proven smoke application methodology was used in all field research. The predominant research focus was on the application of smoke to key grapevine varieties at various growth stages and the effect of smoke density and duration on the creation of smoke taint in wine. All research related to smoke application to field-grown grapevines encompassed wine production with chemical and sensory analysis.

3.1.1 Smoke Application Methodology

A proven smoke application methodology was employed in all field based research investigating smoke effects on wine grape production. The methodology that had been successfully developed and refined in our previous studies (Kennison et al. 2008, 2009, 2011) was again used in this project. The field-based smoke application apparatus included tents (6 m long x 2.5 m high x 2 m wide) that were constructed around grapevines (Figure 1). These tents were made of galvanised steel covered with a greenhouse grade plastic (Solaweave©) for continued light transmission to grapevines to enable plant photosynthesis and functioning (Figure 1A and 1B). Smoke was produced in a 50 L lidded steel drum. Dry barley straw was used as the fuel source and, once ignited in the drum, smoke was forced by air, produced by a 12 volt air pump, from the drum through outlet hosing and into the tent (Figure 1C and 1D). The density and duration of smoke exposure was measured with a portable nephelometer (VESDA LaserFOCUS™ VLF-250). A fuel powered portable generator was used to provide power for the 12 volt air pump, nephelometer and laptop computer. The location of field research and wine grape variety used varied depending on the objective of the research. These factors are discussed further in section 3.1.4 and 3.1.5.

Figure 1. Smoke application apparatus showing (A) smoke drum, smoke tent and supporting field equipment; (B) construction of smoke tent frame around field-grown grapevines; (C) grapevines enclosed within the smoke tent; and (D) smoke being forced through steel piping into the smoke tent for application to grapevines. Photos taken by Peter Maloney © Western Australian Agriculture Authority, 2013.

3.1.2 Winemaking Methodology

The winemaking methodology employed in this study followed standard commercial winemaking practice for red and white wine production. Small-lot wines (range from 11 to 15 kg) were made according to the commercially reproducible techniques employed in our laboratories for the past 30 years. Purpose built small-lot winemaking equipment, including a crusher-destemmer (Figure 2A) and waterbag press (Figure 2B) were utilised during the winemaking process. All field-based smoke treatments were produced in three replicates, therefore each wine was also made in three replicates.

Figure 2. Equipment utilised during the small-lot winemaking process including (A) crusher-destemmer and (B) press.

For red wine production, fruit was hand harvested when the total soluble solids (TSS) content reached 22.2 ± 1.5 ^{o}Brix as measured by refractometry (Iland et al. 2004). Fruit was stored at <5^{o}C overnight. Fruit was crushed and destemmed and 25 mg/L SO_2 was added. Once must temperature reached 16^{o}C it was inoculated with EC1118 *Saccharomyces cerevisiae* yeast (Lallemand Inc., Montreal, Canada) at a rate of 250 mg/L plus 200 mg/L diammonium phosphate (DAP). Musts were fermented on-skins in 15 L stainless steel fermentation vessels with hand plunging of the skin cap conducted twice daily. Musts were fermented at a temperature of 16^{o}C until TSS approached 0^{o}Brix. All wines were pressed off skins at the same time, transferred to 5 L enclosed glass fermentation vessels and inoculated for malolactic fermentation with *Oenococcus oeni* (Viniflora Oenos. Chr. Hansen, Denmark). During malolactic fermentation, wines were maintained at 21^{o}C until completion (indicated by < 0.1 g/L malic acid) as determined by enzymatic analysis. On completion of malolactic fermentation, the sulphur dioxide (SO_2) concentration in wine was measured by aspiration (Iland et al. 2004) and adjusted to 30 ppm. Wines were then cold stabilised for 28 days at 2°C. On completion of cold stabilisation, wines were filtered (at 5 µm) and bottled.

For white wine production, fruit was hand harvested when the total soluble solids (TSS) content reached 22 ± 1.5 ^{o}Brix as measured by refractometry (Iland et al. 2004). Fruit was cooled during storage at <5 ^{o}C overnight. Fruit was crushed, destemmed, pressed off skins with additions of 30 mg/L SO_2 and 5mg/L pectic enzyme added to final extracted juice. Juice was transferred into 5 L enclosed glass containers, lidded and stored at 2^{o}C for 7 to 14 days until the juice had settled. Once the juice had settled, the clear juice was siphoned from the juice solids into a 5 L glass container. Once must temperature reached 16^{o}C it was inoculated with EC1118 *Saccharomyces cerevisiae* yeast (Lallemand Inc., Montreal, Canada) at a rate of 250 mg/L plus 200 mg/L diammonium phosphate (DAP). Musts were fermented at a temperature of 16 ^{o}C until residual sugar was less than 2.5 g/L as determined by Clinitest® (Bayer Diagnostics, Bridgend, UK). Where required, wines were then heat stabilised by bentonite addition as determined by a Bentotest (Rankine 2004). After bentonite addition, wines were left to settle in enclosed 5 L glass containers for 3 weeks at 2^{o}C. Wines were then racked off bentonite lees, SO_2 was adjusted where required (up to 30 ppm FSO_2) and wines were cold stabilised at 2^{o}C for a minimum of six weeks. On the completion of cold stabilisation, wine SO_2 was adjusted (to 35 ppm), wines were filtered (membrane filter, 0.45 µm, Sartorius Stedim Biotech, Goettingen, Germany) and bottled.

3.1.3 Chemical Analysis of Smoke Compounds

Various chemical analysis methodologies were employed in this research to determine the concentration of smoke-related compounds in samples produced in field trials. Grape berry homogenates, grape juice and wine produced in trials were all analysed for smoke-related compounds. Initially, the chemical analysis of samples focused on the detection of two volatile phenols, guaiacol and 4-methylguaiacol. Analysis of guaiacol and 4-methylguaiacol was undertaken due to these compounds being derived from the thermal degradation of lignin (a component of the fuel source used to produce smoke in this research), they are known to be present in smoke and to have ‘smoky’, ‘smoked meat’, ‘burning’, ‘sharp’ and ‘phenolic’ aromas and flavours (Baltes et al. 1981, Boidron et al. 1988, Maga 1988). Guaiacol and 4-methylguaiacol were also selected for analysis as they had previously been used as indicators of smoke taint intensity in similar field studies (Kennison et al. 2009). To measure guaiacol and 4-methylguaiacol concentration, gas chromatography-mass spectrometry (GC-MS) equipment was employed as per previously reported methodology (Spillman et al. 1997, Pollnitz et al. 2004, Kennison et al. 2008). As the project progressed, advances in the detection of smoke-related compounds have occurred and additional compounds responsible for the smoke taint were isolated by various laboratories. These compounds include free and bound *p*-coumaryl, coniferyl and sinapyl alcohol (Singh et al. 2012) including those detected as glycosylated metabolites (Hayasaka et al. 2010a, Dungey et al. 2011). As these methods represented the opportunity for additional information to be obtained from our sample analysis, they were used where possible with only recent analytical results detailed in this report.

3.1.4 Wine Sensory Analysis

A variety of wine sensory analysis techniques were used in this study to elucidate the effect of smoke on the sensory characteristics of wine. The wine sensory analysis techniques employed depended on the purpose and information that was sought from each of the experiments. Of the many proven methods for wine sensory assessment available, this study used Difference Tests and Quantitative Descriptive Analysis (QDA®) (Meilgaard et al. 2007).

Difference tests, such as triangle tests, were used to determine whether a sensory difference existed between samples for the smoke density and duration study. People that participated in the difference test were selected based on their interest and availability, being regular wine consumers in good health and over the age of 21 years. A total of 130 regular wine consumers participated in this type of wine sensory analysis for our study. A large number of wine consumers were recruited for this study to ensure statistical significance. Panellists were untrained as the focus of the study was to determine whether regular wine consumers could detect a difference between the smoked and unsmoked wines and at what level of smoke density and duration a difference was readily perceptible. The sensory method used was the triangle test (Meilgaard et al. 2007) as per Australian Standard 2542.2.2 (2005). Wine samples were evaluated by consumers in a dedicated sensory facility that contains six separate sensory booths. Coloured lighting was used in order to mask any potential colour differences in the wines. Each consumer was required to assess three difference tests (a total of nine wines per consumer) that were presented in International Standards Organisation (ISO) wine glasses. Each wine glass was coded with three digits and was lidded to avoid aroma release and contamination of the tasting environment. Each glass contained 20 mL of wine presented in an incomplete balanced block design so that each wine was tasted a total of 30 times during the wine sensory analysis. Samples of wine produced from fruit exposed to smoke (A) and the control unsmoked wines (B) were presented in a balanced reference design (i.e. AAB, ABA, BAA, BAB, ABB, BBA), randomised in presentation order to the consumers in order to control bias.

Quantitative Descriptive Analysis (QDA®) was used for the analysis of wines from many experiments in this project to quantitatively measure the key wine aromas and flavours. QDA® was used according to the methodology described by Meilgaard et al. (2007). Panellists were selected for QDA® training based on their interest and availability, for being regular wine consumers in good health, and for being non-smokers that have participated in wine education at a tertiary level. The age of panellists ranged from 21 to 50 years and participants utilised in the wine testing phase consisted of panels of up to 11 people (six males and five females) who were selected based on their sensory performance during the training phase. The QDA® training phase included panellists identifying and agreeing on aroma and flavour descriptors to be used when evaluating wines. Panellists were instructed on how to rank the intensity of the aroma and flavour descriptors on an unstructured 100-point line scale and were evaluated on their performance in using the scale. Prior to any formal wine evaluation, all test wines were informally tasted by a panel of up to five winemakers for the presence of any off-flavours and to detect any wine faults. All formal wine evaluation was performed in dedicated wine sensory facilities where each panellist had their own tasting area, or booth, separate from other participants. Panellists were randomly assigned to tasting stations where wines (30 mL) were presented in ISO tasting glasses. All glasses were lidded with glass covers to avoid aroma contamination of the tasting environment and from other samples. All wines were presented in a randomised order in three digit coded glasses. Each glass was coded uniquely for each panellist and presented so that each person did not receive the same wine at any one time. Panellists were required to wait for two minutes between tasting test samples and were encouraged to leave the tasting room to an external environment for regular breaks. All panellist responses were recorded on data sheets that were collated and securely stored for further data analysis.

3.1.5 Smoke Density and Duration

In this project, a key aspect in understanding smoke effects on grape and wine production was to investigate the influence of smoke density and duration. These effects were investigated to further understand the effect of smoke plumes. Smoke occurring in the atmosphere, in plumes, is highly variable and can be influenced by climatic and wind conditions (Garland et al. 2008). This smoke variability could potentially influence the accumulation of smoke related compounds, aromas and flavours in wine and therefore required further investigation.

Prior experiments have concentrated on the resultant wine chemical and sensory effects without understanding the smoke exposure and conditions of the fire itself (Høj et al. 2003, Whiting and Krstic 2007). Controlled applications of smoke to field-grown grapevines have been conducted, however information quantifying the smoke intensity utilised in experimentation has been limited. Smoke has either been applied to grapevines at limited densities (30% obs/m or 200 $\mu g/m^3$) for single (30 min) or repeated ($n = 8$) durations (Kennison et al. 2008 and 2009). As such, these experiments concentrated on heavy smoke densities.

This project built on previous research to further investigate the influence of smoke density and duration. As such, the project aimed to identify the minimum amount of smoke required to create smoke related aromas and flavours in resultant wines. Smoke was applied to field-grown Merlot grapevines within the growing period defined as having heightened sensitivity for smoke uptake (seven days post veraison to harvest) (Kennison et al. 2011). To investigate the effect of a range of smoke densities and durations, smoke was applied to grapevines at high densities (5, 10 and 20% obs/m) for short durations (5, 10 and 20 min) and one low smoke density (2.5% obs/m) for long durations (10, 20, 40 and 80 min). All field smoke treatments were applied in triplicate utilising smoke generating and tent equipment as previously outlined. Control treatments, comprising unsmoked grapes, were also incorporated in triplicate in these experiments. Red wines were produced by our small-lot winemaking procedure and analysed by both chemical and sensory analysis.

3.1.6 Smoke Effects on Key Grapevine Varieties

Previous research has been comprehensive in understanding smoke effects on grapevines throughout the production season. However this research has been limited in its focus on the range of grapevine varieties investigated. For instance, the timing of smoke uptake and taint development in wine is well understood at key phenological growth stages for Merlot (Kennison et al. 2011). However, the influence of smoke on other varieties throughout the growing and production season is unknown. A major focus of this project was to investigate the effects of smoke exposure on a range of varieties throughout the production season. As such, the key varieties Cabernet Sauvignon, Chardonnay and Sauvignon Blanc were utilised in field-based trials based in the Margaret River wine production region. Smoke was applied to the vines at key growth stages, as designated by the modified Eichhorn-Lorenz (E-L) system of grapevine growth classification (Coombe 1995). Smoke was applied to all varieties at the stages of pea-sized berries (berries 7 mm in diameter) (E-L 31), onset of veraison (E-L 35), veraison plus seven days (E-L 35 + 7 days) and harvest (E-L 38). Smoke treatments were applied to all varieties in triplicate for a period of 30 minutes. Control (unsmoked) grape treatments were also established in triplicate for each variety. Wines were produced from all smoke treatments according to the red wine and white wine production methodology previously described. Both grapes and wines were analysed for the presence of smoke-related compounds and wine sensory analysis (by use of Quantitative Descriptive Analysis methods - QDA®) to gain an understanding of smoke-related aroma and flavour intensity (methods detailed previously).

3.1.7 Smoke Generated from a Range of Fuel Types

In this project, a key aspect of the investigation of smoke complexity was the composition of smoke generated by different fuel types, its entry into the vine and subsequent smoke taint in grapes and wine.

3.1.7.1 Assessment of fuel type on the accumulation of phenols as smoke taint in wine

Smoke emissions of different fuels were investigated to examine whether the putative smoke taint compounds that accumulate in wines reflect the lignin composition of the vegetation that is pyrolysed in a bushfire event. The fuel types used in this study were representative of the bush types that burn in wildfire and prescribed burning events that may cause smoke taint in the Margaret River wine region of Western Australia.

3.1.7.2 Fuel composition and analysis

Five fuels were used in this study including the hardwood species jarrah (*Eucalyptus marginata* Donn ex Sm.), karri (*Eucalyptus diversicolor* F. Muell.) and marri (*Corymbia calophylla* Lindl.). To investigate the effect of the large differences in fuel cellulose, hemicelluloses and lignin composition, the softwood species radiata pine (*Pinus radiata* D. Don.) and a pasture grass, wild oats (*Avena fatua* L.) were included. Components of foliage, duff, bark, twigs (diameter < 6 mm) and round wood (diameter > 6 mm) for each fuel were collected from areas in Margaret River that had not been burnt for over ten years and stored in thin layers for several weeks to equilibrate their moisture content. After drying, one kilogram replicates were compiled for each fuel in proportion to the respective components that occur in a 10 years old fuel accumulation (Burrows, 1994; O'Connell and Menage, 1982). For wild oats, all of its above ground biomass was considered as a single component (100% fuel source) since all of it combusts during a fire event.

Sub samples of each fuel were analysed for lignin, cellulose and hemicelluloses using the methods described by van Soest and Wine (1967) and the monolignol composition was determined by pyrolysis gas chromatography mass spectrometry (*py* GC-MS). All analyses were in triplicate.

3.1.7.3 Smoke exposure of Merlot vines
In smoke exposure trials in a commercial vineyard in Margaret River, replicate panels of Merlot vines were exposed to smoke two weeks after veraison. Five replicate panels were chosen for each fuel in a randomised block design with five control (unsmoked) replicates. To generate smoke, 1 kg of fuel was combusted inside a purpose built pyrolysis chamber that allowed a controlled replication of wild fire temperatures (Gould et al. 2007). Smoke was delivered from the pyrolysis chamber via a flexible steel tube into a tent enclosing each replicate vine panel as described by Kennison et al. (2008). Each smoke exposure event lasted 30 min. The smoke density (PM 2.5 as measured by a VESDA Laser FOCUS^{TM} VLF-250 nephelometer; Xtralis, Mawson Lakes, South Australia) was recorded for the duration of each smoke exposure and found to exceed the instrument's maximum reading of 32%. The control replicate panels were enclosed in an identical tent for the same duration without an application of smoke.

3.1.7.4 Analysis of fuel emissions
Smoke samples from each replicate smoke exposure were collected and analysed for lignin derived phenol composition and compared to samples taken at prescribed burning and wildfires by thermal desorption gas chromatography mass spectrometry (TD GC-MS) as described by Vitzthum von Eckstaedt et al. (2011).

3.1.7.5 Vine and harvest assessments
At harvest, the mass of fruit, the berry weight and leaf area were determined to investigate relationships between the derived taint in each replicate and the replicate vine parameters.

3.1.7.6 Wine making
The fruit was harvested at commercial maturity with each replicate remaining separate. Each replicate was crushed and destemmed with a 100 mg/L metabisulphite addition and the total acids were adjusted to 7.0 g/L with tartaric acid. The musts were inoculated with EC1118 yeast and a nitrogen supplement of 100 mg/L diammonium phosphate. The wines were regularly hand plunged, pressed off skins at 3 ^{o}Brix with fermentation continuing to dryness. Each replicate was divided into two, with half inoculated for malolactic conversion. When malolactic fermentation had completed all wines received a 60 mg/L metabisulphite addition and were tartrate stabilised before filtration to 0.2 micron and bottling.

3.1.7.7 Analysis of free and glycosidically bound taint compounds in wine.
To investigate differences in the accumulation of lignin derived taint compounds in the replicate wines, an adaptation of the GC-MS method described by Singh et al. (2011) was used to quantify 21 phenols and the essential oil eucalyptol (Singh et al., 2012).

3.1.7.8 Analysis of metal concentrations in wine

Research investigating the sensory effect of smoke taint in wine (Ristic et al., 2011: Parker et al., 2012) has described a metallic taste to be found in smoke tainted wines. The smoke treatment wines in our study were analysed for a range of metals and compared to the unsmoked (control) replicates. Triplicate samples of each wine were heated to 150^{o}C for one hour to remove the ethanol and adjusted to pH 2 with nitric acid. The samples were analysed by Inductively Coupled Plasma Mass Spectrometry (ICP-MS) and Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES) for 39 metal elements.

3.1.8 Statistical Analysis

For the analysis of data in this research, the Genstat 11th Edition (VSN International Limited, Hemel Hempstead, UK) statistical program was used. The significance of the main effects of any treatments employed in this study and, where appropriate, their interactions were analysed using analysis of variance (ANOVA) with mean comparisons performed by least significant difference (LSD) multiple comparison tests at $P \leq 0.05$. Wine sensory data produced from triangle tests was analysed by use of statistical tables detailed by Meilgaard et al. (2007) and data from Quantitative Descriptive Analysis (QDA®) was analysed by ANOVA and Principal Component Analysis (PCA).

3.2 Field-Based Smoke Detecting Equipment

Environmental smoke is highly variable, with optical smoke properties influenced by combustion conditions, fire location, weather conditions and prevailing winds (Garland et al. 2008). The measurement of smoke is complex with numerous equipment and analysis methodologies available to detect and quantify smoke presence (Adam et al. 2004, Lee et al. 2005). One type of analysis known to be highly sensitive and reliable for the detection of smoke is nephelometry (Adam et al. 2004). Nephelometry equipment has been found to be precise and accurate in the measurement of smoke presence and concentration (Williamson and Bowman 2008) and has been successfully implemented in our earlier research (Kennison et al. 2011). In all smoke experiments conducted in this study, nephelometry equipment (VESDA Laser FOCUS™ VLF-250, Victoria, Australia) was employed. Smoke density was recorded as the percentage of visual obscuration over a distance of one metre and expressed in units of % obs/m. The nephelometer also measured the duration (min) of each smoke density and was able to record date and time. The nephelometers were used in this project not only for their accuracy and reliability but also due to being cost effective and portable for field use. The units used in the study were engineered to be mobile, static and weather proof.

3.2.1 Static Smoke Detecting Units

A number of nephelometers were placed in-field over the duration of the project to monitor and detect the presence of smoke. Two units were placed in close proximity to vineyards in the Manjimup and Pemberton regions of South West WA to detect the presence of smoke in a susceptible area. These units were static and enclosed within weatherproof housing (Figure 3) with remote data access capability over the Telstra 3G network (Figure 4). Nephelometers were connected to mains power to enable the constant recording and data logging of any smoke exposure throughout the year. Data were retrieved and downloaded from the units regularly during the growing season and occasionally during vine dormancy.

3.2.2 Mobile Smoke Detecting Units

Mobile nephelometers were engineered for field employment during fire events. Mobile units included data storage and retrieval capabilities (through a secure USB storage device) and a battery powered source (Figure 5). The units were mounted on a manoeuvrable wheel based trolley for field deployment and transportation. Investigation of the effectiveness of the field units commenced with deployment to field sites during prescribed burns initiated by the forest management agency (Department of Environment and Conservation). As such, the units were positioned for exposure to smoke from actual fire events, to enable a further understanding of smoke density and duration and fire conditions relevant to this research.

Figure 3. Field-based smoke detecting (nephelometer) equipment showing weather proof housing.

Figure 4. Field-based smoke detecting (nephelometer) equipment showing active smoke detection unit, mains power connection, data storage and retrieval.

Figure 5. Mobile nephelometer smoke detection equipment showing active smoke detection unit, data storage, data retrieval and battery power source.

3.3 Regional Grapevine Phenology Study

Phenological development and ripening in grapevines is considered to be mainly regulated by temperature (Winkler et al. 1962, Jones and Davis, 2000, Jones 2003). Forecasted increases in temperature are predicted to cause earlier development and therefore advancement in grapevine phenological stages. From our research, the sensitivity to smoke uptake is associated with grapevine phenology stage. Therefore, understanding how temperature influences the timing of grapevine growth and development as well as identifying variety specific differences in phenology and maturity is crucial. Several process-based grapevine phenological models driven by temperature summations have been developed. In this project we adapted the Spring Warming/Grapevine Flowering Veraison Model (GVF) developed by Parker et al. (2011). We further developed the model to simulate a greater range of grapevine growth stages. The model was calibrated using historical phenology data collected from Western Australian vineyards for a range of varieties.

Grapevines develop through a series of well defined growth stages during the growing season. The Modified Eichorn and Lorenz (E-L) scale which describes 30 stages of grapevine development from bud-burst to harvest ripeness (Coombe, 1995) was used to record the phenological information collected from the vineyards. To validate the model predictions, detailed phenological observations were taken from vineyards in four climatically diverse growing regions in 2011/12 season.

3.3.1 Historical Phenology Records

Historical phenological records were collected from commercial vineyards throughout the nine GI wine growing regions of Western Australia: Great Southern, Pemberton, Manjimup, Margaret River, Geographe, Blackwood Valley, Swan Districts, Peel and Perth Hills. The Vineyard Mapping Project and Client and Resource information System (CRIS) maps and data-base were used to identify representative vineyards within each region to contact. Initially seventy-three vineyard businesses were contacted and the vignerons invited to participate in the project by providing the grapevine growth stage/phenology records and harvest °Brix/°Baume for the varieties grown on their vineyards. The vignerons were contacted by email and follow up phone calls. Vignerons were informed that their phenology data would be used to develop a predictive tool to help decision making on the timing and location of prescribed burns to reduce the incidence of smoke taint in grapes and wine. The model was jointly developed by the Department of Agriculture and Food in collaboration with the University of Western Australia. Their data and that from other vineyards and regions would be used to develop the model for the different wine regions in Australia. Vignerons contacted were aware that wine grape sensitivity to smoke uptake is dependent on the seasonal stage of grapevine development. A spreadsheet (Figure 6) and guide describing the grapevine growth stages and modified Eichhorn and Lorenz (E-L) system (Figure 7) was provided to assist vignerons to record their phenology dates and harvest °Brix/°Baume. If vignerons kept records in a different format these were provided and collated by the project in a standard format for use in the model. Vignerons using the spreadsheet provided were asked to add other growth stages for which they had records. The critical phenology stages required to develop the smoke taint risk model were budburst, flowering, fruit set, bunch closure, veraison and harvest. Vignerons were asked to provide the phenology dates for as many past vintages as possible. The project provided assistance collecting phenology data from vignerons' spray records and vintage reports where required.

NAME OF VINEYARD											
Property ID											
Property Address											
GPS Coordinates		Projected (UTM)									
		Geographic									
		Dates:									
Year	Block	Variety	Bud burst EL4	Shoots 10cm EL12	Flowering beginning EL19	80% cap fall EL25	Fruit set EL31	Bunch closure EL32	Veraison EL35	Harvest EL38	Harvest Brix or Baume

Figure 6. Sample of spreadsheet for vignerons to record phenology dates for varieties on their vineyard

Vignerons were requested to provide the dates for the key phenological stages including budburst (E-L4), shoots 10cm long (E-L12), beginning of flowering (E-L19), full bloom (E-L23), end of flowering (E-L25), fruit set/berries pea size (E-L31), bunch closure (E-L32), veraison (E-L34), and berries harvest ripe (E-L38). The date of each stage was taken as the date when 50% of the shoots, flowers, or berries had reached the specific stage. For example the dates of veraison (E-L34) corresponded with the onset of the ripening period identified as the date when 50% of berries had softened or changed colour from green to translucent for white varieties, or changed colour for red varieties. Data on the °Brix or °Baume at harvest was also collected where available as an indicator of the berry ripeness at harvest. The data collection focused on the key varieties Merlot, Cabernet Sauvignon, Chardonnay and Sauvignon Blanc. Data on other varieties were collected where available and time permitted. These included Chenin Blanc, Semillon, Rousanne, Marsanne, Viognier, Verdelho, Shiraz, Cabernet Franc, Zinfandel, Petit Verdot and Grenache. The collection of historical phenology records is ongoing and the information used to update the phenology model driving STAR.

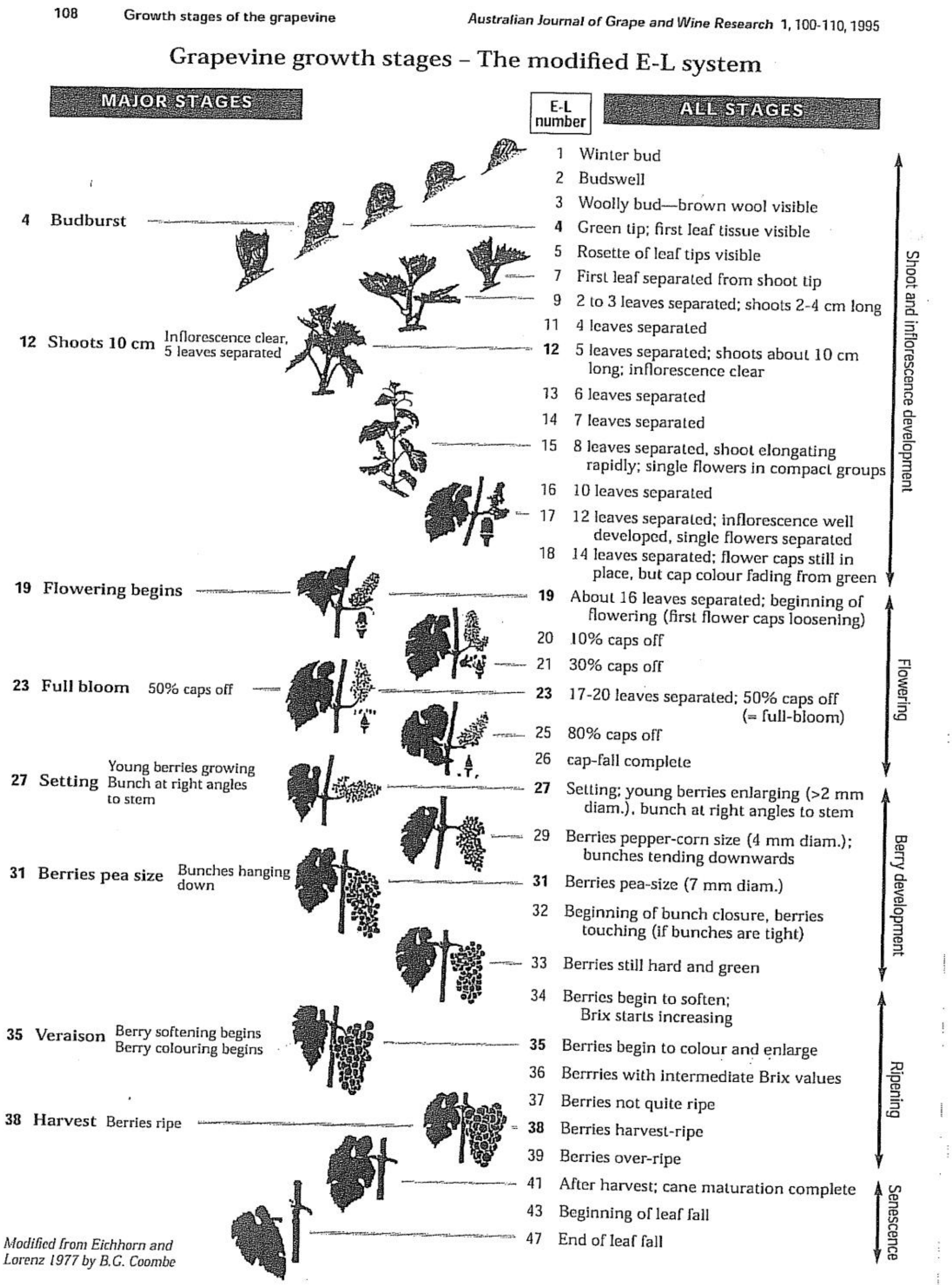


Figure 7. The modified Eichhorn and Lorenz (E-L) system for grapevine growth stages (from Coombe 1995)

3.3.2 Regional Grapevine Phenology

Detailed phenological observations were recorded on vineyards in four climatically diverse regions in 2011/12: Gingin (Swan Districts), Donnybrook (Geographe), Margaret River and Pemberton. Vineyards for the trial were selected on the basis of variety composition and proximity to either a Bureau of Meteorology (BOM) or Department of Agriculture and Food (DAFWA) weather station. The vineyards locations were within 1.3 km to 4.8 km of the nearest BOM weather station. The vineyards were required to have the key varieties Chardonnay, Cabernet Sauvignon, Shiraz and Sauvignon Blanc of mature age and in commercial production. The vineyard location and varieties selected were chosen to give the greatest range in seasonal growing temperatures and phenological development from earliest budburst date to latest harvest date. The vineyards chosen were representative of the phenological development of the selected varieties in their region.

A total of 25 vines were selected per variety per vineyard (100 vines per variety block) with five groups of five vines being selected to represent the variation in phenological development within each variety block. Two shoots per cordon (four per vine) were chosen and tagged on each of the 25 vines to monitor for growth stage development. The grapevine growth stage on each tagged shoot was recorded at weekly intervals from 3 October 2011 through to harvest for each variety using the modified Eichhorn and Lorenz (E-L) system (Coombe 1995). From veraison onwards total soluble solids levels (°Brix) were measured weekly using a hand held refractometer (Atago ATC-1, Japan). A total of 20 berries was selected per group of vines and placed in a plastic bag and crushed to extract the juice, which was then measured on the refractometer. The average °Brix of the five groups of vines was taken as the level of °Brix at that particular date. The berry °Brix corresponding E-L stage was taken to be : E-L34 (7° Brix, berries begin to soften), E-L35 (10° Brix, berries begin to colour), E-L36 (14 °Brix, berries intermediate Brix), E-L37 (18° Brix, berries not quite ripe), E-L38 (22 °Brix, berries harvest ripe) and E-L39 (27 °Brix, berries over ripe) (Coombe 1995).

Data loggers were used to monitor temperatures within the bunch zone in each variety block, to provide a more accurate relationship between temperature and phenological development. Tinytag temperature loggers (Tinytag Ultra 2® TGU-4500 and Tinytag Plus 2® TGP-4020) were placed in the bunch zone either without covers, enclosed in Stevenson screens (Datamate® Stevenson Type Screen) and enclosed in custom made weather screen made from PVC tubing (Figure 8). The PVC tubing enclosures were included as a comparison with the Stevenson screens.

Figure 8. Temperature was recorded using Tinytags® contained in a Stevenson screen (left), PVC tubing (right) or without housing (middle attached to post).

3.4 Vineyard Mapping and Database Generation

Comprehensive mapping and data sets from commercial wine grape properties were captured in WA and Victoria. In WA the information was obtained using the Department of Agriculture and Food Western Australia's Client and Resource Information System (CRIS). CRIS maintains a mapped database of agricultural properties. CRIS was designed primarily for biosecurity surveillance and emergency response and uses aerial photography from the latest available orthophotography from Landgate. This is publically available information. Areas are photographed in a grid pattern at least once every seven years. CRIS identifies parcels of land owned by the same person or company and if adjacent creates a property with a defined boundary and unique property number. The same person or company may own other parcels of land that are not adjacent and these have their own defined property boundary and unique property number. The information stored on each of these properties includes the property owner, manager/s and/or lessee/s name/s and contact details. Additional information stored includes property activities (ie. grape growing). Examples of the information available on CRIS are shown in Figures 9, 10, 11 and 12.

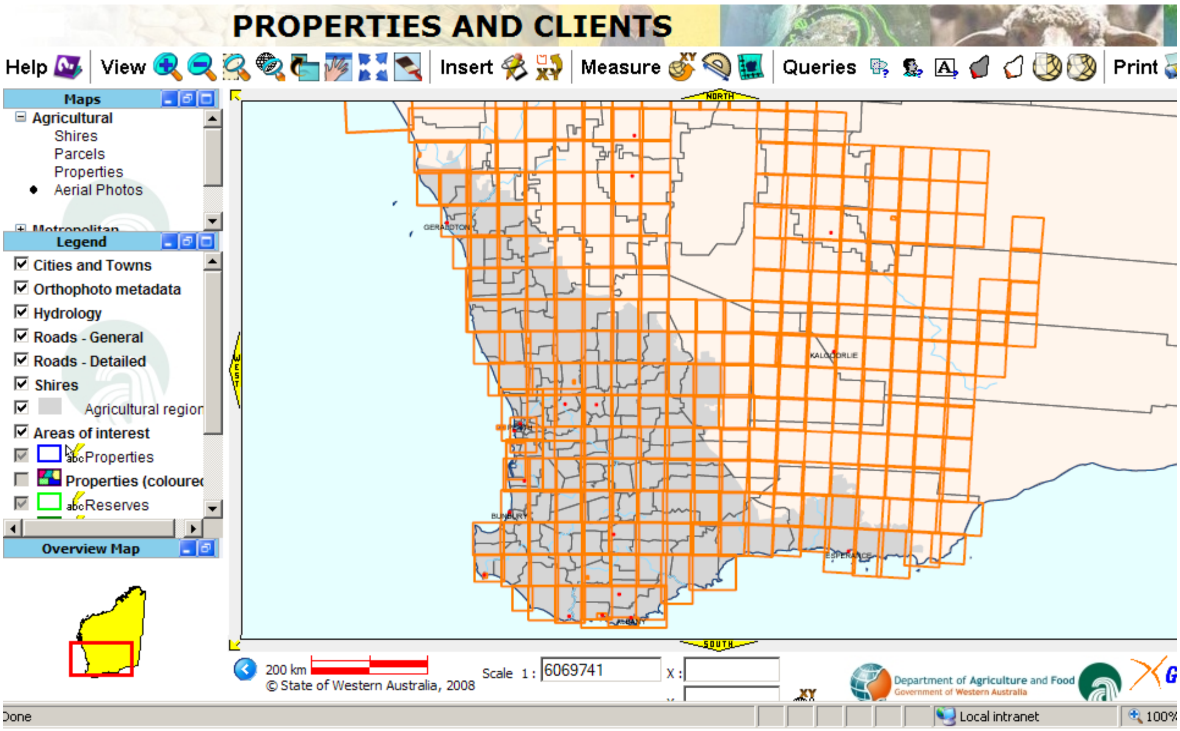


Figure 9. The home page of the CRIS database. Each grid has corresponding aerial photography from orthophotography from Landgate.

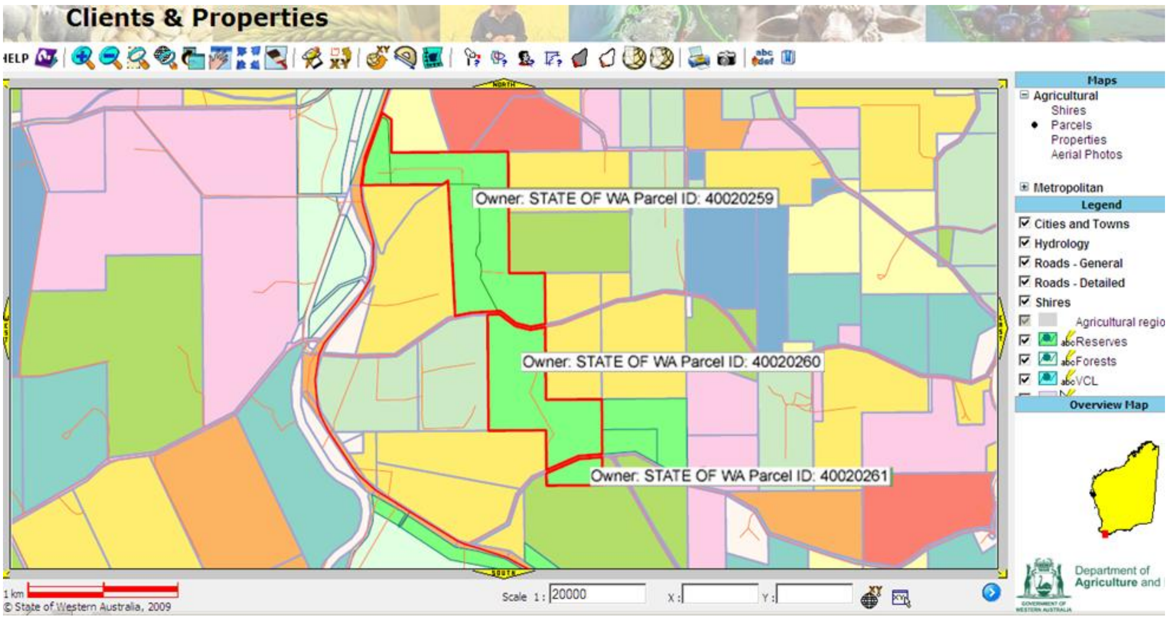


Figure 10. The individual parcels of land owned by the same person or company.

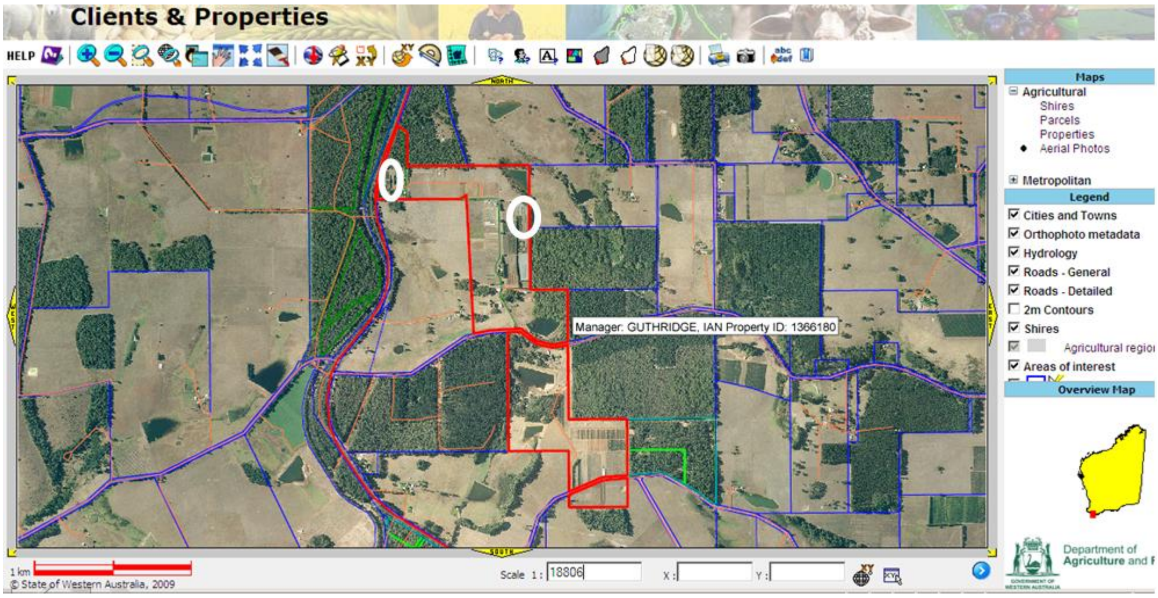


Figure 11. The parcels identified as a property with its unique property identification number. The areas planted with grapes identified on the aerial photography depicted by circles.

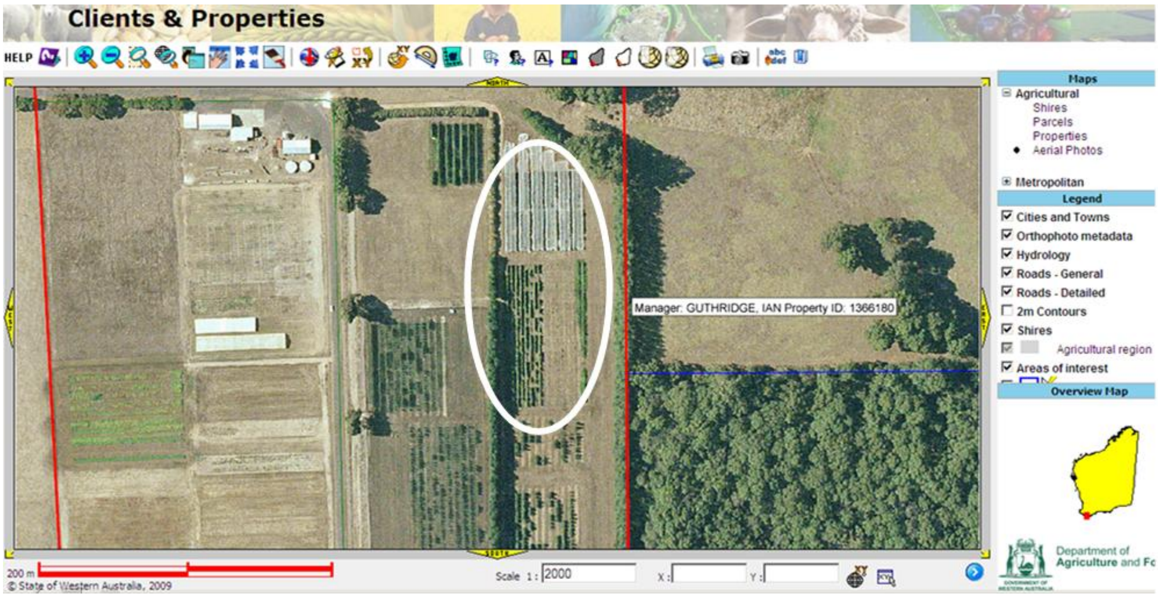


Figure 12. A close up of a planted area of vines of which some is under netting. Vine rows are able to be differentiated from individual tree crops using this method. Other trellised crops such as table grapes and passionfruit may be difficult to determine.

The CRIS database was used to identify properties with grapes being grown on them in the nine Geographical Indications Committee (GIC) wine growing regions in WA: Blackwood Valley, Geographe, Great Southern, Manjimup, Margaret River, Peel, Pemberton, Perth Hills and Swan District (Figure 13).

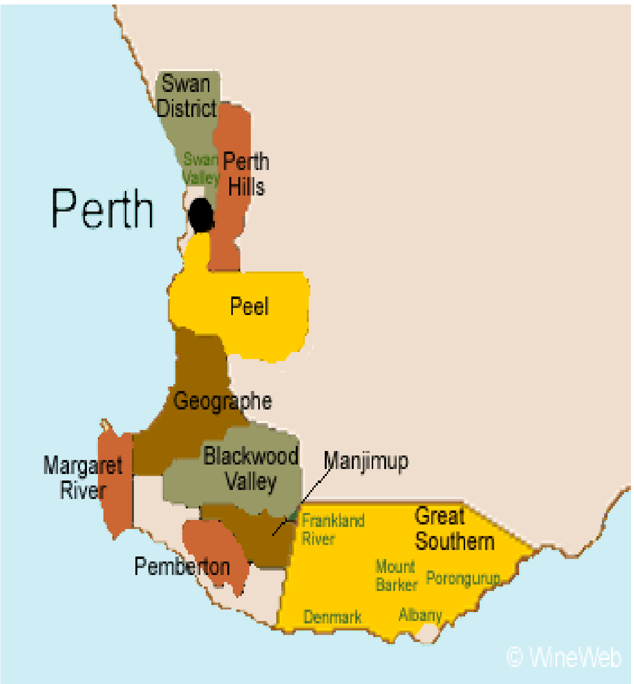


Figure 13. The nine GIC wine growing regions in WA.

These properties were then 'ground-truthed' by driving past each one to ensure that they were still grape growing properties and that they had not been removed since the aerial photography had been taken. Ground-truthing also identified properties with grapes planted that had not been identified from CRIS as they had been planted since the aerial photography had occurred.

All wine grape growing properties identified by CRIS and the follow-up ground-truthing were contacted and requested to provide further information. A letter was sent to all the property owner/s, manager/s and/or lessee/s in seven of the nine GIC wine growing regions. The letter outlined the purpose of the vineyard mapping and database generation and information sought, and included an A3 coloured map of the property (Figure 14) and a Property Data Update (PDU) Form (Figure 15) to be completed and returned in the reply paid envelope supplied. The details obtained included: confirming the property boundary and grape planted area boundary on the map and if incorrect to make appropriate changes; the grape varieties planted and area of each (ha) either marked on the map or listed on the PDU Form; property name; property address; owner/s name and contact details; manager/s names and contact details. As the vineyard mapping and database generation progressed, permission was requested to make available the contact details provided to the state and relevant regional wine Associations.

Figure 14. An example of an A3 aerial property map. The property boundary is in yellow. The grape planted area boundary is in red.

Department of Agriculture and Food
Government of Western Australia

Property Data Update Form

Property ID:	Shire:
Property Name:	
Property Address:	
GIC Region:	
MANAGEMENT CONTACT ☐ Owner ☐ Manager	
Owners Full Name(s):	
Trading / Business Name:	
Postal Address:	
Tel:	Fax:
Mobile:	E-mail:
Managers Full Name(s):	
Trading / Business Name:	
Postal Address:	
Tel:	Fax:
Mobile:	E-mail:

Grape Variety	*Area (Ha)*	*Grape Variety*	*Area (Ha)*
Total Vineyard Area (Ha):			

Figure 15. Example of the Property Data Update Form.

Follow up phone calls were made to non-respondents and neighbours of non-respondents where contact details were available to increase response rates.

The information obtained was loaded into the CRIS system and was provided to the Department of Environment and Conservation (DEC) to assist with their Master Burn Planning (MBP) processes. The MBP is a decision support tool that integrates the factors necessary for developing DEC's six-season indicative and annual prescribed burn programs in forests, parks and reserves. This information was to assist the scheduling of DEC's planned burns so as to minimise clashes between burning and grape maturation and harvesting.

Thank you letters and updated A3 laminated aerial photography property maps were sent to participating property owners/s and/or manager/s. Electronic copies were made available if requested. Client confidentiality was given a high priority. Property boundaries and names were made available in publically available products. Master Maps of each region were produced and made available when relevant to stakeholders in the wine grape industry of WA including the state and relevant regional Association/s and relevant local Shires. These maps showed property location, property boundary and property name for all identified commercial wine grape plantings. The contact details of owner/s and/or manager/s was restricted and maintained by DAFWA staff unless permission was granted on the PDU Form whereby the owner/s and/or manager/s details were sent to the state and relevant regional Associations.

In Victoria the capture of the vineyard mapping and database information was delayed until a suitable system had been developed. DPI Victoria is currently piloting the HIN Mapper, an iPad® application, to capture a comprehensive vineyard database for wine grape properties in Victoria. The information will be linked to the smoke taint risk model and integrated with the Department of Sustainability and Environment (DSE) burn planning and decision systems. Progress on the Victorian vineyard mapping project will be reported separately by the Centre of Excellence for Smoke Taint Research (CESTR).

3.5 Smoke Taint Risk Assessment Software

The Smoke Taint Risk assessment (STAR) software was developed to allow users to predict seasonal grapevine growth stages with associated smoke taint risk. The development of the STAR software included three different components:

- The development of a degree-day-based model of vine growth phenology based on weather records for different vine cultivars
- The development of a model relating vine phenological stages to smoke taint risk
- The development of an interactive user-friendly web-based tool for communicating predictions of these models

(Details of the development and testing of the STAR software to be presented in Renton et al. 2012)

3.5.1 Development of vine phenology model

Historical phenological records were obtained for a selection of key grape cultivars from a number of commercial vineyards in different wine growing regions of Western Australia. For each of these vineyards, the nearest BOM weather station was determined, and data from this weather station was obtained. Automated statistical procedures were developed to use phenological stage by date records in combination with degree day information computed from meteorological records to estimate the number of growth degree days (GDD) required to progress from one growth stage to the next. These methods were then applied for each grape variety at each vineyard, using all available data, to estimate the number of degree days between growth stages calculated for each variety at each vineyard. The degree days between growth stages for each variety were then averaged over all vineyards to improve GDD approximation by incorporation of all available vineyard records. Automated procedures were developed for all aspects of the vine phenology model parameter estimation, so that as additional phenology data became available, or becomes available in future, it is relatively easy to integrate this information to continue to refine the model and improve its predictions.

3.5.2 Quantifying Smoke Risk

An essential component of the STAR model was the incorporation of information to detail the comparative risk of smoke exposure and smoke uptake by key grapevine varieties throughout the growing season. As such, the quantification of smoke risk at key periods was required for the development, application and useability of the STAR model. The development of smoke risk factors required careful consideration to ensure the data was (1) true and accurate; (2) centred on field-based research to grapevines that incorporated both wine chemical and sensory analysis; (3) incorporated a number of key wine grape varieties; and (4) integrated an understanding of grapevine smoke uptake across a range of grapevine phenological stages. Therefore past and current data from research trials was incorporated to calculate the smoke taint risk factors.

From our previous research on smoke exposure to field-based grapevines, a large volume of chemical and wine sensory data exists. For example, Kennison et al. (2009, 2011) conducted research where a high density of smoke (30% obs/m) was applied to field-grown Merlot grapevines for a duration of 30 minutes. Smoke was applied to separate grapevine treatment plots at a range of phenological growth stages (including shoots 10 cm in length; flowers at full bloom; berries at pea-size; bunch closure; onset of veraison; veraison plus 3, 7, 10, 15, 18, and 21 days and at harvest) (Kennison et al. 2009, 2011). In those studies, wines were made from fruit of grapevines exposed to smoke and analysed, by gas chromatography-mass spectrometry (Pollnitz et al. 2004), for the guaiacol and 4-methylguaiacol compounds known to be present in smoke. Also, the wine sensory analysis technique of Quantitative Descriptive Analysis (QDA®) (Meilgaard et al. 2007) by a trained panel was employed. These panellists identified the smoke-like aromas of 'burnt rubber', 'smoked meat', 'leather', 'disinfectant / hospital' and the wine-like aromas of 'red berry fruits' and 'confection' in wines made from smoked and unsmoked fruit (Kennison et al. 2009, 2011). These results were all collated and incorporated into the development of smoke risk factors for the STAR model.

In conjunction with our previously published data, additional information was required to build further rigour into the STAR model. To facilitate this requirement additional field-based research was conducted on Cabernet Sauvignon, Chardonnay and Sauvignon Blanc exposed to smoke. Smoke was applied to the grapevine varieties at the key growth stages of pea-sized berries (berries 7 mm in diameter) (E-L 31), onset of veraison (E-L 35), veraison plus seven days (E-L 35 + 7 days) and harvest (E-L 38). Smoke treatments were applied to all varieties in triplicate for a period of 30 minutes. Wines were produced from this trial and analysed by chemical and sensory methods as previously described (in method section 3).

All data from Kennison et al. (2009, 2011) was collated and analysed by Principal Component Analysis (PCA) and displayed on a biplot to reveal data variance, correlations, inter-unit distance, clustering, multicollinearity and outliers (Kohler and Luniak 2005). As such the PCA provided an indication of the contribution of both the data factors and variates to the overall smoke taint risk associated with smoke exposure during the grapevine growth season. Data employed in the PCA development (Principal Components 1 and 2 output) was further used to develop numerical indices as seasonal risk factors for the susceptibility of smoke taint development in wine. Principal component data together with chemical analysis data was compiled and calculated, as averages, for development of smoke taint risk factors for the STAR model.

3.5.3 Development of model relating vine phenological stages to smoke taint risk

The smoke taint risk factors developed for four wine grape varieties at key growth stages were linked to the vine phenology model to predict the seasonal timing of smoke taint risk. The varieties were Merlot at growth stages: shoots 10 cm, full bloom, berries pea-size, bunch closure, onset of veraison, veraison plus 3, 7, 10, 15, 18, and 21 days and harvest; and Cabernet Sauvignon, Chardonnay and Sauvignon Blanc at growth stages berries pea size, onset of veraison, veraison plus seven days and harvest.

3.5.4 Development of an interactive user-friendly web-based tool for communicating predictions of these models

A user-friendly web-based tool was developed to allow users to interact with the models described above, and to synthesise and communicate their predictions. The development of this tool involved two main components: development of a database and associated code-base with functionality to handle all required data and generate model predictions; and development of a website with a number of interactive features to allow users to interact with the model and obtain predictions as desired.

The modelled estimates described above relating growth stages to smoke taint risk and degree days were stored in the STAR database. Semi-automated procedures were developed to allow updating of these database records as new empirical data become available. We also developed methods for the STAR database to access the DAFWA weather database, so that weather data used in STAR can be updated regularly and often. Finally, we developed methods for predicting future weather scenarios according to different 'deciles' (see below for more detail).

We wanted the web-based interface to include a number of different features and options for user interaction. We wanted the user to be able to specify the location of the vineyard or the general region they are interested in, and for the model to then provide relevant predictions for this location or region. We wanted the user to be able to specify the variety or varieties they were interested in, or even a specific combination of varieties in specific proportions as used in their vineyard or region. We wanted to allow the user to specify a temperature offset for vineyard location relative to weather station, to allow for differences due to distance from the station, or differences in aspect (north-facing vs. south-facing slopes). As well as giving predictions for current growth stages and smoke taint risk, based on historical weather data up to the present, we wanted the model to provide predictions for a spectrum of possible future weather scenarios, with these scenarios based a synthesis of past weather data for the location or region. We wanted to provide smoke risk predictions in several complementary formats: a simple risk over time for a single specified variety; a simple risk over time for multiple specified varieties; a stacked plot showing risk over time for a number of different specified varieties weighted by the proportions of these varieties specified by the user; and a composite risk profile showing risk over time as an average of the risks for the different specified varieties, weighted by the proportions of these varieties specified by the user. We also wanted to allow the user to adjust the model's predictions based on their own past real observations to provide better future predictions, particularly when the estimated date for budburst differed from the observed date (since this is a particular difficult thing to estimate using a model, and observation of this event can be made well before smoke taint risk becomes significant). The web-based interface was developed to enable all these different desired features and options for user interaction.

The tool combining the web-based interface and the database was developed to work as follows. Using the STAR interface, the user specifies information regarding date range, location (nearest weather station), the future weather 'decile' they are interested in (decile 1: very cold to decile 5: average to decile 9: very hot) and potentially a constant temperature offset. This information is sent from the STAR web interface on the user's computer to the database on the DAFWA server. Weather data is retrieved for the appropriate location and date range. Past weather data is used directly and simulated weather is produced for future dates by drawing the appropriate decile records from the location's historical data. In the absence of additional information, vines are assumed to lose dormancy on August 30 (242nd day of year), as per Parker et al, (2012) Grapevine Flowering Veraison model. Real, past and simulated future weather data are used to produce degree day summations from this date. If specified, the temperature offset is applied each day, increasing or decreasing degree day summation to simulate a location which is consistently warmer or cooler than the local weather station. A time series array of predicted phenological stages for each variety is produced from these degree day summations. Each growth stage in the array is next associated with smoke taint risk value according to the values stored in the database previously derived from the experimental findings. The time series array of growth stages and risks is returned from the server to the STAR web interface, where risk array is plotted against time for each species (or synthesised into the stacked plot or composite risk profile described above, as specified by the user).

3.5.5 Validation of the phenology model

The degree-day based vine phenology model developed using historical phenology records from commercial vineyards and weather records was validated for the key varieties Chardonnay, Sauvignon Blanc, Shiraz and Cabernet Sauvignon for which detailed observation were made in 2011/12. The model was validated for key growth stages including five leaves separated (E-L12), full bloom (E-L23), fruit set (E-L31), bunch closure (E-L32), onset of veraison (E-L35) and berries harvest ripe (E-L38).

3.6 Ground-truthing of STAR Model

The STAR model was ground-truthed during the development and prototype phases with stakeholders and potential users from the wine industry, land management agencies and research and development groups in WA and Victoria.

Initially, meetings were held with stakeholders to determine the scope of the model based on the requirements of the end users. It was decided that the scope should:

- Include the development of a tabular web page of smoke taint risk based on a vine phenology model and real time weather data.
- Modify and adapt existing vine phenology models as needed to meet the objectives of the project: ‘to develop a web based model (easily update and user friendly) to predict the seasonal vine phenological stage of the development and associated susceptibility to smoke uptake as a decision making tool for prescribed burning activity’.
- Ground truth the smoke taint risk program and webpage information.
- Evaluate the feasibility of linking the smoke taint risk calculator with CRIS mapping system and decision making tools for prescribed burning activity and implement to the extent possible.

3.7 National Extension of Project Outcomes to the Wine Industry

Information generated by the project was collated to develop extension materials for presentation of project results to industry nationally. A toolkit of information produced includes a publication on the ‘Key Information on the Effect of Smoke in Grape and Wine Production’, the Vineyard Mapping and Database information and the STAR model webpage tool.

The project results and outcomes were communicated to industry nationally throughout the life of the project (Appendix 1). This was achieved through publication of results in industry publications and scientific journals, and in presentations at industry workshops, seminars, symposia and meetings within WA and nationally.

4. Results / Discussion

4.1 Smoke Application to Field-Grown Grapevines

A number of field based investigations were initiated during this project to elucidate further information to contribute to the STAR model. Research investigated the effect of smoke exposure to grapevines on smoke-related chemical and sensory properties of wines. This included (1) the effect of a range of smoke densities and durations applied to field-grown vines; (2) smoke exposure to various varieties including Cabernet Sauvignon, Chardonnay and Sauvignon Blanc; and (3) the influence of smoke produced from a range of forest fuel types.

4.1.1 Effect of Smoke Density and Duration

To investigate the effect of a range of smoke densities and durations on the creation of smoke-related aromas, flavours and compounds in wine a number of trials were initiated where smoke was applied at high densities (5, 10 and 20% obs/m) for short durations (5, 10 and 20 min) and one low smoke density (2.5% obs/m) for long durations 10, 20, 40 and 80 min. All smoke applications were applied to separate Merlot vines and replicated wines (n = 3) were made from all treatments. These wines were assessed by both chemical and sensory methods as outlined in the report methodology.

Results from both the high smoke density / short duration and low smoke density / long duration experiments showed that smoke application did not influence the fruit yield (results not shown). That is, there was no treatment difference in fruit yield per vine or the yield components of bunch weight, berry weight or bunch number per vine at harvest. The total soluble solids (TSS) content of fruit was not affected in the high smoke density / short duration experiment however an effect was noted in the low smoke density for long durations experiment. The treatment of 2.5% obs/m of smoke for 80 minutes produced fruit with an average TSS content of 22.3 ^{o}Brix in comparison to all other grape musts, including the control, that had a higher average TSS (23.2 ^{o}Brix) content (Kennison et al. 2012a). This observation is supported by previous studies that discovered similar occurrences. Kennison et al. (2009) found a single heavy smoke exposure to field-grown vines for 30 minutes duration to result in an average decrease of TSS content of fruit at harvest of 1.6 ^{o}Brix whereas repeated smoke exposures (n = 8) to the same vines for 30 minutes each in duration resulted in an average fruit TSS content decrease of 3 ^{o}Brix. Therefore, the increased durations of smoke had the effect of decreasing the vine's ability to effectively ripen fruit. This decrease in fruit ripening may be related to smoke effects on photosynthetic capacity. Previous studies have shown smoke exposure to plants inhibits plant gas exchange therefore affecting the plant's photosynthetic capacity (Davies and Unam 1999, Gilbert and Ripley 2002). This phenomenon shows some application to grapevines although it requires further investigation to elucidate the exact mode of action.

To determine the effect of smoke on grape production, GC-MS analysis for guaiacol and 4-methylguaicol was conducted in both grape berry and wine samples. Interestingly, GC-MS analysis did not detect any guaiacol or 4-methylguaiacol in harvest berry samples produced from grapevines exposed to high smoke densities for short durations and low smoke densities for long durations. However guaiacol and 4-methylguaiacol were detected in wine samples made from the same grapes. Wines produced from grapes exposed to high smoke densities for short duration contained guaiacol and 4-methylguaiacol concentrations equal or higher than those exhibited in the unsmoked (control) wine (Table 1 A). In this study, guaiacol and 4-methylguaicol levels were clearly elevated in those wines produced from grapes exposed to longer durations of smoke at higher smoke densities such as 20% obs/m for 20 min (6.3 and 2.7 µg/L respectively) and 10% obs/m for 20 min (6.3 and 2.3 µg/L respectively). Similarly, concentrations of guaiacol and 4-methylguaiacol were elevated in all wines produced in the low smoke density / long duration experiment in comparison to the unsmoked (control) wine (Table 1 B). The highest detection of guaiacol and 4-methylguaiacol (10 and 2 µg/L respectively) was found in wines exposed to 2.5% obs/m smoke for the longest duration (80 min).

Table 1. Concentration (µg/L) of guaiacol and 4-methylguaiacol detected in wines made from fruit of vines exposed to (A) high smoke densities (5, 10 and 20%) for short durations (5, 10 and 20 min) and (B) a low smoke density (2.5% obs/m) for long durations (10, 20, 40 and 80 min) (Kennison et al. 2012a).

(A) Smoke density and duration	**Concentration (µg/L) of[‡]**	
	guaiacol	**4-methylguaiacol**
Control	2.3[c]	1.3[c]
5% 5 min	4.0[bc]	2.0[abc]
5% 10 min	4.3[b]	2.0[abc]
5% 20 min	3.3[bc]	2.0[abc]
10% 5 min	2.3[c]	1.3[c]
10% 10 min	3.7[bc]	2.0[abc]
10% 20 min	6.3[a]	2.3[ab]
20% 5 min	3.0[bc]	1.7[bc]
20% 10 min	3.7[bc]	2.0[abc]
20% 20 min	6.3[a]	2.7[a]

(B) Smoke density and duration	**Concentration (µg/L) of[†]**	
	guaiacol	**4-methylguaiacol**
Control	1.7[d]	n.d.
2.5% 10 min	2.6[c]	n.d.
2.5% 20 min	3.3[c]	0.3[b]
2.5% 40 min	7.7[b]	1.7[a]
2.5% 80 min	10.0[a]	2[a]

[†]For each analyte, means followed by the same letter within columns are not significantly different at $P \leq 0.05$, $n = 3$; n.d. = not detected. Both (A) and (B) are separate treatment units.

The smoke exposure treatments also produced an influence on the sensory properties of resultant wines. Panellists were trained to assess wines by Quantitative Descriptive Analysis (QDA®) as described in the project methodology. During wine sensory training and analysis, panellists identified ‘red berry aroma’, ‘red berry flavour’, ‘smoke aroma’, ‘smoke flavour’, ‘eucalypt aroma’, ‘eucalypt flavour’, ‘hospital aroma’, ‘dried meat flavour’ and ‘ashy palate’ in wines made from fruit exposed to smoke and unsmoked (control) wines. Wines produced from unsmoked (control) grapes showed a clear elevation in ‘red berry flavour’ and ‘red berry aroma’ and low concentration of the smoke-related wine characteristics of ‘smoke aroma’, ‘smoke flavour’, ‘hospital aroma’, ‘dried meat flavour’ and ‘ashy palate’ when compared to other wines (Figure 16 and 17) (Kennison et al. 2012a). In the high smoke density for short duration study, the smoke related wine characteristics of ‘dried meat flavour’, ‘smoke aroma’, ‘smoke flavour’ and ‘ashy palate’ were elevated in wines made from fruit of grapevines exposed to 20% obs/m smoke for 20 min (Figure 6). In comparison, all other wines in this study contained lower concentrations of the smoke related aroma and flavour sensory attributes.

Wines produced from the low smoke density for long durations experiment contained variable levels of both smoke and wine related aroma and flavour characteristics which were dependent on the duration of smoke exposure. Wines made from fruit of vines exposed to 2.5% obs/m smoke for 80 minutes contained the highest intensity of the smoke related characteristics of ‘ashy palate’, ‘dried meat flavour’, ‘smoke aroma’ and ‘smoke flavour’ than any other wine (Figure 17). All other wines produced from grapes exposed to 2.5% obs/m smoke for 10, 20 and 40 minutes contained less smoke-related aromas than wines produced from 2.5% obs/m smoke for 80 minutes and less wine-related aromas (‘red berry flavour’ and ‘red berry aroma’) than the unsmoked (control) wine. From these results it is evident that a clear relationship exists between the duration and density of smoke exposure and the accumulation of smoke-related compounds and sensory attributes in wines. In particular the length of smoke exposure has demonstrated a cumulative effect on smoke related characters in wine. This cumulative effect of smoke exposure has also been demonstrated in our earlier research (Kennison et al. 2009).

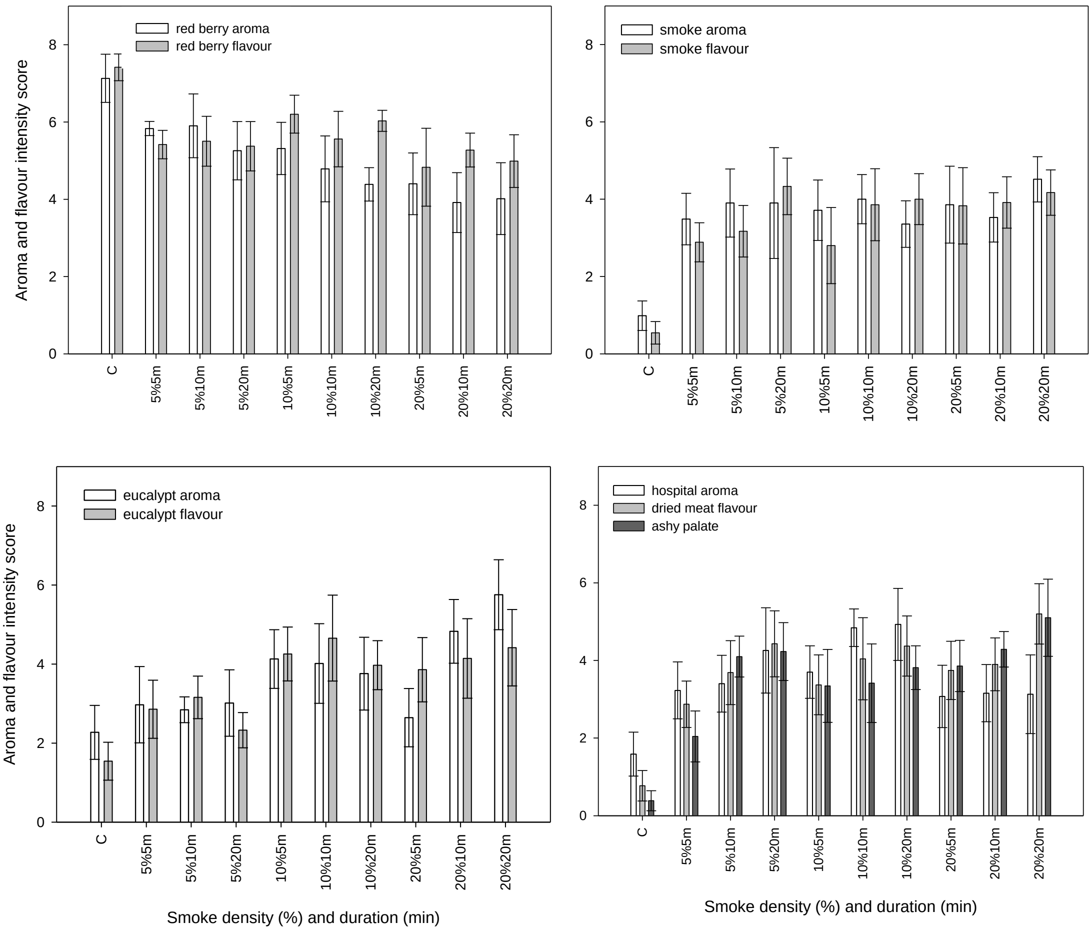


Figure 16. Mean intensity scores for 'red berry aroma', 'red berry flavour', 'smoke aroma', 'smoke flavour', 'eucalypt aroma', 'eucalypt flavour', 'hospital aroma', 'dried meat flavour' and 'ashy palate' for wines made from grapes of vines exposed to either 5, 10 or 20% obs/m smoke for either 5, 10 or 20 min and wines made from unsmoked grapes (control). Scale represents 0 = non-detectable to 8 = highly detectable aroma or flavour. Error bars indicate two standard errors of the mean (Kennison et al. 2012a).

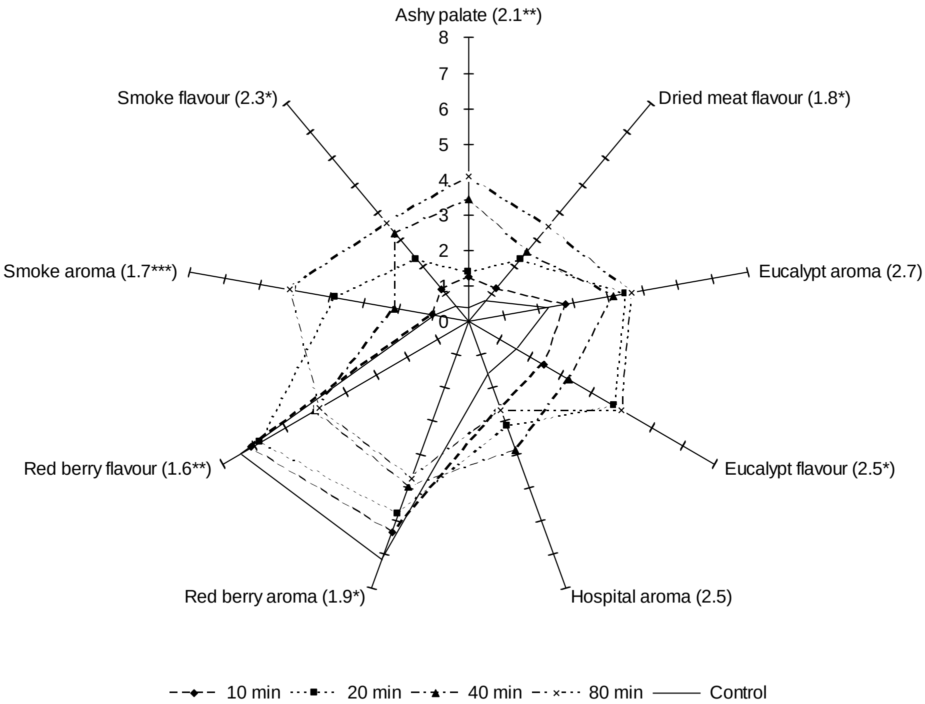


Figure 17. Mean intensity ratings of smoke related characteristics of 'smoke aroma', 'smoke flavour', 'ashy palate', 'dried meat flavour', 'hospital aroma' and wine related characteristics of 'red berry flavour', 'red berry aroma', 'eucalypt aroma' and 'eucalypt flavour' in wines made from fruit of grapevines exposed to 2.5% obs/m smoke for 10, 20, 40 or 80 min and wines made from unsmoked grapes (control). Scale represents 0 = non-detectable to 8 = highly detectable aroma or flavour. LSD is indicated in parenthesis with significance at $*P < 0.05$, $**P < 0.01$ and $***P < 0.001$ (Kennison et al. 2012a).

Results from the density and duration study have provided a better understanding of the implications of atmospheric smoke deposition on grapevines. In summary, the research has shown that exposure of vines to a high smoke density and / or for long durations accentuated smoke-related chemical and sensory attributes in wine. This has a further application for practical use for interpretation of smoke effects in-field. That is, field-based smoke detecting equipment (such as nephelometers) could be used to detect the density and duration of smoke exposure. From our current work, smoke detection in-field is useful as a tool to understand whether a smoke event has been of sufficient duration and density to create potential smoke taint in wine. This work is currently in further development by DAFWA.

4.1.2 Smoke Effects on Key Grapevine Varieties

During this project, field-based research was initiated to gain a further understanding of smoke effects on a range of grapevine varieties. As such, smoke was applied to separate grapevine treatments at the growth stages of berries pea size, veraison, veraison plus seven days and harvest to elucidate the effect on the chemical and sensory properties of wine. As the majority of previous field-based smoke exposure work had been conducted on Merlot, this current work focused on Cabernet Sauvignon, Chardonnay and Sauvignon Blanc.

Cabernet Sauvignon, Chardonnay and Sauvignon Blanc wines showed variation in their accumulation of smoke-related chemical and sensory characteristics. This variation was dependent on the timing of smoke exposure. Cabernet Sauvignon wines displayed a large range in guaiacol concentration, from 0 µg/L to 123 µg/L, when compared to the white wines of Chardonnay (0 to 2 µg/L) and Sauvignon Blanc (0 to 7.3 µg/L) (Figure 18) (Kennison et al. 2012b). The accentuated concentrations of guaiacol in Cabernet Sauvignon wines may be due to the winemaking style. That is, the fermentation of Cabernet Sauvignon grapes involved juice and skin contact (red winemaking method), whereas the fermentation of Chardonnay and Sauvignon Blanc juice followed the white winemaking methodology that did not contain berry skins. Wines made from Cabernet Sauvignon grapes also showed heightened levels of guaiacol from the smoke application at berries pea size (123 µg/L), whereas Chardonnay and Sauvignon Blanc wines had the highest concentration of guaiacol from a smoke application at harvest, that was 2 and 7.3 µg/L respectively (Figure 8).

Previous investigations of the phenological timing of smoke applications have identified three key periods of Merlot sensitivity to smoke uptake. The first period of sensitivity, of grapevine shoots at 10 cm in length through to full bloom, found low levels of smoke uptake and taint development in resultant wines (Kennison et al. 2011). The second period, from berries at pea size through to the onset of veraison, resulted in variable levels of smoke taint in wine with the third period, from seven days post veraison to harvest, resulting in a high level of grapevine sensitivity to smoke uptake and taint development in wine (Kennison et al. 2011). The average guaiacol concentrations in wine for these periods was 1.0 µg/L in period 1, 21.4 µg/L in period 2 and 48.9 µg/L in period 3 (Kennison et al. 2011). Our current research investigating smoke effects on other grapevine varieties has not followed the trends demonstrated by Merlot. As such, all wines produced from grapes of white varieties (Chardonnay and Sauvignon Blanc) contain significantly lower levels of guaiacol. Also, the red wines, Cabernet Sauvignon, are heightened in smoke uptake at berries pea size which, according to the Merlot research, would coincide with the ‘variable period’ (period 2) and not the ‘high sensitivity period’ (period 3). The average guaiacol concentration in Cabernet Sauvignon wines in period 2 is 88.8 µg/L a four-fold increase on that described by previous Merlot studies, however the average guaiacol concentration in Cabernet Sauvignon wines for period 3 is 51 µg/L which is comparable to the same period for the Merlot study being 48.9 µg/L.

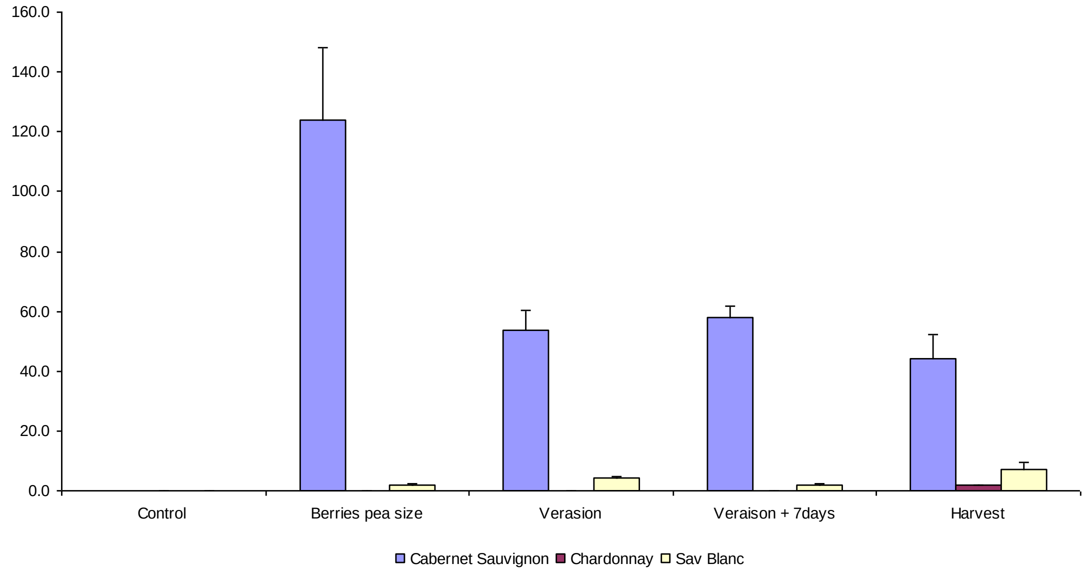


Figure 18. Detection of guaiacol (µg/L) in Cabernet Sauvignon, Chardonnay and Sauvignon Blanc wines made from fruit of vines exposed to smoke at berries pea size, veraison, veraison plus 7 days, harvest and associated control (unsmoked) wines. Error bars indicate data standard deviation (Kennison et al. 2012b).

Sensory analysis of wines was conducted by Quantitative Descriptive Analysis by a trained panel. During training the panellists identified a range of aromas and flavours that contribute to both the wine-related and smoke-related characteristics in Cabernet Sauvignon, Chardonnay and Sauvignon Blanc wine. In Cabernet Sauvignon wines panellists identified the wine-related aromas and flavours of 'red berries' and 'mint' and the smoke-related aromas of 'hospital', 'smoke' and flavours of 'ashy' and 'dried meat' (Table 2). Wine-related aromas of 'peach', 'spice' and 'straw' were isolated by panellists in Chardonnay wines with flavours of 'spice', 'lemon' and 'acid'. Smoke-related aromas of 'rubber' and 'disinfectant' with flavours of 'ash' and 'burnt' were further used to describe smoke tainted Chardonnay wines. 'Banana' and 'tropical' aromas with 'capsicum', 'lime' and 'acid' flavours were used to describe wine-related characters in Sauvignon Blanc wines whilst the smoke-related aromas of 'ash', 'sweaty socks' and flavours of 'ash' and 'charred' were also identified by panellists.

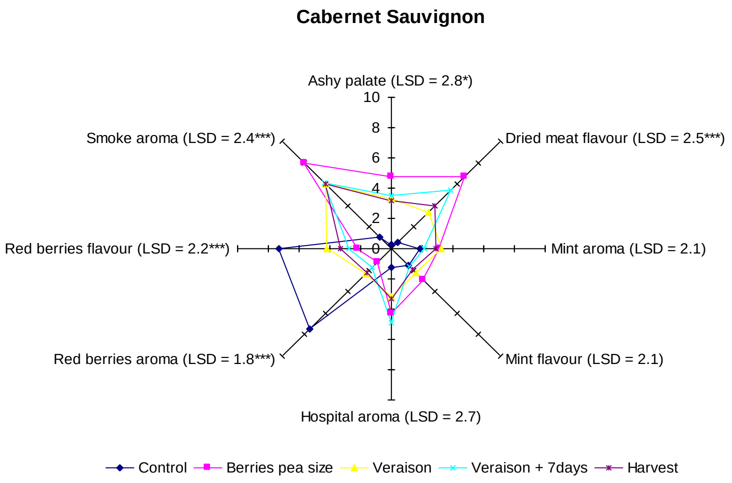
Table 2. Wine-related and smoke-related aroma and flavour characteristics of wines made from fruit of Cabernet Sauvignon, Chardonnay and Sauvignon Blanc grapes exposed to smoke and their associated unsmoked (control) wines. Aromas and flavours were identified by panellists during wine sensory analysis training (Kennison et al. 2012b).

	Wine-related		**Smoke-related**	
	aromas	**flavours**	**aromas**	**flavours**
Cabernet Sauvignon	red berries	red berries	hospital	ashy
	mint	mint	smoke	dried meat
Chardonnay	peach	spice	rubber	ash
	spice	lemon	disinfectant	burnt
	straw	acid		
Sauvignon Blanc	banana	capsicum	ash	ash
	tropical	lime	sweaty socks	charred
		acid	smoke	

During the testing phase of wine sensory analysis, panellists ranked the identified aromas and flavour characteristics on an unstructured line scale and, in general, they found these aromas and flavours to differ greatly between the smoke timing treatments. Panellist responses have been represented in cobweb graphs that show the components of both the smoke-related and wine-related characteristics for each wine (Figure 9). Cabernet Sauvignon unsmoked (control) wines were distinguished by their accentuated 'red berries' flavour (7.3) and aroma (7.5) with wines produced from the berries pea size treatment displaying heightened concentrations of 'smoke aroma' (8), 'ashy palate' (4.7) and 'dried meat flavour' (6.7) that further dominated the wine-related characters of 'red berries' aroma (1.3) and 'red berries' flavour (2.2). Wines produced from unsmoked (control) Chardonnay fruit predominantly contained 'peach' (7.5) aromas with 'acid' (8) and 'lemon' (9.1) flavours whereas wines produced from the harvest smoke treatment contained heightened 'ash' (7.3) and 'burnt' (6.6) flavour characters. Interestingly, Chardonnay wines produced from the veraison treatment also displayed heightened 'disinfectant' (6.7), 'rubber' (4.4) and 'straw' (7.3) aromas with a 'burnt' (6.8) flavour. Control (unsmoked) wines produced from Sauvignon Blanc grapes displayed the highest concentrations of 'tropical' (6.9) and 'banana' aromas that was in contrast to the wines produced from the smoke treatment at veraison that showed accentuated aromas of 'ash' (7), 'smoke' (6.8) and 'sweaty socks' (3.5) and flavours of 'ash' (5.6) and 'charred' (3.5) (Figure 19) (Kennison et al. 2012b).

A substantial difference in the smoke-related chemical and sensory properties in wines of Cabernet Sauvignon, Chardonnay and Sauvignon Blanc grapes exposed to smoke at key growth stages has been demonstrated in this research. The mechanism for this difference is unknown and may be related to the mode of smoke uptake by vines and taint development in wine. Initially, the low levels of smoke-related compounds in Sauvignon Blanc and Chardonnay wines in comparison to Cabernet Sauvignon wines may be due to winemaking methodology. That is, Cabernet Sauvignon wines followed a red style winemaking procedure incorporating the berry skins during fermentation, whereas the white wine varieties were not fermented with skin contact. Other physiological factors may be of influence in the different varietal accumulation of smoke-related characteristics. These factors could include differences in varietal morphology. Little is known on the mode of uptake of smoke compounds by the grapevine however in a study utilising glasshouse grown vines Hayasaka et al. (2010b) demonstrated guaiacol assimilation by grapevine leaves, conjugation and translocation between leaves and grape berries. Albeit the rates of translocation were considered to be slow in this study (Hayasaka et al. 2010b). Further considerations for the variability in smoke uptake throughout the growth period, within and between varieties, may be related to the strength of source-sink relationships between the leaves and fruit (Ollat and Gaudillère 2000, Ollat et al. 2002) and physiological changes that occur during grape berry ripening (Coombe 1992). Further mechanisms are currently being investigated.

A



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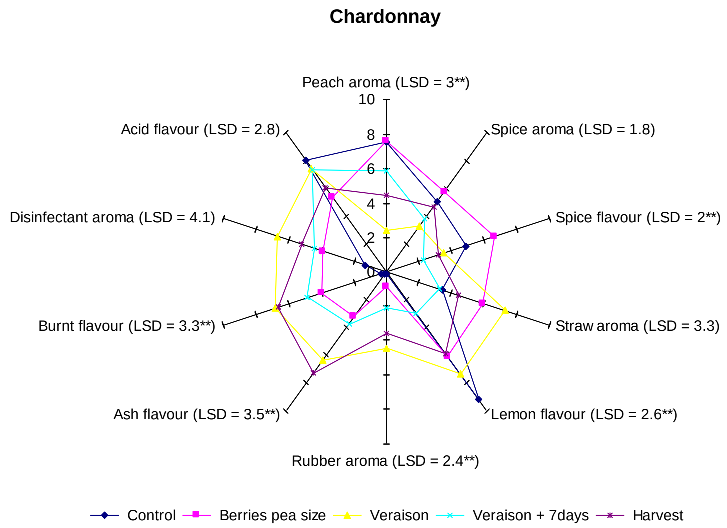

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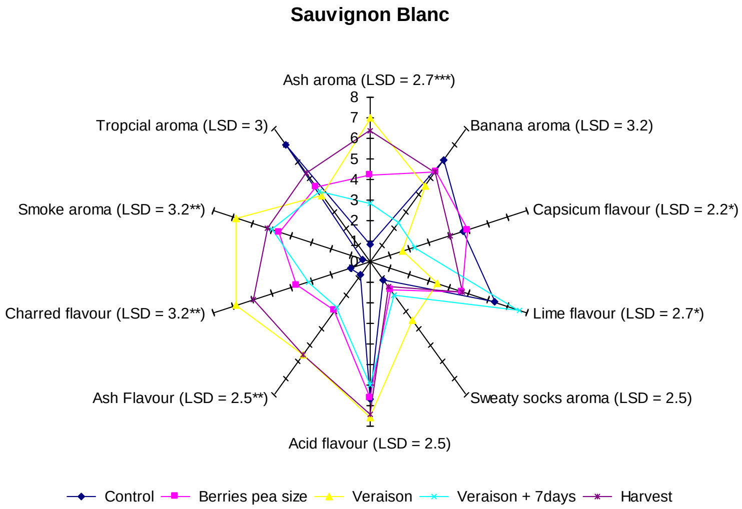


Figure 19. Cobweb graph of wine-related and smoke-related aroma and flavour characteristics of (A) Cabernet Sauvignon, (B) Chardonnay and (C) Sauvignon Blanc wines made from smoked and unsmoked (control) fruit. LSD (Least Significant Difference) is indicated at significance levels of * *P*<0.05, ** *P*<0.01, *** *P*<0.001 (Kennison et al. 2012b).

4.1.3 Influence of Smoke Produced from a Range of Fuel Types

4.1.3.1 Fuel Analysis

The fuels used in this study had large differences in their lignin and monolignol content (Table 3). The oats fuel contained the lowest lignin at 7.8%, the pine fuel the highest at 44.5% and the three hardwood fuels averaged 26%. The monolignol content of the fuels also had large differences. In particular the pine fuel had no syringyl lignin units and contained 78.2% guaiacyl units.

Table 3: Lignin and monolignol percentage composition. (nd, not detected)

		Percentage monolignols		
Fuel	Lignin Percentage	*p*-Hydroxy phenyls	Guaiacyls	Syringyls
Jarrah	29.3	20.0	39.0	41.0
Karri	23.5	15.5	32.8	51.7
Marri	24.9	8.1	41.7	50.2
Oats	7.8	10.2	70.0	19.8
Pine	44.5	21.8	78.2	nq

4.1.3.2 Smoke Analysis

The smoke emissions in each of the fuels contained a range of lignin derived phenols with relatively high levels of phenol derivatives including phenol and the three cresols. Guaiacol was the dominant phenol of the guaiacyl derivatives in each of the fuel emissions (data not shown). As expected, while the four angiosperm fuels contained syringol derivatives the emissions from the pyrolysis of pine fuel had no syringyl compounds.

4.1.3.3 Wine Analysis

Smoke exposure from each of the fuel types significantly increased the total concentrations of lignin derived compounds in wine compared to the unsmoked (control) wines. This increase varied from 74% in karri fuel to 146% in the wild oats (Table 4). Each class of monolignol derived taint compounds was also significantly elevated compared to the control. This included a significant elevation of syringol derivatives in the pine smoked wines, a fuel with no sinapyl monolignol monomers and no syringyl derivatives in its smoke. While guaiacol and 4-methylguaiacol have typically been used as indicators of taint accumulation in wine, the syringyl derivatives accounted for 54% to 78% of the total taint in the smoke replicate wines (see Table 4). The total glycoside bound taint compounds were also significantly higher (more than 2.8 times) for each of the treatments in each of the lignin derived classes of compounds and the total free taint phenols were nearly double the level found in the controls. After 19 months of bottle storage time, the phenol and guaiacol derivatives were predominantly glycosidically bound whereas the syringol derivatives were predominantly in a free form (61%-78%). The wild oats smoked wines were significantly higher in total taint compounds than the pine smoked wines despite having less than 8% total lignin compared to the 44.5% lignin in the pine fuel.

Table 4: Effects of fuel type on volatile, glycosidically bound and total phenol levels (µg/l) in Merlot wines after 19 months of bottle storage.

Treatment	Control	Jarrah	Karri	Marri	Oats	Pine
p-Hydroxy-phenyl						
Volatile	5.5	23.1	14	31.8	41.9	28.6
Bound	36.6	92.3	77.7	137.8	131.6	118.2
Total	**42.1**	**115.4**	**91.7**	**169.6**	**173.5**	**146.8**
Guaiacyl						
Volatile	4.6	23.7	11.7	29.8	50.5	33.4
Bound	22.7	69.8	65	96.6	127.4	124.4
Total	**27.3**	**93.5**	**76.7**	**126.4**	**177.9**	**157.8**
Syringyl						
Volatile	169.2	287.1	227	302.6	301.7	317.9
Bound	72.3	162	144.9	131.5	111.5	88.4
Total	**241.5**	**449.1**	**371.9**	**434.1**	**413.2**	**406.3**
Total taint	**310.9**	**658.0**	**540.3**	**730.1**	**764.6**	**710.9**

4.1.3.4 Analysis of metal concentrations in wine

The analysis of 39 different metal elements found concentrations of 20 elements above the limits of quantification in the replicate wines. No element concentrations were found to be significantly elevated in the smoke treatment wines when compared to the unsmoked, control wines. As wildfire smoke has been reported to contain a number of metal elements (Alves et al., 2010), the analysis was used to investigate if the metallic sensory descriptor reported by Ristic (2011) was possibly caused by an accumulation of metals in smoke tainted wines. The results, however, showed no evidence that smoke exposure elevates concentrations of metal elements in wines.

4.1.3.5 The effect of malolactic decarboxylation on putative taint concentrations.

In collaboration with Dr. Yoji Hayasaka of the Australian Wine Research Institute, a comparison of free and glycosidically bound lignin derived phenols was made on the wine replicates with and without malolactic fermentation. The concentrations of free and glycosidically bound taint compounds, as described by Hayasaka et al. (2010a), in the wines that underwent malolactic decarboxylation compared to the wines that did not, were inconclusive as were the ratios of free to glycosidically bound taint phenols. Further investigations into the effect of malolactic decarboxylation are underway.

4.1.3.6 The influence of fruit mass berry size and canopy leaf area on taint accumulation.

The concentrations of most of the total, free and glycosidically bound taint concentrations were negatively correlated to the canopy leaf area and the leaf area per bunch. A possible pathway for taint uptake is through foliar uptake with translocation and sequestration in the berries, however the negative correlation found here between taint and total replicate leaf area is contrary to this. The negative correlation suggests the uptake through the berries is most likely a significant contributor to the accumulation of taint in fruit.

4.2 Field Based Smoke Detecting Equipment

Three mobile nephelometers were employed in the Manjimup and Pemberton wine regions in 2011/12. They were based at a commercial vineyard in Pemberton, the DAFWA Horticulture Research Institute in Manjimup and with DEC to deploy during a prescribed burn.

The nephelometer in the commercial vineyard in Pemberton captured smoke data during 2011/12 season (Table 5). The smoke levels peaked during the Northcliffe bushfires from 12 to 22 February 2012. Highest levels were recorded on 21 February with smoke density 0.401 %/m for duration of 5hrs 18 min. Background levels between 0.004 and 0.064 %/m were recorded from October to the end of December 2011/12. These smoke density levels (up to 0.4%/m) were well below the lowest density used in our trials (2.5%/m) which resulted in smoke taint in wine. Grapes of three varieties (Chardonnay, Pinot Noir and Cabernet Sauvignon) were sampled from the vineyard on 20 and 27 February for analysis. The results (Table 6) indicate that grapes were below the threshold levels that cause smoke taint. The commercial vineyard was located within about 50 km northwest of the source of the fires.

Table 5. Smoke density and duration records (nephelometer) from commercial vineyard in Pemberton 2011/12

Date	Smoke duration	Smoke density (%/m)	
		High	Low
21-Feb-12	5hr 18min	0.401	0.035
20-Feb-12	5hr 54min	0.304	0.007
16-Feb-12	7hr 40min	0.151	0.092
15-Feb-12	8hr 57min	0.09	0.001
14-Feb-12	19hr 28min	0.104	0.004
13-Feb-12	3hr 52min	0.313	0.065
30-Dec-11		0.006	
28-Dec-11	6min	0.058	0.008
21-Dec-11		0.004	
11-Dec-11		0.004	
9-Dec-11		0.004	
2-Dec-11	2min	0.064	0.014
15-Nov-11		0.005	
7-Nov-11		0.004	
2-Nov-11	3hr 50min	0.057	0.007
22-Oct-11		0.005	
21-Oct-11		0.055	
14-Oct-11		0.005	
8-Oct-11	7hr 3 min	0.059	0.111
5-Oct-11		0.065	

Table 6. Analysis of volatile phenols in grapes sampled from commercial vineyard in Pemberton 2012.

Variety	Sample date	4-Methylguaiacol	Guaiacol	m-Cresol	Methyl Syringol	o-Cresol	p-Cresol	Syringol
Pinot Noir	20/2/12	nd	2	nd	nd	3	nd	nd
Pinot Noir	27/2/12	nd	2	nd	nd	3	nd	nd
Cab Sauv	20/2/12	nd	nd	nd	nd	nd	nd	nd
Cab Sauv	27/2/12	nd	1	nd	nd	2	nd	nd
Chardonnay	20/2/12	nd	nd	nd	nd	1	nd	nd
Chardonnay	27/2/12	nd	nd	nd	nd	nd	nd	nd

nd=not detected

The nephelometer at DEC was not deployed due to a decrease in prescribed burning activity. The nephelometers are undergoing further field trials.

In a case study, grapes were sampled from another 8 vineyards at various distances from the Northcliffe fire. Grapes were sampled within 2 weeks of harvest on 21 and 27 of March depending on variety. Grape and bench top ferment wine samples were analysed for volatile and bound phenols. The results (Table 7a, b) indicate that the levels were generally greater in the red varieties compared to white. The results have been colour coded to indicate whether the levels are below, borderline or above the typical background levels. The following varieties and vineyards had grape and/or bench top ferment wine samples which exceeded typical background levels for some of the smoke compounds: Shiraz (Vineyards 1 and 3), Cabernet Sauvignon (Vineyards 2 and 8), Chardonnay (Vineyards 3 and 5) and Sauvignon Blanc (Vineyard 6). These levels may cause perceptible taint in the resultant wines. The commercial wines from these grapes have not been sampled for analysis to date.

4.3 Regional Grapevine Phenology Study

4.3.1 Historical phenology record

The historic phenological records collected (Table 8) spanned 1995 to 2011 from 28 vineyards across 5 regions (Great Southern, Pemberton, Margaret River, Geographe, and Swan Districts). The observations represented 17 varieties (Chardonnay, Sauvignon Blanc, Chenin, Semillon, Rousanne, Marsanne, Viognier, Verdelho, Viognier, Merlot, Malbec, Shiraz, Cabernet Franc, Cabernet Sauvignon, Zinfandel, Petit Verdot, Grenache, Muscado) and 252 separate blocks of varieties and clones. All records were from vines grown on their own roots and irrigated. The frequency of recordings and number of growth stage observations varied considerably between vineyards, varieties and years. The number of phenology stages recorded by vineyards ranged from 7 to 19. A total of 8,500 observations were recorded. The most common phenological stages recorded were budburst (E-L4), beginning of flowering (E-L19), flowering at 50% cap-fall (E-L21), flowering at 80% cap-fall (E-L25), bunch closure (E-L32), veraison (E-L35) and berries ripe for harvest (E-L38).

Table 7a. Analysis of volatile phenols in grapes and bench top ferment samples from commercial vineyards in Pemberton 2012. Results are colour coded to indicate whether the levels are below (green), borderline (yellow) or above (pink) the typical background levels measured by AWRI over 2010 and 2011. Merlot and Sauvignon Blanc results use baseline data for Cabernet Sauvignon and Riesling respectively as base line data was not available for these varieties.

Variety	Vineyard	Distance from fire	4-MGu		Gu		m-Cr		4-MSy		o-Cr		p-Cr		Sy	
			Grapes	Wine	Grapes	Wine	Grapes	Wine	Grapes	Wine	Grapes	Wine	Grapes	Wine	Grapes	Wine
Shiraz	V1	8km	1	3	9	19	0	0	0	1	4	3	0	1	0	6
	V3	20km	0	1	3	13	0	0	0	0	1	2	0	0	0	3
	V7	36km	0	0	2	9	0	0	0	0	0	1	0	0	0	1
Merlot	V2	30km	0	1	0	3	0	0	0	0	0	1	0	0	0	2
	V4	21km	0	1	0	3	0	0	0	0	0	0	0	0	0	1
	V7	36km	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	V8	35km	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cabernet Sauvignon	V2	30km	0	0	2	4	0	0	0	0	3	3	0	0	0	3
	V5	28km	0	0	1	2	0	0	0	0	2	2	0	0	0	3
	V7	36km	0	0	1	2	0	0	0	0	1	2	0	0	0	3
	V8	35km	0	0	2	3	0	0	0	0	2	3	0	0	0	4
Chardonnay	V3	20km	0	0	0	1	0	0	0	0	2	0	0	0	0	0
	V5	28km	0	0	0	0	0	0	0	0	2	0	0	0	0	0
Sauvignon Blanc	V5	28km	0	0	0	0	0	0	0	0	1	0	0	0	0	0
	V6	36km	0	0	2	1	0	0	0	3	2	0	0	0	0	0

4-MGu = 4-methylguaiacol: GU=Guaiacol; m-Cr=m-Cresol; 4-MSy=Methyl Syringol; 0-Cr=0-Cresol; p-Cr=p-Cresol; Sy=Syringol

Table 7b. Analysis of bound phenols in grapes and bench top ferment samples from commercial vineyards in Pemberton 2012

Variety	Vineyard	Distance from fire	SyGG		MSyGG		PhRG		CrRG		GuRG		MGuRG		Total	
			Grapes	Wine	Grapes	Wine	Grapes	Wine	Grapes	Wine	Grapes	Wine	Grapes	Wine	Grapes	Wine
Shiraz	V1	8km	167.9	83.1	52.4	14.6	6.4	9.2	13.9	16.0	9.1	14.4	12.4	15.1	262.1	152.4
	V3	20km	94.2	26.7	18.6	2.6	8.4	11.8	20.3	17.9	9.8	13.6	11.4	10.7	162.8	83.2
	V7	36km	45.9	17.0	7.9	1.7	4.1	6.4	9.8	9.3	4.7	6.3	5.0	4.4	77.5	45.1
Merlot	V2	30km	37.2	11.5	7.9	0.8	3.4	4.1	7.5	6.7	2.6	2.0	4.3	2.8	62.8	27.9
	V4	21km	67.3	54.7	12.7	8.4	6.8	18.2	12.3	24.6	5.0	9.9	6.8	11.3	110.9	127.2
	V7	36km	33.1	na	5.2	na	3.6	na	8.4	na	2.5	na	3.8	na	56.6	na
	V8	35km	31.6	na	5.3	na	2.4	na	5.7	na	2.3	na	3.3	na	50.4	na
Cabernet Sauvignon	V2	30km	26.9	12.9	3.6	0.8	3.8	6.4	7.2	6.8	3.3	4.4	3.1	2.6	47.9	33.8
	V5	28km	15.0	8.2	2.1	0.6	4.1	5.7	5.9	5.2	2.2	2.8	1.8	1.6	31.1	24.1
	V7	36km	18.9	8.0	2.3	0.4	3.6	4.6	5.7	3.7	2.2	2.3	1.8	1.0	34.5	20.1
	V8	35km	34.9	18.3	4.6	2.3	5.1	6.4	7.7	10.0	3.6	6.0	3.0	4.0	59.0	47.0
Chardonnay	V3	20km	32.5	2.1	6.0	0.1	6.9	2.3	13.5	3.3	3.6	0.7	4.9	1.2	67.3	9.7
	V5	28km	23.1	6.8	7.2	0.4	13.7	7.6	11.0	7.3	8.3	2.9	3.3	1.4	66.7	26.5
Sauvignon Blanc	V5	28km	8.4	3.0	1.5	0.2	2.0	1.6	4.2	1.9	1.0	0.5	1.5	0.6	18.6	7.8
	V6	36km	17.2	4.0	4.9	0.3	6.1	0.7	8.8	0.3	5.5	0.1	3.8	0.2	46.3	5.6

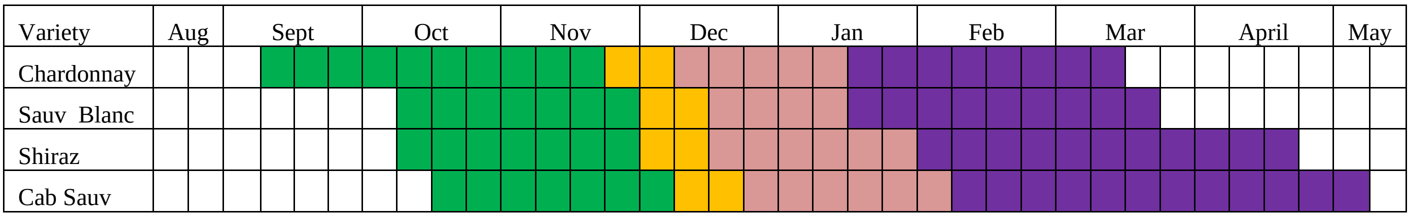
GG=Syringol glucosylglucoside; MSyGG= Methyl Syringol glucosylglucoside; PhRG=Phenol rutinoside; CrRG=Cresol rutinoside; GuRG=Guaiacol rutinoside; MGuRG=4-methylguaiacol rutinoside; Total=Total glycocongugates (bound forms of the smoke compounds)

Table 8. Description of historical phenological records by region, vineyard, years, varieties and number of vineyard blocks or clones collected in the database

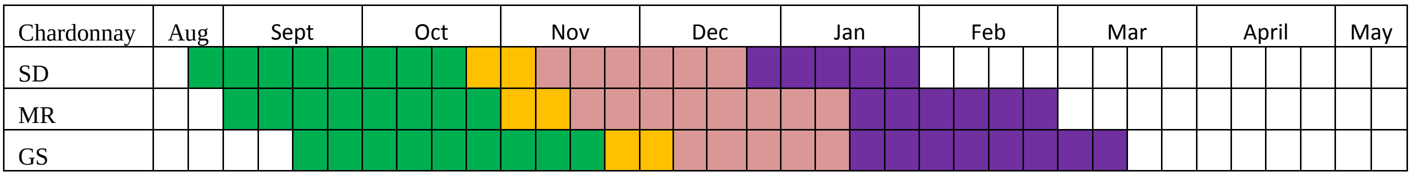
Region	Vineyard	Years	Phenological stages	Variety (No Blocks or Clones)
Great Southern	1	2002-2011	E-L: 4, 12, 19, 23, 25, 31, 32, 34, 38	Chardonnay (1), Sauvignon Blanc (1), Shiraz (1), Cabernet Sauvignon (1)
	2	2008 - 2011	E-L: 4, 9, 12, 15, 17, 19, 23, 25, 27, 29, 31, 32, 33, 35, 36	Semillon (1), Shiraz (1), Cabernet Sauvignon (1)
	3	2008 - 2011	E-L: 1, 9, 12, 15, 19, 21, 23, 31, 32	Chardonnay (1), Sauvignon Blanc (3), Semillon (2)
Pemberton	4	2002 - 2011	E-L: 4, 23, 31, 32, 35, 38	Chardonnay (1), Sauvignon Blanc (1), Semillon (1), Merlot (1)
	5	2000 - 2011	E-L: 4, 23, 31, 32, 35, 38	Chardonnay (1), Semillon (1), Shiraz (1)
	6	1995 - 2011	E-L: 4, 23, 31, 32, 35, 38	Chardonnay (1), Pinot Noir (1), Merlot (1), Cabernet Sauvignon 1)
	7	1997 - 2011	E-L: 4, 19, 25, 31, 32, 35, 38	Chardonnay (7), Pinot Noir (1), Semillon (1), Verdelho (1), Sauvignon Blanc (7), Merlot (2), Shiraz (2), Cabernet Sauvignon (1)
	8	2008 - 2011	E-L: 4, 9, 12, 13, 15, 16, 17, 18, 19, 25, 29, 31, 32, 33, 34	Chardonnay (2), Verdelho (2), Sauvignon Blanc (4), Semillon (1), Cabernet Sauvignon (2)
Margaret River	9	2006 - 2001	E-L: 4, 12, 19, 23, 25, 31, 32, 35, 38	Chardonnay (4), Merlot (3), Petit Verdot (4), Malbec (1), Shiraz (1), Cabernet Sauvignon (3), Muscato (2)
	10	2002 - 2011	E-L: 4, 12, 19, 23, 25, 31, 32, 35, 38	Chardonnay (1), Sauvignon Blanc (1), Semillon (1), Merlot (1), Shiraz (1), Cabernet Sauvignon (1)
	11	2008 - 2011	E-L: 3, 4, 5, 8, 11, 12, 13, 14, 15, 19, 21, 23, 25, 27, 31, 32, 33, 34, 38	Chardonnay (2), Sauvignon Blanc (5), Semillon (5), Chenin (1), Shiraz (1), Cabernet Franc (2), Merlot (1), Cabernet Sauvignon (1)
	12	2008 - 2011	E-L: 4, 5, 6, 7, 9, 10, 12, 14, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 29, 30, 31, 32, 33, 34, 35, 36	Chardonnay (3), Merlot (2), Semillon (1), Sauvignon Blanc (3), Shiraz (1), Cabernet Sauvignon (3)
	13	2008 - 2010	E-L: 7, 9, 10, 11, 12, 14, 15, 16, 17, 18, 20, 21, 22, 23, 24, 26, 27, 29, 30, 31, 32, 33, 35	Chardonnay (4), Semillon (4), Merlot (1), Sauvignon Blanc (3)
	14	2008 - 2011	E-L: 2, 3, 4, 9, 15, 17, 18, 19, 21, 23, 25, 28, 29, 31, 31, 32, 33, 34, 35	Chardonnay (3), Sauvignon Blanc (3), Semillon (4), Cabernet Sauvignon (2)
	15	2009 - 2010	E-L: 7, 9, 11, 13, 14, 16, 17, 18, 19, 20, 2325, 27, 29, 31, 37,	Chardonnay (1), Sauvignon Blanc (1), Semillon (1), Merlot (1), Cabernet Sauvignon (1)
	16	2007 - 2011	E-L: 7, 8, 9,10, 11, 12, 14, 15, 17, 18, 19, 20, 25, 27, 28, 31, 32, 33, 34, 35	Semillon (1), Rousanne (1), Marsanne (1), Sauvignon Blanc (1), Chardonnay (1), Viognier (1), Verdelho (1), Merlot (1), Shiraz (1), Cabernet Franc (1), Cabernet Sauvignon (1), Zinfandel (), Petit Verdot (1), Grenache (1)
	17	2008 - 2011	E-L: 4, 6, 12, 14, 18, 19, 20, 21, 22, 23, 25, 25, 27, 29, 30, 31, 32, 33, 34, 35, 36.	Chardonnay (3), Sauvignon Blanc (3), Semillon (1), Merlot (2), Shiraz (1), Cabernet Sauvignon (3).
	18	2008 – 2011	E-L: 10, 12, 14, 16, 18, 19, 20, 21, 23, 25, 28, 29, 30, 31, 32, 33, 34, 35, 36.	Chardonnay (3), Sauvignon Blanc (3), Semillon (4), Cabernet Sauvignon (2)
	19	2008 - 2011	E-L: 3, 4, 9, 12, 15, 17, 19, 21, 23, 25, 28, 29, 30, 31, 32, 33, 34, 35, 36.	Chardonnay (3), Sauvignon Blanc (3), Semillon (4), Cabernet Sauvignon (2)
	20	2008 - 2011	E-L: 7, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 23, 25, 26, 27, 29, 31, 32, 33.	Chardonnay, Sauvignon Blanc, Semillon, Merlot, Cabernet Sauvignon.
Geographe	21	2008 - 2011	E-L: 4, 7, 9, 11, 12, 14, 15, 17, 19, 21, 23, 25, 26, 27, 29, 31	Verdelho (1), Sauvignon Blanc (1), Semillon (1), Shiraz (1), Cabernet Sauvignon (1).
	22	2008 - 2011	E-L: 1, 3, 8, 9, 14, 15, 16, 19, 20, 21, 25, 27, 29, 31, 32, 33, 34.	Chardonnay (2), Sauvignon Blanc (3), Tempranillo (1), Semillon (7), Shiraz (4), Verdelho (2).
	23	2010 - 2011	E-L: 5, 12, 17, 27, 31, 32, 33, 34, 35.	Viognier (1)
Swan District	24	2010 - 2011	E-L: 9, 11, 12, 16, 19, 21, 23.	Chardonnay (7), Chenin (4), Verdelho (2), Shiraz, (1), Cabernet Sauvignon (3)
	25	2008 - 2011	E-L: 1, 4, 7, 11, 12, 18, 23, 27, 28, 29, 32, 33, 35, 36.	Chenin, Verdelho, Shiraz, Cabernet Sauvignon.
	26	2008 - 2010	E-L: 7, 11, 17, 19, 25, 29, 32, 33	Chardonnay, Verdelho, Chenin, Shiraz, Cabernet Sauvignon
	27	2010 - 2011	E-L: 4, 7, 9, 12, 19, 23, 31, 34	Chenin, Verdelho, Semillon
	28	2008 - 2011	E-L: 1, 7, 9, 17, 18, 19, 25, 29, 32, 33	Chardonnay (1), Chenin (1), Verdelho (1), Sauvignon Blanc (1), Semillon (1)

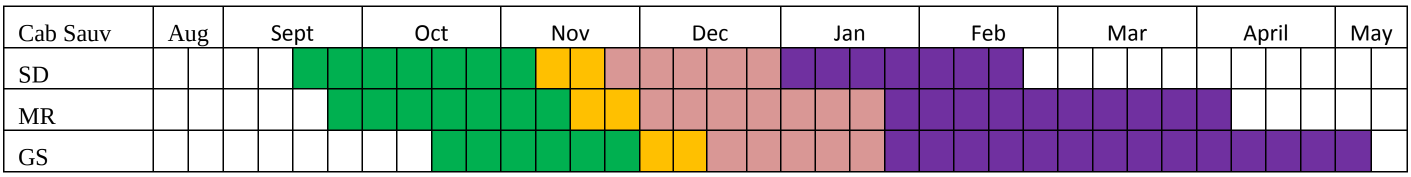
The information collected indicated the wide range in the timing of grapevine growth stages depending on varieties, regions and years (Figure 20a, b and c).

(a) Variety differences for Chardonnay, Sauvignon Blanc, Shiraz and Cabernet Sauvignon in the Great Southern 2003/04

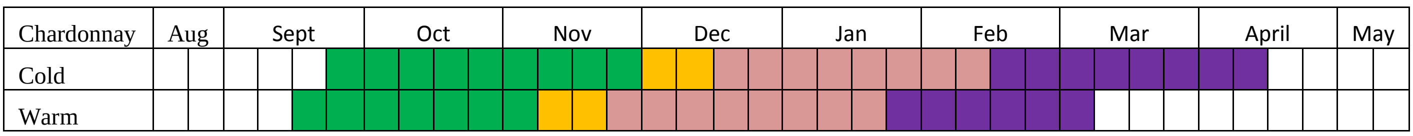


(b) Regional differences for the Swan Districts (SD), Margaret River (MR) and Great Southern (GS) for Chardonnay and Cabernet Sauvignon in 2004/05





(c) Seasonal differences for Chardonnay and Cabernet Sauvignon in a cold season (2005/06) and a warm season (2010/11) in the Great Southern region



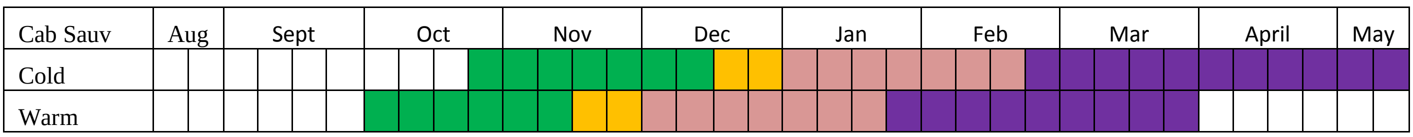
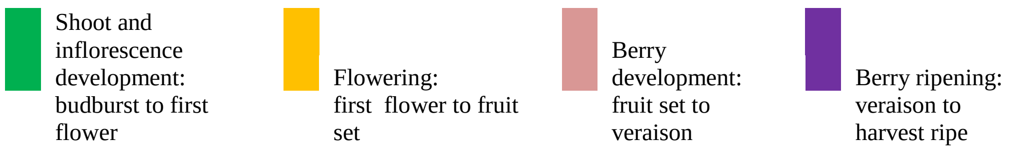


Figure 20. Variation in the timing of grapevine growth periods by variety (a), region (b) and season (c).



The results indicate that Chardonnay has the earliest budburst, flowering and harvest dates followed by Sauvignon Blanc, Shiraz and the latest Cabernet Sauvignon (Table 20a). There are significant differences between regions (Table 20b). In 2004/05 the start of the growing season (budburst) for Chardonnay is 1-2 weeks earlier than Margaret River and 3-4 weeks earlier than the Great Southern. These differences are extended considerable by the time of harvest. Chardonnay is harvested in the Swan 4-5 weeks earlier than Margaret River and 6-7 weeks earlier than the Great Southern. The differences in budburst dates between the regions for Cabernet Sauvignon are similar to Chardonnay but harvest dates are even further extended: 6-7 weeks later in Margaret River and 10-11 weeks in the Great Southern. Season also has a major influence on the timing of phenology in grapevines. The very cold season 2005/06 is compared to a very warm season 2010/11 in Table 20c. The differences in phenology timing between seasons are much greater for a longer growing season variety such as Cabernet Sauvignon. Bud burst was 3 - 4 weeks later and harvest by 6-7 weeks later for Cabernet Sauvignon in 2005/06 compared to 2010/11.

Only the most complete sets of data at the time of collection were used to calculate GDD to develop the phenology model. These data were from five vineyards with multiple blocks of varieties and clones in three regions (Great Southern, Pemberton and Margaret River). The observations corresponded to six varieties (Chardonnay, Sauvignon Blanc, Merlot, Cabernet Sauvignon, Shiraz and Pinot Noir) and 226 budburst (E-L4), 36 shoots at 10cm (E-L12), 166 flowering beginning (E-L19), 104 full bloom, 50% cap fall (E-L23), 170 flowering ends, 80% cap fall (E-L25), 52 fruit set, berries pea size (E-L31), 209 bunch closure (E-L32), 205 veraison, berries begin to soften (E-L 35). 231 berries harvest ripe (E-L38) and 92 harvest °Brix/°Baume observations, a total of 1399 phenology observations.

4.3.2 Regional Grapevine Phenology

4.3.2.1 Gingin

Gingin was the most northern and warmest of the sites. Grapevine phenological development for the three varieties assessed at Gingin (Chardonnay, Shiraz and Cabernet) was more advanced than the sites further south. Growth stages ranged from 4 and 12 leaves separated (E-L11 to 17) when observation began on 11 and 12 October. Grapevine growth stages were more variable earlier in the season and became more uniform as the season progressed (Figure 21).

Chardonnay was well advanced on the first assessment date with shoots ranging from E-L 14 to E-L 17. Growth stages ranged from E-L16 to 23 on 19 October and became more uniform throughout the growing season. Berries were harvest ripe (E-L 38) on 24 January 2012.

The growth stages in Shiraz ranged from 4 to 10 leaves separated (E-L11 to 16) on 11 October. Growth was relatively variable up to the beginning of flowering (E-L19) and became uniform for the remainder of the growth period. Berries were harvest ripe (E-L38) on 2 March 2012.

Grapevine growth in Cabernet Sauvignon at Gingin was highly uniform throughout the entire growing season except on the third sampling date where growth stages ranged from E-L 17 to 26. Berries were harvest ripe (E-L 38) on 23 February 2012.

4.3.2.2 Donnybrook

Of the three varieties (Sauvignon Blanc, Chardonnay and Shiraz) assessed at the Donnybrook site; Sauvignon Blanc was pruned in early October and this may have influenced phenological growth. Grapes from this vineyard were not harvested and therefore phenology recordings were completed on 7 February 2012 for all varieties (Figure 22).

At the first sampling date for Chardonnay the majority of vines were at E-L stage 9, following this a rapid period of growth occurred covering several E-L stages. On 15 November the majority of the shoots had progressed to the 80% cap fall stage (E-L 25) and distinct E-L stages were evident for the remainder of the season.

All Sauvignon Blanc shoots were at E-L stage 9 on 5 October. There was a large degree of variability in growth stages from this date until 9 January where the majority of vines were at E-L stage 33. The majority of the vines were at E-L 37 or berries not quite ripe based on °Brix recordings on the last sampling date. A total of 22 tagged shoots were lost during the season for this variety.

Shiraz growth was spread over four E-L stages for the first five assessment dates. Shoots ranged between 10 and 50% flowering on 15 November. Once cap fall was completed (E-L 26) on 22 November the majority of the vines were at the same stage. Based on °Brix recordings the Shiraz was at E-L 36 or E-L 37 at the final sampling date.

4.3.2.3 Margaret River

The Chardonnay shoots exhibited a range of E-L stages at the first three sampling times, spanning across at least seven stages (Figure 23). After 21 November the growth of the Chardonnay shoots were more uniform, as indicated by high and pronounced peaks, with harvest officially occurring on the 23 February. Only two of the tagged shoots were lost during the recording period.

The majority of Sauvignon Blanc shoots on 12 October were at E-L stage 9 (Figure 25). High variability occurred after this time until 28 November when the majority of the shoots were at E-L 26 or cap-fall complete. The fruit from these vines was not harvested so the growth of the vines continues in a uniform manner until E-L 39 or berries over-ripe. A total of nine shoots were lost during the season.

There was little variability in E-L stages with the Shiraz shoots for the first four assessments. On 28 November the majority of the shoots completed cap fall. Based on °Brix levels the progression of the berries remained on E-L 37 and E-L 38 for several weeks prior to being officially harvested on 26 March. A total of 22 tagged shoots were snapped off during the course of the season.

Cabernet shoots had relatively uniform growth until 14 November. On 19 December the majority of the shoots had progressed to the bunch closure stage. The tagged shoots remained on E-L 36 and 37 for several weeks during the ripening period before progressing. These vines were not harvested but Cabernet in a similar area was harvested on 28 March. A total of 24 tagged shoots were lost during the season.

4.3.2.4 Pemberton

Chardonnay exhibited a wide range of E-L stages (up to seven) for the first five sampling dates. The majority of the shoots underwent cap fall complete (E-L 26) on 22 November and this uniformity of phenology continued for the remainder of the season (Figure 24). The Chardonnay was officially harvested on 18 February.

Initial sampling dates of the Sauvignon Blanc showed a high level of uniformity. During the middle of the season there was variability in the number of each shoots at each E-L stage. From berry set (E-L 27) on 6 December uniformity returned and this continued until harvest on 28 February. A total of 24 shoots were snapped off during the season.

Shiraz vines showed a distinct prominent E-L stage for each sampling date except for the 22 November where the phenology covers E-L 17 (12 leaves separated) to E-L 21 (30% cap fall). Thirty-one shoots were snapped off during the course of the season. Official harvest date for the Shiraz was 27 February.

Cabernet initially exhibited uniform E-L stages but a high degree of variability occurred from the 15 November. In particular there were 13 E-L stages recorded on the 29 November where the various flowering stages were occurring. After flowering the E-L stages became more uniform before harvest occurred officially on 21 March. A total of 17 shoots were lost or snapped off during the season.

Figure 21: Grapevine growth stages (E-L) observed for Chardonnay, Shiraz and Cabernet Sauvignon in vineyard in Gingin during 2011/12.

Gingin

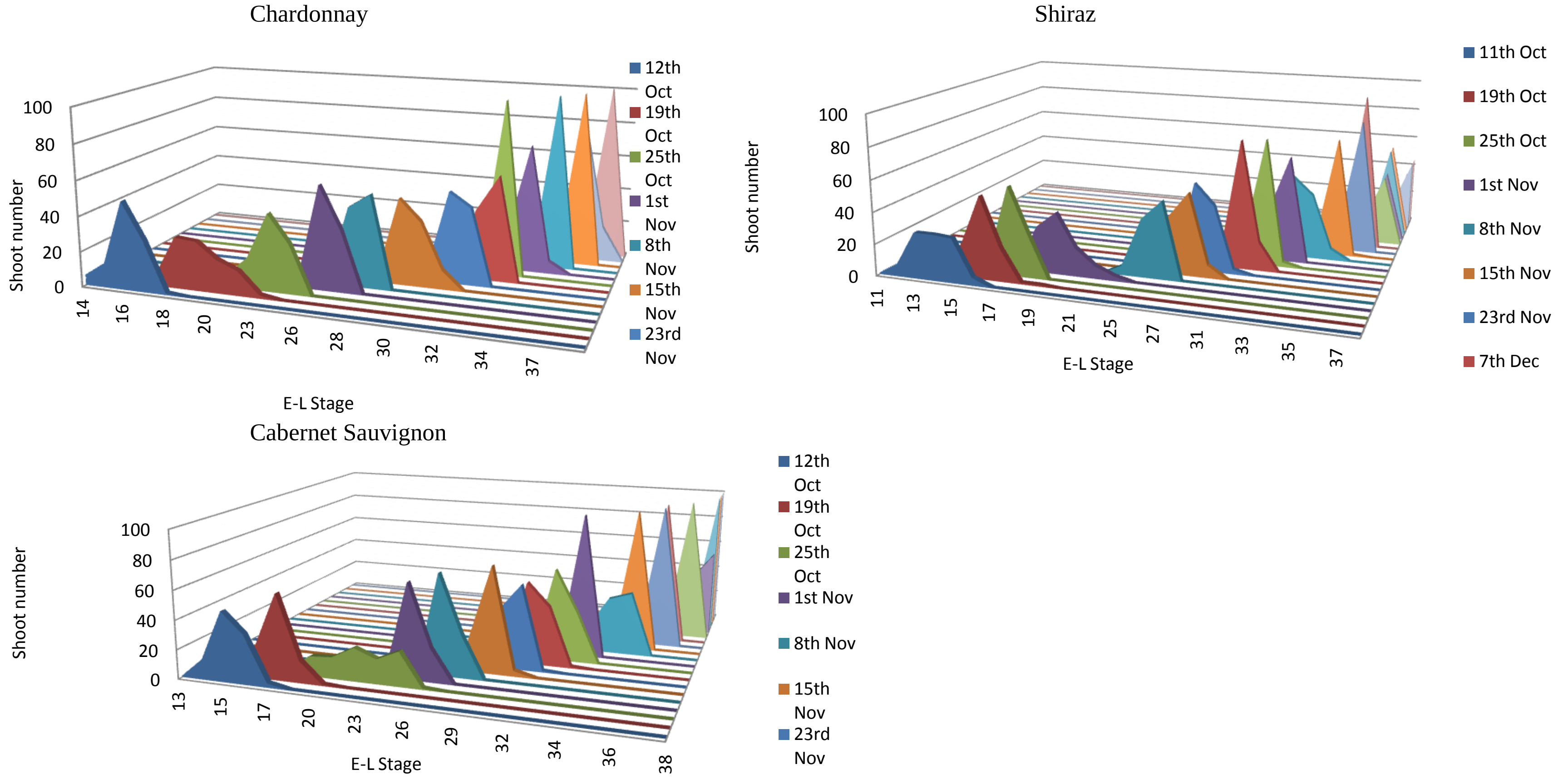
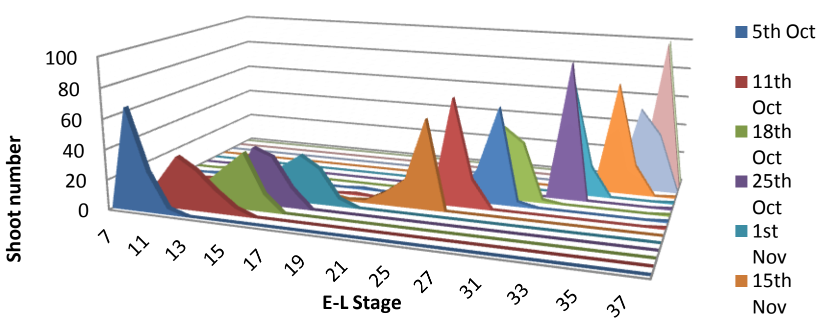
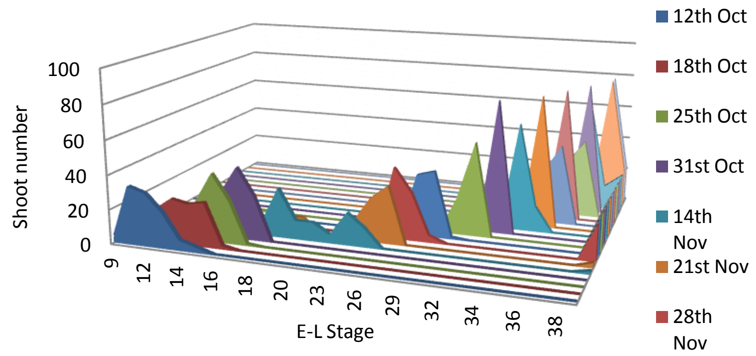


Figure 22: Grapevine growth stages (E-L) observed for Chardonnay, Shiraz and Sauvignon Blanc in vineyard in Donnybrook during 2011/12.

Chardonnay



Shiraz



Sauvignon Blanc

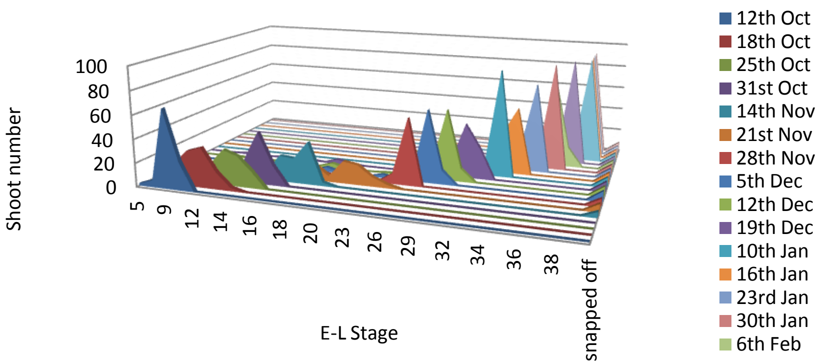


Figure 23: Grapevine growth stages (E-L) observed for Chardonnay, Shiraz, Sauvignon Blanc and Cabernet Sauvignon in vineyard in Margaret River during 2011/12.

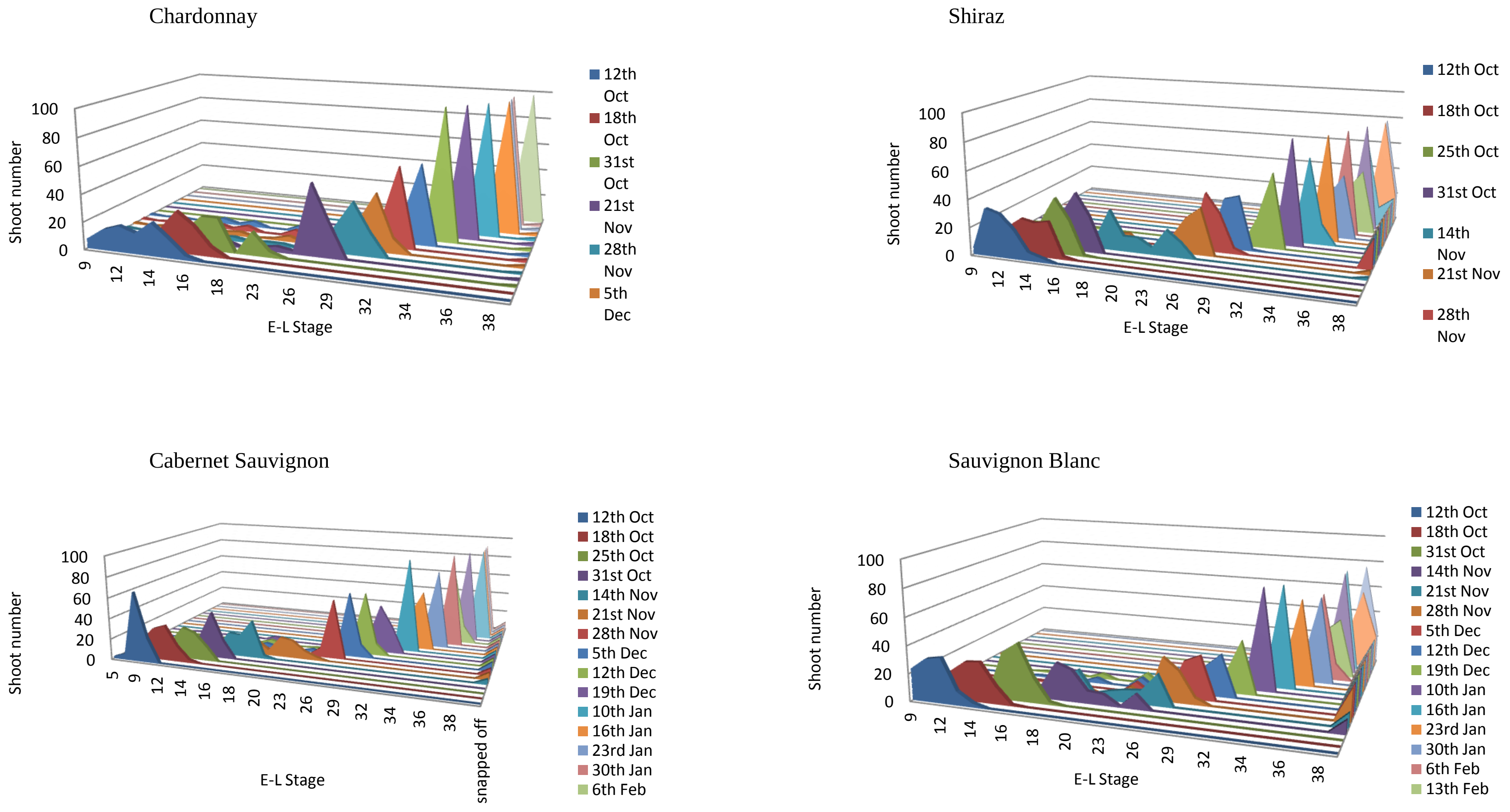
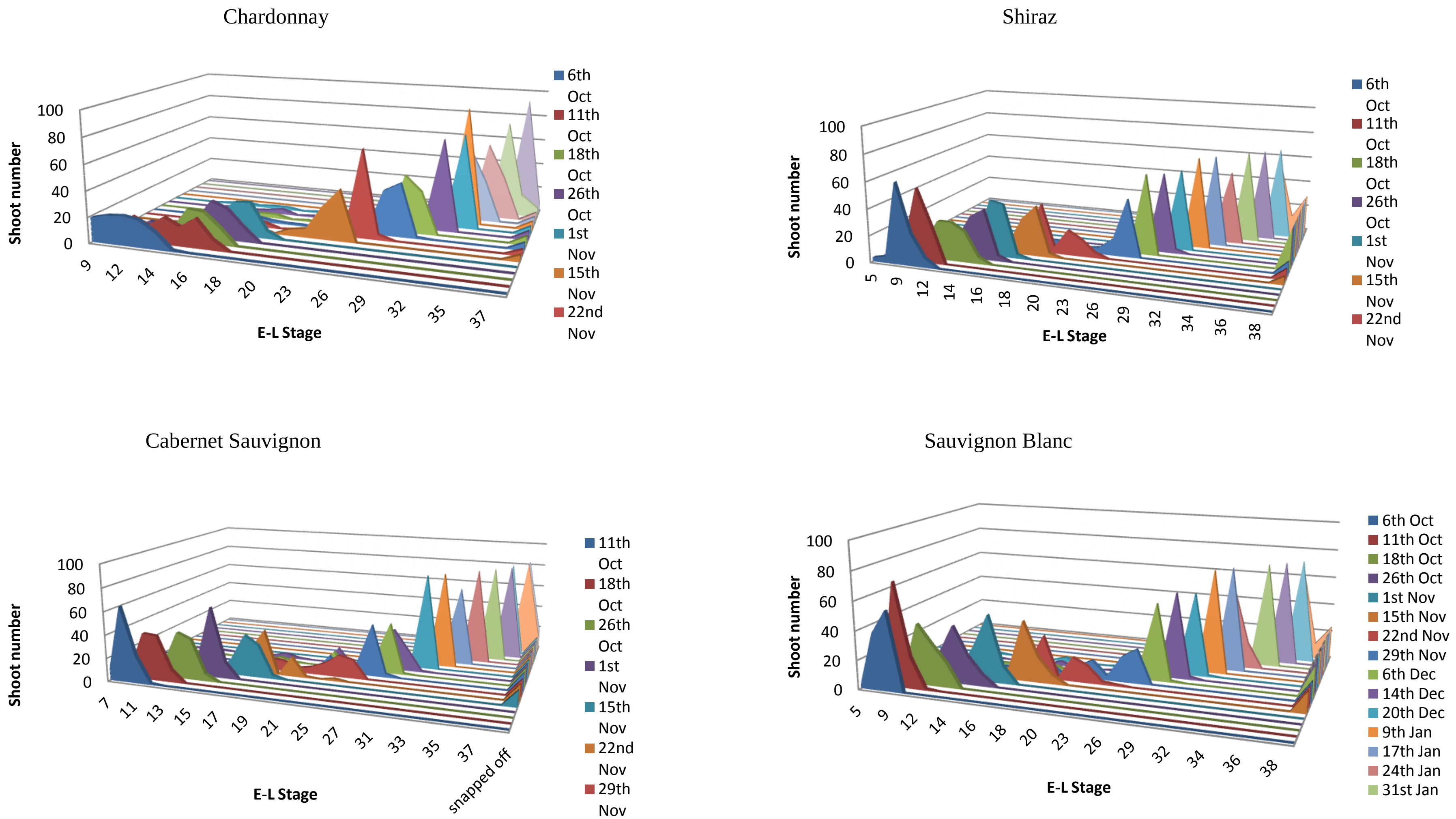


Figure 24: Grapevine growth stages (E-L) observed for Chardonnay, Shiraz, Sauvignon Blanc and Cabernet Sauvignon in vineyard in Pemberton during 2011/12.



4.3.2.5 °Brix increase over time

The development of the berries, as measured by the increase in °Brix for all varieties, indicates that the Chardonnay, Shiraz and Cabernet from the Gingin site developed faster than those from the Donnybrook, Margaret River and the Pemberton sites (Figure 25). For the varieties where Gingin was not present the Donnybrook site was slightly more advanced than the Margaret River and the Pemberton sites. For Sauvignon Blanc, Shiraz and Cabernet at the Pemberton site there appears to be a distinct lag period where the °Brix remains steady for the first three sampling periods (approximately 113 days after 3 October) before rapidly increasing. This lag period is not evident at any of the other sites or varieties. The varieties all ripened at different times with the Chardonnay being the first variety on average to reach 20 °Brix after 127 days followed by Sauvignon Blanc after 141 days and Shiraz and Cabernet after 147 days.

4.3.2.6 Temperature comparisons

Temperature measurements as patch point data sets for each region show Gingin had the highest maximum temperature average for the 2011/12 season at approximately 30°C, followed by Donnybrook at 28.5°C, Margaret River at 25.9°C and finally Pemberton at 25.3°C (Figure 26). Similar trends were also seen in the average minimum temperature for each site. Data from the Tinytags, Stevenson screens and PVC tubes were not included due to the variability seen within temperature recordings.

4.3.2.7 Vineyard Growth Records

Although 100 shoots were tagged for each variety at each site there were numerous shoots that were lost throughout the trial at various stages. The Pemberton site lost a substantial number of shoots due to a hail storm prior to flowering that particularly affected the Sauvignon Blanc variety. Another major reason for the loss of shoots is the use of mechanical shoot thinning devices that reduced the number of shoots in several of the varieties. Shiraz in particular with its upright growth habit and natural vigour appeared to be particularly susceptible to having shoots snapped off during the season.

Coombe (1995) indicated that a careful assessment of a limited number of selected shoots gives a more useful record than casually scanning a block. In this study the shoots selected for each variety at each location were generally uniformly at a specific E-L stage, or within a couple of E-L stages, except in certain key stages of flowering and just after bud burst. This variability is likely to have resulted in the rapid nature of the growth of the vines at these stages. For instance Coombe (1995) noted that flowering occurred rapidly and was completed within ten days for most varieties in their study. As this study measured vines on a weekly basis this would not have been frequent enough to capture the complete progression of the vines during these rapid growth periods. Flowering time variability has been noted within field trials and within inflorescences previously and is one of the major factors influencing latent infection of *Botrytis cinerea* (Keller et al. 2002).

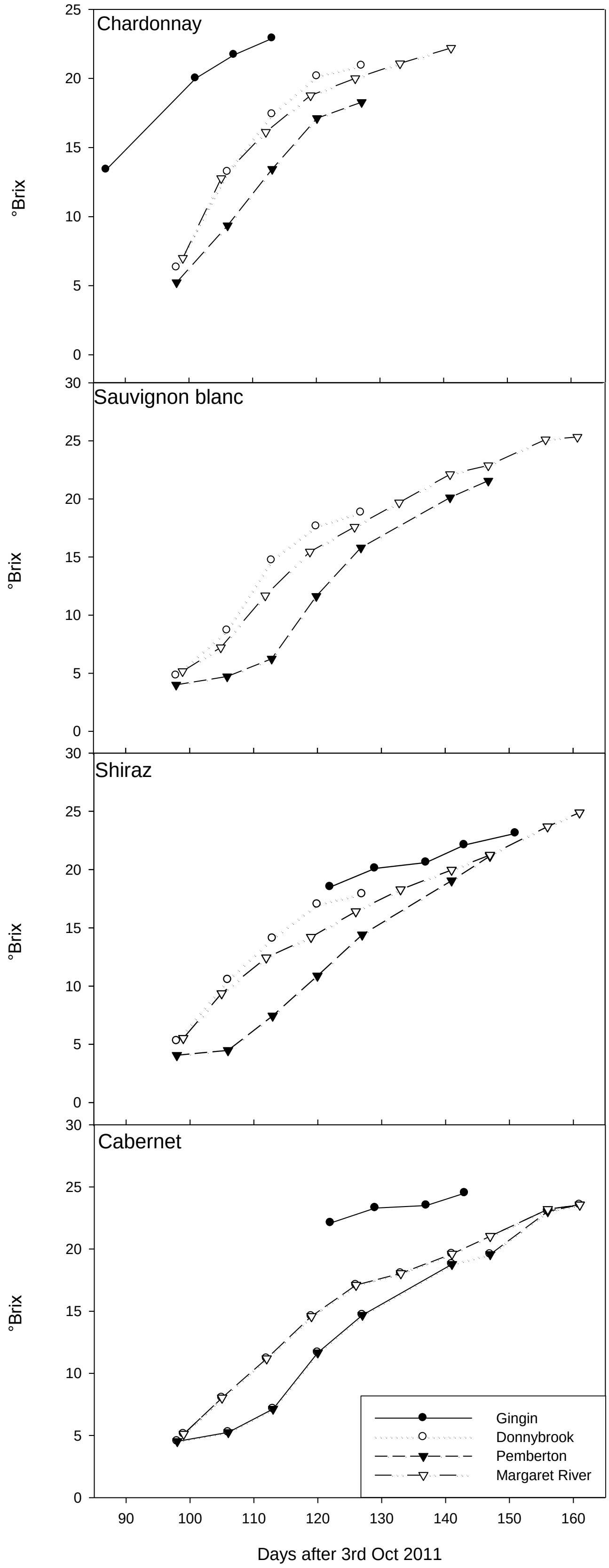


Figure 25: Average °Brix increase over time for the four varieties, Chardonnay, Sauvignon Blanc, Shiraz and Cabernet at four sites, Gingin, Donnybrook, Margaret River and Pemberton for the 2011/12 season.

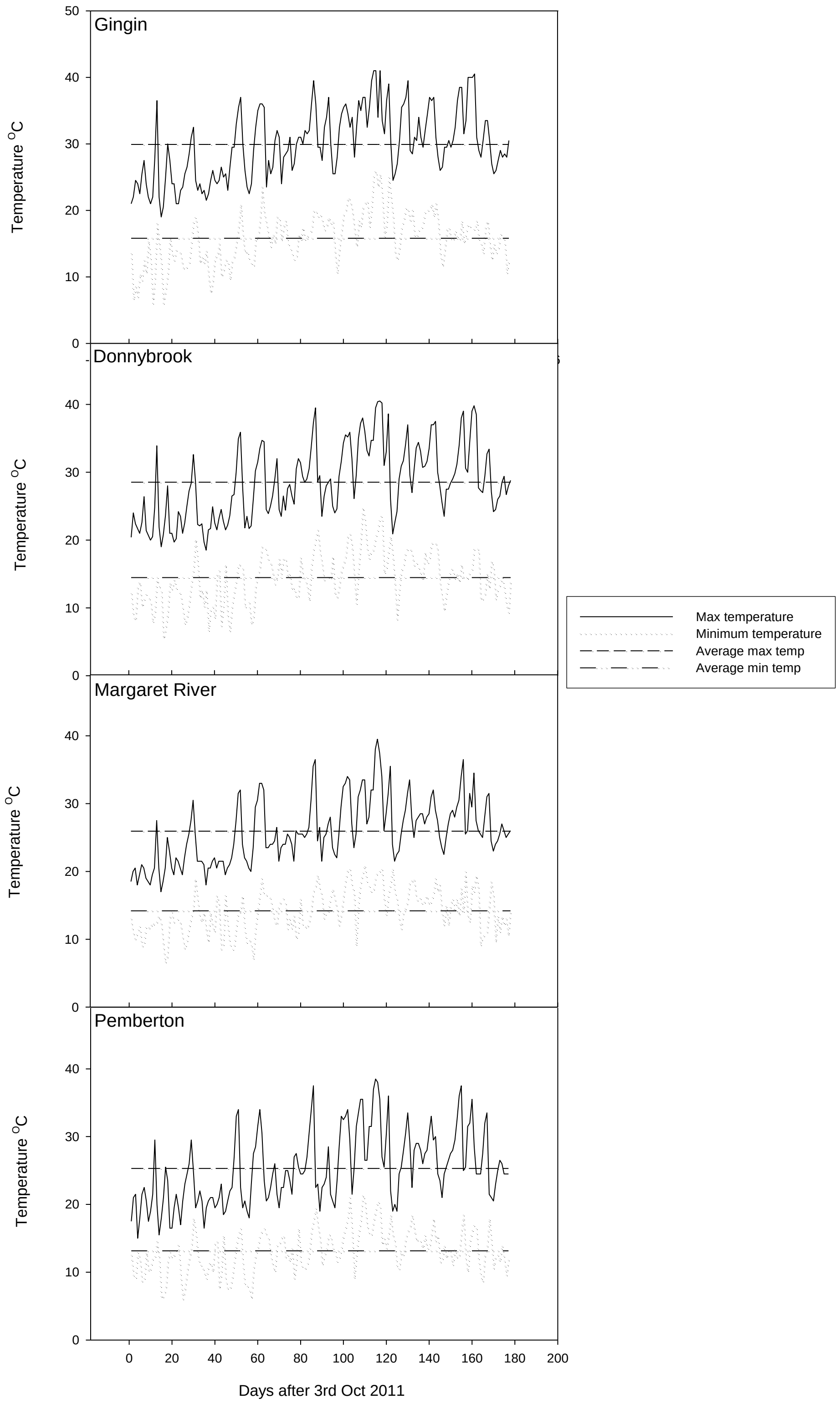


Figure 26: Patch point temperature data (°C) for the four regions showing maximum and minimum temperature over the growing season 2011/12 with average maximum and minimum during this period included.

4.4 Vineyard Mapping and Database Generation

In Western Australia, Master Maps were generated from information obtained from the CRIS database, ground-truthing, mail outs and follow up phone calls. Master Maps were created for all nine GIC Regions in WA. Perth Hills and Swan District as well as Manjimup and Pemberton Regions Master Maps were combined. Master Maps were created from a collection of maps for each region. Figure 27 below shows Map 10 of the 16 maps that collectively make up the Master Map for Margaret River. Individual property maps are displayed in Figure 28. The Master Maps assist with identifying the location of a wine grape property in relation to a planned burn on public land as well as a burn-off on private land. They have the added advantage of assisting with other industry and regional issues such as the prevention of off-target spray damage, location of a poorly managed property in relation to an existing commercial property and land use planning within Shires.

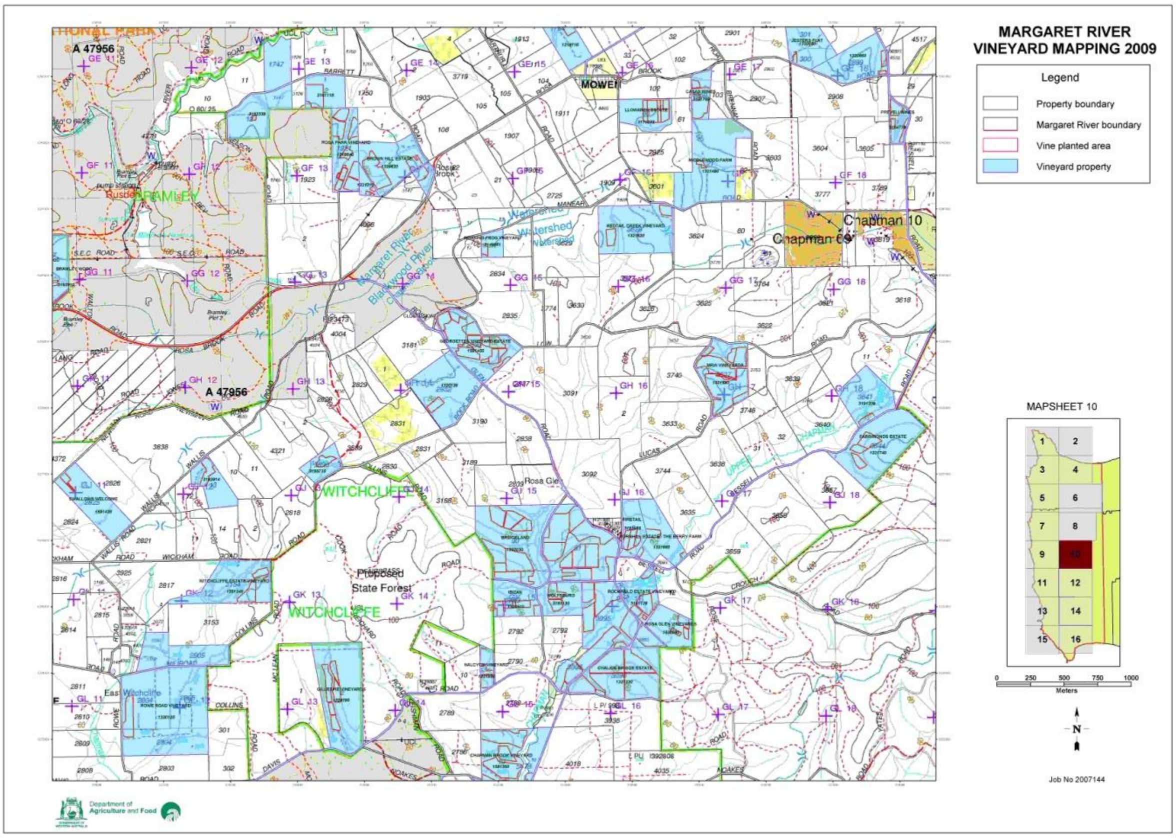


Figure 27: Example of one of the Master Maps created for the Margaret River Region.

Figure 28: Individual property maps that were updated and mailed to participating owner/s and/or manager/s. Permission granted by Georgette's Vineyard Estate to use this vineyard map as a demonstration.

Datasets were created from the information obtained from the CRIS database, ground-truthing, mail outs and phone call. Examples are shown in Tables 9, 10 and 11.

Table 9: Data collected on Western Australian vineyard properties from the vineyard mapping project 2008 to 2012.

Region	Number of properties*	Response %**		Area planted to wine grapes (ha)	Percentage of total wine grape area
Blackwood Valley	49	83	94	435	3.3%
Geographe	107	62	96	869	6.6%
Great Southern	150	65	70	3424	25.9%
Margaret River	386	71	76	5960	45.1%
Manjimup	28	86	89	393	3.0%
Peel	13	23	85	108	0.8%
Pemberton	45	80	96	971	7.3%
Perth Hills	46	na	na	168	1.3%
Swan District	249	na	na	897	6.8%
Total	1073			13225	

* An owner may have more than one property if they have separate property boundaries.
** Response % - The first figure indicates property owner/s or/and manager/s who responded to the survey and provided all information requested. The second figure indicates property owner/s or/and manager/s who responded and provided some information requested or information was obtained from follow up phone calls but specific variety area planted information not obtained. Regions with follow up phone calls included Blackwood Valley, Geographe, Manjimup, Peel and Pemberton. No data were obtained for Perth Hills and Swan District.
# Planted area is based on responses and non-responses (aerial photography).

Table 10: Most popular red and white wine grapes planted for six of the GIC Regions of WA 2008 to 2012 based on response % column 1 from Table 9.

Region	**Colour**	**Variety (hectares)**							
Blackwood Valley	White	Sauvignon Blanc	61	Chardonnay	56	Semillon	32	Viognier	5
	Red	Shiraz	102	Cabernet Sauvignon	85	Merlot	23	Tempranillo	3
Geographe	White	Sauvignon Blanc	67	Chardonnay	65	Semillon	54	Riesling	4
	Red	Shiraz	149	Cabernet Sauvignon	95	Merlot	53	Tempranillo	10
Great Southern	White	Chardonnay	487	Sauvignon Blanc	376	Semillon	182	Riesling	154
	Red	Shiraz	523	Cabernet Sauvignon	400	Merlot	103	Pinot Noir	57
Manjimup	White	Chardonnay	98	Sauvignon Blanc	61	Semillon	19	Verdelho	19
	Red	Cabernet Sauvignon	58	Shiraz	49	Merlot	47	Pinot Noir	16
Margaret River	White	Sauvignon Blanc	842	Chardonnay	830	Semillon	644	Chenin Blanc	8
	Red	Cabernet Sauvignon	1165	Shiraz	725	Merlot	431	Cabernet Franc	50
Pemberton	White	Sauvignon Blanc	277	Chardonnay	269	Verdelho	39	Semillon	37
	Red	Merlot	84	Cabernet Sauvignon	69	Shiraz	59	Pinot Noir	57

Note: No data on varieties were obtained for Perth Hills and Swan District. Due to the limited number Response % column 1 (23%) for Peel Region the most popular red and white planted area information was not listed in Table 10.

Table 11: Varieties not reflected in Table 10 from seven of the GIC Regions of WA.

Region	Varieties
Blackwood Valley	Verdelho, Chenin Blanc, Cabernet Franc, Malbec, Riesling, Muscadelle, Taminga and Pinot Noir.
Geographe	Grenache, Sangiovese, Chenin Blanc, Viognier, Verdelho, Nebbiolo, Pinot Noir, Zinfandel, Malbec, Barbera, Muscat, Savagnin Blanc, Cabernet Franc, Petit Verdot, Mataro (Mourvedre), Fiano, Dolcetto, Durif, Graciano, Mondeuse, Tokay.
Great Southern	Malbec, Viognier, Cabernet Franc, Verdelho, Tempranillo, Grenache, Nebbiolo, Sangiovese, Chenin Blanc, Pinot Gris, Fiano, Petit Verdot, Marsanne, Mataro (Mourvedre), Carnelian, Sagrantino, Zinfandel, Ruby Cabernet, Gamay, Mueller Thurgau.
Margaret River	Verdelho, Riesling, Malbec, Viognier, Petit Verdot, Pinot Noir, Alicante, Sangiovese, Nebbiolo, Tempranillo, Vermentino, Fiano, Petit Manseng, Zinfandel, Touriga, Tinta Cao, Souzao, Touriga, Graciano, Savagnin blanc, Marsanne, Rousanne, Grenache, Mataro, Carnelian, Barbera, Pinot Gris, Gamay, Bastardo, Muscat a Petit Grains, Traminer, Muscadelle, Muscat.
Manjimup	Riesling, Cabernet Franc, Sangiovese, Viognier, Gwertztraminer, Carnelian, Malbec, Nebbiolo, Tempranillo.
Peel*	Cabernet Sauvignon, Merlot, Shiraz, Chardonnay, Sauvignon Blanc, Semillon, Chenin, Cabernet Franc, Tempranillo, Verdelho, Zinfandel, Nebbiolo, Rousanne, Tinta Cao, Tinta Amarelle, Touriga, Souzao.
Pemberton	Viognier, Pinot Gris, Riesling, Cabernet Franc, Gwertztraminer, Petit Verdot, Malbec, Zinfandel, Marsanne, Rousanne.

* All varieties recorded as being grown in Peel Region from the Response % from Table 1.
Note: No data were obtained on varieties for Perth Hills and Swan District.

The maps and datasets generated by the project have the potential to provide multiple benefits to the wine grape industry of WA. They are assisting to minimise the effect of smoke from planned burns on grapes and wine, enhancing public safety from wildfires, improving biosecurity surveillance and emergency response and helping to facilitate extension of research and development. The statistical information gained has the potential to assist with lobbying state and local governments, provide information on the value of the wine industry and its contribution to regional communities as well as information on current trends and capacity requirements within the WA wine industry. For example the total area planted in hectares for a region as shown in Table 9 or the most popular wine grape varieties in hectares a shown in Table 10.

The information obtained from the vineyard mapping and database generation is very dynamic. Property owners and/or managers, contact details, as well as area and variety planted could and does change frequently. The vineyard mapping and database generation from this project have had many benefits for the WA wine industry but it requires additional funding for the datasets to be maintained for the continuation of these benefits. An ongoing partnership with industry is critical to realise this goal.

The vineyard mapping and database collection was not undertaken in Victoria and other states in this project. Because of the recent significant changes in vineyard plantings it was decided that a detailed methodology of vineyard mapping that could be applied to all wine production regions in Australia be developed and ground-truthed through the pilot mapping program in WA. DPI Victoria is currently piloting the HIN Mapper, an iPad® application, to capture a comprehensive vineyard database for wine grape properties in Victoria. The information will be linked to the smoke taint risk model and integrated with the Department of Sustainability and Environment (DSE) burn planning and decision systems. Progress on the Victorian vineyard mapping project will be reported separately by the Centre of Excellence for Smoke Taint Research (CESTR).

4.5 Smoke Taint Risk Assessment Software

4.5.1 Development of Smoke Risk Factors for STAR Model

Investigations of the effect of smoke on grape and wine production has been utilised to develop smoke risk factors for the STAR model. As such sensory and chemical research data of wines produced from Merlot grapevines exposed to smoke at various stages of grapevine growth has been key to the development of the risk factors. This research was conducted over three years where smoke was applied to Merlot grapevines at shoots 10 cm in length; flowers at full bloom; berries at pea-size; bunch closure; onset of veraison; veraison plus 3, 7, 10, 15, 18 and 21 days; and at harvest (Kennison et al. 2011). Results from this research included the key chemical analytes of interest, guaiacol and 4-methylguaiacol data, together with wine sensory scores for ‘smoke-like’ and ‘wine-like’ aromas. As previously described (method section) data employed in the Principal Component Analysis (PCA) (Principal Components 1 and 2 output) was employed to develop numerical indices as seasonal risk factors for the susceptibility of smoke taint development in wine. PCA data was combined with the chemical analysis data and calculated as averages for development of smoke risk factors for the STAR model.

PCA results were utilised in the model development as they were found to be reliable for Merlot, Cabernet Sauvignon, Chardonnay and Sauvignon Blanc data. For Merlot the PCA biplot accounted for a large proportion of data variation (98.93%) with principal component 1 (PC1) accounting for 93.99% and principal component 2 (PC2) accounting for 4.94% (Figure 29) (Renton et al. 2012). PC1 is contrasted by positive loadings on the attributes pertaining to smoke taint in wine, being guaiacol (0.85), 4-methylguaiacol (0.16) and smoke-like aroma (0.30), with a negative loading on wine-like aroma (-0.4). PC2 is further distinguished with positive loadings on 4-methylguaiacol (0.01) and smoke-like aroma (0.55) and negative loadings on both guaiacol (-0.5) and wine-like aroma (-0.66). The smoke compounds of guaiacol and 4-methylguaiacol are highly correlated ($r = 0.95$) as is guaiacol and smoke aroma ($r = 0.84$). In contrast, wine aroma is negatively correlated with guaiacol ($r = -0.87$), 4-methylguaiacol ($r = -0.88$) and smoke-like aroma ($r = -0.93$) (Renton et al. 2012).

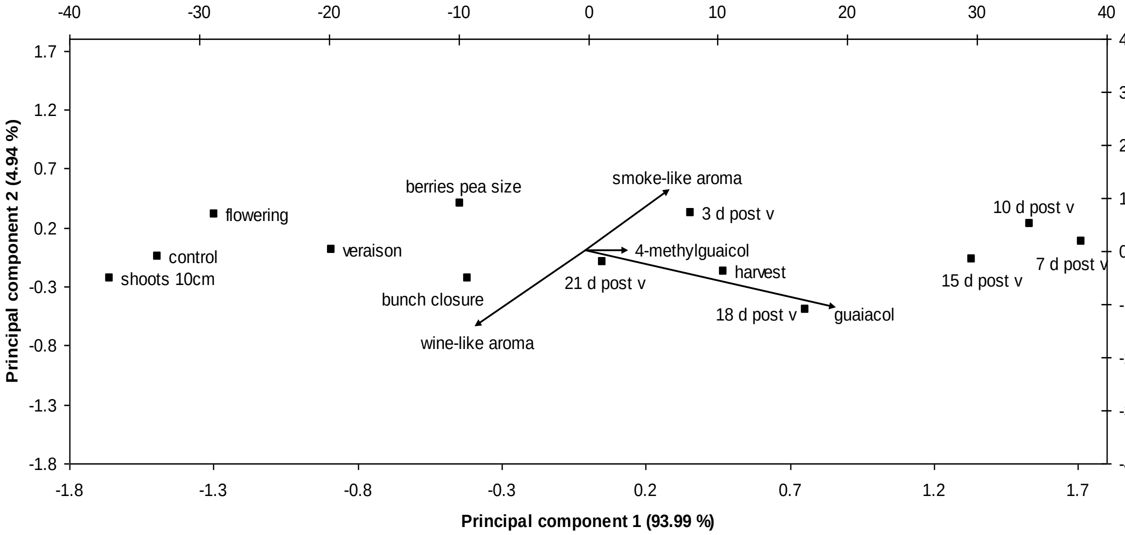


Figure 29. Principal component analysis (PCA) biplot of mean smoke-like aromas, wine-like aromas, guaiacol and 4-methylguaiacol detected in unsmoked wine (control) and wine made from grapes of Merlot grapevines exposed to smoke at the grapevine growth stages of shoots 10 cm in length; flowering; berries pea size; bunch closure; onset of veraison; 3, 7, 10, 15, 18 and 21 days post veraison; and harvest. Data derived from Kennison et al. (2009, 2011). (Renton et al. 2012)

In conjunction with PCA results, the average results of the Merlot guaiacol and 4-methylguaiacol chemical data for each wine (Kennison et al. 2011) were incorporated into the calculation of the STAR risk factors. The risk factors were generated to indicate the risk probability of smoke uptake and taint development ranging from 0.0, representing an extremely low risk (no risk) of smoke uptake, to 1.0 that represents a very high risk of smoke uptake. The risk factors for Merlot show that wines produced from fruit of grapevines exposed to smoke at shoots 10 cm, flowering and the onset of veraison have a low risk of developing smoke taint-related characteristics (Figure 30). In contrast, wines from a smoke exposure to grapevines at 7, 10, 15, 18 days post veraison and at harvest have the risk of an elevated intensity of guaiacol, 4-methylguaiacol and smoke-related aromas. All other timings of grapevine phenology smoke exposure demonstrate a variable, but moderate, risk of smoke uptake and taint development in the final wine.

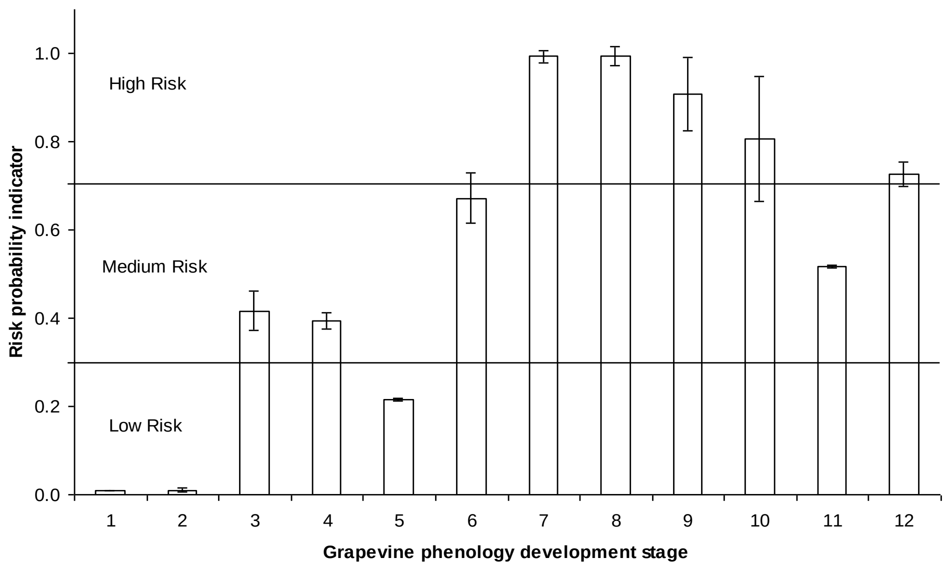


Figure 30. Mean risk probability of smoke uptake and taint development in Merlot wines from smoke application to grapevines at development stage 1 (shoots 10 cm in length), 2 (flowering), 3 (berries pea size), 4 (bunch closure), 5 (onset of veraison), 6 (3 days post veraison), 7 (7 days post veraison), 8 (10 days post veraison), 9 (15 days post veraison), 10 (18 days post veraison), 11 (21 days post veraison) and 12 (harvest). Error bars indicate two standard errors of the mean and are obscured in some cases by the chart bars (Renton et al. 2012).

Following the calculation of smoke risk factors for Merlot, STAR smoke risk factors were also generated from the chemical and sensory research data produced for Cabernet Sauvignon, Chardonnay and Sauvignon Blanc wines. As with the chemical and sensory data, the risk factors show high variability between the smoke risk factor for both variety and grapevine phenological timing of smoke application (Figure 31). For instance, Cabernet Sauvignon shows a high risk probability (0.8) of smoke uptake and taint development in wine from a smoke application at berries pea size whereas Chardonnay and Sauvignon Blanc risk factors for the same stage are relatively lower, 0.2 and 0.3 respectively. In comparison, the Cabernet Sauvignon risk factor for smoke uptake is lower at harvest (0.4) than that of Chardonnay (0.78) and Sauvignon Blanc (0.76) that shows the highest risk probability of smoke uptake and taint development during the grapevine growth season.

The calculation of the risk factors for smoke uptake and taint development has been essential for the development of the STAR model. The incorporation of these risk factors into the model, their usability and function are detailed further in the following sections of this report. Further investigation is currently being conducted to elucidate the timing of smoke effects to a wider range of grapevine varieties. Furthermore, research of smoke effects to a range of grapevine varieties is being conducted over years to reduce the within-season data variation.

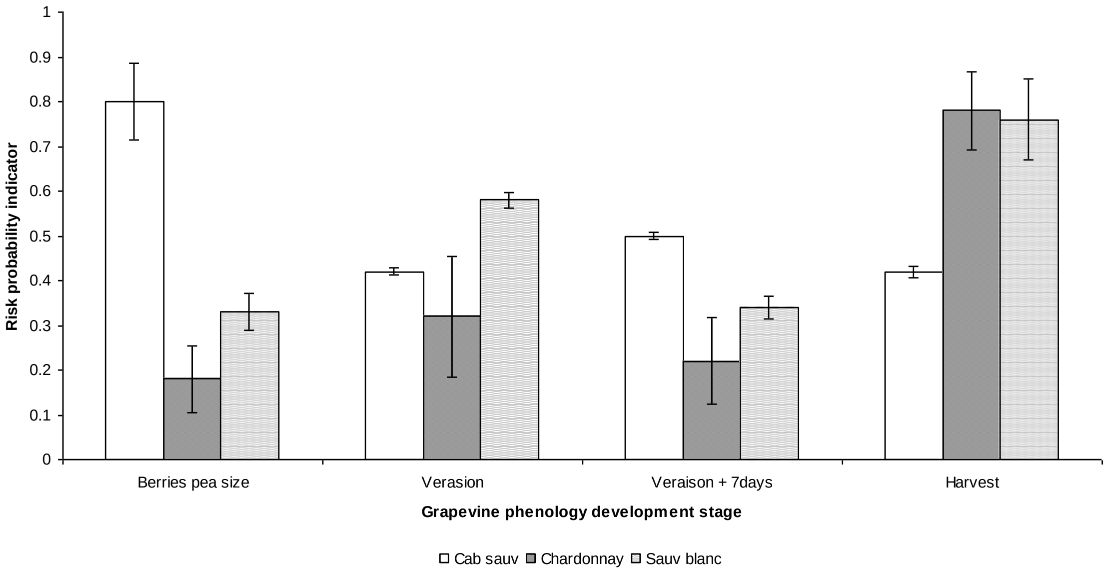


Figure 31. Mean risk probability for smoke uptake and taint development in Cabernet Sauvignon, Chardonnay and Sauvignon Blanc as developed from chemical and sensory data of wines produced from grapevines exposed to smoke at berries pea size, veraison, veraison plus seven days and harvest. Error bars indicate two standard errors of the mean (Renton et al. 2012).

4.5.2 STAR Model of Phenology and Association with Smoke Taint Risk

Models of the GDD required for grapevine growth stages and the risk factors associated with grapevine growth stage were successfully developed for key cultivars (Table 12 and 13).

Table 12: Growing degree day model[1]

GROWTH STAGE	E-L stage	Merlot	Cabernet Sauvignon	Chardonnay	Sauvignon Blanc	Shiraz	Pinot Noir
Bud burst	EL4	192	394	175	380	342	266
Shoots 10cm/5 leaves separated	EL12	NA	835	565	826	701	NA
Flowering begins	EL19	1220	1236	1090	1312	1255	1097
Full Bloom/50% cap fall	EL23	1285	1337	1177	1444	1348	1203
Flowering ends, 80% cap fall	EL25	1386	1471	1294	1547	1462	1341
Fruit set/berries pea size	EL31	1652	1972	1689	1871	1983	NA
Bunch closure	EL32	1999	2105	1730	1984	2013	1641
Veraison	EL35	2815	2614	2471	2573	2561	2636
Veraison + 3 days		2874	2678	2531	2635	2623	2696
Veraison + 7 days		2953	2763	2611	2721	2709	2772
Veraison + 10 days		3014	2826	2671	2783	2773	3832
Harvest	EL38	3754	4031	3425	3366	3718	3281

[1] GDD model based on Parker et al, (2012)

Table 13: Smoke risk factors[1] associated with grapevine growth stage

GROWTH STAGE	E-L stage	Merlot	Cabernet Sauvignon	Chardonnay	Sauvignon Blanc
Bud burst	EL4	0.00	0.00	0.00	0.00
Shoots 10cm/5 leaves separated	EL12	0.01	0.01	0.01	0.01
Full Bloom/50% cap fall	EL23	0.01	0.01	0.01	0.01
Fruit set/berries pea size	EL31	0.40	0.80	0.18	0.33
Bunch closure	EL32	0.40	0.80	0.18	0.33
Veraison	EL35	0.30	0.42	0.32	0.58
Veraison + 3 days		0.70	0.42	0.32	0.58
Veraison + 7 days		1.00	0.50	0.22	0.34
Veraison + 10 days		1.00	0.50	0.22	0.34
Berries intermediate °Brix	EL36	0.9	0.50	0.22	0.34
Berries intermediate °Brix + 3d		0.8	0.50	0.22	0.34
Berries not quite ripe	EL37	0.50	0.50	0.22	0.34
Harvest	EL38	0.70	0.42	0.78	0.76

4.5.3 Validation of the STAR model

To validate the STAR model the dates for the key grapevine growth stages predicted by the degree-day-based phenology model were compared to the dates observed in the detailed regional phenology study in 2011-12 season. The validation data was for four varieties (Chardonnay, Sauvignon Blanc, Shiraz and Cabernet Sauvignon) from four vineyards in different climatic regions (Swan Districts, Geographe, Margaret River and the Great Southern).

The phenology model accurately predicted the dates of full bloom (E-L23), veraison (E-L35) and berries harvest ripe (E-L38 and 39) for Chardonnay, Sauvignon Blanc and Cabernet Sauvignon in Margaret River, Pemberton and Donnybrook (Table 14). The model was less accurate for Gingin. The dates predicted by the model were significantly later than the observed dates for the key grapevine phenology stages. When the STAR model was adjusted for the observed date of full bloom it accurately predicted veraison and berries harvest ripe for the Gingin region (Table 15). This indicates that in the warmer regions such as Gingin vines may break dormancy earlier than the assumed date (August 30 or 242nd day of year) in the Flowering Veraison Model. Break of dormancy is determined when the grapevine reaches a critical state of chilling which is dependent on the chilling temperatures during the dormancy period and the chill requirement of specific varieties. Dormancy break can also be influenced by the time of winter pruning, rootstock, post-harvest water stress in the previous season and other factors. Consequently, the date grapevines break dormancy cannot be estimated accurately. To adjust for this variable the observed dates for specific growth stages can be entered into STAR. The observed date of budburst would be particularly good to use as this stage occurs well before smoke taint risk becomes significant.

Automated procedures have been developed for all aspects of the vine phenology model parameter estimation, so that as additional phenology data become available in future, it can be relatively easily integrated to continue to refine the model and improve its predictions.

Table 14: Phenology dates predicted by STAR and observed dates for Chardonnay, Sauvignon Blanc and Cabernet Sauvignon in 4 different climatic regions Gingin (Swan District), Donnybrook (Geographe), Margaret River and Pemberton in 2011/12

Chardonnay

Growth stage[1]	E-L	Gingin		Donnybrook		Margaret River		Pemberton	
		Model	Observed	Model	Observed	Model	Observed	Model	Observed
DB	1	31-Aug-11	na	31-Aug-11	na	31-Aug-11	na	31-Aug-11	na
BB	4	12-Sep-11	na	12-Sep-11	na	12-Sep-11	na	13-Sep-11	na
FLS	12	08-Oct-11	na	09-Oct-11	09-Oct-11	09-Oct-11	08-Oct-11	10-Oct-11	06-Oct-11
FB	23	10-Nov-11	25-Oct-11	14-Nov-11	15-Nov-11	15-Nov-11	14-Nov-11	16-Nov-11	18-Nov-11
FS	31	16-Dec-11	23-Nov-11	11-Dec-11	13-Dec-11	14-Dec-11	26-Dec-11	16-Dec-11	20-Dec-11
BC	32	04-Dec-11	30-Nov-11	09-Dec-11	21-Dec-11	12-Dec-11	30-Dec-11	14-Dec-11	27-Dec-11
BS (7^{o}Brix)	34	na	22-Dec-11	na	10-Jan-12	na	10-Jan-12	na	13-Jan-12
V (10^{o}Brix)	35	06-Jan-12	29-Dec-11	13-Jan-12	17-Jan-12	19-Jan-12	13-Jan-12	21-Jan-12	18-Jan-12
IR (14^{o}Brix)	36	na	31-Dec-11	na	19-Jan-12	na	19-Jan-12	na	25-Jan-12
BNR(18^{o}Brix)	37	na	12-Jan-12	na	26-Jan-12	na	28-Jan-12	na	06-Feb-12
HR1 (23^{o}Brix)	38	11-Feb-12	24-Jan-12	20-Feb-12	21-Feb-12	29-Feb-12	28-Feb-12	05-Mar-12	07-Mar-12
HR2 (25^{o}Brix)	39	na	na	na	na	na	na	na	na

Sauvignon Blanc

Growth stage1	E-L	Gingin		Donnybrook		Margaret River		Pemberton	
		Model	Observed	Model	Observed	Model	Observed	Model	Observed
DB	1	31-Aug-11	na	31-Aug-11	na	31-Aug-11	na	31-Aug-11	na
BB	4	29-Sep-11	na	27-Sep-11	na	27-Sep-11	na	28-Sep-11	na
FLS	12	23-Oct-11	na	25-Oct-11	16-Oct-11	26-Oct-11	22-Oct-11	26-Oct-11	22-Oct-11
FB	23	24-Nov-11	na	28-Nov-11	18-Nov-11	30-Nov-11	28-Nov-12	02-Dec-11	02-Dec-11
FS	31	10-Dec-11	na	15-Dec-11	21-Dec-11	19-Dec-11	19-Dec-11	21-Dec-11	27-Dec-11
BC	32	17-Dec-11	na	23-Dec-11	28-Dec-11	27-Dec-11	26-Dec-11	29-Dec-11	03-Jan-12
BS (7oBrix)	34	na	na	na	13-Jan-12	na	16-Jan-12	na	25-Jan-12
V (10oBrix)	35	11-Jan-12	na	18-Jan-12	20-Jan-12	23-Jan-12	21-Jan-12	25-Jan-12	29-Jan-12
IR (14oBrix)	na	na	na	na	23-Jan-12	na	27-Jan-12	na	04-Feb-12
BNR(18oBrix)	37		na	na	31-Jan-12	na	07-Feb-12	na	14-Feb-12
HR1(23oBrix)	38	09-Feb-12	na	18-Feb-12	28-Feb-12	27-Feb-12	27-Feb-12	03-Mar-12	07-Mar-12
HR2(25oBrix)	39		na	27-Feb-12	na	07-Mar-12	07-Mar-12	12-Mar-12	na

Cabernet Sauvignon

Growth stage[1]	E-L	Gingin		Donnybrook		Margaret River		Pemberton	
		Model	Observed	Model	Observed	Model	Observed	Model	Observed
DB	1	31-Aug-11	na	31-Aug-11	na	31-Aug-11		31-Aug-11	
BB	4	28-Sep-11	na	29-Sep-11	na	28-Sep-11		29-Sep-11	
FLS	12	23-Oct-11	29-Sep-11		na	26-Oct-11	16-Oct-11	27-Oct-11	22-Oct-11
FB	23	21-Nov-11	29-Oct-11	24-Nov-11	na	26-Nov-11	25-Nov-11	27-Nov-11	02-Dec-11
FS	31	17-Dec-11	07-Dec-11	22-Dec-11	na	27-Dec-11	26-Dec-11	21-Dec-11	27-Dec-11
BC	32	23-Dec-11	15-Dec-11	28-Dec-11	na	02-Jan-12	01-Jan-12	05-Jan-12	03-Jan-12
BS (7^{o}Brix)	34	na	na	na	na	na	14-Jan-12	na	23-Jan-12
V (10^{o}Brix)	35	12-Jan-12	05-Jan-12	19-Jan-12	na	24-Jan-12	21-Jan-12	27-Jan-12	29-Jan-12
IR (14^{o}Brix)	36	na	na	na	na	na	29-Jan-12	na	05-Feb-12
BNR(18^{o}Brix)	37	na	na	na	na	na	13-Feb-12	na	18-Feb-12
HR1 (23^{o}Brix)	38	na	09-Feb-12	na	na	na	05-Mar-12	na	07-Mar-12
HR2 (25^{o}Brix)	39	07-Mar-12	23-Feb-12	17-Mar-12	na	29-Mar-12	26-Mar-12	04-Apr-12	02-Apr-12

[1] Grapevine growth stages: DB=dormancy break, BB=budburst, FLS=shoots with five leaves separated, FB=full bloom (50% capfall), BC=bunch closure, BS=berry softening, V=veraison (berries start colouring), IR=berries intermediate ripe, BNR=berries not fully ripe, HR1=berries harvest ripe for white varieties, HR2=berries harvest ripe for red varieties

Table 15: Phenology dates predicted by STAR, after adjustment for observed date of Full Bloom (yellow), and observed dates for Chardonnay and Cabernet Sauvignon in Gingin in 2011/12

Growth stage	E-L stage	Chardonnay			Cabernet Sauvignon		
		Model	Model adjusted	Observed	Model	Model adjusted	Observed
DB	1	31-Aug-11		na	31-Aug-11		na
BB	4	12-Sep-11	31-Aug-11	na	28-Sep-11	31-Aug-11	na
FLS	12	08-Oct-11	18-Sept 11	na	23-Oct-11	29-Sept-11	29-Sep-11
FB	23	10-Nov-11	25-Oct-11	25-Oct-11	21-Nov-11	29-Oct-11	29-Oct-11
FS	31	4-Dec-11	21-Nov-11	23-Nov-11	17-Dec-11	28-Nov-11	07-Dec-11
BC	32	16-Dec-11	23-Nov-11	30-Nov-11	23-Dec-11	4-Dec-11	15-Dec-11
BS (7^{o}Brix)	34	na	na	22-Dec-11	na	na	na
V (10^{o}Brix)	35	06-Jan-12	25-Dec-11	29-Dec-11	12-Jan-12	26-Dec-11	05-Jan-12
IR (14^{o}Brix)	36	na	na	31-Dec-11	na	na	na
BNR(18^{o}Brix)	37	na	na	12-Jan-12	na	na	na
HR1 (23^{o}Brix)	38	11-Feb-12	30-Dec-12	24-Jan-12	na	na	09-Feb-12
HR2 (25^{o}Brix)	39	na		na	07-Mar-12	19-Feb12	23-Feb-12

4.5.4 Ground-truthing of STAR Model

The smoke taint risk model and webpage information was demonstrated both in prototype form and live on the DAFWA intranet at a number of meetings, workshops, symposia and seminars during the project. User feedback on the design, functionality, interactivity and accuracy of the model and webpage was used to modify and refine STAR to its current format.

The feasibility of linking STAR with CRIS mapping system to spatially display vineyard vulnerability to smoke taint in real time or future projections for use as a decision making tool for prescribed burning activity will be further explored.

4.5.5 STAR Web-based Tool

The web-based interface and underlying server-based database and functionality was successfully developed to meet all required features described in Methods. The following screen shots (Figures 34, 35, 36 and 37) provide an indication of the final product and the webpage can be viewed on the DAFWA website http://www.agric.wa.gov.au/star. STAR will be regularly updated with observed phenology data from different regions and seasons as the information is collected.

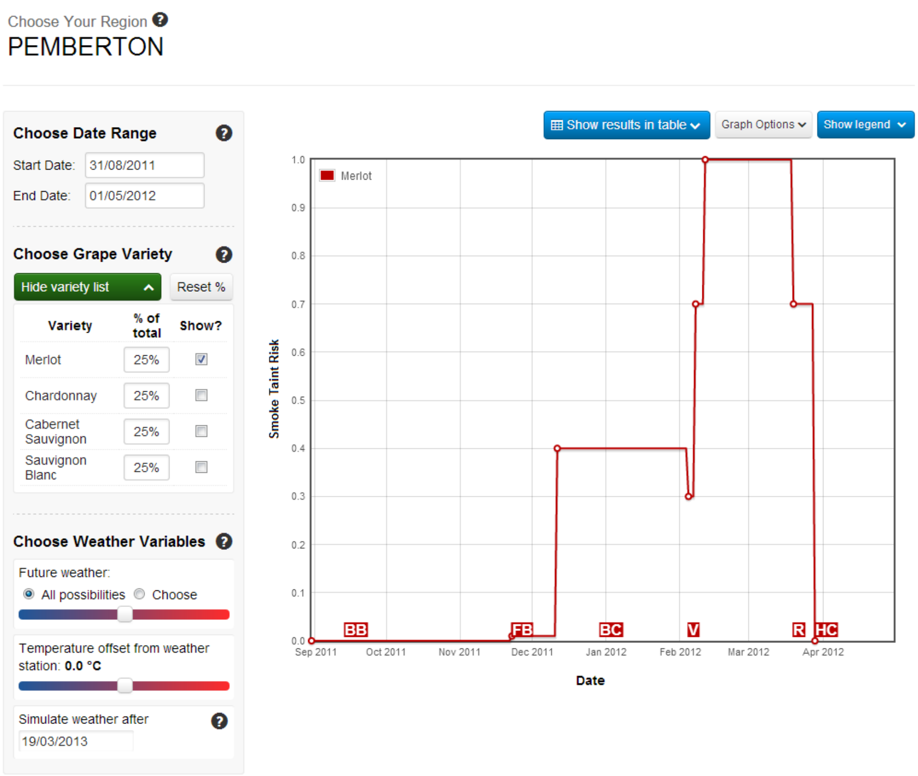


Figure 34: Smoke taint risk profile for Merlot in Pemberton region 2011/12

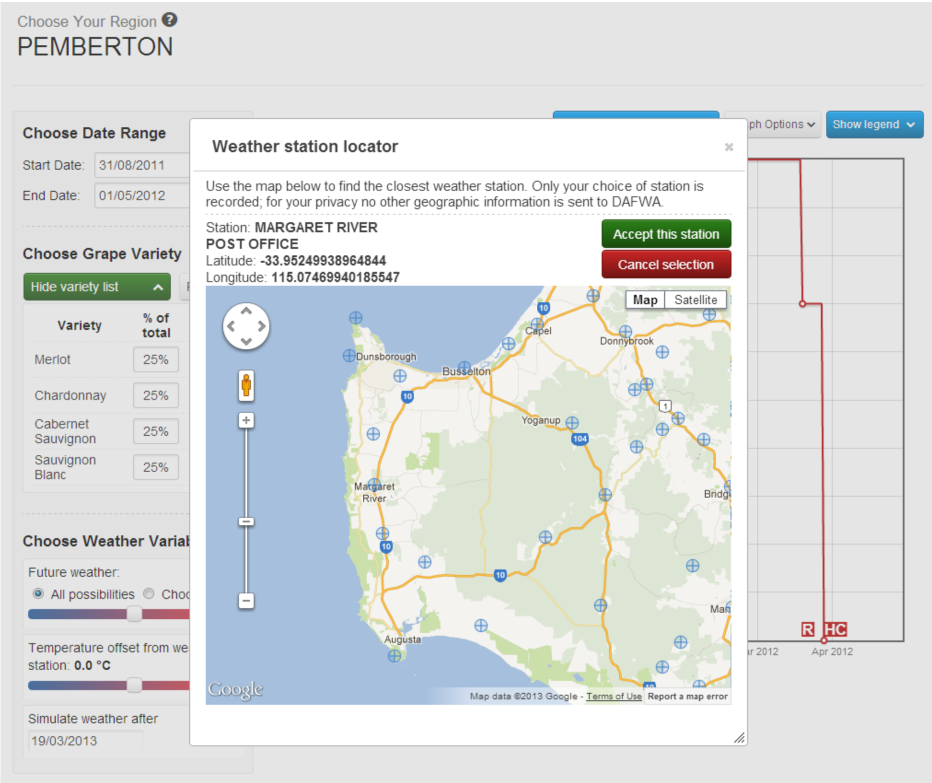


Figure 35: Selecting region and closest weather station to vineyard locations

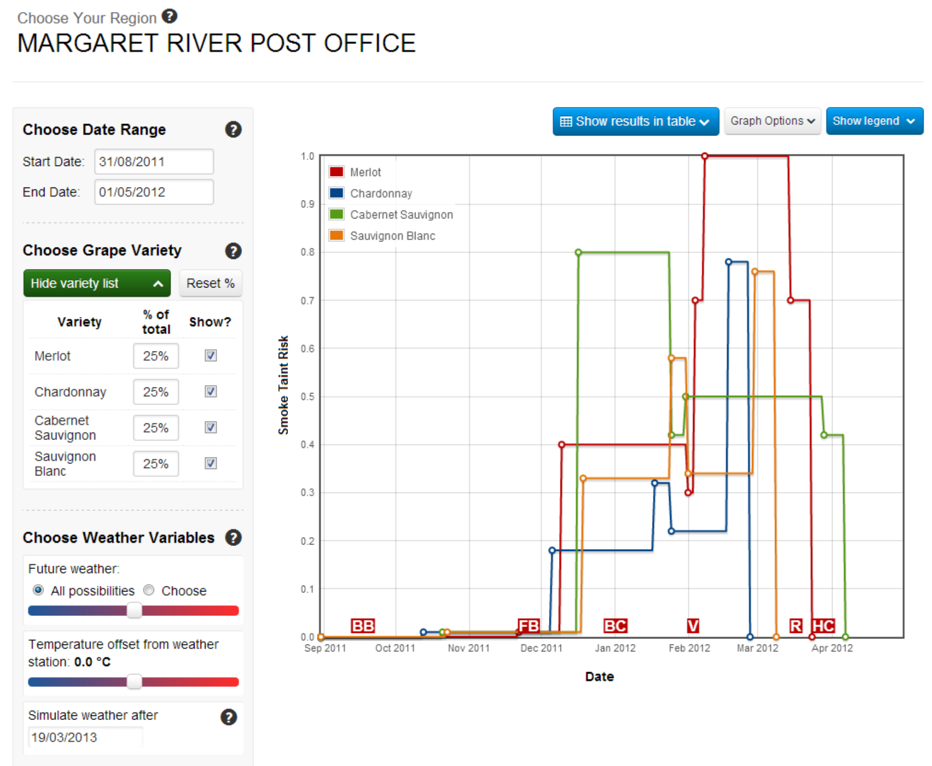


Figure 36: Smoke taint risk profile for multiple varieties in Margaret River 2011/12

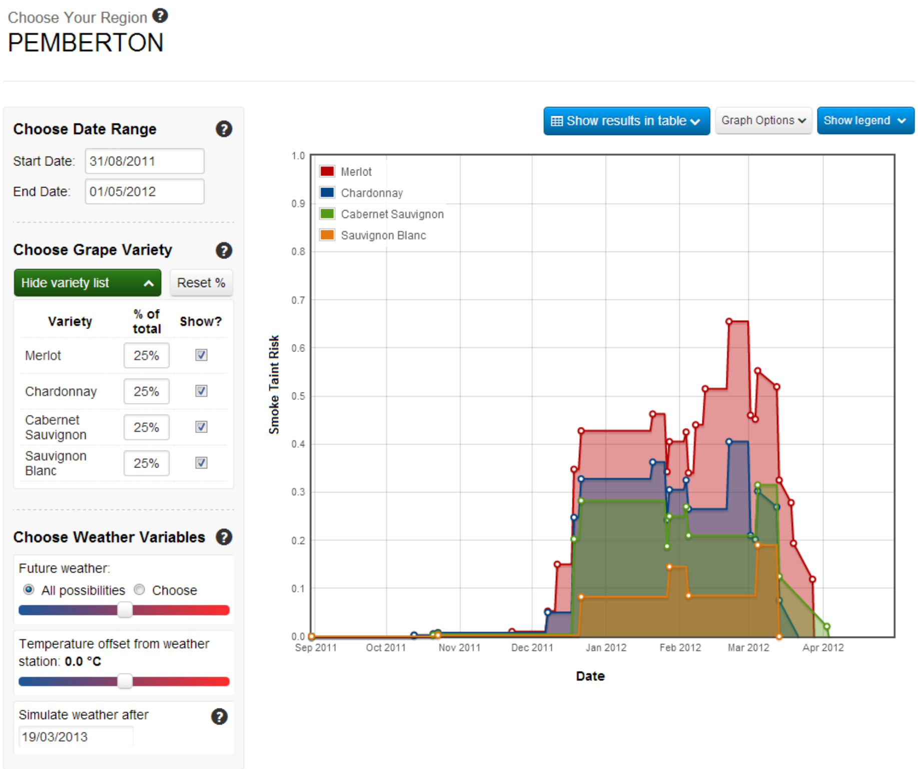


Figure 37: Multiple varieties stacked risk for Pemberton 2011/12

4.6 National Extension of Project Outcomes to the Wine Industry

The extension materials produced in the 'smoke reduction toolkit' include:

1. Bulletin on the 'Key Information on the Effect of Smoke in Grape and Wine Production'. This publication summarised the latest information in three main areas: the 'effects of smoke on grape and wine production', the 'smoke effect reduction system' and 'what to do in the case of a smoke event in the vineyard'
2. Vineyard Mapping and Database Information. Master Maps have been produced for all the nine GI wine regions in Western Australia. These maps highlight the location and identification of all the vineyard plantings in each of the regions
3. STAR model webpage tool. The interactive web-based risk management tool that allows the seasonal smoke taint risk to grapes to be seen at a glance. The tool informs the decision making of land managers to plan and schedule burns and vignerons to plan and manage vineyards in order to reduce exposure of grapevines to smoke during high risk periods.

The project results and outcomes were communicated to industry nationally throughout the life of the project (Appendix 1). This was achieved through publication of results in industry and scientific journals, and in presentations at workshops, seminars, symposia and meetings within WA and nationally.

A series of workshops in collaboration with DPI Victoria and AWRI is planned to roll out the smoke reduction toolkit to vignerons in most of the smoke susceptible wine grape regions in WA, Victoria, NSW and Tasmania in 2013, following the submission of this final report. It was not possible to co-ordinate the national workshops as planned in the original project because of the delays in making STAR accessible online.

5. Outcome / Conclusion

This project achieved all outputs and performance targets as outlined in the original project application with project objectives successfully met with the methodology employed. From this research a comprehensive smoke taint reduction package containing tools that directly reduce the risk of smoke uptake at the vineyard level has been developed and communicated to the Australian grape and wine industry and landscape management agencies. It is recommended that the tools and knowledge generated by this research be used for the reduction of smoke taint in grapes and wine.

A major outcome of this study has been the development of an interactive web based Smoke Taint Risk calculator (STAR) that allows vignerons, landscape managers and other stakeholders to predict seasonal smoke taint risk to wine grapes. By translating the smoke taint research into seasonal risk profiles for any wine-producing location and key wine grape variety, the STAR model enables landscape managers to determine the best times to schedule burns and vignerons to implement strategies to reduce smoke taint in grapes and wine. The quantification of smoke taint risk for key grapevine varieties and grapevine growth stages and a degree-day-based model for grapevine growth were essential components of the STAR model.

The model clearly demonstrates that seasonal timing of grapevine growth stages and associated smoke taint risk are highly variable between wine grape varieties, growing regions, seasons and vineyard locations. The model enables predictions to be made for different weather forecasts and to be adjusted for individual vineyards if the temperature differences between the vineyard location and nearest weather station are known. STAR will automatically simulate grape growth stages, and from that predict a time series of likely smoke taint risk. It can be used for any weather station in south-western WA and selected regions in eastern Australia. It uses real weather data when available, and predicts using simulated weather of any decile (or an average of all deciles). It uses a sensible default date range, and allows selection of any date range (one year maximum). The STAR model is a very powerful communication tool in co-operative efforts to manage the risk of smoke taint at the vineyard level.

STAR will be continually improved through new research and information on smoke taint risk and grapevine phenology. This will include the incorporation of weather data for other Australian wine growing regions, research on additional varieties, the collection of historical phenology data from more vineyards and regions and the inclusion of other risk factors as they are identified. STAR also provides a framework for the incorporation of factors and the integration of planning systems for prescribed burns, smoke management and viticulture production.

The research demonstrates a clear relationship between the duration and density of smoke exposure and the accumulation of smoke-related compounds and sensory attributes in wines. In particular the length of smoke exposure has a cumulative effect of smoke related characters in wine. Smoke exposure to grapevines that is of a high smoke density and/or for long durations accentuated smoke-related chemical and sensory attributes in wine. Results from the density and duration study have enabled a better understanding of the implications of atmospheric smoke deposition on grapevines. This research has a further application for practical use for interpretation of smoke effects in-field. Field-based smoke detecting equipment (such as nephelometers) located within grape producing regions could be used to detect the density and duration of smoke exposure. From our current research, smoke detection in-field is useful as a tool to understand whether the smoke event has been of sufficient duration and density to create potential smoke taint in wine. This work is currently in further development by our and other agencies.

There are substantial differences in the smoke-related chemical and sensory properties in wines of Merlot, Cabernet Sauvignon, Chardonnay and Sauvignon Blanc grapes exposed to smoke at key growth stages. Although previous investigations identified three key periods of Merlot sensitivity to smoke uptake in grapes and development of taint in wine our research shows that other varieties do not follow the trends demonstrated by Merlot. Wines produced from grapes of white varieties (Chardonnay and Sauvignon Blanc) contain significantly lower levels of guaiacol than red varieties (Merlot and Cabernet Sauvignon). Cabernet Sauvignon showed heightened sensitivity to smoke uptake much earlier in the season at berries pea size compared to Merlot. The mechanism for this difference is unknown and may be related to the mode of smoke uptake by grapevines and taint development in wine. The low levels of smoke-related compounds in Sauvignon Blanc and Chardonnay wines in comparison to Cabernet Sauvignon wines may be due to winemaking methodology. Cabernet Sauvignon wines were fermented on berry skins while the white wine varieties were not fermented with skin contact. Other physiological factors that may influence the different varietal accumulation of smoke-related characteristics include varietal morphology, mode of uptake and translocation of smoke compounds by the vine. The variability in smoke uptake throughout the growth period, within and between varieties, may be related to the strength of source-sink relationships between the leaves and fruit and physiological changes that occur during berry ripening. Further considerations are currently being investigated.

Smoke taint risk factors were generated from the chemical and sensory research data produced for Merlot, Cabernet Sauvignon, Chardonnay and Sauvignon Blanc. As with the chemical and sensory data, the risk factors were highly variable between variety and growth stage at time of smoke application. Cabernet Sauvignon shows a high risk probability (0.8) at berries pea size (E-L31) compared to Chardonnay (0.2), Sauvignon Blanc (0.3) and Merlot (0.4) at the same stage. In comparison, the Cabernet Sauvignon risk factor is lower at harvest (0.4) than that of Chardonnay (0.78), Sauvignon Blanc (0.76) and Merlot (0.7). Further investigation is currently being conducted to elucidate the timing of smoke effects to a wider range of varieties.

The project developed a degree-day-based model to predict seasonal grapevine growth stages. The model used historical phenology records from vineyards in climatically diverse Western Australia wine regions and the historic weather data to calculate the growing degree days (GDD). By using these data with the Grapevine Flowering Veraison Model which calculates GDD using a base temperature of 0^{o}C and a start day-of-year 242 days our model was able to accurately predict the timing of key grapevine growth stages. A detailed phenology study of four key varieties Cabernet Sauvignon, Chardonnay, Sauvignon Blanc and Shiraz in commercial vineyards in four climatically diverse wine regions validated the grapevine growth stage model.

The jarrah, karri, marri, pine and pasture grass (wild oats) fuels used in this study were chosen to investigate whether the lignin and monolignol composition of vegetation fuels influenced the types of smoke compounds that accumulate in wines. The results revealed that the qualitative profile of lignin derived compounds that accumulate in wine do not reflect that of the source of vegetation. However the number of compounds found to accumulate in the wines of smoke exposed vines increased which suggests more compounds are likely to contribute to the overall effect of smoke taint. Several of these compounds were found at higher levels than guaiacol and 4-methylguaiacol, the commonly used indicators of taint accumulation in wine. Syringyl derivatives typically accounted for 54% to 78% of the total smoke derived taint compounds in the smoke effected wines indicating that these compounds may be a better measure of smoke taint in wine. In finding significantly elevated levels of syringyl derivatives in pine smoke affected wines suggests some mechanism of transformation occurs and further work is underway to understand the cause. The findings of this research are described in greater detail by Singh et al. (2012) and Kelly et al. (2012). The results further elucidated the mode of uptake of smoke derived compounds into grape berries and suggests that smoke uptake through the berries is significant.

The comprehensive maps and database of wine grape properties generated in this project have assisted landscape managers and vignerons in minimising the effect of smoke on grapes and wine in WA. The detailed Master Maps of vineyards created for each of the nine GI wine regions in WA have assisted in identifying at risk vineyards when planning burns on public land and burn-off on private land. The information is provided to the Department of Environment and Conservation (DEC) to overlay their Master Burn Planning (MBP) system to assist the scheduling of prescribed burns and minimise clashes during grape maturation and harvesting periods. The Master Maps are also shared with Shires, regional wine associations and other stakeholders to improve communication about the risk of grapes and wine to smoke.

Vineyard mapping is at various stages around Australia. DAFWA has a comprehensive set of maps and database for vineyards in all nine WA wine regions. This is housed on the CRIS system and is shared with DEC and other stakeholders. DPI Vic has developed the HIN Mapper and iPad® 'app' which is being used to map and collect extensive information from vineyards throughout Victoria and will be piloted under licence in other states. In South Australia the Phylloxera and Grape Industry Board has legislative powers for the collection of this and other information. Wine Tasmania has developed a map of vineyard locations showing vulnerable stages of grape (dormant, growing or ripening) in real time.

The vineyard maps and datasets are providing multiple on-going benefits to the wine grape industry of WA. They assist to minimise the effect of smoke on grapes and wine, in responding to smoke events in vineyards, enhancing public safety from wildfires, improving biosecurity surveillance and emergency response and help to facilitate extension of research and development. The statistical information has assisted with lobbying state and local governments; calculating the value of the wine industry and its contribution to regional communities; determining vineyard planting and variety trends, and capacity of the WA wine industry. The information obtained from the vineyard mapping and database generation is very dynamic. Property owners and/or managers, contact details, as well as area and variety planted changes frequently. It would require additional funding to be maintained for the continuation of these benefits. An ongoing partnership with industry is critical in realising this goal.

6. Recommendations

During the development and implementation of the 'Completing the Smoke Effect Picture' project, a number of further research opportunities have been identified. One such opportunity is to further understand the mechanism of smoke uptake by the grapevine. Information is lacking on how grapevines assimilate smoke and how smoke may be translocated throughout the vine between or within plant organs. A model understanding of smoke uptake would enable the true effects of smoke complexity to be known and further linked to any one smoke event. This investigation should also encompass a range of grapevine varieties which would enable a better understanding of individual varieties' uptake of smoke at any one time throughout the growing season.

Similarly, an investigation of the mode of smoke uptake by grapevines should ideally encompass a holistic approach to vine physiology and environment. An opportunity exists to further understand the effect of grapevine environmental and intrinsic influences, such as temperature, diurnal timing and grapevine water status on the uptake of smoke.
A further recommendation and research opportunity arising from this project is to gain a comprehensive understanding of smoke composition and its effects on grapevines, smoke uptake and taint development. Prior investigations of smoke composition and variability are limited in the literature. Our current investigation has concentrated on the purposeful application of smoke to grapevines using a tent structure and an investigation of smoke from wildfires. The measurement of smoke is highly complex with reliable nephelometer equipment being utilised in our project. However, direct sampling and diagnosis of the smoke composition linked to its effects on smoke presence in wine would potentially provide additional information to further understand the effect of smoke.

Furthermore, a recommendation arising from this project is to further investigate the chemical effect of smoke on grapes and wine. Currently, grape and wine chemical analysis has centred on the identification of smoke marker compounds, guaiacol and 4-methylguaiacol. The analytical capacity in this area is currently undergoing further investigation with a number of analytical techniques recently identified. However, analytical analysis of grapes that can provide a true indication of the intensity of smoke taint content of the final wine is currently unavailable and warrants further investigation.

The Smoke Taint Risk management tool, STAR, provides a framework for the incorporation of risk factors and the integration of planning systems for prescribed burns, smoke management and viticulture production. A recommendation arising from this project is to further develop and update the STAR model to improve its robustness and applicability. Additional information that could be incorporated over-time to update STAR includes weather data for other Australian wine growing regions, research on sensitivity to smoke of other varieties, historical phenology data from more vineyards and regions, and other factors driving risk (e.g. rootstocks, smoke complexity). It is highly recommended that STAR be developed to integrate with the mapping, database, planning and operating systems for prescribed burns and viticulture production.

Similarly, the future maintenance of the Western Australian vineyard mapping and database system and extension to other states is a high priority recommendation from the project. DPI Victoria is developing a new mapping and database collection system, the

‘HIN Mapper’ an iPad ‘app’ which will be piloted in other states. South Australia’s Phylloxera and Grape Industry Board has a comprehensive vineyard register and Tasmania has developed the ‘tasvine’ system. Further work is required in this area.

Further recommendations concern both the amelioration of smoke tainted wine and protection of vines from the uptake of smoke. Numerous techniques currently exist for limiting the accumulation of smoke-related chemical and sensory characteristics during the harvesting and winemaking processes (as identified in our current study). Methods also exist for the treatment of smoke tainted wine, such as reverse osmosis technology. Suggestions have been raised as to the effectiveness of chemical protectants (protective spray treatments) that could reduce smoke uptake by the vine. However, no one such method appears to be effective on its own. Therefore we recommend further investigation for the amelioration of smoke taint in wine and protection of grapevines from smoke uptake and taint development.

Appendix 1: Communication

Papers, verbal and poster presentation at conferences

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Appendix 2: Intellectual Property

No intellectual property has been generated as part of this research.

Appendix 3: References

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Appendix 4: Staff

Numerous staff from a diverse range of disciplines and organisations have been engaged in this project at various stages during its operation, including:

- Dr Kristen Brodison, Viticulture Research and Development Officer, Department of Agriculture and Food WA (0.4 FTE). Chief Investigator.
- Mr Glynn Ward, Manager Wine and Grape Project, Department of Agriculture and Food WA. Project Supervisor (0.2 FTE)
- Ms Diana Fisher, Development Officer, Department of Agriculture and Food WA (0.1 FTE).
- Mr Andrew Taylor, Research Officer, Department of Agriculture and Food WA (0.1 FTE).
- Mr Richard Fennessy, Research Officer, Department of Agriculture and Food WA (0.2 FTE).
- Mr Mark Stanaway, Senior Technical Officer, Department of Agriculture and Food WA (0.1 FTE).
- Mr David Kelly and Dr Mark Gibberd, Department of Environment and Agriculture, Curtin University, Margaret River WA.
- Mr Michael Airey, School of Plant Biology, University of Western Australia.
- Mr Art Diggle, Climate and Modelling Science, Department of Agriculture and Food WA
- Dr Michael Renton, School of Plant Biology, University of Western Australia.
- Mr Cory Louis, Advanced Technology Products, Belmont, Western Australia
- Mr Peter Gardiner, Research Officer, Geographic Information Services, Department of Agriculture and Food WA
- Client and Resource Information Systems (CRIS) Team, Department of Agriculture and Food WA
- Vineyard Mapping Ground Truthing Team, Department of Agriculture and Food WA (Mrs Elizabeth Blincow, Mr Graham Blincow, Mr Mark Stanaway, Mr Rob Hetherington).
- Ms Diane Rose, Department of Agriculture and Food WA.
- Ms Aymee Mastaglia and Mr Keith Pekin, Wines of Western Australia.
- Mr Drew Haswell and Mr John Gillard, Department of Environment and Conservation WA.
- Wines of Western Australia Smoke Effect Working Group
- Dr Mark Krstic, Australian Wine Research Institute
- Dr Mark Downey and Dr DP Singh, DPI Victoria
- Ms Joanne Butterworth-Grey, Victoria Wine Industry Association

Appendix 5

Not applicable

Appendix 6: Budget Reconciliation

The End of Project Financial Statement has been submitted online in CIMS and is available from GWRDC.